



HAPHAZARD REALITY

IOT IS A METAPHOR

Shoumen Palit Austin Datta

Principles and Practice of Connectivity and Convergence

The education of a boy, may influence the fate of a man.

The education of a girl, may change the destiny of a nation.

HAPHAZARD REALITY – IOT IS A METAPHOR
PRINCIPLES AND PRACTICE OF CONNECTIVITY AND CONVERGENCE

A Collection of Amorphous Ideas

by

Shoumen Palit Austin Datta

HAPHAZARD REALITY – IOT IS A METAPHOR

Shoumen Palit Austin Datta

© Copyright

This collection is available from the MIT Library and is free from any copyright protection. These ideas may be used for any purpose including for-profit operations.

TABLE OF CONTENTS

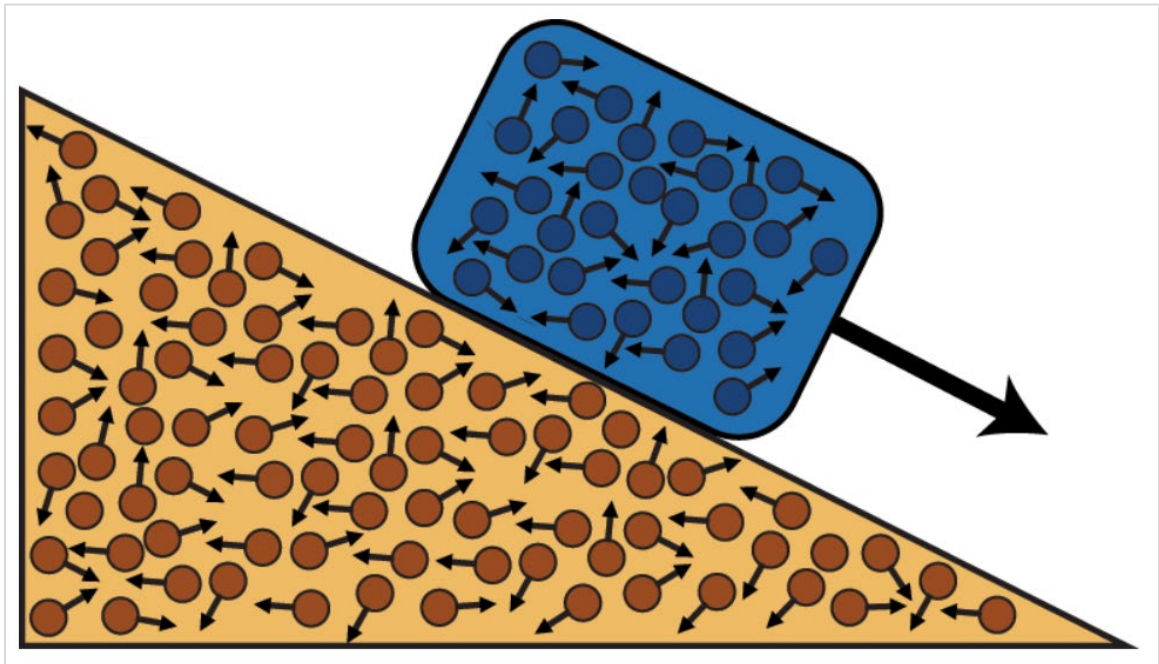
CHAPTER 1 ▪ CONNECTING ATOMS TO BITS	3
CHAPTER 2 ▪ CYBERSECURITY	47
CHAPTER 3 ▪ EMERGENCE OF DIGITAL TWINS	61
FOLLOWING ARE ATTACHED WITH THIS DOCUMENT (SEPARATE PDFs)	
CHAPTER 4 ▪ ARTIFICIAL INTELLIGENCE	
CHAPTER 5 ▪ DIGITAL ENTERPRISE X.0	
CHAPTER 6 ▪ HEALTHCARE – DIGITAL IN 4D	
CHAPTER 7 ▪ HEALTHCARE – MEDICAL IoT	
CHAPTER 8 ▪ HEALTHCARE – Book Chapter	
HEALTHCARE from the MIT LIBRARY ▪ https://dspace.mit.edu/handle/1721.1/107893	
APPENDIX I ▪ IPv6 in identification (preBlockchain)	
APPENDIX II ▪ Big Data (before “Big Data” era)	
APPENDIX III ▪ Adaptive Value Networks	
APPENDIX IV ▪ Review of IoT Tools	
COMMENTARY [A] ▪ Social Disequilibrium	
COMMENTARY [B] ▪ Commencement Address	
COMMENTARY [C] ▪ World Sensor Organization	
COMMENTARY [D] ▪ The New Wealth of Nations	
COMMENTARY [E] ▪ Synergistic Integration Platforms	
COMMENTARY [F] ▪ Forum for Global Public Goods Applications	
TRANSLATION ▪ ITALIAN ▪ Connecting Atoms to Bits	
MORE INFO from MIT LIBRARY ▪ https://dspace.mit.edu/handle/1721.1/111021	

A FEW PAGES ARE LEFT BLANK TO FACILITATE TWO SIDED PRINTING

CHAPTER 1 ▪ CONNECTING ATOMS TO BITS

WHY IT MAY NOT BE ENOUGH

IOT IS A DESIGN METAPHOR for DIGITAL TRANSFORMATION X.0



INTRODUCTORY ESSAY

CONNECTING ATOMS TO BITS

Shoumen Palit Austin Datta

Senior Member, MIT Auto-ID Labs, Research Affiliate, Dept of Mechanical Engineering
Massachusetts Institute of Technology, 77 Massachusetts Ave, Cambridge, MA 02139

Senior Scientist, Medical Interoperability Program, MDPnP Laboratory
Massachusetts General Hospital, Harvard Medical School
Partners MGH Research, 65 Landsdowne St, Cambridge, MA 02139

Managing Director, NSF Center for Robots and Sensors for Human Well-Being
RoSeHuB, School of Engineering Technology, Purdue Polytechnic, Purdue University,
156 Knoy Hall, W Lafayette, IN 47907

shoumen@mit.edu ▪ sdatta8@mg.harvard.edu

ABSTRACT

Threads of amorphous discussions, historical references and atypical examples, the author admits, is unconventional. In one prior engagement, the author was repeatedly excoriated for garrulity. Some people do not like to read more than a page, managers seek executive summaries, executives limit reading to bullet points and VCs prefer elevator pitches, under thirty seconds. The trend in this article may disappoint those individuals.

Synthesis of information helps us to illustrate the evolution of thought. Digital transformation, is a pragmatic topic of interest to industry and business, but it is vast. The scope of digital penetration remains unfathomable. Innovation is quintessential in this context. Old ideas must be viewed by the youth with a set of different eyes. Hence, the “think different” adage rings true. Pursuit of ideas, must reflect on a large number of issues, combined and connected with diverse domains. Leaders must resist the “hype begets hype” trend and ignore slick marketing attempts to perpetuate hype cycles.

**That's Not
How We
Do It Here!**

If this approach discombobulates your comfort zone, or if you prefer convention, then, you are at the mental stage possessed by billions. *That* stage will change, sooner or later. In some regions, we are almost at the end of the lag, and ready to begin a climb. The metaphorical climb is not magical. It is due to the evolution of IoT and digital transformation. On this journey, rational digital economics will serve as our compass, as we navigate through the sign posts of progress, and attempt to map the road, ahead.

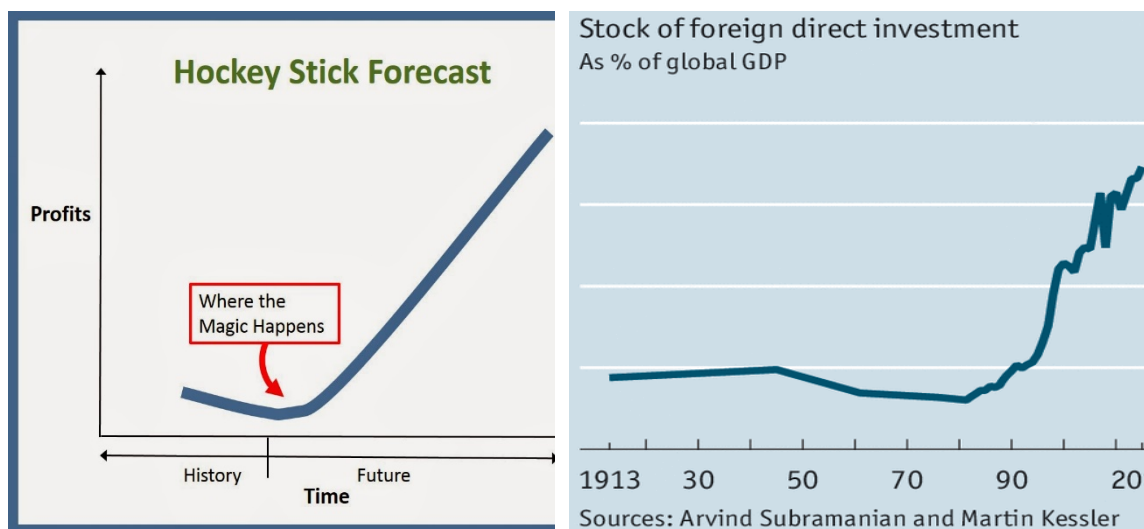


Fig 0: *Hockey stick* model illustrating a preparatory phase followed by rapid growth.

PREFACE

The ideas relevant to the internet of things (IoT) has a rich history. Perhaps, it was seeded by the short stories authored by Isaac Asimov. In 1953, Asimov's "Sally" was conceived as an autonomous vehicle¹, cruising our streets in 2057. Herbert Simon² in 1986 and Mark Weiser³ in 1991 are notable visionaries who contributed to the evolution of our thoughts, related to the metaphor of internet of things (IoT). In 1999, at the MIT Auto ID Center, Kevin Ashton, a marketing expert, loaned to MIT from Procter and Gamble (P&G), proposed the term internet of things⁴ or IoT. In the past few years, it has been suggested⁵ that the exact term (IoT) was first used by Peter Lewis⁶ in 1985, which was even before the seminal talk by Herbert Simon in 1986. Parallel observations and discoveries are nothing new, as acknowledged in a recent publication⁷ by Sanjay Sarma.

In this discussion, I have offered "my version" of a sense of the future, partially with respect to IoT. My purpose is not to be correct or right about these ideas, but to propose them, try to disseminate these ideas, allow experts to dig deeper and provide students with a few clues, about the principles and practice of connectivity and convergence. It is a sentiment borrowed⁸ from Pierre-Gilles de Gennes (1932-2007).

This article is aimed at informing [a] experts, who may talk, generally, to other experts in their field, most of the time, [b] faculty, who are digging deeper and deeper, into fewer and fewer micro-domains, accumulating vast repertoire of knowledge and research publications, but may not have the time to explore the connected world, or the networked society, or the chasm precipitated by the socio-economic disequilibrium catalyzed by the quantum leaps of technology, [c] industry executives, forced to focus on financials, but eager to view the big picture, yet handicapped to provide leadership due to the alarming frequency with which the next quarter rapidly approaches, and P&L results which influences the 'writing on the wall' by analysts, peddling prosperity [d] heads of government agencies or aides to legislative bodies or think tank gurus or the heads of governments, in quest of ideas or vision for public goods, or tools for economic growth, [e] administrators of global organizations, institutions, non-governmental organizations and multi-national platforms (standards bodies, policy roundtables, economic forums), who may influence the direction of future growth, development of science as a service to society, the pursuit of human values, and the elusive quest for *égalité*.

The most important purpose of this article is to inform students, about known unknowns, clues to unknown unknowns, and how to challenge conventional wisdom, about IoT concepts, in order to develop a broad spectrum of IoT umbrella initiatives. But, in conclusion, I point out that digital transformation and IoT is only a part of the picture.

My purpose is not to provide answers, even if the content may appear, in parts, to offer suggestions/solutions. Ideas in the article, often disjointed, may trigger the reader to delve into her own thoughts on the topic. The content is supposed to act as "hooks" or unfinished structures, the reader may choose to extend, or continue to build, or demolish, the idea. The failure of my ideas may be considered a success if it triggers new ideas.

My emphasis on debate, dissent and discussion of ideas, is due to my belief that IoT, a digital-by-design metaphor, represents connectivity and convergence, partially, in a plethora ways, known and unknown, at this time. Scientists, engineers, professors and professionals, cannot provide all the answers, cannot imagine the future where students may travel, and cannot address tomorrow's initiatives, armed only with yesterday's tools.

Hence, my zeal to distribute these and other ‘different’ thoughts, not to be revered, but to serve as whipping blocks, to be proven incorrect, to be questioned. Perhaps, in an attempt to prove them wrong, or in questioning the suggestions, the next generation of leaders, and students, may find the triggers to ignite their imagination. They may invent and innovate solutions, with tangible benefits, which could lift many boats.

Commodities makes the world go around. Energy, water, food, health, education, sanitation, communication and civil safety, are the pillars of life on earth, as we know.

GDP, CMOS, IPv6, SVM, GARCH, RBC, ANN, are parts of the “Alphabet” *soup* which the primary care nurse recommends, in addition to an *Apple* a day, to keep the doctor away. This *soup*, and its many ingredients, may help to deliver the commodities.

IoT is a metaphor for solutions and applications, in the ‘*service*’ of these and other commodities, to the global population, for socio-economic progress of humanity. Multi-domain application of the IoT metaphor has the potential to catalyze social re-engineering. By lowering transaction costs, IoT lowers the barrier to entry. Hence, IoT may penetrate markets of billions, rather than a few nations, with the affluent millions. The tsunami of changes on the road ahead will not be fostered by didactic pedagogy in closed loop disciplines or any one nation or a few institutions or corporate oligopolies.

Mobility has, and will continue to redefine, security, energy, education, health, finance and emergency response systems. Conglomerates and products may be reformed by personalization, experiences and services. Vertical integration may regress in the face of horizontal platform aggregation, for consumers and industries. Consumption of things and objects may be substituted by data of things. Consumers may only pay for integrated information at the point of need or point of care or point of transaction. Subscriptions to services and premiums (insurance) may be transformed by pay-per-use micro-payments. The penchant for next quarter earnings may no longer be a key performance indicator.

Decisions⁹ and processes may be optimized by humans in the loop, using tools from AI, ML and DL, but humans may not be replaced by AI *avatars*, much to the chagrin of Hollywood. AI and automation will accelerate repetitive manufacturing, may aid humans in dangerous jobs (cleaning nuclear leaks, spills), improve precision and accuracy in certain domains, offer assistance to people immersed in monotonous tasks, provide occasional relief to workers for bio-breaks, assist the transportation industry and serve laughter, through comic relief, by winning against humans in GO or may jeopardize George Alexander "Alex" Trebek’s job as the host for Jeopardy. In the world at large, except the space station, automation may not serve us tea via robots, deliver palliative care to geriatric patients or care for pre-term infants in the neonatal intensive care unit.

The metaphor of IoT, and ideas in this article, may seem haphazard, yet real. This is borrowed from *Haphazard Reality* by Hendrik Brugt Gerhard Casimir (1909-2000), the famed Dutch physicist, known for the eponymous Casimir effect and the Casimir-operator in quantum mechanics. Part of the ideas are also borrowed, from the past, present and the future. It is presented here after processing through a different lens, often synthesized in the context of different thinking and hopefully, may be reviewed by different audiences. Part of the problem is my inclination to write in complete sentences and not in bullet points or executive summaries with a predicted “time stamp” of how long it will take an “average” reader to read the material (as often found “stamped” on articles published by the august Harvard Business Review and McKinsey Quarterly).

If *reading* was equivalent to comprehension, then we may not have witnessed the impact of invention of printing, for example, on poetry. When a poem can be read, and re-read, the emphasis shifts from the rhyme and the rhythm, to the allusion and the allegory. The latter is akin to a painting, it adds color to our *imagination*.

Part of the strength of this approach (you may choose to disagree) are its frequent, and haphazard, digressions, to connect the dots, from a myriad of sources, disciplines, and history. This is not a conventional mechanism to *teach* you any subject, but it may help you to *think, learn, connect* and, ask *questions*, hopefully, the *correct questions*. Asking the correct questions, remains the most difficult task, through the ages.

“In the 1970’s, atomic energy [will be] replaced by solar energy as an inexhaustible source of new power...solar energy [will] revolutionize the world through supplying man with an inexhaustible and previously largely untapped source of cheap power. The amount of such cheap power available to the world in 2000 will be beyond comprehension.”

Source: Henry C. Nicholas, “Cheer Up! World to be Wonderful 50 Years From Now, Savants Say,” Kentucky New Era, Wednesday, **March 5, 1952**, p. 10, about meeting of the International Congress of Astronautics (London) and the Convention of the American Chemical Society (New York)



Fig 1: Article by Henry C. Nicholas in *Delta Democrat-Times* (Greenville, MS) on February 8, 1952. The article quotes James Bryant Conant, then President of Harvard University. Courtesy of Alain Louchez. Source: www.smithsonianmag.com/history/the-world-will-be-wonderful-in-the-year-2000-110060404/

INTRODUCTION

The thorn in any transformation is the perspective of the leadership. Pre-set mental boundaries, in some humans, once imprinted, engages in a herculean attempt to gain comfort, and then, controls the metaphorical *turf* or territory. It clings desperately and tries very hard, to remain oblivious of change, it prefers to stay cloistered, remain inside the *box* and try to disregard advances, as fads, soon to evaporate from reality.

The ‘hockey stick’ illustration (Fig 0) and generic sigmoidal curves, exhibit an initial period of diminished activity, or lag, represented by a slow growth (flat) trajectory. This is contributed by, among other things, the resistance to change. The latter weighs down attempts to adopt change, even when necessary. It creates barriers to embrace the *next new* economy. Digital economics, at this time, perhaps, is the next “new” economy.

Figure 2 reflects a ‘hockey stick’ embedded in the sigmoidal trajectory, emerging from the work of Norman Poire¹⁰, an economist and economic historian. Poire’s model uses observations attributed to Austrian economist Joseph Schumpeter, circa 1940, who noted a 50+ year cycle of ebb and flow, accompanying “new economies” leading to global economic growth and developments.

In the illustration below (Fig 2), I have included my projections (circa 2000), to highlight the progression from the physical world of atoms, to the transformation, in terms of the digital economy, where information about atoms may be represented by bits (**Digital Twins**) or bits, *per se*, may be information or data from decisions, processes and things, referring to the internet of things or IoT and industrial IoT. A few projections¹¹ did not materialize¹² but exceptions may prove the rule, albeit, partially. Other models by Poire (see Figure 24) suggests that the 2020’s may witness transformative changes.

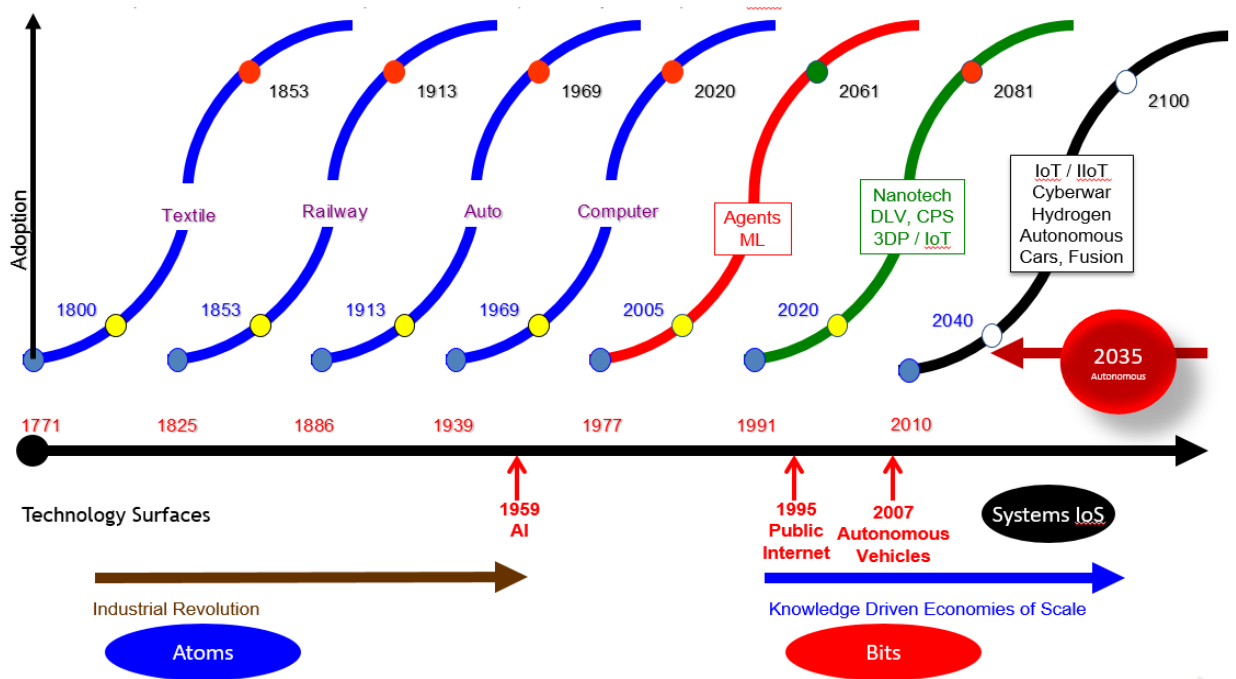


Fig 2: Advances follow a pattern, punctuated by certain intervals, in models by Poire.

THE PROPHASE FOR DIGITAL TRANSFORMATION

Before eukaryotic cells can replicate (cell division in plants, animals, including humans), the cell undergoes a prolonged phase of internal changes. The cell takes time to prepare, prior to the commencement of active phases, preceding the actual division of the cell. This phase is referred to as the prophase in the cell's cycle of replication or division.

As an analogy, the prophase for digital transformation may be divided into two parts, prophase 1 and prophase 2. Prophase 1 starts with hand stencils, which appears to be about 35,000 years old. The culmination of prophase 1 may be the Cuneiform script, circa 3500 BC, in Sumeria (Mesopotamia). It was probably the first time that thoughts or ideas, were transferred from the mind, via the stencils and then the scripts or pictographs, to tablets. Prophase 2 started in the Far East, with wood block printing circa 200 AD, but sprang to life with the discovery of the printing press by Johannes Gutenberg, circa 1440.

From the cuneiform script to the printing press spans about 5,000 years. This is the time it took to create tools for democratization of information. How many people read the Epic of Gilgamesh, which was written in cuneiform and carved on the Deluge tablet¹³ circa 2000 BC? How many read "If" by Joseph Rudyard Kipling? One had to be a Queen to have the resources, to read the Epic of Gilgamesh. The transaction cost, was too high. In the post-printing press society, 'If' was accessible to people during Kipling's lifetime (born on 30 December 1865 in Bombay and died on 18 January 1936, in London). In the 21st Century, 'If' may be downloaded for free. If the transaction cost is approaching zero, then please thank the digital economy, for lowering the barriers to market penetration.

Transaction cost¹⁴, pioneered as an economic staple by Ronald Coase (1937), is not the only lubricant for digital transformation. The human transformation to capture information and replicate information (stone tablets, papyrus, paper, books, bits) have had profound impact. The King as well as the citizen, the CEO as well as the clerk, the President as well as the janitor, can, now, access the same information. Ideas by Marshall McLuhan¹⁵ promotes that anyone, anywhere, may consume the same information. We are now able to democratize data due to advances in digitization and digital transformation.



Fig 3: The President and janitor may access the same information in a digital democracy.

The broad spectrum of digital transformation, which includes a future where Digital Twins¹⁶ may exist, may transform Marshall McLuhan’s suggestion to reality, for diverse verticals, ranging from manufacturing to robotics, energy systems to healthcare.

The preparation for digital transformation, the prophase, is nearing its concluding segment in OECD nations, but still struggling, in pockets, within ASEAN and USAN nations. The discrepancy between the economic zones is mostly due to structure of investments in infrastructure. Meaningful convergence of technologies is catalytic for digital transformation to grow sufficient roots, adequately fertilize markets in order to boost economies of scale, and improve profitable outcomes for economic development.

TOOLS FOR DIGITAL TRANSFORMATION

It bears reminding that the plural of anecdote is not evidence. This observation concerns Microsoft and the context is the infrastructure for digital transformation. In other words, the tools we need, must evolve and be available to the masses, in order to support digital transformation. Figure 4 shows the market cap of top 10 companies from 2001-2011. During this period¹⁷, US companies faced a return to the economic phase of 17th century England when NASDAQ lost 78% of its value (5046.86 to 1114.11) between March 11, 2000 and October 9, 2002. The “dot com” bubble was attributed, by some observers, to laissez faire economics. In contrast, the collapse of the Lehman Brothers in the US, ignited a global recession. The collapse was manufactured by deliberately structuring financial instruments, to peddle greed, by a few financial institutions. The S&P 500 declined 57% from its high in October 2007 of 1576 to its low in March 2009 of 676. Only Microsoft (and ExxonMobil) remained in the top 10, by market cap, during this decade (2001-2011) of “dot com” and “sub-prime” mediated financial turbulence.

2001	Name	HQ	Industry	Market Cap USD million	2008 [3]	Name	HQ	Industry	Market Cap USD m	2011 [1]	
1	GE	US	Various	477,406	1	Exxon Mobil	US	Oil and gas	403,366	1	Exxon Mobil 417,166.7
2	Cisco	US	Network	304,699	2	PetroChina	China	Oil and gas	325,320	2	PetroChina 326,199.2
3	Exxon Mobil	US	Oil & Gas	286,367	3	GE	US	Various	253,674	3	Apple Inc. 321,072.1
4	Pfizer	US	Pharma	263,996	4	Microsoft	US	Software	243,687	4	Industrial and Commercial Bank of China 251,078.1
5	Microsoft	US	Software	258,436	5	Wal-Mart	US	Retail	235,605	5	Petrobras 247,417.6
6	Wal-Mart	US	Retail	250,955	6	P&G	US	Retail	211,460	6	BHP Billiton 247,079.5
7	Citigroup	US	Banking	250,143	7	Industrial Commercial Bank of China	China	Banking	208,397	7	China Construction Bank 232,608.6
8	Vodafone	UK	Telco	227,175	8	Berkshire Hathaway	US	Insurance	202,901	8	Royal Dutch Shell 226,128.7
9	Intel	US	Computer	227,048	9	China Mobile	China	Telco	198,558	9	Chevron Corporation 215,780.6
10	Royal Dutch Shell	NL/UK	Oil & Gas	206,340	10	J & J	US	Health care	193,602	10	Microsoft 213,336.4

Fig 4: Microsoft survived the economic turbulence (Top 10 list by market capitalization)

In another analysis (Fig 5), which covers about a decade (from 2005 to 2015), economic volatility created a sinusoidal path, but failed to eject Microsoft (and ExxonMobil) from the top 10 list¹⁸ of globally dominant companies.

2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
General Electric	General Electric	Exxon Mobil	Petrochina	Exxon Mobil	Petrochina	Apple Inc	Apple Inc	Apple Inc	Apple Inc	Apple Inc
Exxon Mobil	Exxon Mobil	General Electric	Exxon Mobil	Petrochina	Exxon Mobil	Exxon Mobil	Exxon Mobil	Exxon Mobil	Exxon Mobil	Alphabet Inc
Microsoft	Citigroup Inc	Microsoft	General Electric	Microsoft	Apple Inc	Petrochina	Petrochina	Microsoft	Alphabet Inc	Microsoft
Citigroup Inc	Microsoft	Citigroup Inc	China Mobile	China Mobile	ICBC	BHP Billiton	Microsoft	Petrochina	Microsoft	Berkshire Hathaway
Wal-Mart	BP Plc	Gazprom Pao	ICBC	Wal-Mart	Wal-Mart	ICBC	ICBC	ICBC	Berkshire Hathaway	Exxon Mobil
BP Plc	Wal-Mart	Petrochina	Gazprom Pao	ICBC	CCB	Petrobras	IBM	China Mobile	General Electric	Amazon.com
Pfizer Inc	Bank Of America	ICBC	Microsoft	General Electric	Microsoft	CCB	Chevron	Alphabet Inc	Johnson & Johnson	Facebook
Bank Of America	HSBC	Bank Of America	AT&T	AT&T	HSBC	Microsoft	Alphabet Inc	Wal-Mart	Wal-Mart	General Electric
Johnson & Johnson	Johnson & Johnson	AT&T	Petrobras	Apple Inc	Petrobras	BHP Billiton	Wal-Mart	Berkshire Hathaway	Chevron	Johnson & Johnson
HSBC	Toyota Motor	BP Plc	BP Plc	Johnson & Johnson	Alphabet Inc	China Mobile	China Mobile	General Electric	Wells Fargo	Wells Fargo

Fig 5: Global tech dominance by US companies (illustration from Goldman Sachs)

Can we make any sense about digital transformation from these illustrations? It may be a bit heretic to arrive at any conclusion, but perhaps there is a suggestion lurking between the lines. The only other US company that kept pace with Microsoft in these lists, is ExxonMobil. It is a commodity company. Will it be too much of a stretch to suggest that Microsoft, too, may be viewed as “digital” commodity company?

Technology companies are producing and servicing the *digital commodities* necessary to pursue digital transformation. Tech companies are purveyor of tools, to accelerate the adoption and diffusion of digital transformation. Tech companies servicing *digital commodities* may continue to amplify their profitability, seed global economic growth and lead the digital economy. If digital economy were to grow deeper roots, all forms of digital transformation must be pervasive and form a part of our daily lives. The latter is one definition of a commodity. If WiFi isn't a commodity, then what is it?

Digital tools and their applications are commodities, for citizens in a connected world, the networked physical world of things or objects and the networked society. From that perspective, the portfolio representing the primary source of revenue, for five tech behemoths (Fig 6), suggests why Microsoft, as a purveyor of digital commodities, may weather storms, endure turbulence and survive economic volatility. Connectivity and commodities (products) are essential, hence, continued optimism for Apple and Amazon.

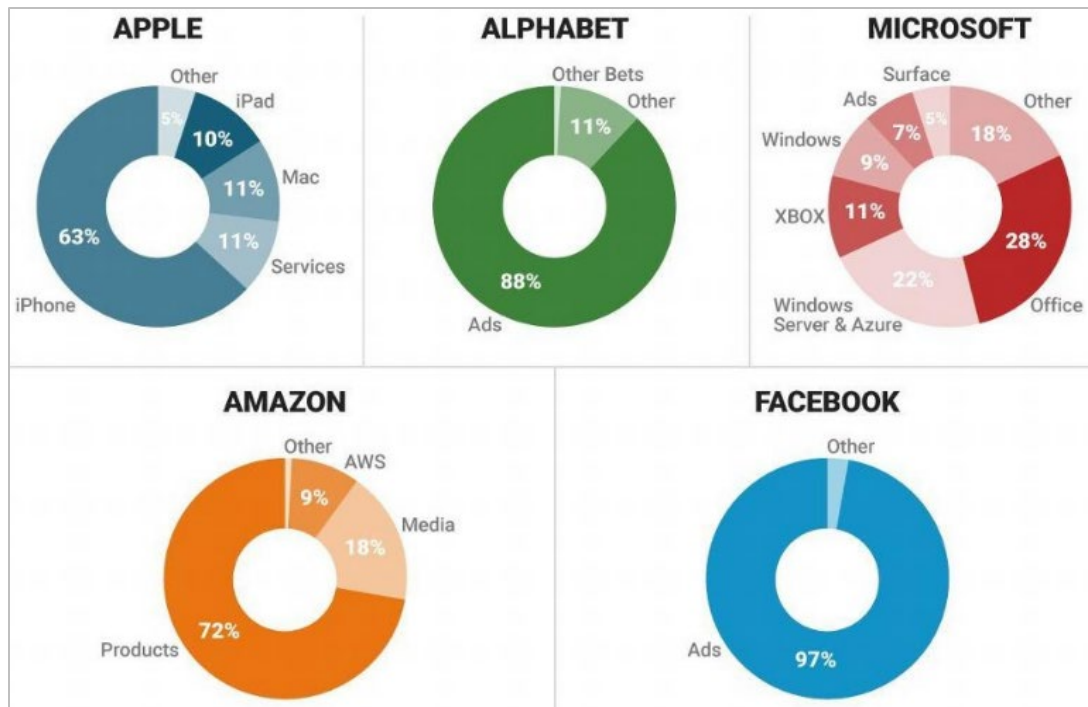


Fig 6: Revenue streams¹⁹ of US technology behemoths and the “ads” percentage in each.

Products may be simplified into two categories – push and pull. Products in the pull category are “things” (products, services) which are consumed (B2B, B2C, C2C). Push is distributed, almost irrespective of demand. Microsoft (Fig 6) produces and serves the digital commodities sector, the “pull” category because consumers consume.

Advertisement (ads), which are pushed, may have restricted viability. In other words, there is only so much that an advertisement can expect to achieve. Hence, the dependence on ads, sooner or later, may approach its growth limit. Disproportionate reliance on ads as a revenue stream, offers room for doubt about the viability of such a business model. Yet, in the short term, both tech giants (Fig 6) seem infallible, in their approach. Perhaps there is still enough advertising budget yet to move from print and other audio-visual media to the digital domain, which can tailor customer-specific ads.

The question of how much advertisements can achieve, in terms of sales, is worth exploring. Perhaps a model can be created (may exist) where a product or service (being advertised) may be assigned a penetration score based on [1] cost of product or service [2] purchasing power parity vs the “need” for the product/service [3] demographic spread of income vs disposable income or discretionary spending by households/individuals and [4] other factors, for example, brand recognition, social trajectory (status), philanthropy.

Using an “area under the ROC curve” tool, the model may suggest the boundaries of buying power. No matter how much you advertise, the outcome may be restricted within a buying power “area” under the ROC (Receiver Operating Characteristic) curve.

ROC analysis is part of "Signal Detection Theory" developed during World War II for analyses of radar images. Its current usage spans a vast spectrum of applications, including medical applications²⁰ pioneered²¹ by Charles Metz²².

DATA IN DIGITAL TRANSFORMATION: INFORMATION ARBITRAGE

The importance of data in decision making is not a new facet for the 21st century. Bargaining was the key *modus operandi* to negotiate dynamic pricing, in the bazaars of Mohenjo-Daro²³ and Harappa²⁴, during the “modern part” (3500 BCE-1800 BCE) of the Indus Valley Civilization which dates back²⁵ to 7000 BCE. Bargaining was the life blood of commerce for traders on the Silk Roads²⁶ and Silk Routes (500 BCE to 500 CE).

From 2nd century BC to end of 14th century AD, a trade route originated from Chang'an (now Xian) in the east and ended at the Mediterranean in the west, beyond Venice. Hence, linking China with the Roman Empire. The Great Bazaar²⁷ in Istanbul is rooted in the Silk Route. Kapalıçarşı²⁸ or Büyük Çarşı, began as a small strong room, the Bedestan, built in 1461. It grew to cover 100 acres, and now has 18 gates and about 4000 shops, drawing about 91 million annual visitors. All kinds of bargaining behavior evolved; complex negotiations done simply by hand gestures, carried out beneath the cover of a shawl to prevent prying eyes from knowing what deals were being struck.

Bargaining, hence, was the first form of data arbitrage or information arbitrage. The importance of data is neither unique to digital transformation nor did it dawn upon us in the recent past. Data and decisions are inextricably linked and has always been, even ***before*** the evolution of human speech. Imagine humans using gestures to signal or warn that an animal is approaching.

It is ironic that pre-Neanderthalic gesture communication is being re-invented by BMW²⁹ to enhance the ultimate driving experience. Gesture appears to be the new toy³⁰ in the connected world but has the potential to serve humans with speech impediments.



Fig 7: Silk Roads and Silk Routes – trading valid for the period 500 BCE to 500 CE. In 1877 the term "Seidenstraße" (Die Seidenstrassen, literally "Silk Road") was coined³¹ by the German geographer, cartographer and explorer Ferdinand von Richthofen.

Perhaps even more incredible, is the use by the United States, the ethos of the messengers on the Persian Royal Road. During the Achaemenid Empire (500-330 BCE), the Persian Royal Road ran from Susa (modern day Iran), to the Mediterranean Sea in Asia Minor (modern day Turkey). It served as one of the main arteries of the Silk Road, the network of trade routes, formally established during the Han Dynasty of China, which linked the regions of the ancient world, for commerce. The Persians maintained the Royal Road carefully and, in time, expanded it through smaller side roads. These paths eventually crossed down into India, across Mesopotamia, and over into Egypt.

The Persian Royal Road featured postal stations³² along the route, with fresh horses, for envoys to quickly deliver messages throughout the empire. Herodotus, writing of the speed and efficiency of the Persian messengers, stated:

“There is nothing in the world that travels faster than these Persian couriers. Neither snow, nor rain, nor heat, nor darkness of night prevents these couriers from completing their designated stages with utmost speed.”

These lines, from his Histories, 8.98, would, centuries later, form the creed of the United States of America’s postal service³³(USPS).

Data, and its time-sensitive arbitrage, as well as exchange and communication, are central to human evolution. The amount of data, its visual representation and extracting its contextual significance, has evolved over time. Digital transformation is yet another chapter in this evolution, as we sharpen our repertoire of analytical tools and continue to add new techniques for analysis of data, to make sense of its meaning and visualize data.

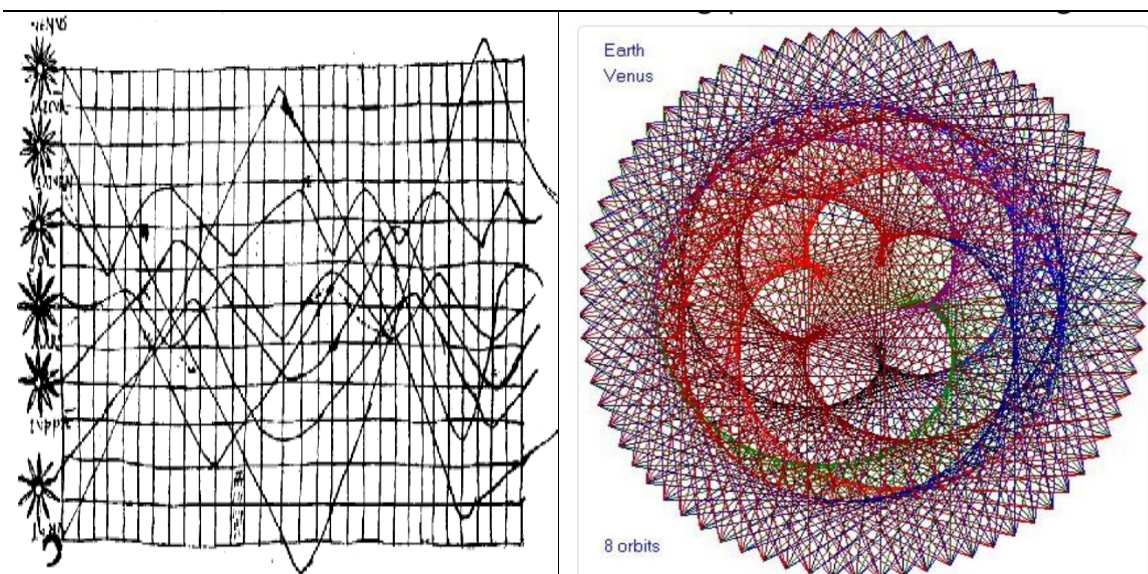


Fig 8: Visualization – (Left) Positions³⁴ of Sun, Moon, Planets, from 950 AD, Europe. (Right) Positions³⁵ of Earth and Venus (?) over 8 years (science³⁶). A fractal³⁷ pattern?

In the evolution of internet of things, the principal emphasis is on data. In other words, we can think of IoT, to serve as a design metaphor for DoT or “data of things” implied in the principle of connecting bits to bits. That is, connecting not only data about things (bits about atoms) but also data about data or information store (bits about bits).

Because these data stores and things must be connected to be a part of a system or ecosystem, the network of the internet serves as the connectivity medium and gives rise to the recent concept of NoT or network of things³⁸ advocated by NIST. NoT reinvents a concept which shares common grounds with Metcalfe’s Law.

Metcalfe's law³⁹ states the value of a telecommunications network is proportional to the square of the number of connected users of the system (n^2). Attributed to Robert Metcalfe in regard to Ethernet, Metcalfe's law was originally presented, circa 1980, not in terms of users, but rather of "compatible communicating devices" (for example, fax machines, telephones, etc.). Later, with the globalization of the internet and the rapid diffusion of the concept of IoT, the idea was carried over to include, perhaps erroneously, users and networks. Its original intent was to describe Ethernet connectivity.

The significance of the “network effect” in these concepts relates to the value of information from one node versus a network of nodes. A multitude of nodes can act as a *swarm*. Data from such *swarms* may lend itself to analysis using the principles of swarm intelligence, for example, ant-based algorithms, used in network optimization routines⁴⁰ and sensor networks⁴¹ in addition to emerging applications in digital twins (see Chapter 3 in *Haphazard Reality – IoT is a Metaphor*⁴²).

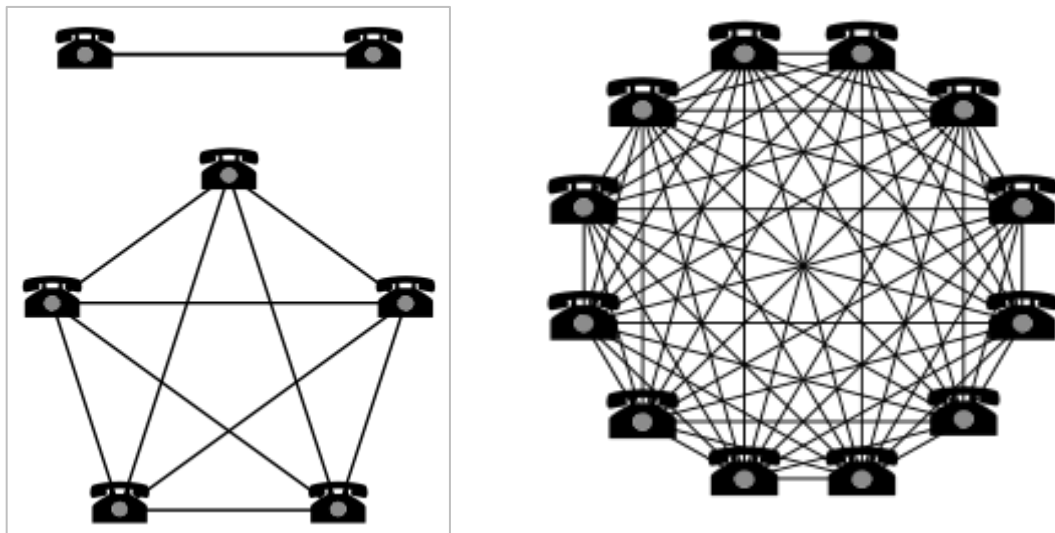


Fig 9: Two phones can make one connection, 5 can make 10 connections, and 12 can make 66 connections $[12(12-1)/2]$. Metcalfe's Law is related to the fact that the number of unique connections in a network of a number of nodes (n) can be expressed as the triangular number $n(n - 1)/2$, which is proportional to n^2 asymptotically (ref 39). In other words, the apparent value of the network increases with the number of connections. Hence, Metcalfe’s Law, adapted to serve special interests, highlights the “value” of social networks. The latter has created grand illusions, catalyzes various forms of delusions and increasingly, we witness the transmutation of tabloid fodder, from speculation, to truth.

HYPE OF ARTIFICIAL INTELLIGENCE IN DIGITAL TRANSFORMATION

The present day unscrupulous marketing, about the power of, and benefits from, artificial intelligence, is reminiscent of the campaign of lies orchestrated by the US sugar industry. These “lies” stretch over the past 50 years⁴³ and the most egregious act⁴⁴ by the sugar industry was to bribe Harvard researchers⁴⁵ to publish false results, to shield the ill effects of excessive use of sugar⁴⁶, exposed in a JAMA⁴⁷ paper on September 12, 2016.

The exponential volume of deliberate false marketing and claims about AI by certain corporate behemoths, is increasingly amplified through ill-informed “me-too” social networkers, craving self-promotion.

This disingenuous AI barrage has all but drowned out the reasoned voices of credible scientists and genuine thought leaders, who are reluctant to be pro-active and abide by a code of decorum, prefers understatement, and are generally not narcissistic.

Artificial Intelligence (AI) and its lack of intelligence, is neither news nor new (see Chapter 4 in *Haphazard Reality – IoT is a Metaphor*⁴⁸). The term AI is a misnomer but has caught the public imagination. John McCarthy coined the term and used it in the August 31, 1955, proposal for the Dartmouth Conference⁴⁹ to be held during the Summer of 1956. The usefulness of AI is a fact but not in the manner advertised, at present.

Making sense of data is central to profitability in the digital economy. Traders who were bargaining in the ancient bazaars had a limited set of data (for example, price of goods). The data set was sufficient for humans, with good memory, to develop astute bargaining skills, through data arbitrage, and excel in dynamic price optimization.

Even super-humans, with photographic memory, may not be able to navigate the pricing data from one single vendor, Amazon⁵⁰, which sells over 480 million products in the US. Amazon's product selection expanded by 235 million since Q1 of 2016. It has added, approximately half a million new products (485,000 SKUs), per day.

Dealing with such immense data volume is a major handicap for humans and the primary benefit from computation and data analytic tools, including AI type applications. Imagine the delivery planning⁵¹ optimization problem for goods delivery from Amazon.

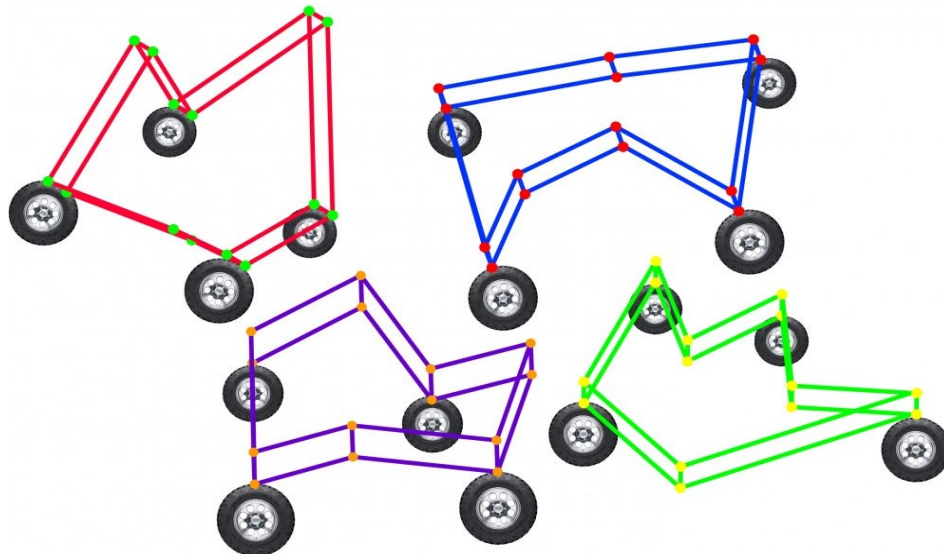
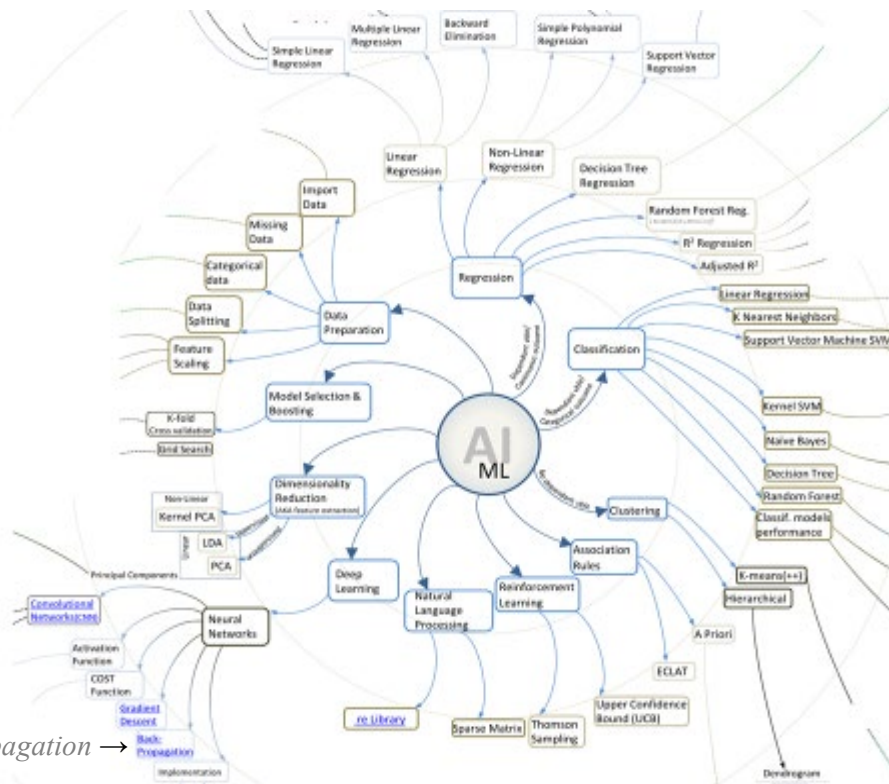
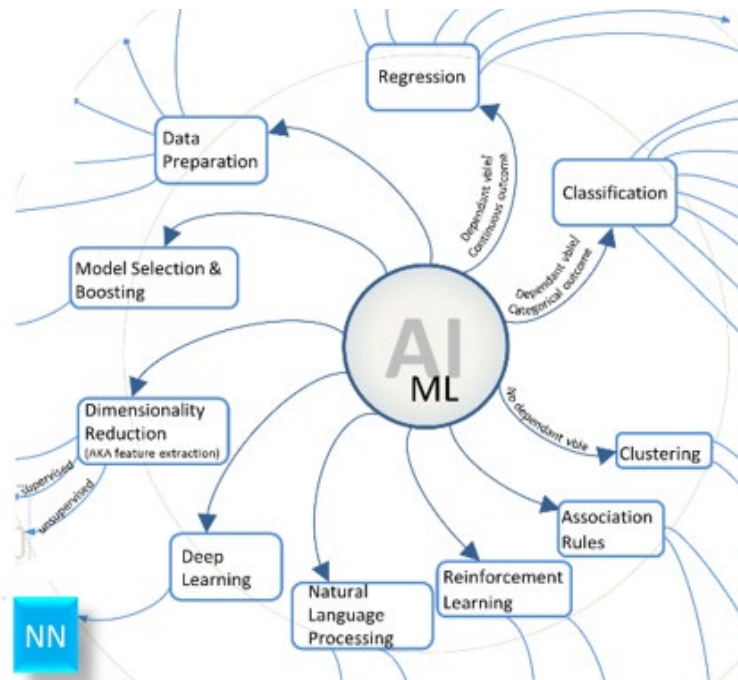


Fig 10: Algorithms are key for transportation routes and sequence for delivery (ref 51)



Backpropagation →

Fig 11: Artificial Intelligence and Machine Learning are umbrella terms for many different tool sets and subsets. Knowledge of the problem space, context of the data, structure and quality of data, feature engineering and deep conceptual understanding of convergence, holds the key, in selecting the appropriate portfolio of techniques⁵² and algorithms, which, if combined, in proper sequence, may deliver an optimal outcome.

In the real world application space, selection of AI/ML tools must be context-dependent. In practice, the individuals who have industry knowledge, for example, in retail and fast moving consumer goods, may not be skilled as supply chain optimization analysts. The latter is classically the domain of specialists in operations research (OR). The retail industry may employ OR experts, to grasp the nuances of the retail business, in the *context* of the markets (understanding demand, demographics, distribution, etc).

In the realm of digital supply chain, the retail analyst is expected to use or apply AI/ML tools to optimize outcomes (for example, Fig 12). The confluence of knowledge, understanding of data, and selection of algorithms, must converge, for harmonization of the processes. Analysts must frame the correct questions, expect actionable information, and use it to improve decision systems, *before* the value of the data/information perishes.

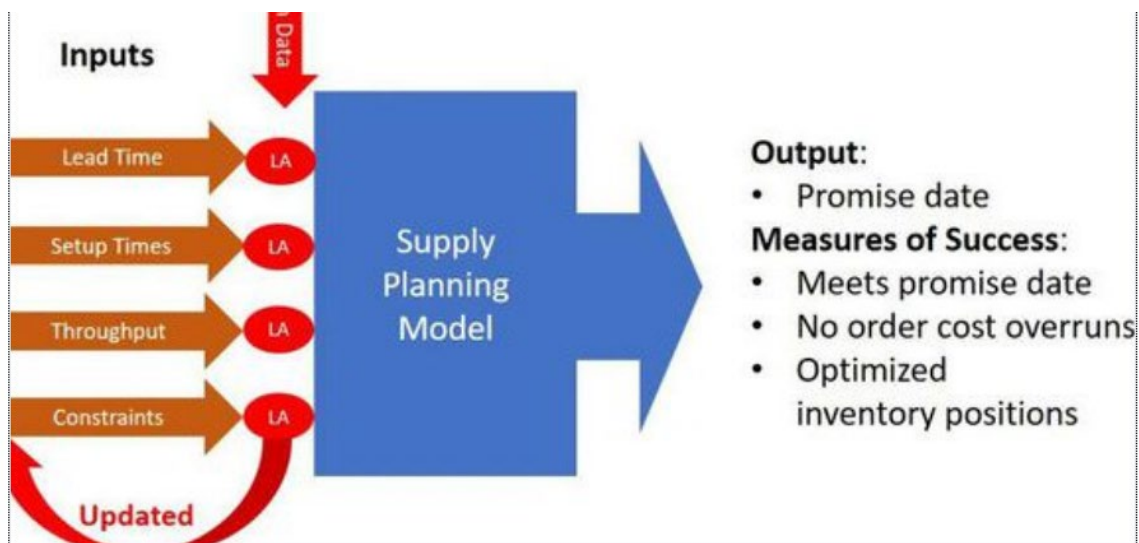


Fig 12: Supply Chain Production, Planning and Optimization, using AI/ML tools. The coordination of these tasks within the enterprise, in the context of digital transformation, may be, still, largely in a “power-point” phase. Connecting data acquisition tools (RFID, sensors, market data) with the data curation domain, followed by the data analytics tools, in *context* of feature selection, with respect to the business/market logic, is the essence of the design at the heart of the internet of things concept. Connecting data about things, processes and decisions, is a part of the broad spectrum of the *atoms to bits* paradigm.

Transforming enterprises to digital enterprises is a herculean undertaking. It may take *decades* before actual transformation takes hold, survives the “pilot” phase and is accepted by business units, as a part of *their* operations. Human resource changes are necessary to transform ideas into reality, and, the seat of greatest uncertainty. Perspective of the leadership, and the ability of the executive management to lead these changes, are often in doubt. Even when the leaders seem to understand and champion the change, the pace of change is, at best, sluggish, or contained within a specific domain or business unit. Diffusion of change throughout the organization is difficult. The latter created buzz about “change management” and “open innovation” which are often lame and bit vague.

To add insult to injury, big consulting firms take advantage of these “gaps” and rake in billable hours. Publicists and marketing moguls, in pursuit of sound bites and media attention, create and disseminate, fantasies, which are empty, vapid and callous (Fig 13).

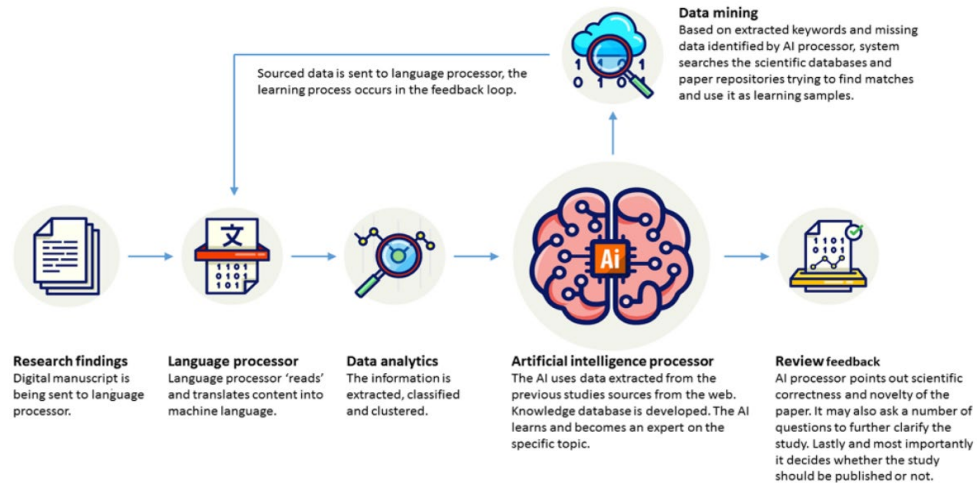


Fig 13: Mindless drivel created⁵³ as AI and sourced by a “show-biz” organization⁵⁴ as a window dressing, to peddle AI tools and enhance the “optics” of erudite imagery.

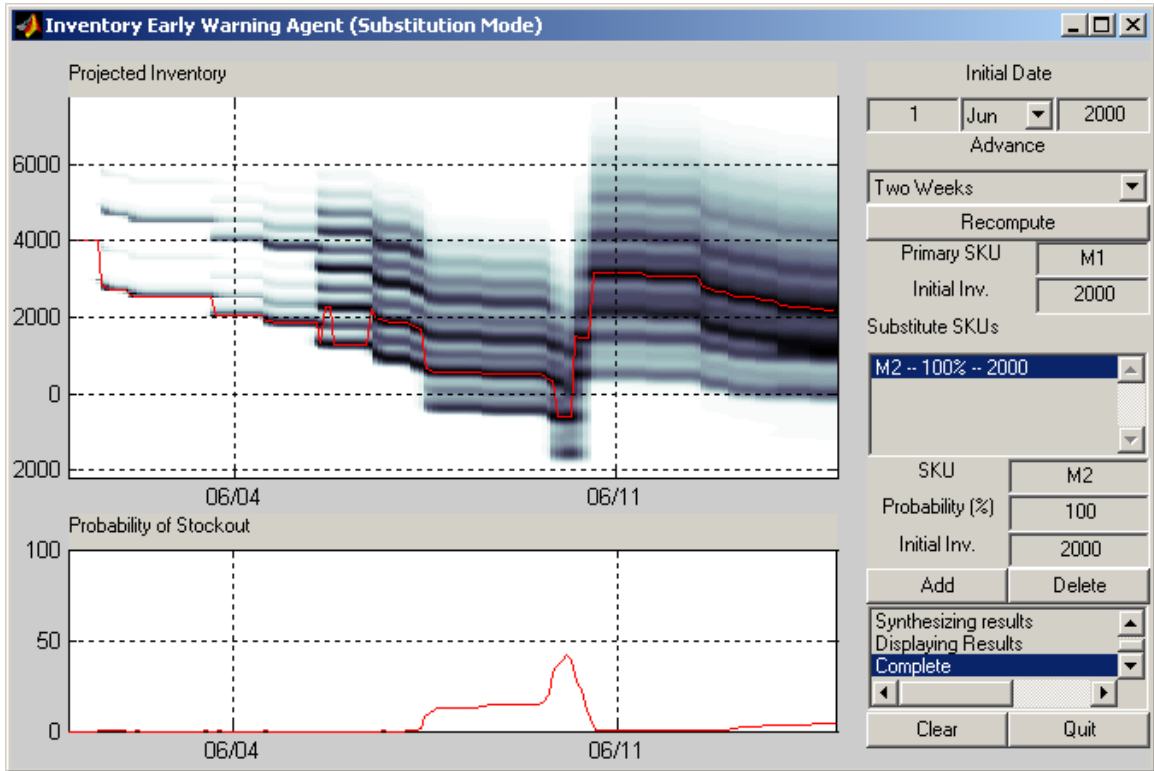


Fig 14: Model application using AI tools (SAP screen shot taken on June 1, 2000). Use of RFID, sensor data, and software agents, to reduce out of stock for inventory management.

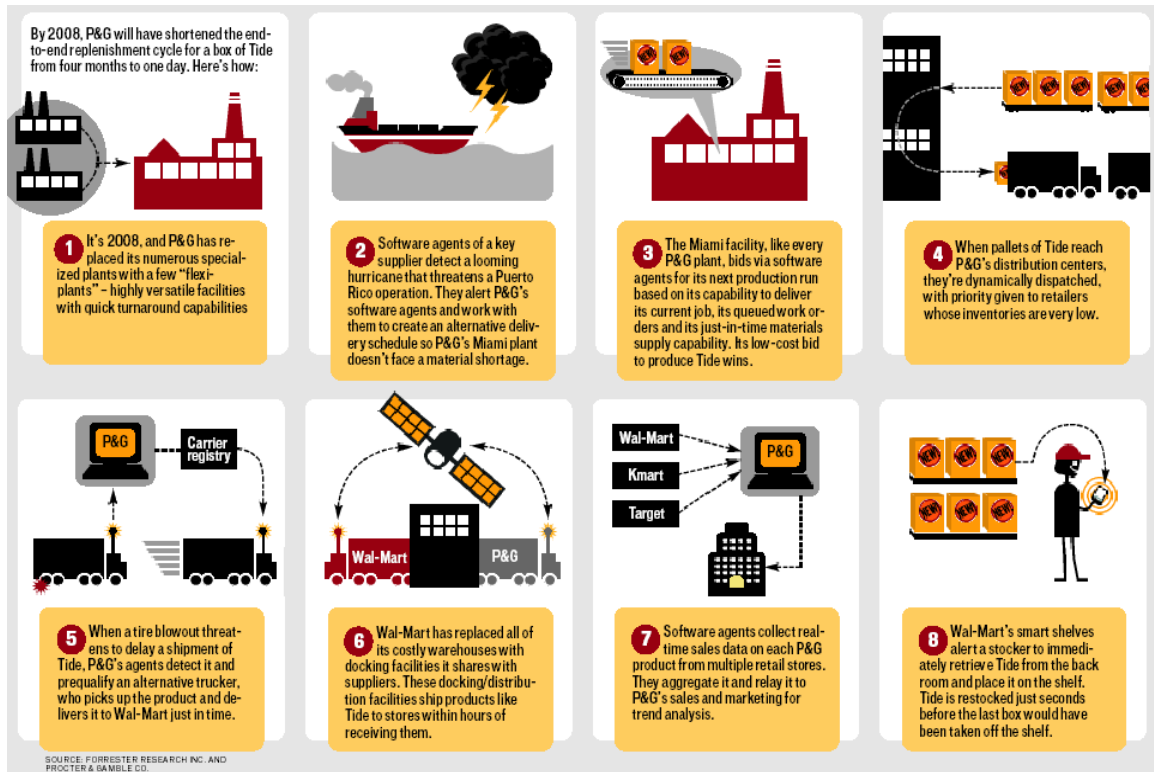


Fig 15: An example from circa 2001, which did not happen. Created by a consulting firm for a retail behemoth, the cartoon shows *digital transformation by "power-point"* based on RFID EPC advances from MIT Auto ID Center and the model application in Fig 14.

Figure 14 illustrates the pragmatic benefits of digital transformation, one may expect, from reasonable use of tools (given their limitations), sourced from the portfolio of techniques, broadly referred to as AI/ML (artificial intelligence / machine learning). AI lacks intelligence, naturally. That is not the problem. The lack of the ability of humans, to understand *why* AI lacks intelligence, is the fuel which perpetuates the conundrum. But, enigma sells news, pseudo-sensational news accelerates publicity and the combination, spells profit. Hence, the penchant for industry to prolong the myth of intelligence in AI.

Figure 15 was created with great fanfare but failed to be functionalized due to business reasons. Open Source Interconnect (OSI) model shown in Figure 16 (bottom) is the structure of the infrastructure which makes it possible for us to access bits. But access is not the same as connectivity, in the *context of process*. Connecting business partners and domains (Figure 15) with business processes (Figure 16, IoT layers,) may be far more difficult. Access and analysis of bits, from *intra-enterprise* data silos, is impotent.

Failure to implement the AI application (outlined in Figure 14) or execute the P&G vision (Figure 15) is due to the immense procedural difficulties and intrinsic human resistance, to link process, and data flow, in *context* of the business *relationships*, which must converge, to generate the outcome (illustrated in Fig 16, top; seven layers of IoT). Connecting bits (Fig 16, bottom) to atoms (Fig 16, top) is a simple design metaphor, in principle, but difficult to execute in practice. We are still in the "*power-point*" phase.

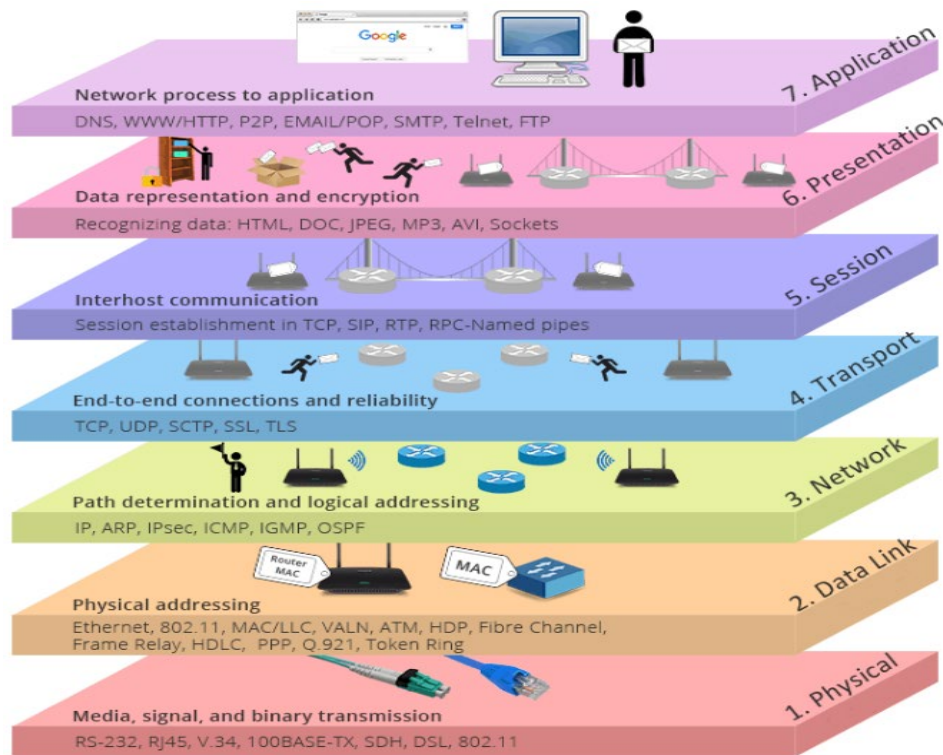
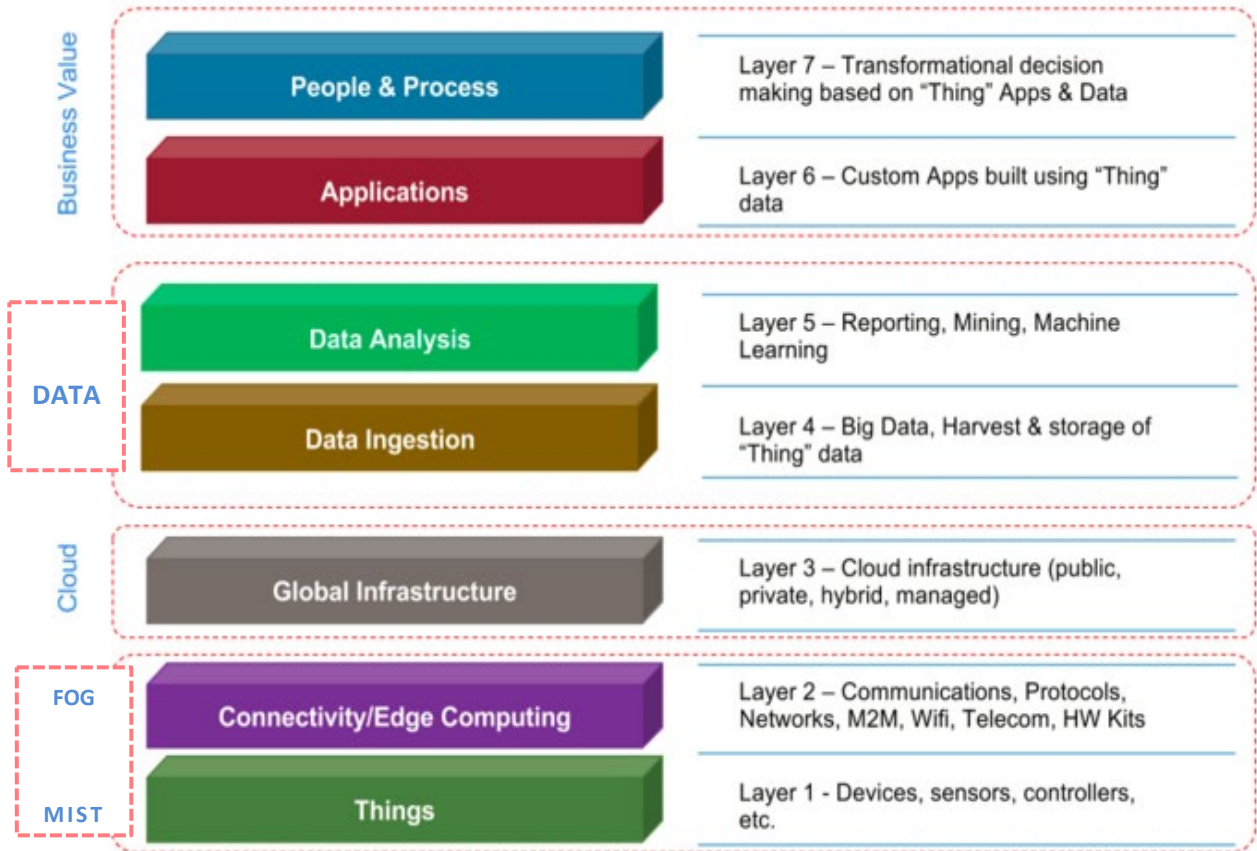


Fig 16: Structure of connectivity (atoms to bits) - OSI⁵⁵ vs IoT (top). Dynamics of cloud, fog and mist computing, and QoS⁵⁶, will be influenced⁵⁷ by bandwidth, latency and jitter.

Systems integration of AI tools at various data analytical nodes (core vs edge, cloud vs fog computing, real-time mist computing) within an ecosystem, is far from reality. Add-on or external data analytical engines are, logically, the first point of entry for new tools, including AI/ML. The analytical outcome is fed back into the system or the decision process. Processing high volume unstructured data is immersed in trial and error.

Application of AI/ML tools are a part of this “learning” process. The learning process itself is bereft with problems. The algorithms are plagued with misconceptions about how the human brain works, in particular, the neural networks (see Chapter 4 in *Haphazard Reality – IoT is a Metaphor*⁵⁸), which generates artificial neural networks.

An example is the backpropagation algorithm⁵⁹ which is a staple in the AI world. In 1986, Geoffrey Hinton co-authored the seminal paper, which, three decades later, is central to the marketing explosion of AI. In YYZ, on Sep 13, 2017, Hinton said⁶⁰ his method should be dispensed with and he is “*deeply suspicious*” of the back-propagation⁶¹ method, which underlies the hype marketed as AI, including the capacity to sort through photos and talk to Siri. “*My view is throw it all away and start again,*” Hinton said.

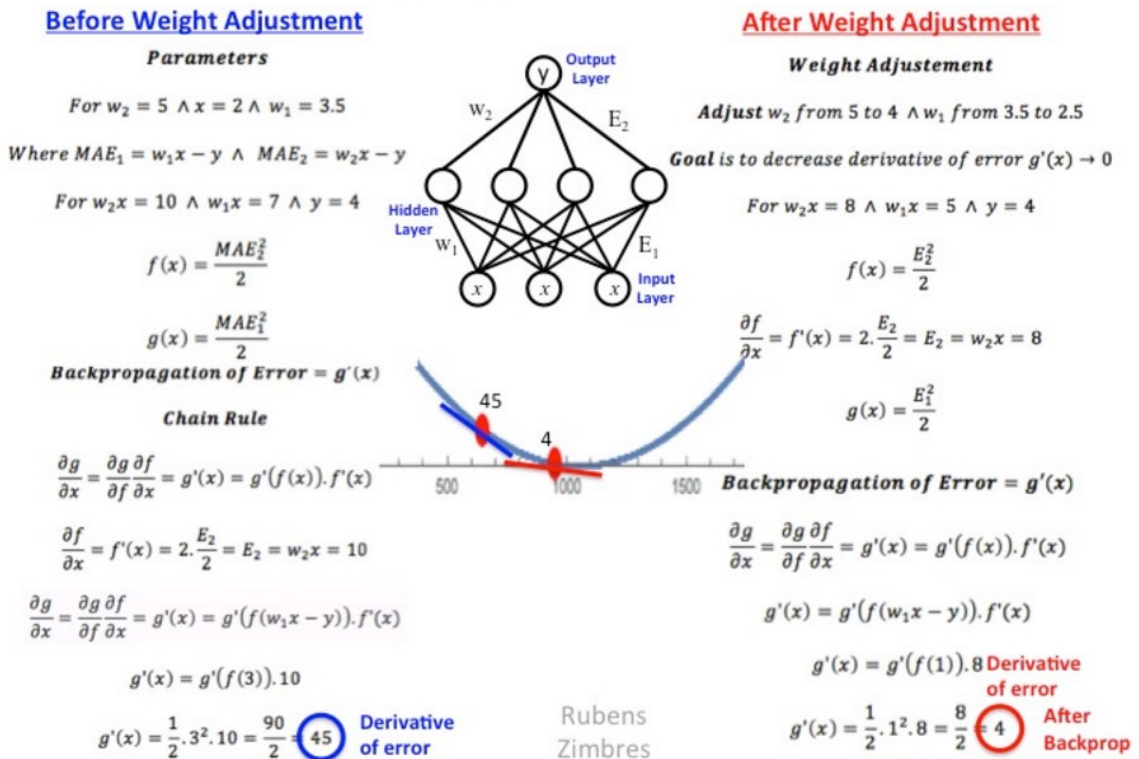


Fig 17: Backpropagation algorithm⁶² (see Figure 11), in principle, is an error correction routine. It is a form of “supervised” learning⁶³ to train artificial neural networks (ANN). After the training, the ANN should do what the trainer expects (the output), for example, recognize a hot dog, from a photo of a hot dog vendor, on the streets of New York City. If the output of ANN fails to recognize the “hot dog” (if the output is *baseball bat*) then the training algorithm, goes *back* and adjusts the “weights” associated with each step, in order to drive the neural net to output “hot dog” as the outcome of supervised learning.

Error correction is a staple and invaluable mathematical tool, in science and engineering. It is of critical importance in many fields. Without error correction codes, information theory⁶⁴ may not function. Applications in finance⁶⁵ and supply chain⁶⁶ pre-dates the buzz of “big data” by at least a quarter century. Hence, error correction routine in backpropagation, in principle, is extremely valuable, and conceptually, is essential.

The discontent about backpropagation stems from the forced fitting of weights to deliver *anticipated learning*. Adjusting weights is a blend of stochastic and heuristic methods. It is not reflective of biomimetic processes in higher organisms and unlikely to represent neural networks in humans. Thus, the call to “*start again*” is both judicious and justified. The application of error correction, in the *context* of training neural networks, may be revisited or reviewed by “new” eyes, to deliver new tools, to complement or even replace backpropagation method. However, true AI/ML tools are *essential* for our future.

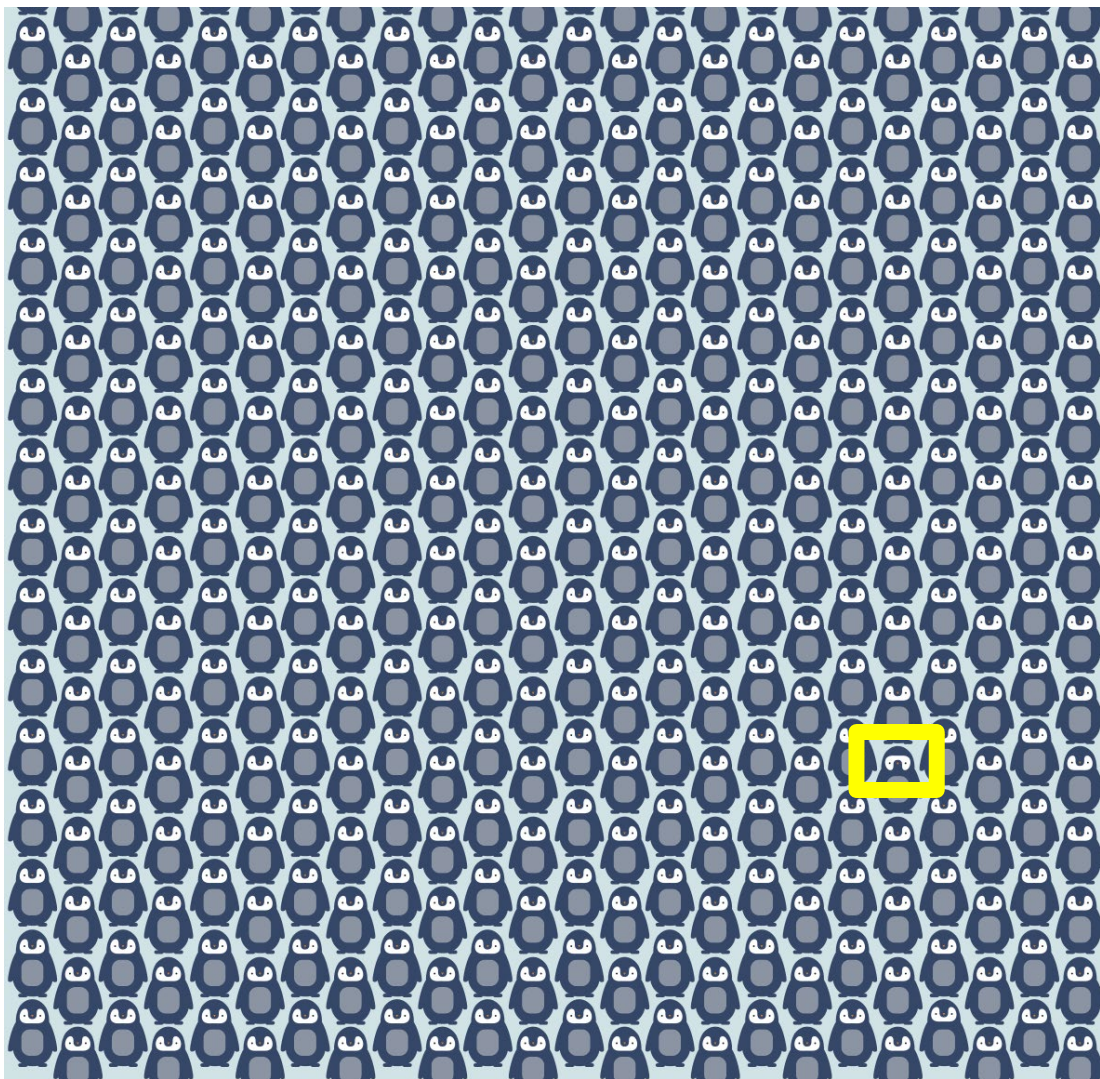


Fig 18: Machine Learning (ML) may be one way to detect anomalies⁶⁷ in large data sets. The importance of AI/ML in data analytics will depend on the question and its *context*.

Moving forward, beyond backpropagation, Geoffrey E Hinton of Google Brain has now, thankfully, re-invented a grand idea that was shining in relative obscurity, for more than half a century. Hinton's "capsule" papers⁶⁸ are "the emperor's new clothes" made from Marvin Minsky's "cube-on-cube" (Hinton's "capsule"). Minsky's idea dates back several decades but it was published⁶⁹ in a book format in 1985. The illustration from "Society of Mind" is reproduced in Figure 19. In combination with Agent based hierarchical solutions (Agent, Agents, Agency, Agencies), the principles and practice of using ant-based algorithms in multi-agent systems⁷⁰ have been around since 1960's.

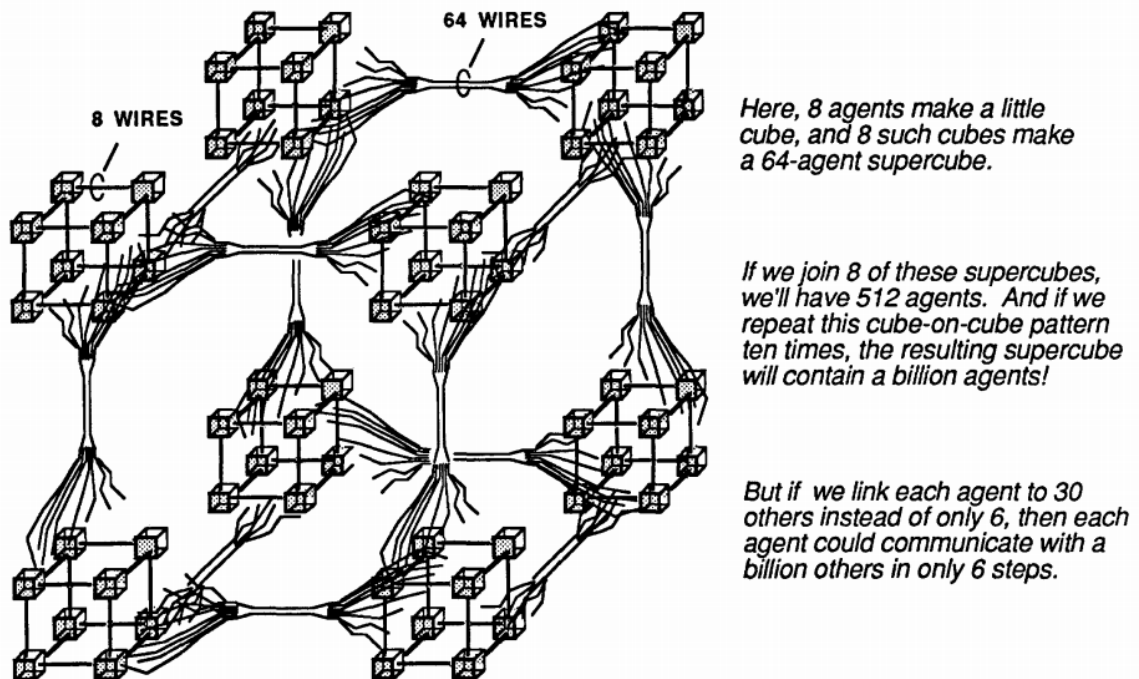


Fig 19: The network concept is obvious in this illustration by Marvin Minsky (ref 69). The abstraction is loosely based on synaptic connections made by neurons (in brains) and may have also inspired Charles Babbage, circa 1850, to lay the foundation of the design (but not build) the difference engine (ref 77). Each unit of data or information or parameter or variable or value (binary) may be captured in **cubes** in Marvin Minsky's diagram. It may be extrapolated to the novel "**capsule**" concept, suddenly re-invented by Geoffrey E Hinton, of Google Brain, and presented at the 31st Conference on Neural Information Processing Systems (NIPS 2017, Long Beach, California, USA). The power of the "cube-on-cube" concept is evident due to several "re-inventions" of this principle and certain forms of commercial products which may have borrowed its salient features (for example, the "containers" software⁷¹). Cube-on-cube reappears in several chapters in my book *Haphazard Reality – IoT is a Metaphor*⁷² to illustrate various ideas, including the concept of hash tables⁷³ and blockchain⁷⁴ as well as the key essence of connectivity.

ELUSIVE QUEST FOR BIO-INSPIRATION IN DIGITAL TRANSFORMATION

From the dawn of computer design⁷⁵ the management of architectural complexity (lower levels of logical circuits to higher levels, nested above one another) has drawn on the biology⁷⁶ of neurons, in general, and neuronal scaling, in particular, as a bio-inspired model. The history of artificial intelligence research, and difference engines, proposed by Charles Babbage⁷⁷, appear to take cues from neural structures found in worms, animals, mammals and, of course, humans. The human brain is often compared to a computer. It is a gross error, and distortion, of astronomical proportions. The brain is ***not*** a computer.

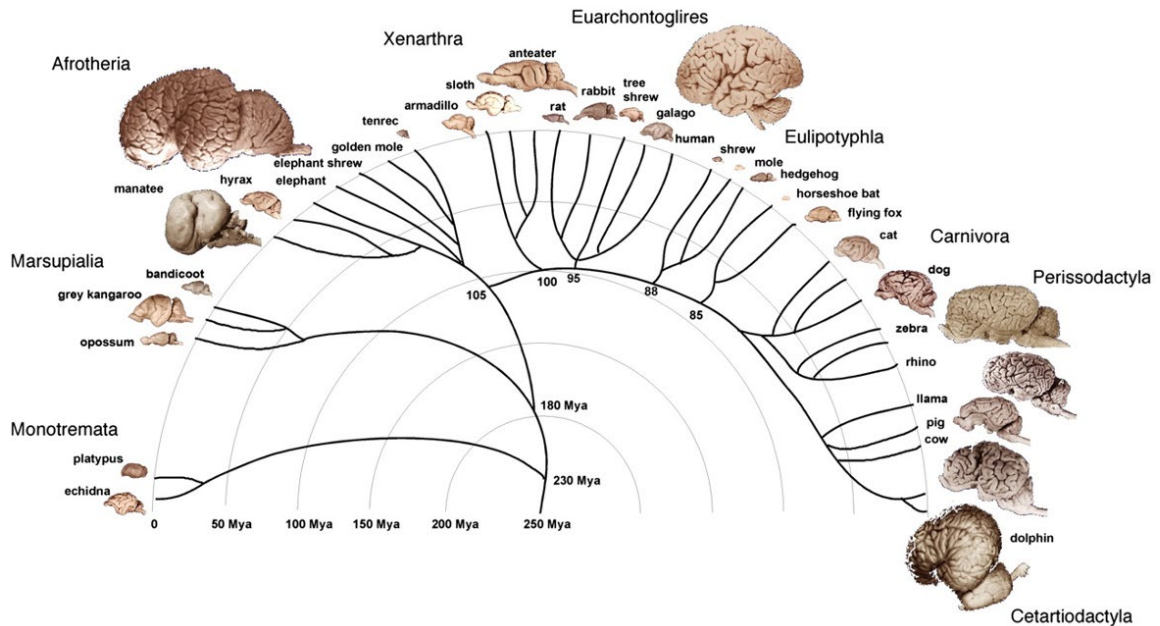


Fig 20: The myth⁷⁸ of the human “large” brain. *Homo sapiens* are not special. Large brains appear several times in the mammalian radiation (Mya = Million years ago).

In terms of an analogy, the roughest approximation, if one may dare to simplify, is the notion that the brain may partially perform functions resembling a very advanced systems integration platform. The brain is not a computer but computation may be a part of the platform analogy. The elusive quest for bio-inspired systems is justified because “nature” created structures and functions which successfully survived evolutionary tests.

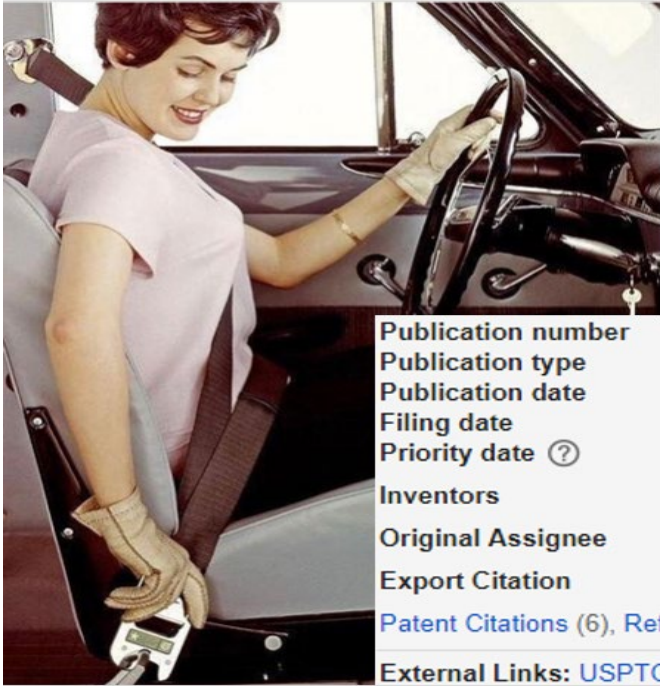
Lessons from bio-mimicry suggests that we should invest heavily on sensors and sensing. Why? Because the epidermis (for example, human skin) is a whole body touch sensor (pressure). Other sensors are located, all around the skull (optical-eyes, auditory-ears, olfactory-nose, gustatory-tongue). Bio communication medium is electrochemical (analogy - telecommunication) and operates in a hub-spoke system. Brain is the hub and the spoke (motor neurons) are muscles. Signal processing⁷⁹ happens in the brain, hence, the analogy, brain as a systems integration platform, with a “cloudy” component. Other signal processing (reflex arc⁸⁰) occurs through the spinal cord (analogy to fog or mist computing), for example, the patellar reflex (also, analogous to *in-network* processing).

Digital transformation is bursting at its seams with sensors, but making sense of data, to yield actionable information, is the quagmire of “*haphazard reality*”⁸¹ in IoT.

CRITICAL FOR DIGITAL TRANSFORMATION: CYBERSECURITY

Inviting digital annihilation is inevitable, without cybersecurity. If data and information exchange is desired beyond the closed “stand-alone” paradigm, then security cannot be “layered” as an after-thought.

Implementing security by design, through engineering principles in the backbone, is not only prudent, but may boost profit and brand recognition. The example from the auto industry, illustrated below, is of historic interest, with a message for practitioners, to think first about, and integrate cybersecurity, with digital transformation.



volvogroupeu [Follow](#)

volvogroupeu In 1959, #Volvo invented the 3-point seat belt, then gave a free license to all other manufacturers to use it. #tbt #throwbackthursday

Publication number	US3043625 A
Publication type	Grant
Publication date	Jul 10, 1962
Filing date	Aug 17, 1959
Priority date [?]	Aug 29, 1958
Inventors	Ivar Bohlin Nils
Original Assignee	Volvo Ab
Export Citation	BiBTeX, EndNote, RefMan
Patent Citations (6), Referenced by (16), Classifications (4)	
External Links: USPTO, USPTO Assignment, Espacenet	

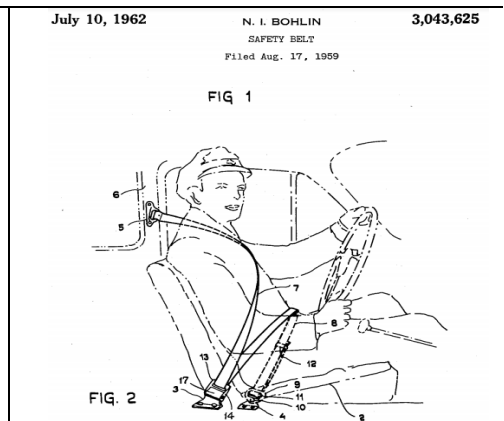
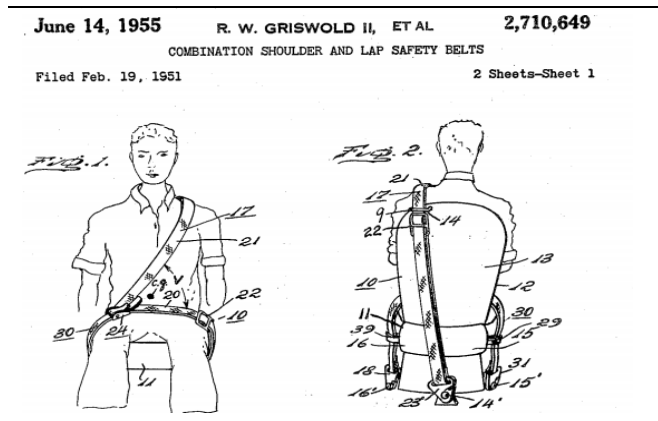


Fig 21: E J Claghorn patented a safety belt⁸² in 1885 but medical studies⁸³ and work from Griswold⁸⁴ and Volvo’s Bohlin⁸⁵ were necessary for widespread adoption. Swedish automobile Saab GT750 (Gran Turismo 750 produced between 1958 and 1960) introduced at the New York International Auto Show, in 1958, featured safety belts, as a standard.

The dramatic cybersecurity story of 2016 came to a quiet conclusion⁸⁶ on December 8, 2017, in an Anchorage (Alaska) courtroom, as three young American computer savants pleaded guilty to masterminding the unprecedented Mirai botnet, powered by unsecured internet-of-things devices like security cameras, wireless routers, that unleashed DDoS attack using an internet device on October 21, 2016. The Mirai "packet" strategy (PCAP) targeted IPv4 addresses and related DNS registries (Dyn).

Could IPv6 offer better protection for cybersecurity by engineering design? The economics of the resistance, to move from IPv4 to IPv6, is due to behemoths in the routing business, who have a lot invested in IPv4 and are simply guarding their profits.

DIGITAL TRANSFORMATION X.0

Do you have your compass? We are at the dawn of a new evolution. The road ahead is still under construction, plagued with ambiguity, potholes and gross missteps (Fig 22). Constructive convergence, and synthesis of ideas, may not be so easy.



Fig 22: Wearables are a new direction for the consumer internet of things (IoT). It is hyped up to measure vital signs and a tool for remote monitoring. The potential exists but the current practice is deeply flawed. In part, because software technicians are meddling in medicine. The heart monitor on the wrist band displays pulse rate of 40 BPM (beats per minute) but the medically verifiable heart rate recorded by Dr Wayne Whitwam, MD, is 147 BPM. This type of an error may spell the difference between life and death.

In *Darwin's Middle Road*⁸⁷ Stephen Jay Gould wrote, "if genius has any common denominator, I would propose breadth of interest and the ability to construct fruitful analogies between fields." This article hints at a lot of different domains and offers clues. I have alluded to diverse domains, which must converge, in order to transform the vision and weave it into the fabric of digital transformation.

The principle of connecting atoms to bits may be pervasive and it may gain ubiquity, in view of increasing computational power and decreasing cost of computation, as well as storage. However, the ideas relevant to internet of things (IoT), industrial IoT (IIoT), data of things (DoT) and network of things (NoT), are only a small part⁸⁸ of the connected world. The forthcoming tsunami of changes will be far greater than digital transformation. We need changes to improve quality of life⁸⁹ for billions of people.

For readers still willing to explore digital transformation, I may suggest my book "*Haphazard Reality - IoT is a Metaphor*" which is available⁹⁰ from the MIT Library.

TEMPORARY CONCLUSION: SIGN POSTS ON THE DIGITAL SILK ROAD⁹¹

Transformation is not limited to the digital economy. The scope of the economy itself is subject to change, based on other purveyors of civilization, for example, energy, food, water, health and diffusion of education. The cycle of economic evolution may span several generations and cover centuries, before these changes appear striking (Figure 23).

Prediction about the course of these changes are not easy but they are in abundant supply. Careful economic studies are few and far between. It is generally agreed that in the modern world (early 21st Century), we are equally, or more concerned, with access to sustainable and renewable energy, respectful of the ecological and environmental issues.

Hence, breakthrough in energy science and engineering, as well as, healthcare and sanitation⁹², can change the future of nations, and as a consequence, the global economy.

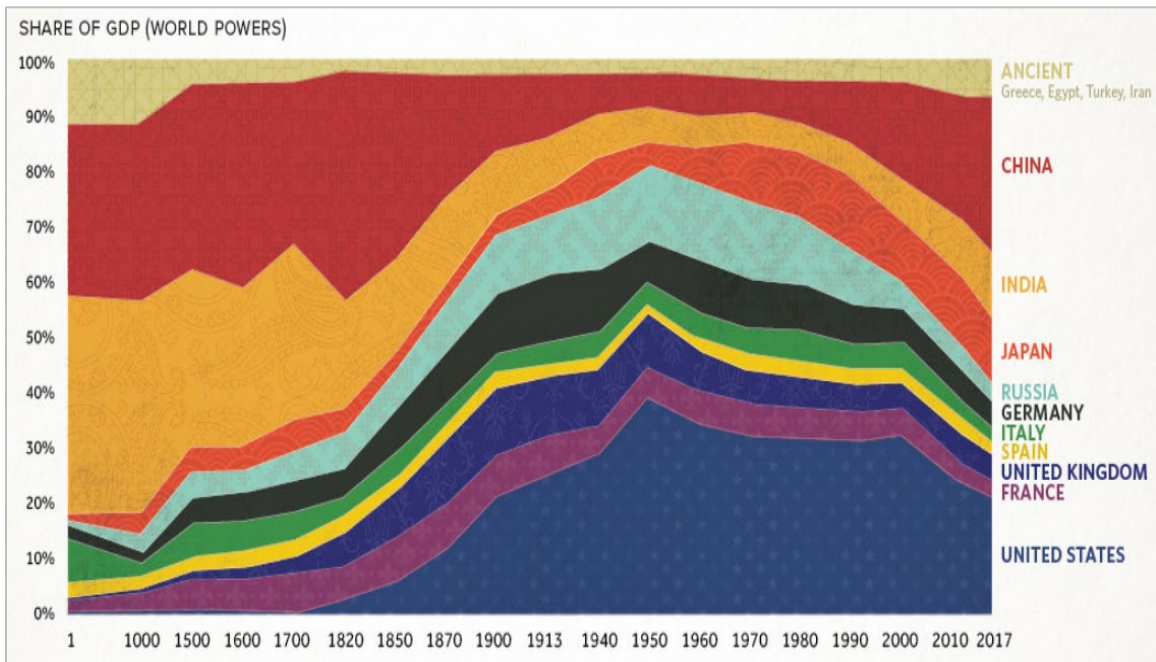


Fig 23: Changes⁹³ in the share of GDP (gross domestic product) for the past 2,000 years.

Science, engineering, and technological feasibility, will determine whether good ideas from energy research, may find their way to reality of execution, and adoption. To change the economic indicators of the world, the availability of such energy must reach the billions. Paths to adoption are going to be inextricably linked to investment. It may be co-dependent on other forms of infrastructure, for example, communications and roads.

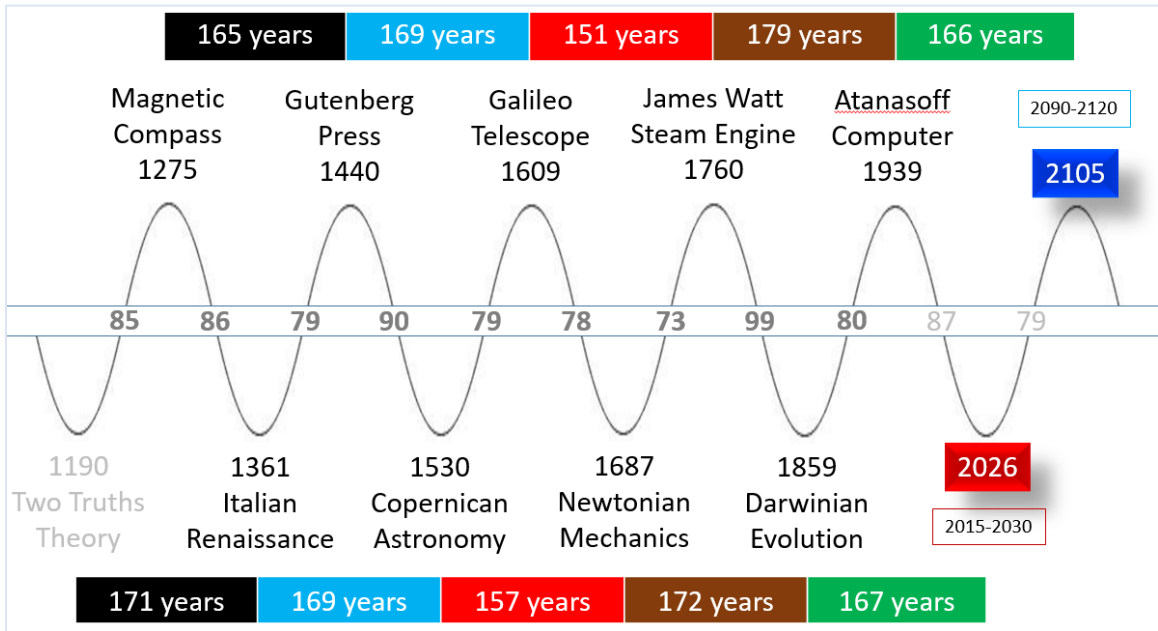


Fig 24: Norman Poire’s (ref 10) sinusoidal “march of reason” based on work by several economists including Joseph Alois Schumpeter⁹⁴, an Austrian-born political economist, at Harvard University (8 Feb 1883 – 8 Jan 1950) and the original Kondratieff⁹⁵ Waves.

Based on the sinusoidal pattern (Figure 24), it appears that the next decade (circa 2026), may witness the emergence of new global direction, followed by transformative technological progress, poised to emerge at the dawn of the 22nd Century.

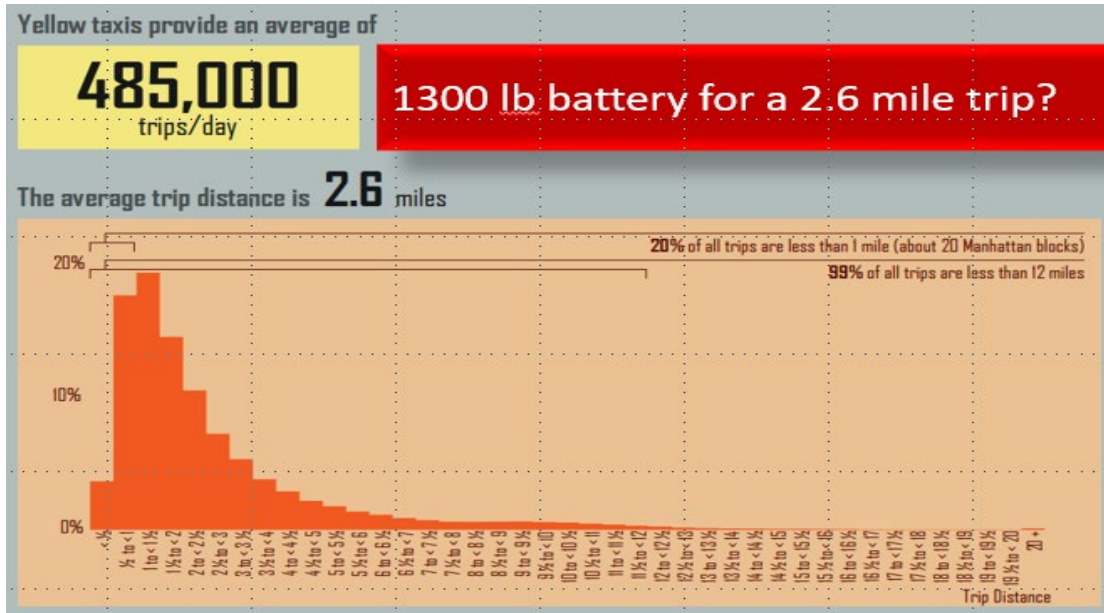
One may be tempted to predict that the technological breakthrough (circa 2105) may involve energy. The sourcing of energy will revolutionize the global supply chain.

Perhaps the development of hydrogen fuel cells, fashioned as an average sized mobile phone (form factor), or even better, a credit card sized *fuel cell, in every pocket*, may be the then Presidential⁹⁶ slogan. The future may increasingly witness FCV (fuel cell vehicles) and a decline in EV (electric vehicles). The form factor of PEM fuel cells may be the size of a credit card or slim iPhone. Will one size fit all? Perhaps not. But, imagine you can insert the credit card (cc) configuration, proton-exchange membrane fuel cell, also known as polymer electrolyte membrane (PEM) fuel cell (PEMFC), in your laptop or smartphone or tablet, to power the devices. Now *re-imagine* the energy supply chain.

The same ccPEMFC may be inserted in the dashboard of your automobile, as its energy source. The “range anxiety” justifiably, will be of concern. How far the car may travel for “one dose” of ccPEMFC? But, before that, *re-imagine* the smart city concept.

Assume a vehicle can travel 10 miles per unit ccPEMFC. You are a taxi in New York where the average distance⁹⁷ per trip is 2.6 miles. Have you lost or gained, in the context of the *massive shift* from lugging around 700 kg in battery weight (for EVs) or 15-30 gallons of gasoline (ICE) *versus* dash-board ccPEMFC weighing 10-100 grams?

Swap your energy-exhausted ccPEMFC with a fresh ccPEMFC and you have just entered the era of “swappable atoms” where the form factor of portable mobile energy enables you to *swap atoms*. Carry a 6-pack of ccPEMFC or swap ccPEMFC in a grocery store or convenience store, eg 711. The reality of the ‘swap’ may be in practice⁹⁸ in India.



India’s electric vehicle revolution will begin with auto-rickshaws running on swappable batteries



Fig 24: Complementarity between “atoms to bits” & the paradigm of “swappable atoms”

Fuel cell "cards" (ccPEMFC) may fade away in favor of energy in the form of a microUSB flash drive. *Re-imagine* the mobile, grid-free, swappable ccPEMFC but in a new reincarnation: a slim flash-drive inserted into a microUSB-like port.

The energy source may be *solid* hydrogen. Contrary to the standard textbooks of chemistry, J. D. Bernal suggested⁹⁹ that gaseous substances, under very high pressure, may be transformed into metallic or valence lattices. In 1935, Wigner and Huntington (see reference 99) theoretically calculated the energy of a body-centered lattice of hydrogen as a function of the lattice constant (which corresponds to a density many times higher than that of the ordinary, molecular lattice of solid hydrogen).

I did not read or understand Eugene Wigner's paper until Glenn Seaborg¹⁰⁰ (element Seaborgium¹⁰¹ atomic number 106) explained the prediction. The notion of solid hydrogen, in a thimble-sized container, was the basis of a suggestion, I proposed, in a publication¹⁰² in 2005-2006 (published by TEKES, Government of Finland).

At that time (2005), I did not mention solid hydrogen and did not state that one unit of the slim flash-drive-like microUSB device may be sufficient to operate a Boeing 787 or Airbus 380 or the largest container ship, the Hong Kong-registered CSCL Globe, measuring more than 400m (1,312ft) and carrying about 20,000 standard containers.

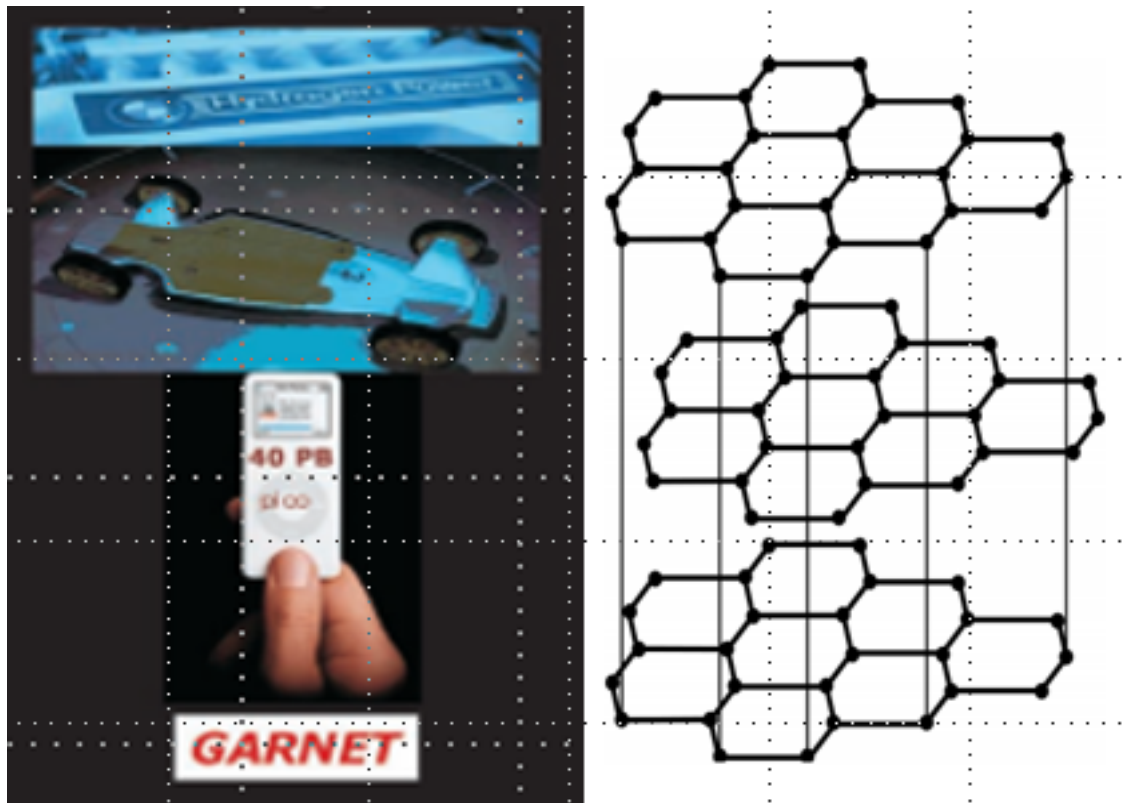


Fig 25: (Left) Energy for a vehicle using a slim credit card sized form factor, proposed in 2005. (Right) Schematic representation of layered lattice of graphite. Metallic hydrogen may assume this type of lattice structure, according to Wigner & Huntington (see ref 99).

In 2017, the impossible was made possible¹⁰³ by Ranga Dias, a graduate student at Harvard University, who claimed the formation of metastable (solid) Hydrogen¹⁰⁴ at a pressure of 495 GigaPascals (Fig 26). As with all seminal discoveries, congratulations¹⁰⁵ and greetings poured in from all corners of the globe (Fig 27 quoted from reference 105).

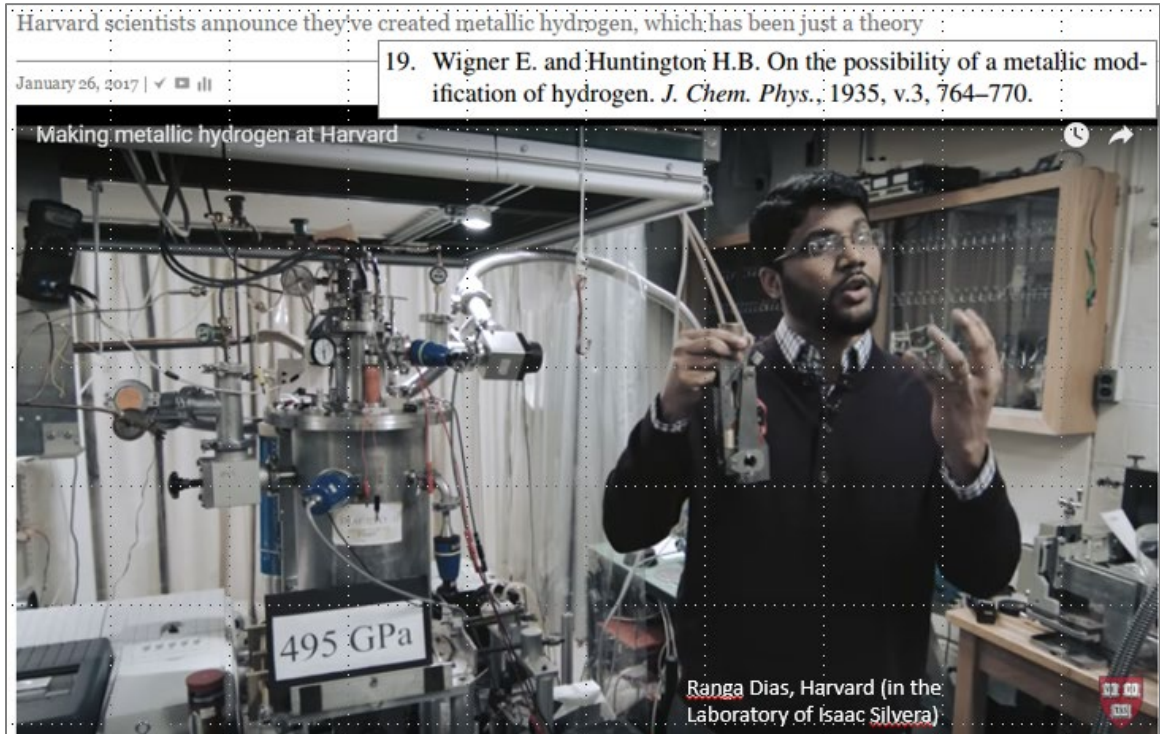


Fig 26: The formation of metallic Hydrogen by Harvard University student Ranga Dias.

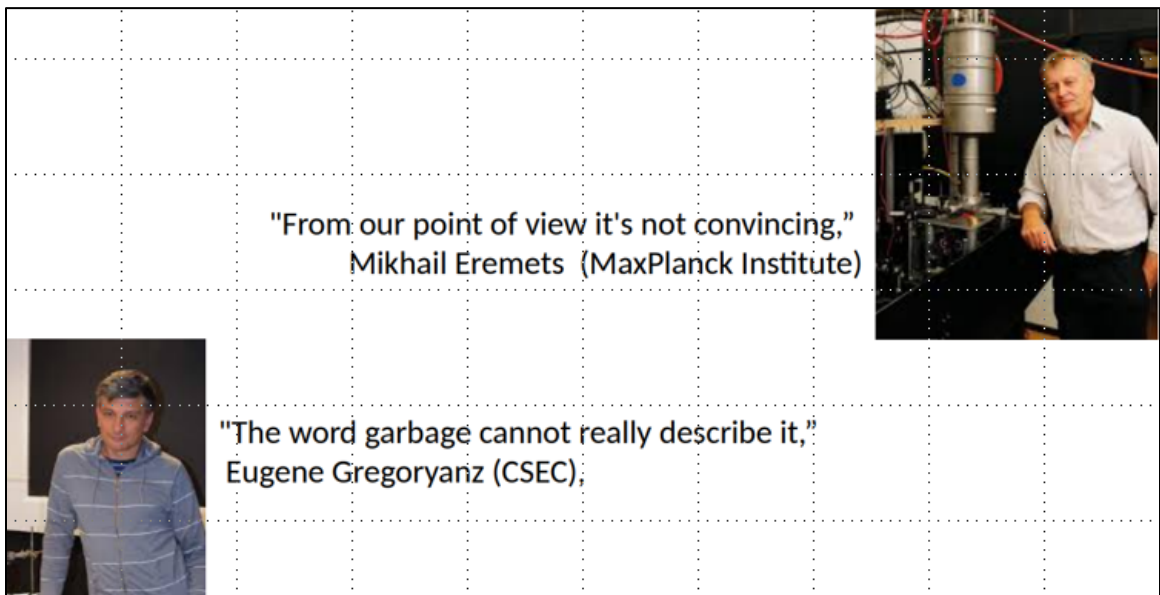


Fig 27: *In Praise of Imperfection* – congratulations poured in from other great scientists.

Packed with metastable hydrogen (solid hydrogen), anything that needs energy ("electricity") may wish to incorporate a standard microUSB port in the design of the device. Insert pH (power Hydrogen) to a phone, laptop, automobile, airplane, building, lawn mower and submarine. Today we may plug in a EV in our homes to charge the vehicle. The fusion-less, grid-less, powerless, struggling economies may change for the better when they can plug-in their homes to the future FCV, to power up their living.

The form factor of portable, mobile, grid-free energy may undergo a radical evolution, which may reach its zenith around 2105-2120 (Figure 24). The metaphor of connecting *atoms to bits* (IoT) may embrace the complementarity which will evolve from *swappable atoms*. The paradigm shift in energy cost, access and distribution, will impact all supply chains. It may catalyze an unstoppable wave of freedom, development and economic growth. *Power to the people* will cease to be merely a political platitude.

A portfolio of inexpensive energy will swing open the final frontier for business and commerce, by further accelerating the creation of markets on the continent of Africa.

The benefits from the energy reshuffle will meet with resistance in the advanced Western nations, due to the dead weight of old technology, linked to the political lobby of the wealthy few. Asia and Africa may leapfrog into the future with solar, hydrogen and fusion, as a part of their renewable, carbon-neutral and sustainable, energy portfolio.

The strength of science behind the chemistry of metastable hydrogen makes it less speculative to suggest that the future of hydrogen-based energy, may be packaged in a micro-USB mini-device, with metallic hydrogen¹⁰⁶ as the fuel. For immobile objects and traditional functions (buildings), the commercialization¹⁰⁷ of fusion energy¹⁰⁸ may be an equally important economic leap for the 22nd Century (see Figure 2). Solar, hydrogen and fusion, may co-exist as pragmatic commercial solutions, globally, in the year 2121.

But what about the expected change in global direction (predicted in Fig 24), in the next decade? It is tempting to speculate that the global forces for good, may begin to tackle gender¹⁰⁹ inequality. Boosting women's opportunities, in the labor market, could add US\$12 trillion to the annual global GDP, over the next decade. Gender parity will indeed be a new direction, a transformation which will change the fabric of civilization.



Fig 28: Ubiquitous computing meets ubiquitous energy in the 22nd century.

EPILOGUE

Connecting atoms to bits is an important step for global development and decision systems. Digital transformation is one of many key areas that must march in lockstep, with other facets. The Digital Silk Road¹¹⁰ promises anything but to be smooth¹¹¹ as silk. The forecast about energy, and supply chain, will add turbulence to anticipated changes. The journey will be mired in false promises, snake-oil sales and rabid sensationalism.

No one may escape the travails of time, especially those inflated with hubris. The cyclical rise and fall of General Electric¹¹² is one example. On August 28, 2000, GE was at its prime with a stock price of \$34.55 (Fig 29). More recently, on 20 December 2016, shares of GE¹¹³ were \$32.25 per share. By 29 December 2017, GE's share price was nearly halved to \$17.45 per share. In a recent¹¹⁴ analysis, from six CEO regimes at GE (Wilson, Cordiner, Borch, Jones, Welch and Immelt), the megalomania of Jack Welch may have disproportionately sowed the seeds of GE's decline¹¹⁵ but Jeff Immelt¹¹⁶ is not without blame. Transforming GE to an energy company, or to a software company, are good slogans, for on-stage glitz and glamour, for "*Minds and Machines*" showmanship.

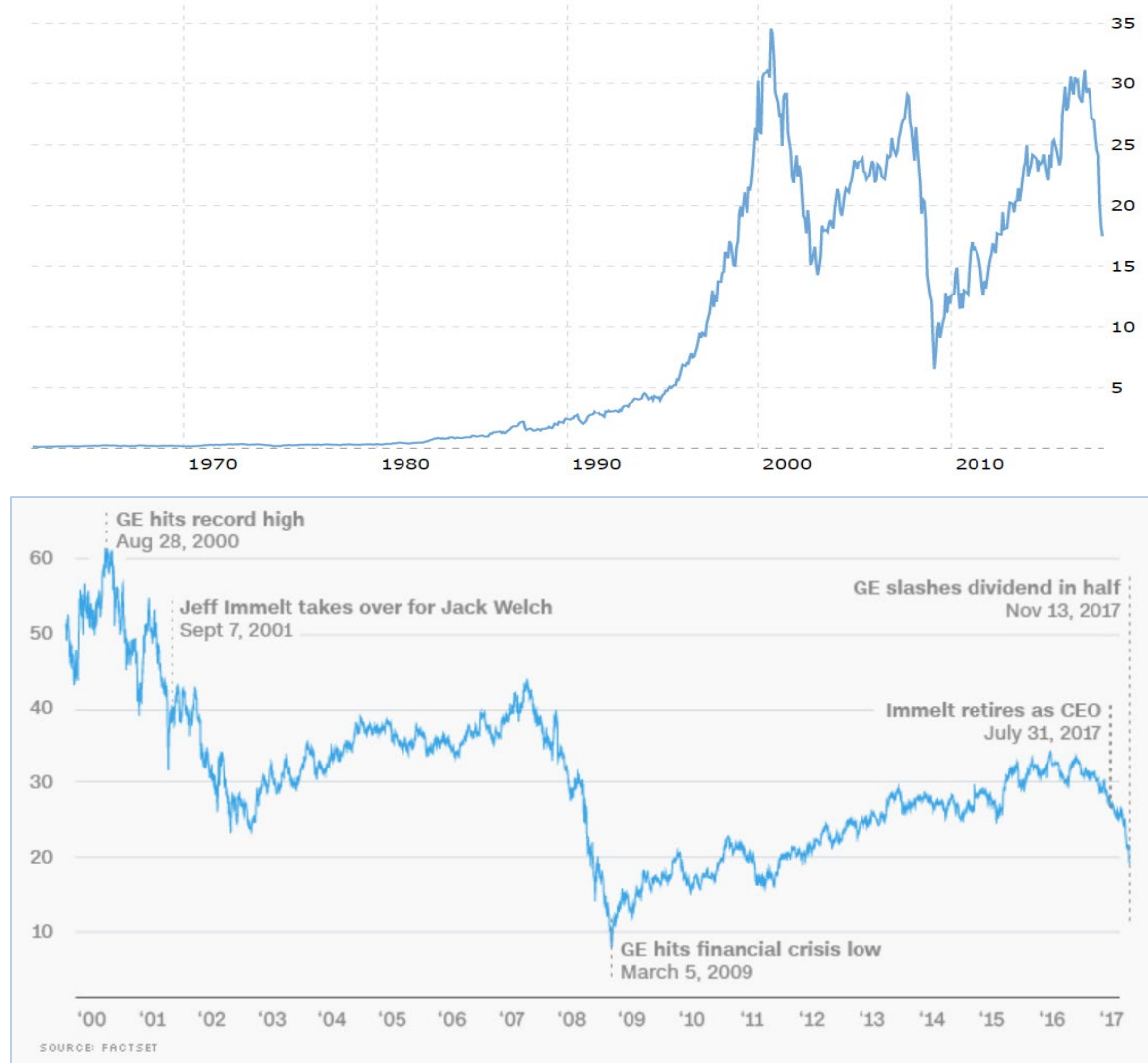


Fig 29: GE share prices¹¹⁷ from 1962-2017 (top) vs changes in GE leadership (bottom).

The economic disequilibrium¹¹⁸ due to technological chasm may be tearing apart¹¹⁹ the fabric of society, according to one¹²⁰ report. The undue emphasis on digital transformation in this and other articles, is, therefore, an alarming example of bias. GE is an example of what happens when leaders lead by hubris or fall for hype¹²¹ and act as marketing agents rather than visionaries. Quick and dirty may win, but, for how long?

Based on my very limited knowledge and multiple other inadequacies, it may be an act of stupidity, on my part, to suggest what domains are equally (or more) important.

Feeding the world tops the list, not only because of its short term need (daily hunger) but its long term impact on the evolution of the brain¹²². In parallel, reasonable elimination of sugar¹²³ in our diet, and in processed foods, may be crucial for nutrition.

The bitter politics of sugar¹²⁴ and its collusion with big pharma, may be sowing the seeds of an epidemic, called diabetes. Hence, to empower people, self-monitoring of blood glucose¹²⁵ is quintessential, in order to prevent excess sugar in their daily diet.



Fig 30: Over the course of a 15-year study¹²⁶ on added sugar and heart disease, participants who took in 25% or more of their daily calories as sugar were more than twice as likely to die from heart disease as those whose diets included less than 10% added sugar.

Inexpensive clean energy may be a key economic performance indicator, which will influence industry, commerce, workforce, financial arbitrage and globalization. The path to inexpensive energy may still run through political minefields (see Figure 1).

It is of general opinion that the trio of sanitation, water and health, as well as healthcare, are critical¹²⁷ necessities for billions, mostly ignored by the affluent world.

Emergency management, telecommunication and roads (infrastructure) are the bread and butter of the connected world. 5G is icing on the cake, not an immediate staple.

Advancing any domain for human progress is rooted in science and engineering. The tools for public goods, for example, nanotech and graphene for solar photovoltaic cells, as well as, desalination, and purification, of water, are fruits of academic *research*.

It is ironic that GE's strength is in energy and healthcare. It is still taking the company on a downward trajectory. One reason may be its extreme affinity for the Western idea of business profitability. GE aims to serve its shareholders and maximize profit. If a business, such as GE, were to serve the community and, then, rake in the micro-payments from billions of users, it may generate trillions in revenue, *over time*.

The Western business school ethos of more and more profit is the yardstick of capitalism. In part, it fuels the lifestyle and luxuries we take for granted in the West. We are not without blame for the greed¹²⁸ that may decimate families due to medical bills. Yet, we are too timid and cautious¹²⁹ to raise our voices or act with purpose. The cost of prescription medicine in the US (Table 1), by law, cannot be subjected to price control.

Glybera \$1,000,000	Elaprase \$375,000 pa	Myozyme \$300,000
Luxturna \$850,000	Naglazyme \$365,000 pa	Arcalyst \$250,000 pa
Spinraza \$750,000	Folotyng \$360,000 pa	Cerezyme \$200,000 pa
Soliris/Ionis \$750,000	Cinryze \$350,000 pa	Fabrazyme \$200,000 pa
Kymriah \$475,000	ACTH \$300,000	Aldurazyme \$200,000

Table 1: The adulation¹³⁰ for cure for blindness at a cost of \$425,000 per eye per dose far outweighs the muted outcry¹³¹ about the outrageous acts by US and EU pharmaceuticals.

A *pillar* of Western business is optimizing “shareholder value” which may be archaic to some but still peddled by the Jack Welch¹³² school. It is clear from demand of “executive education” courses from elite US universities that the emergent economies are keen to emulate the Western practices, based more on pillars and less on building bridges.

The Chinese and Indian business schools are preaching personal wealth creation and how to catalyze ROI. But, what worked for the affluent Western society (US and EU) may not be reproducible in the East, with billions of hungry people who can neither afford healthcare nor education. The Eastern penchant for Western business practices is a form of myopia that neither Joshua Silver¹³³ nor his mission¹³⁴ or his vision¹³⁵ can cure.

Globally, there is a lack of understanding. Tools and technologies, by themselves, are impotent for sustained improvements, hence, are incapable of generating long term profitability and wealth of nations. When tools and technologies are a part of a *system*, in the *systems approach* to a solution, *then*, the outcome may favor long term profitability.

Use of *ad hoc* tools are often mired by initial failures. The use of RFID, as an identification tool for tracking and tracing goods in the supply chain, is still a grand idea. In 2000, retailers expected *that* productivity, instantly, simply by slapping on a RFID tag. It was catalyzed by hype and the stampede for a new source of *billable hours* from a variety of consultants and consulting firms, oblivious of the *systems* approach.

The lessons¹³⁶ of *productivity* are steeped in *complementarity*. You cannot have one without the other. Complementarity is about *systems* where multiple tools and many technologies¹³⁷, both new and old, may *converge* to produce an impact, greater than the sum of the parts. Elegantly illustrated by the history¹³⁸ of electrification, similar lessons apply to most tools (RFID, sensors, AI, ML, blockchain, 3D printing, digital foundry).

Taken together, what does it mean for global transformation and its subset, the digital transformation? Unfortunately we shall witness catastrophic clashes, especially with respect to the ongoing parade of expectations from AI¹³⁹ and its apparently super-natural powers. Even more troubling is the observation that once-admired companies, mammoth consulting firms and so-called “captains” of industries are marketing untruths.

Having said all of this, we must hasten to return to reality, to face the brutal facts in Figure 31, about the global gaps which continues the morbidity. It is not enough to blame the policies and politics of unethical humans in the loop, pre-occupied with treachery, lechery and debauchery, rather than helping to catalyze science to serve society, deliver human values and dignity.

Each one of us has a role to play, no matter how small. Our existence is based on compassion and knowledge. Compassion without knowledge is ineffective. Knowledge without compassion is inhuman¹⁴⁰. In our pursuit of ideas, we must strive to think about the correct¹⁴¹ questions. Wrong questions will generate wrong answers¹⁴². Humanity needs compassionate dreamers¹⁴³, an ethical sense of higher purpose, and humility.

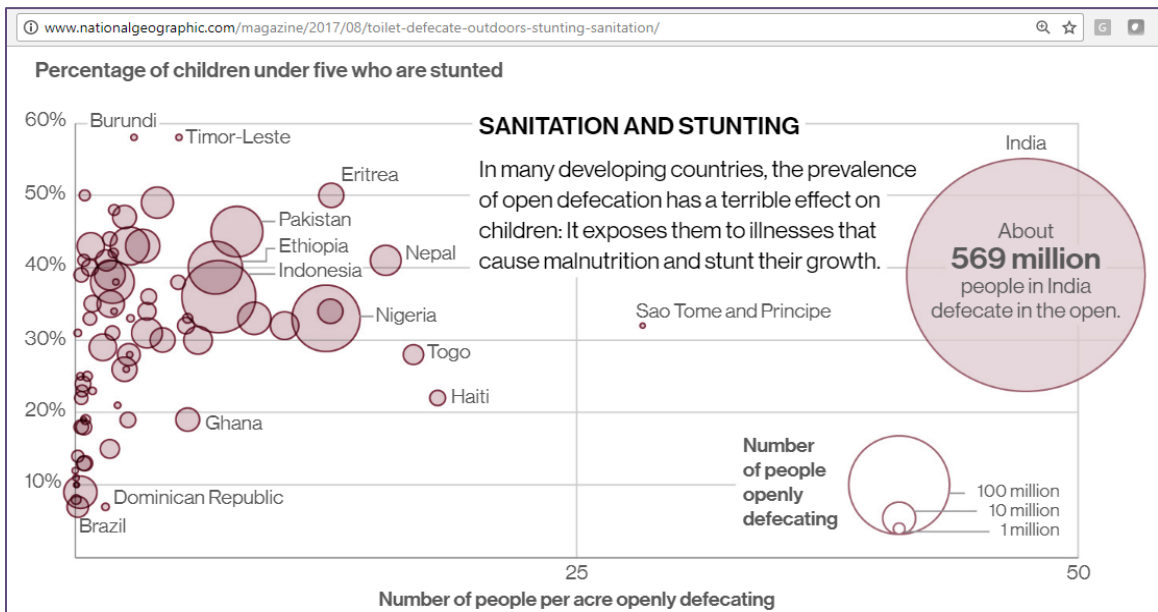


Fig 31: Remediable injustice? How lack of adequate sanitation may be robbing billions of children in the world, from a healthy childhood (ref 92). Can science help society?

Notes

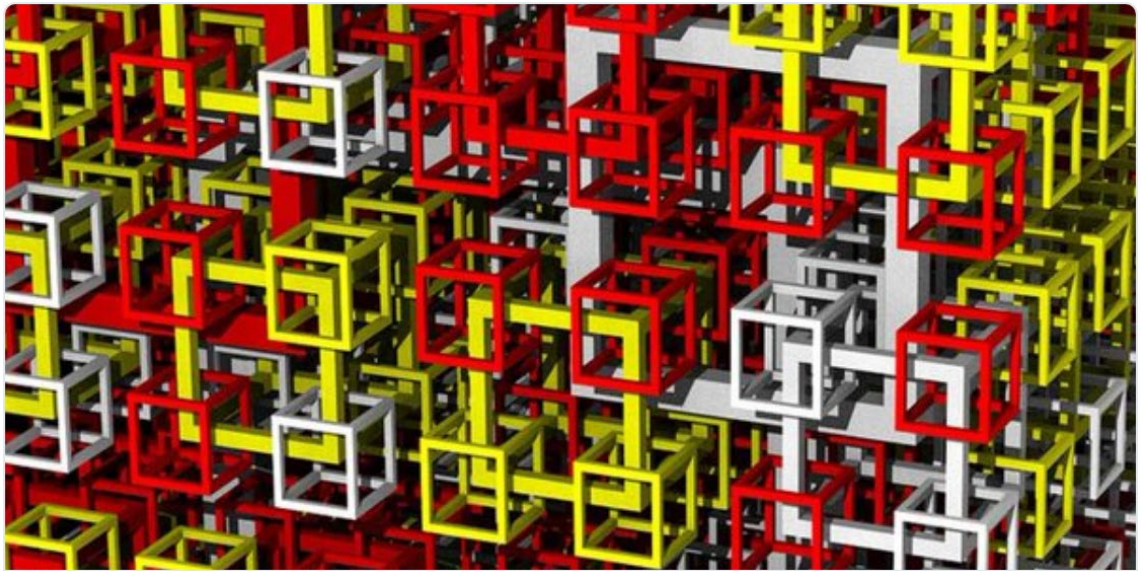
- ¹[https://en.wikipedia.org/wiki/Sally_\(short_story\)](https://en.wikipedia.org/wiki/Sally_(short_story))
- ²<http://digitalcollections.library.cmu.edu/awweb/awarchive?type=file&item=34057>
- ³<https://www.ics.uci.edu/~corps/phaseii/Weiser-Computer21stCentury-SciAm.pdf>
- ⁴<https://www.postscapes.com/internet-of-things-history/>
- ⁵<http://www.chetansharma.com/correcting-the-iot-history/>
- ⁶<https://www.linkedin.com/in/petertlewis/>
- ⁷<https://mitpress.mit.edu/books/inversion-factor>
- ⁸Le vrai point d'honneur [d'un scientifique] n'est pas d'être toujours dans le vrai. Il est d'oser, de proposer des idées neuves, et ensuite de les vérifier. *La Science des Rêves*, Science et Vie Junior, 214, (18 May 2007), page 13
- ⁹Ajay Agrawal, Joshua S Gans and Avi Goldfarb (2017) *Human Judgment and AI Pricing*. Economic Consequences of AI and Robotics. Annual Meeting of the American Economic Association (Jan 6, 2018) www.aeaweb.org/conference/2018/preliminary/1476
- ¹⁰Poire, Norman P. (2011) The Great Transformation of 2021. <http://www.lulu.com/shop/norman-poire/the-great-transformation-of-2021/paperback/product-14729057.html>
- ¹¹http://intersticia.com.au/wp-content/uploads/2014/12/Semantic_Technologies_White_Paper.pdf
- ¹²<http://knowledgeweb.semanticweb.org/o2i/menu/KWTR-whitepaper-43-final.pdf>
- ¹³https://en.wikipedia.org/wiki/History_of_poetry
- ¹⁴<http://www3.nccu.edu.tw/~jsfeng/CPEC11.pdf>
- ¹⁵McLuhan, M. (1964). *Understanding Media: The Extensions of Man*. http://robynbacken.com/text/nw_research.pdf
- ¹⁶<https://dspace.mit.edu/handle/1721.1/107989>
- ¹⁷<http://www.investopedia.com/features/crashes/>
- ¹⁸<http://www.goldmansachs.com/our-thinking/pages/2015-10-favorite-charts.html>
- ¹⁹<http://www.visualcapitalist.com/chart-5-tech-giants-make-billions/>
- ²⁰<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3523200/pdf/nihms417135.pdf>
- ²¹<http://amos3.aapm.org/abstracts/pdf/77-22628-310436-101934.pdf>
- ²²http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/11/541/11541418.pdf
- ²³www.nationalgeographic.com/archaeology-and-history/archaeology/mohenjo-daro/
- ²⁴<https://en.wikipedia.org/wiki/Harappa>
- ²⁵<https://en.wikipedia.org/wiki/Mehrgarh>
- ²⁶https://www.ancient.eu/Silk_Road/
- ²⁷https://www.goodreads.com/book/show/251270.Stories_From_The_Silk_Road
- ²⁸https://en.wikipedia.org/wiki/Grand_Bazaar,_Istanbul
- ²⁹<http://driving.ca/bmw/7-series/auto-news/news/how-it-works-bmw-gesture-control>
- ³⁰<https://www.myo.com/>
- ³¹<http://www.silkroutes.net/orient/mapssilkroutestrade.htm>
- ³²www.ancient.eu/Silk_Road/
- ³³https://en.wikipedia.org/wiki/United_States_Postal_Service_creed
- ³⁴http://data-art.net/resources/history_of_vis.php

- ³⁵<http://www.itsokaytobesmart.com/post/13691235184/alleluiaaa-these-are-the-patterns-of-planets>; <https://johncarlosbaez.wordpress.com/2014/01/04/the-pentagram-of-venus/>; <http://blog.recursiveprocess.com/2015/05/19/tracking-venus-and-earth-over-8-years/>; <https://www.geogebra.org/material/show/id/67741>; <http://freemasonry.bcy.ca/anti-masonry/venus.html>
- ³⁶<https://ia902708.us.archive.org/11/items/astronomyexplai00ferggoog/astronomyexplai00ferggoog.pdf>; <http://xxx.lanl.gov/pdf/astro-ph/0305536v1>
- ³⁷http://users.math.yale.edu/~bbm3/web_pdfs/encyclopediaBritannica.pdf
- ³⁸<http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-183.pdf>
- ³⁹https://en.wikipedia.org/wiki/Metcalfes_law
- ⁴⁰https://ti.arc.nasa.gov/m/pub-archive/archive/ACO_SGD.pdf
- ⁴¹<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3280839/pdf/sensors-09-00909.pdf>
- ⁴²<https://dspace.mit.edu/handle/1721.1/111021>
- ⁴³<http://www.motherjones.com/environment/2012/10/sugar-industry-lies-campaign/>
- ⁴⁴www.pbs.org/newshour/health/sugar-industry-artificially-sweetened-harvard-research
- ⁴⁵<http://www.downloads.imune.net/medicalbooks/Jama%20-%20Sugar%20Industry%20and%20Coronary%20Heart%20Disease%20Research.pdf>
- ⁴⁶<http://www.teethforlife.co.za/images/Pure,%20White%20and%20Deadly%20-%20John%20Yudkin.pdf>
- ⁴⁷<https://jamanetwork.com/journals/jamainternalmedicine/article-abstract/2548255?redirect=true>
- ⁴⁸<https://dspace.mit.edu/handle/1721.1/111021>
- ⁴⁹<http://www-formal.stanford.edu/jmc/history/dartmouth.pdf>
- ⁵⁰<https://www.businesswire.com/news/home/20171026006422/en/Amazon.com-Announces-Quarter-Sales-34-43.7-Billion>
- ⁵¹<https://www.technologyreview.com/s/608640/inside-the-increasingly-complex-algorithms-that-get-packages-to-your-door/>
- ⁵²<https://www.slideshare.net/jgorchs/jose-gorchs-machine-learning-az>
- ⁵³<https://www.weforum.org/agenda/authors/bart-kolodziejczyk>
- ⁵⁴www.weforum.org/agenda/2017/05/your-next-peer-review-will-be-done-by-a-machine
- ⁵⁵<https://community.fs.com/blog/tcpip-vs-osi-whats-the-difference-between-the-two-models.html>
- ⁵⁶<https://www.rfc-editor.org/rfc/pdf/rfc/rfc2598.txt.pdf>
- ⁵⁷<http://ieeexplore.ieee.org/abstract/document/1203740/>
- ⁵⁸<https://dspace.mit.edu/handle/1721.1/111021>
- ⁵⁹https://www.iro.umontreal.ca/~vincentp/ift3395/lectures/backprop_old.pdf
- ⁶⁰<https://www.axios.com/ai-pioneer-advocates-starting-over-2485537027.html>
- ⁶¹<https://cs.stanford.edu/~quocle/tutorial1.pdf>
- ⁶²<https://www.datasciencecentral.com/profiles/blogs/neural-networks-the-backpropagation-algorithm-in-a-picture>
- ⁶³<https://en.wikipedia.org/wiki/Backpropagation>
- ⁶⁴<http://affect-reason-utility.com/1301/4/shannon1948.pdf>
- ⁶⁵http://www.ntuzov.com/Nik_Site/Niks_files/Research/papers/stat_arb/EG_1987.pdf
- ⁶⁶<http://www.tandfonline.com/doi/full/10.1057/palgrave.jors.2602419>
- ⁶⁷<https://www.anodot.com/>

⁶⁸<https://arxiv.org/pdf/1710.09829.pdf>; <https://openreview.net/pdf?id=HJWLFGRb>
⁶⁹<http://www.acad.bg/ebook/ml/Society%20of%20Mind.pdf>
⁷⁰<http://ieeexplore.ieee.org/document/1541948/>
⁷¹[https://en.wikipedia.org/wiki/Docker_\(software\)](https://en.wikipedia.org/wiki/Docker_(software))
⁷²<https://dspace.mit.edu/handle/1721.1/111021>
⁷³https://en.wikipedia.org/wiki/Hash_table
⁷⁴<https://en.wikipedia.org/wiki/Blockchain>
⁷⁵<https://mitpress.mit.edu/books/computing>
⁷⁶<http://www.suzanaherculanohouzel.com/lab>
⁷⁷<http://www.computerhistory.org/babbage/>
⁷⁸http://www.pnas.org/content/109/Supplement_1/10661.full
⁷⁹<https://neurology.mhmedical.com/book.aspx?bookID=1049>
⁸⁰https://www.asu.edu/courses/pgs461/Reflexes%20Arcs_PGS%20461.pdf
⁸¹<http://en.aup.nl/books/9789089642004-haphazard-reality.html>
⁸²<https://www.google.com/patents/US312085>
⁸³<http://jamanetwork.com/journals/jama/article-abstract/302856>
⁸⁴<https://docs.google.com/viewer?url=patentimages.storage.googleapis.com/pdfs/US2710649.pdf>
⁸⁵<https://docs.google.com/viewer?url=patentimages.storage.googleapis.com/pdfs/US3043625.pdf>
⁸⁶<https://www.wired.com/story/mirai-botnet-minecraft-scam-brought-down-the-internet/>
⁸⁷http://www.sjgouldessays.com/content/nh_essay_summaries_content/02%20The%20Pandas%20Thumb.pdf
⁸⁸<https://www.automationworld.com/article/internet-things-search-critical-mass>
⁸⁹Daron Acemoglu and Pascual Restrepo (2017) *Artificial Intelligence, Automation and Work* Economic Consequences of AI and Robotics. Annual Meeting of the American Economic Association (Jan 6, 2018) www.aeaweb.org/conference/2018/preliminary/1476
⁹⁰<https://dspace.mit.edu/handle/1721.1/111021>
⁹¹<http://www.universityworldnews.com/article.php?story=20150611130705830>
⁹²<https://www.nationalgeographic.com/magazine/2017/08/toilet-defecate-outdoors-stunting-sanitation/>
⁹³<https://ourworldindata.org/economic-growth>
⁹⁴https://en.wikipedia.org/wiki/Joseph_Schumpeter
⁹⁵https://www.researchgate.net/profile/A_Korotayev/publication/294086817_Kondratieff_Waves_Juglar_-_Kuznets_-_Kondratieff/links/56bda73308aefe60e4c572af/Kondratieff-Waves-Juglar-Kuznets-Kondratieff.pdf
⁹⁶<https://www.presidentsusa.net/1928slogan.html>
⁹⁷http://www.nyc.gov/html/tlc/downloads/pdf/2014_taxicab_fact_book.pdf
⁹⁸<https://qz.com/1001518>
⁹⁹<https://doi.org/10.1063/1.1749590>
¹⁰⁰https://www.nobelprize.org/nobel_prizes/chemistry/laureates/1951/seaborg-bio.html
¹⁰¹<https://en.wikipedia.org/wiki/Seaborgium>
¹⁰²<https://dspace.mit.edu/handle/1721.1/56251>
¹⁰³<http://news.harvard.edu/gazette/story/2017/01/a-breakthrough-in-high-pressure-physics/>

- ¹⁰⁴<http://science.sciencemag.org/content/early/2017/01/25/science.aal1579/tab-figures-data>
- ¹⁰⁵<https://www2.ph.ed.ac.uk/~gja/thermo/HydrogenGI.pdf>
- ¹⁰⁶<https://nature.berkeley.edu/garbelottoat/wp-content/uploads/hydro2017a.pdf>
- ¹⁰⁷www.sciencealert.com/the-uk-has-just-switch-on-its-tokamak-nuclear-fusion-reactor
- ¹⁰⁸<http://news.mit.edu/2016/alcator-c-mod-tokamak-nuclear-fusion-world-record-1014>
- ¹⁰⁹<https://www.mckinsey.com/global-themes/employment-and-growth/how-advancing-womens-equality-can-add-12-trillion-to-global-growth>
- ¹¹⁰<http://www.telegraph.co.uk/sponsored/china-watch/technology/11764541/tech-companies-to-build-digital-silk-road.html>
- ¹¹¹https://en.wikipedia.org/wiki/One_Belt_One_Road_Initiative
- ¹¹²<http://ieeexplore.ieee.org/document/477434/>
- ¹¹³<https://seekingalpha.com/article/4125284-ge-fall>
- ¹¹⁴Ocasio, William and Joseph, John. (2008) Rise and Fall or Transformation? The Evolution of Strategic Planning at the General Electric Company, 1940–2006. *Long Range Planning*, **41** 248–272 DOI: 10.1016/j.lrp.2008.02.010
- ¹¹⁵https://www.nytimes.com/2017/06/15/business/ge-jack-welch-immelt.html?_r=0
- ¹¹⁶<https://finance.yahoo.com/news/general-electric-co-ge-fall-143554997.html>
- ¹¹⁷<http://www.macrotrends.net/stocks/charts/GE/prices/genl-electric-stock-price-history>
- ¹¹⁸<https://journals.fe.up.pt/index.php/IJMAI/article/view/190/133>
- ¹¹⁹https://www.nytimes.com/2017/01/16/world/eight-richest-wealth-oxfam.html?_r=2
- ¹²⁰<https://www.oxfamamerica.org/static/media/files/2017-Oxfam-America-Annual-Report-web.pdf>
- ¹²¹Edward W. Felten, Manav Raj and Robert Seamans (2017) *Linking Advances in Artificial Intelligence to Skills, Occupations, and Industries*. Economic Consequences of AI and Robotics. Annual Meeting of the American Economic Association (Jan 6, 2018). <https://www.aeaweb.org/conference/2018/preliminary/1476>
- ¹²²http://www.pnas.org/content/109/Supplement_1/10661.full.pdf
- ¹²³<http://www.teethforlife.co.za/images/Pure,%20White%20and%20Deadly%20-%20John%20Yudkin.pdf>
- ¹²⁴<http://blogs.plos.org/publichealth/2013/03/28/the-not-so-sweet-politics-of-sugar-consumption/>
- ¹²⁵https://www.leeds.ac.uk/news/article/3723/non-invasive_device_could_end_daily_finger_pricking_for_people_with_diabetes
- ¹²⁶<https://jamanetwork.com/journals/jamainternalmedicine/fullarticle/1819573>
- ¹²⁷http://www.who.int/water_sanitation_health/monitoring/jmp2012/fast_facts/en/
- ¹²⁸<https://www.penguinrandomhouse.com/books/3901/the-truth-about-the-drug-companies-by-marcia-angell-md/9780375760945/>
- ¹²⁹<http://www.nejm.org/doi/pdf/10.1056/NEJM200410073511522>
- ¹³⁰www.vanguardngr.com/2018/01/treatment-blindness-sell-850000-us/
- ¹³¹<https://www.health.harvard.edu/blog/the-11-most-expensive-medications-201202094228>
- ¹³²https://en.wikipedia.org/wiki/Jack_Welch
- ¹³³<http://www.stcatz.ox.ac.uk/node/625>
- ¹³⁴<http://www.globaleyesightnow.org/self-adjusting-glasses/>

- ¹³⁵<http://www.vdwoxford.org/about/>
- ¹³⁶https://eml.berkeley.edu/~bhhall/e124/David90_dynamo.pdf
- ¹³⁷<https://pdfs.semanticscholar.org/05d5/971cec0ddb43f19f615ef820b873fa216cde.pdf>
- ¹³⁸<https://www.nuffield.ox.ac.uk/economics/history/paper31/a4.pdf>
- ¹³⁹<http://www.nber.org/papers/w24001>
- ¹⁴⁰<http://web.mit.edu/dikaiser/www/Kaiser.Weisskopf.pdf>
- ¹⁴¹https://studies2.hec.fr/jahia/webdav/site/hec/shared/sites/czellarv/acces_anonyme/OringJASA_1989.pdf
- ¹⁴²<http://www.bmj.com/content/bmj/360/bmj.j5808.full.pdf>
- ¹⁴³<https://www.iupac.org/publications/ci/2011/3301/jan11.pdf>



Shoumen - I finally had some time to complete a thorough reading of your recent paper, "Adapting Decisions, Optimizing Facts and Predicting Figures." It was certainly thought-provoking. As you know, we have been thinking about some of these ideas, but it is nice to see them woven together more completely than I have before. I think the trick for industry will be to fearlessly use these ideas instead of rejecting them out of ignorance, cynicism, or short-sightedness.

JAW

17 June 2004

Jeffrey A. Wilke

Jeffrey A. Wilke
CEO
AMAZON

Jeff Wilke (JAW) has served as CEO Worldwide Consumer since April 2016. From February 2012 to April 2016, Jeff served as Senior Vice President, Consumer Business, from January 2007 until February 2012, he served as Senior Vice President, North American Retail, and from January 2002 until December 2006, he was Senior Vice President, Worldwide Operations. Jeff joined Amazon.com as Vice President and General Manager, Operations in September 1999. He left AlliedSignal (Honeywell) where he was Vice-President and General Manager, Pharmaceutical Fine Chemicals. Jeff spent the preceding six years in a variety of operations and general management assignments in the chemical, polymer, and electronics industries. Jeff did his graduate work (MBA and MS in Chemical Engineering) at MIT's Leaders for Global Operations (formerly Leaders for Manufacturing) program where he focused on Total Quality and Process Improvement techniques. He began his working career writing software and leading software development at Andersen Consulting (now Accenture). Jeff also holds a BSE degree in Chemical Engineering (*summa cum laude*) from Princeton University, NJ.



<https://people.csail.mit.edu/brooks/> and https://en.wikipedia.org/wiki/Rodney_Brooks

Rodney Brooks is the Panasonic Professor of Robotics (emeritus) at MIT.

He is a robotics entrepreneur and Founder, Chairman and CTO of [Rethink Robotics](#) (formerly Heartland Robotics). He is also a Founder, former Board Member (1990 - 2011) and former CTO (1990 - 2008) of [iRobot Corp](#) (Nasdaq: IRBT). Dr. Brooks is the former Director (1997 - 2007) of the MIT Artificial Intelligence Laboratory and then the MIT Computer Science & Artificial Intelligence Laboratory ([CSAIL](#)). He received degrees in pure mathematics from the Flinders University of South Australia and a Ph.D. in Computer Science from Stanford University in 1981. He held research positions at Carnegie Mellon University and MIT, and a faculty position at Stanford before joining the faculty of MIT in 1984. He has published many papers in computer vision, artificial intelligence, robotics, and artificial life.

Dr. Brooks served for many years as a member of the International Scientific Advisory Group (ISAG) of National Information and Communication Technology Australia ([NICTA](#)), and on the Global Innovation and Technology Advisory Council of [John Deere & Co](#). He is currently an Xconomist at [Xconomy](#) and a regular contributor to the [Edge](#). Since June 2014 he has been a member of the Visiting Committee on Advanced Technology, [VCAT](#), at the National Institute of Standards and Technology, [NIST](#). Since June 2015 he has been an external member of GE's Robotics Advisory Council. Since January 2016 he has been Deputy Chairman of the Advisory Board of Toyota Research Institute.

Dr. Brooks is a Member of the National Academy of Engineering (NAE), a Founding Fellow of the Association for the Advancement of Artificial Intelligence (AAAI), a Fellow of the American Academy of Arts & Sciences (AAAS), a Fellow of the American Association for the Advancement of Science (the other AAAS), a Fellow of the Association for Computing Machinery (ACM), a Fellow of the Institute of Electrical and Electronics Engineers (IEEE), a Corresponding Member of the Australian Academy of Science (AAS) and a Foreign Fellow of the Australian Academy of Technological Sciences and Engineering (ATSE).

He won the Computers and Thought Award at the 1991 IJCAI (International Joint Conference on Artificial Intelligence). In 2008 he won the IEEE Inaba Technical Award for Innovation Leading to Production. In 2014 he won the Robotics Industry Association's Engelberger Robotics Award for Leadership. And he won the 2015 IEEE Robotics and Automation Award. He was awarded honorary Doctor of Science degrees from Flinders University in 2016, and Worcester Polytechnic Institute in 2017.

CHAPTER 2 • CYBERSECURITY

Personal Security Agents: Modular Models represent People, Process, Atoms & Bits

Abstract

The DDoS attack using an internet device on October 21, 2016, was predicted by experts and generated a flurry of suggestions from pundits. What if the attacks were not limited to social media but disrupted implanted devices in patients with cardiac arrhythmia? The potential of personal security agents (PSA) is proposed as a modular tool to model people, process, bits and atoms (objects) with layers to address trust, privacy, security and wrappers, within these layers, to include cognitive firewalls to mitigate other risks.

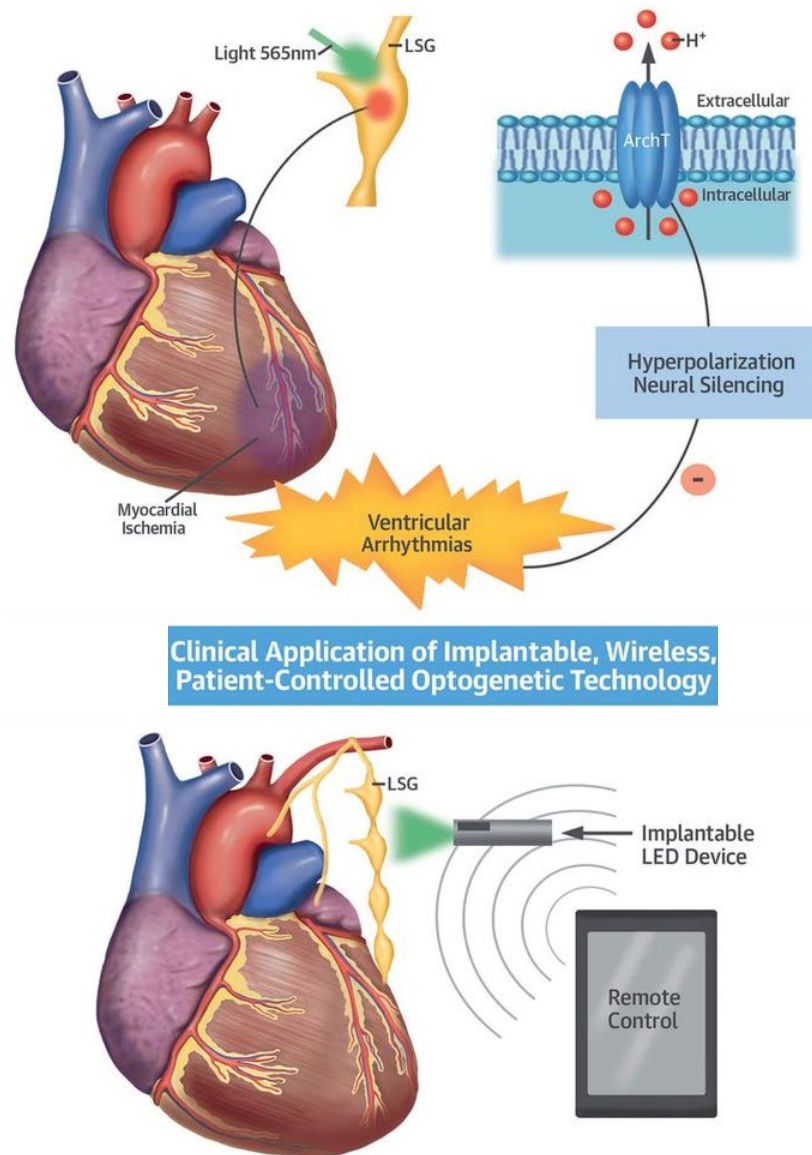


Fig 0 – Is cybersecurity essential for medical devices¹ operated by wireless signals?

Distributed Trust Management

The distributed denial of service (DDoS) attack originating from IoT type devices infected by the Mirai botnet^[2] was predicted^[3] by experts. The news about tracking individuals by name and location^[4] to profit from advertisements, was also perpetrated by experts. Objects and people appear to be equally vulnerable to cyber-intrusion.

The concept^[5] of personal security agent (PSA) may not be new. PSA may not be restricted to individuals. Devices may have PSA linked to a registry, for example GHR^[6] maintained by CNRI^[7]. Other, less robust, examples include mobile device management tool and rosy predictions^[8] about MDM, which are attracting a new^[9] class of entrants.

In light of revelations^[10], which continues to accumulate, it is worth considering security-as-a-service. Manufacturers of devices may provide a layer of security, but, other independent layer(s) may be procured, installed and managed by the user, based on source(s), trusted by the user. It may be analogous to accessing a secure box in a bank vault. It requires two keys to open, an example of a modular approach in an analog world.

Let us extend this over-simplification to a hotel room. The key card or mobile code, to open the door, may not allow the help (house-keeping) to enter the room, if the occupant dead-bolts or uses the security chain, from inside the room.

Re-imagine the scenario where neither the dead-bolt nor the security chain is affixed to the door surface, facing the inside of the room. On entering the hotel room, you find a bag of screws, a screw driver and four relevant holes on the door frame to insert and fix the dead-bolt or chain. You can use the widgets provided by the hotel or use your own widgets, as long as it is a *standard* that fits relevant “holes” in the hotel door frame.

In the digital world, there are no widgets. The digital equivalent (screws and holes) may be a *dynamic* API. The digital equivalent for dead-bolt is a digital certificate, with mobile duo authentication, provided by a third party trusted vendor (of your choice). Once you enter the room, the mobile app on your smartphone, which you used to enter the room code, prompts you to select a personal encrypted key, from a menu of providers. You choose a key, authenticate and transmit it, to the hotel door lock. Neither room service nor hotel manager can use any over-riding “master” code (a version of a public key) to unlock your hotel room door, unless you authenticate, and transmit your private key, to the electronic door lock. Dual keys will unlock the hotel door.

If you are in the shower, and the breakfast trolley is outside your door, you can use your smartphone to transmit your key to the lock, without getting out of the shower.

However, if you suffered a myocardial infarction and passed away in the shower, you need something more than breakfast. The room service assistant delivering the breakfast trolley gets concerned and calls the hotel security. Hotel manager calls 911. Upon arrival, emergency services uses a “bue button” emergency code, which over-rides private keys, to enable access to the hotel room, when there is a medical emergency.

For a more dramatic example, a jewel thief is hiding inside a room, after a heist. Tim McGee from NCIS can hack the digital key to unlock the door. But, if Zeevah is not quick enough to burst inside the room, the DID system (digital intruder detection system) is activated to sound an alarm. The jewel thief escapes through the window.

In another scenario, Mr Bond is inside a hotel villa. Dr No is trying to enter the villa. Dr No simultaneously hacks the digital key and silences the DID system. DID detects intruder activity but cannot trigger the sound software to elicit an audible signal.

Dr No hacked the DID alarm by using the 3rd party sound wave software (think 3rd party tire pressure sensor in a highly secure autonomous vehicle) necessary to create the audible response when triggered by the DID system. Dr No could not hack DID, but just turning off the audible alarm, accomplished the task, functionally, rendering the DID impotent by inactivating the sound.

However, despite the technical wizardry of Dr No, he is stumped to find, not one, but a triple layer cascade, engineered by the MI6 boffin Q for Mr Bond's protection.

The MI6 version of the standard key offers a triple layer key. For the intruder, it will take three times the effort, to hack three keys, in order to complete unlocking. It is a waterfall cascade, requiring three jumps. For cybersecurity, it is a time trap. Hacking the first key gets you in, but you must hack the second key, and a third key, to complete the set. The time trap offers the bonafide user to take precaution. The tri-layered DID system triggers back-up signals for intruder detection, anticipating inactivation of the sound.

Dr No is a sitting duck in his DeLorean parked outside the entrance of the hotel villa occupied by Mr Bond and Miss Eva Gaele Green. Alerted by the redundancy of the DID system, Vesper Lynd springs into action, from the adjoining villa. She perforates Dr No's left vertebral artery with her Walther PPK, even before Dr No can utter, yes or no.

Modus Operandi

The drama aside, the suggestion involves the purchase of security-as-a-service (SECaaS) from one or more trusted vendor(s). This is, at this time, a hypothetical idea.

This is a business opportunity in cybersecurity. Distributed modularity for *ad hoc* cybersecurity via mobile delivery, installation, activation, intruder detection and third party response connectivity (for example, to police, emergency, FEMA or other humans).

A similar approach, but without mobile delivery, may be installed via a flash drive with microUSB, which may be inserted in the hotel door lock, to deliver the user preferred private key to the electronic door lock. In future, all door locks may have microUSB ports as well as compliance with WiFi, Bluetooth and other wireless protocol standards, to download, install and activate device drivers for security keys, DID systems.

Security as a service (SECaaS) on a microUSB flash drive may port security not only to hotel doors but any device, including millions using FPGAs. SECaaS drives may be bought from gas station (petrol pump) vending machine, at Walmart or Tesco or 711. It can be personalized by re-formatting the drive using a biometric tool (finger print or voice). The drive based system may be better protected from hacking, or time spoofing, compared to mobile delivery of the security app via wireless telecommunications.

Variations may create other forms, formats and ASICS. The essence is a SECaaS system which is modular, and distributed with such granularity, that the sheer volume may pose a hurdle for intruders, to identify which one to track and hack. The delivery of multi-component apps through different media (physical flash drive, mobile keypad) introduces complexity, a source of resistance. The number of providers decreases the potential for agency or industry sponsored espionage (by installing software ports with universal access or "back" doors to siphon and transmit data, unbeknownst to the user).

Albeit imperfect, mobile or USB SECaaS, may confer some degree of security to any system or device, which can be controlled by the user. Absolute reliance on external security systems may be plagued with trust issues, related to suppliers the provider may use, in order to deliver the service. User controlled SECaaS enhances the user experience.

SECaaS providers may include NGOs in the developing economies, government-academic-industry consortia, consumer watchdogs, global organizations or standards body (eg GS1, EAN, ITU^[11], IEEE). These organizations may offer an independent service as a pay-per-use micro-payment. The assumption is that an august “external” agency, removed from direct corporate influence, is less likely to pilfer or compromise security. Hence, we may trust their security-as-a-service (SECaaS) offer.

Vendors of devices (shop floor machines, healthcare robots, heart monitors^[12], airplane turbines, valves for oil pipelines, refrigerators, automobile parts, prosthetics, phones, hotels) will offer APIs to digitally receive, install and activate the security service (SECaaS). In future, devices which generate, transmit or acquire data, may not be sold without APIs. Interface standards will enable users to install one or more layers (think containerization of the sand-box concept) of security protocols, from one or more SECaaS providers, from different global regions, to create a secure cascade, as a system.

Mobility makes it imperative that security-as-a-service is user controlled and calls for new software tools. SECaaS may draw on vendors specializing in a smorgasbord of dynamic security engines, for example, random number generation tools, prime number cryptography, biometrics (finger print, iris scan) and composites (RFID EPC + SSN).

Partners in the SECaaS ecosystem requires secure storage (cloud, fog, mist) and connectivity with other domains (intruder detection, non-obvious relationship analysis, fraud monitoring). Data protection^[13] rules and new policies^[14] makes it essential for users to store and access their SECaaS data in their preferred nations. Redundancies introduced by the user may make it difficult to penetrate all layers of security, which did not originate from device vendors, or may be difficult to hack from distributed (cloud) storage, wrapped in cognitive firewalls, in separate locations or different geographies.

A Complex Path

Device-linkage is only one version of a personal security agent (PSA) for objects. But how an individual wishes to interact with the cyber-world, what data one wants to share, or which information one chooses to keep private, is inextricably linked to one’s identity. Protecting this identity, and keeping it secure, is another function for the PSA. Hence, it helps to differentiate between object-PSA (OPSA) and individual-PSA (IPSA).



Fig 1 – World Bank proposes to endow each individual with a digital identity. It may be a vehicle to embed individual personal security agents, for example, social security system.

Starting with medical records^[15] and continuing^[16] with the World Bank Group's Identification for Development (ID4D) initiative^[17], also advocated^[18] by GSMA, we need tools to deliver identity, security and privacy, for any citizen, with a digital footprint linked to their digital identity. The medium of delivery for IPSA may be linked to OPSA, because humans need a *medium* to interact with cyberspace. *That* medium is provided by the convergence of objects, hence, IoT, and telecommunications, via various applications.

There is little debate to refute the need for national policy^[19] and global tools. The latter must be redundant and distributed with very high fault tolerance. These tools must be capable of *ad hoc* dynamic composition when the *status quo* is challenged due to threats arising from breach of cybersecurity. Because *post hoc* security is useless in the IoT-by-design paradigm, the emphasis is on the dynamic composable architecture, and its ability to “discover” atoms and bits, in real-time, related to people, process and/or events.

IoT related cybersecurity is in need of IPv6, a key protocol for connectivity. It is a fundamental routing layer in packet communications. The rapid diffusion of connectivity catalyzed by IoT is increasingly and inextricably linked with our lives, perhaps, our digital twin^[20] representations, which may include information about information^[21]. In this scenario, information arbitrage by “avatars” may help decision support systems.

Individual Personal Security Agents (IPSA) may protect privacy, regulate data sharing and communicate (including emergencies) between individuals and their digital world(s), which may include digital twins, especially for industrial systems.

IPSA must be globally unique and coupled with individual id systems^[22] eg social security number (USA) or Aadhaar (UIDAI, India). We propose a digital twin^[23] approach (see Chapter 3), handled by creating a mobile software intelligent agent, for each citizen of the world (think of IPSA as an avatar from ‘Second Life’ games, 2003).

To tamper-proof the digital footprint and protect the digital records of this agent (IPSA), we may seek tools from “blockchain” (see Appendix I) to document, authenticate and grant permissions (‘handshake’), for interoperability and multi-tasking across diverse applications (eg healthcare, banking, fintech, e-vote and remote 3D printing-on-demand). Using public key cryptography and personal agents to protect private keys, PSA may be equipped with tools to de-identify data, in course of case-specific dynamic composition of responses. Hence, the potential to use IPSA in e-vote, or sharing de-identified private data, for example, healthcare data collection, for census or public policy surveys.

The agency of agents (APSA), acting on your behalf (IPSA), or on behalf of machine (OPSA) components or devices, associated with you, must be trained, updated and maintained, to be in tune with your personal likes/dislikes/preferences for allowing or *not* allowing your data (location, medical data) to be shared (or not), when external agents or bots query your digital ecosystem. What if a mapping service queries your phone for your location data? Who will protect you and offer privacy, if you so desire?

Your IPSA may be pre-programmed by you to respond, according to your preferences, which *you may change* using another remote device (OPSA), or modify associated dependencies, using digital assistants (time of day, office or home, travelling for business or in clandestine meetings, medical status or trigger emergency *blue button*^[24] over-ride). Perhaps similar approaches are necessary for Agents (OPSA) overseeing sensors, machine parts, medical devices, turbine blades, PLC controllers, smart grids, automobile brake pads, water filters and trillions of inanimate objects or things or processes using IoT, as a digital by design metaphor, in developing applications.

APSA, IPSA, OPSA and other PSAs, need standards. The road taken by trusted organizations may drive standards based operations, for security-as-a-service, to evolve. However, standards or policies for every possible situation cannot be conceived *a priori*. Systems must be installed to trigger dynamic composition of *ad hoc* micro-directives^[25].

Open data sharing may be as essential as selective de-identification schemes, when anonymity and privacy must be balanced, in the interest of the individual. For example, Sam collapses on the steps of Vittoriano^[26] due to exhaustion and rushed to Ospedale Fatebenefratelli, nearby. But, they are unable to access her Epic-locked EHR from Massachusetts General Hospital. Sam is injected with a steroid and drifts to a coma. When staff in Rome speaks with Sam's physician in Cambridge, they learn that Sam is diabetic. Injecting the steroid was a nail on her coffin, but, her death was preventable.

In certain scenarios, IPSA and OPSA, if adequately tuned, may be a life saver. In other cases, the responses handled by the agents may be denuded of certain data or values to protect personal ID (convergence of public key encryption^[27] with editable blockchain principles and IPv6 for mobile e-vote). Machines and devices (OPSA) may need data, information and metrics, to remain vigilant for intruders, as well as industrial espionage.

Bio-inspired Modularity, Dynamic Connectivity, Composability and Convergence

The community of PSAs must converge, connect, communicate and continuously monitor, to curate diverse digital threads, to analyze threats, estimate risk and synthesize the threshold necessary to elicit an alert, alarm or instantiate action, to preserve security.

The example of community as a *function* based on components as a *form* is a robust time-tested bio-inspired theme of modularity. One example is anchored in the principles surrounding the evolution of nano-biomes with respect to life forms in the oceans^[28]. Rather than combining all life functions into a single organism, the nano-biome works as a network of specialists, each with a special form (module) that can only exist as a community. The forms must converge in a complex spatio-temporal interplay, to give rise to systemic interactions, which, in turn, will manifest the desired function.

In the modular approach to cybersecurity, the form may be equivalent to agents, each specifically created to execute a particular task or role. When the agents aggregate, as an agency, to support a system, the overall outcome from convergence of these forms generates the function, in this case, an agency tasked to protect the security of the system.

How do we determine that the individual agents and their related tasks are secure?

This is where one begins to appreciate the value of modularity, convergence and the formation of agencies (groups of agents) which enhances the function (cybersecurity).

For example, you receive a SMS from your wife to warm up the lunch casserole for 5 minutes in the microwave. You proceed to perform this task and enjoy your lunch. What if you received a message from your wife to heat up the lunch for 500 minutes in the microwave? You (the human) wouldn't comply with the command. Would you? Your sense of *what is reasonable* prevents the execution of the message. This action represents the concept^[29] of a "*cognitive*" *firewall*, designed to raise an alarm based on what is reasonable, as determined by our sense of cognition (Joshua E Siegel, PhD thesis, MIT; Sanjay Sarma, personal communication). If a security system is semantically challenged, it will not be able to distinguish between the *values* in the field, 5 vs 500, because both are numbers, hence, allowable, unless there is a pre-set range, coded in the instruction.

Consider a command to a temperature sensor in a critical environment (cooling tower in a nuclear facility or combustion chamber in a jet engine or turbine). Usually, an external command may trigger the sensor to sense the temperature and report back to the data center every *5 minutes*. An intruder-designed action or malware mimics the command but changes the time to *5 seconds*. This action may appear benign but the *battery life* of sensor may be depleted in a few hours and sensor will cease to function.

If the temperature of the cooling tower or combustion chamber exceed the limits, it may result in a meltdown or some other form of catastrophe, including loss of lives, injuries and contamination, due to failure of cybersecurity. The sensor and the micro-system functioned exactly in the manner it was designed - sense temperature on demand. But, the micro-system was not *designed to reason* that there may be a breach of security because the task demanded – sense and respond every five seconds – did not include within its scope the validation process, whether or not a particular command “makes sense” for the whole system, taking into consideration the *battery life* of the hardware.

A cognitive firewall and its “supervisor” function, if installed, as separate yet linked modules, could evaluate the system’s “health” and test incoming commands, to ensure that a particular command “makes sense” for the connected system. Supervisor may proactively monitor the system’s pattern and identify anomalous behavior, due to system model breakdown, physical system failure, or other self-inflicted mechanisms.

Labelling this function as “cognitive” may invite justifiable criticism because the science of cognition is far more complex. Use of “cognition” is at best like using a new language without a dictionary or knowledge of the grammar. It may be analogous to learning a language like a child - through imitation and trend identification in complex examples of linguistic usage.

Similarly, claims of “intelligence” by unscrupulous corporations are vapid, trite and shoddy, if one considers the rigor of neural underpinnings of intelligence, compared with the pedestrian, apocalyptic, momentum attributed to artificial intelligence^[30] by those who are uninformed or ill-informed or inspired solely by profit.

Connectivity of these forms and agents, via IPv6, is one mechanism by which each entity level unit may communicate, when the systems are distributed, or where long range interactions are essential. The concept of *cube-on-cube* was proposed by Marvin Minsky, MIT (page 311 in this^[31] PDF). The convergence of Minsky’s *cube-on-cube*, with connectivity between the cubes, using IPv6 as the medium, is touted by companies^[32], claiming “containerization” as a new and novel software innovation.

Connectivity using IPv6 draws on an earlier (2006) paper^[33] which is included in Appendix I. In that paper, I suggested using the internet protocol version six (IPv6) **format** to uniquely identify, not only things (objects in IoT), but processes, relationships (syntax, semantics) and interfaces (sensors). The design key in the earlier paper (2006) relied on using the 128-bit IPv6 global standard (which offers 3.4×10^{38} unique “names or addresses”) to uniquely identify **every instance** of any transaction, any state change and follow their trail, even when distributed (routed). If re-imagined, the 2006 paper may appear to contain elements related to the concept^[34] of blockchain^[35] triggered^[36] by the bitcoin principle^[37], which is related to the idea of digital ledgers. Implementing digital ledgers may monetize PSA but there aren’t any low hanging fruits, in this scheme.

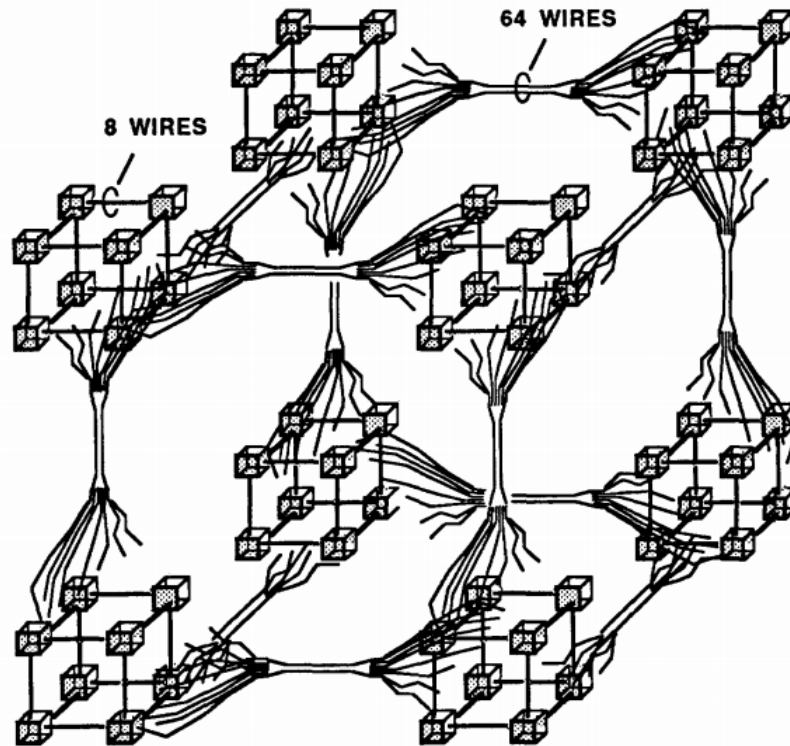


Fig 2 – Marvin Minsky’s bio-inspired *cube-on-cube* concept [30] is extrapolated from, and may be a representation of, the *topological* connectivity between neurons or neuronal circuits, representing the *form* but not the *function* of biological neural networks.

Paths to Monetization

New business growth from security-as-a-service (cybersecurity software) may serve about 10 billion consumers by 2050 and trillions of B2B operations, much sooner. One must create/sell/lease/rent/train the Agents (IPSA, OPSA) for security-as-a-service. Monetization of software for security-as-a-service (SECaaS) calls for innovation, using the principle of “digital ledger” for innovative tracking of each instance of action, generally an event, and logging its associated changes (for example, change in state function) or relationships, for example, a log that reflects the pre- and post- states as well as the provider (vendor) associated with those states. The latter is essential for billing.

The management of micro-payments from a pay-per-use model, needs service requests, and service delivery documentation, as well as quality of service (QoS) compliance. The trusted vendor must be dissociated from the service delivery, once the service is activated, in order to reduce the risk, from point of entry, for the threat. The sales of the software license by the trusted vendor may not be the only transaction (in the old model a fixed payment was offered for a fixed term). If the trusted vendor wishes to charge by usage, then the ability of the trusted vendor to *monitor* the use of the service is pivotal. Dissociating the trusted vendor from keeping tabs on your security service is essential to improve security for the user. The latter introduces loss of opportunity for the trusted vendor, in this pay-per-use model, because the vendor is in the dark about how many times the user is accessing the security-as-a-service (SECaaS) application.

Consider the camera on the front door of your house. You are in Princeton, NJ and your smartphone app shows FedEx Fiona walking up your driveway to deliver a package. Fiona rings the bell. You open the door to your home in Cambridge, MA while visiting Tom (203 Lewis Thomas Lab) using remote key pad on your Iris app connected to the Schlage digital lock on your door. Fiona goes inside the house. She exits from the house and door locks behind her. You see on your app Fiona walking down the drive.

What did FedEx Fiona do inside your home? She left the package on the table. What else did she do? Did she re-apply her lipstick? Did she use the toilet?

You wouldn't know what happened inside your home unless you have a camera inside. Trusted vendor for security-as-a-service needs the equivalent of a "camera outside" to know when you ping SECaaS. It chooses to remain oblivious of your use (what you accomplish). The latter constitutes data from "camera inside" the house but trusted vendor is dissociated from that function. Trusted vendor does not need "inside" data because the trusted vendor charges micro-payments based on pay-per-use each time you ping the SECaaS app. It does not matter what you do but what matters is the *duration* of the use (unit rate or cost) and the time of the day (traffic volume, bandwidth, latency may be factors in the quality of service or priority queue determination). Thus, the time-stamp is important for monetization. It is equivalent to house entry/exit data captured by the external camera. Privacy inside the house (data) remains unshared.

Distributed digital ledger, in practice, if combined with IPv6 transaction identity, can guarantee authenticity to bill for time-based micro-payment for service delivery (in any industry, eg, automobile, retail, healthcare). Each unit of this distributed digital ledger is in the form of an agent module. The nature of the service can "drag and drop" the "lego" "block" for the selected service units (modules) necessary to complete the function. The same modular principle, which applies to each distributed task sub-unit, is applicable in the distributed digital ledger paradigm.

Concurrent execution, co-location and semantic interoperability between standards and/or platforms, are key elements of this vision, if we wish to transform the suggestions to implementations. But, who will build these blocks? Part of the answer may germinate the next massive business opportunity, if distributed security is modularized to the lowest common denominator. To demolish the barrier to entry, a "pay-a-penny-per-use" SECaaS may enable any individual to "buy" security using a mobile app, from any virtual store, in a manner similar to buying a lock and a key, from a convenience store, to secure the suitcase or luggage, before handing it over to the airline, when travelling.



Fig 3 – The *lego* business of cybersecurity, convergence of system of ecosystems³⁸

The Road Not Taken

The sign posts on the road ahead suggests confluence of telecommunications, mobile apps, data, analytics, AI, IoT, blockchain, edge services, with individual identity and identification. The system must map humans and machines, tools and widgets, components and systems, with digital precision, in the correct sequence, to track and trace, each instance. One aim is to uniquely identify *that* event or process or instance which provided the opportunity for the intruder to enter or introduce a threat, which may be propagated or percolate in the system, and eventually, cause direct or indirect harm.

This granularity is one reason why one may find the 128-bit format of IPv6 such an interesting scheme and use the IPv6 unique addresses, as a globally unique id (GUID).

These concepts, digitally threaded with IPv6, may be a mechanism to improve cybersecurity, by engineering security, by design. There is ample room for convergence between IPv6 and blockchain, with selective use of public/private key encryption, for digital object architecture^[39] and IPSA.

How can we (can we?) use the 40 bits, or an extension of the security domain in the current IPv6 design, to serve as a cybersecurity base in the engineering design? Digital crypto-tokens, concealed in an alphanumeric stretch, may be connected with software security agents to authenticate (handshake) transactions, data transmissions or user activated action (the nature of which may be immensely diverse and vast in number).

The hypothetical concept of a set of *cascading locks*, is suggested. The header of the lock may be part of the 40-bit design of IPv6. Data related to the lock and its functional activation (I/O, open/close) may reside in a separate agent. It may mimic how RFID^[40] EPC^[41] contains a reference^[42] to the location where the actual data^[43] (or data agent) is stored, as a part of the broader context of the EPC information system⁴⁴.

The locks may only open (allow, activate) with a digital key, or digital token, which must be generated in real-time (if triggered), using reference data (authentication?) secured by an agent in another location (potential for network verification at the edge). The “open lock” status in tier-x, could trigger the process to open the lock in tier-y (next lock in the cascade), using information (dependencies) from tier-x. This hypothetical cascade of locks, and the sequential effect (outcome), may offer the ability to trap an intruder, in time. The system may sacrifice a few locks but eventually the aberration due to the intrusion or anomaly (if detected through alerts or alarms) can turn off the cascade (remaining locks, sequences in queue) to prevent the remaining steps (remaining locks stay locked). This is the type of function one may also expect from the supervisory layer of the cognitive firewall, if a threat is detected or potential intruder is identified.

The hypothetical idea of cascading functions (with lagged dependencies) is my attempt, to theoretically propose a tool, or mechanism, to prevent or contain an attack (intruder detection, repulsion, protection). I do not possess the depth of knowledge to determine if cascading functions are at all possible, or can be implemented, in practice. Because the suggestion does not violate any natural laws of physics, it may not be impossible. On the other hand, this suggestion may trigger a better idea, in the reader.

If feasible, and deployed, this system of security may be useful for autonomous transportation (prevent vehicle from being hacked) or machines (prevent turning off the engine when a plane is in flight) or healthcare (prevent over-dose of morphine in post-operative surgical care) or energy grid brown-outs (time spoofing synchrophasors by creating anomalies in time-sensitive networking or inducing protocols to malfunction).

Concluding Commentary

Being Digital^[45] may not benefit from any hasty conclusions about people, bits and atoms. Controversies due to cybersecurity will continue to accumulate. Questions may soon outweigh answers, and good answers may be very few, and far between.

Is cybersecurity essential, at its maximum strength, for every instance, in any or all digital transactions? If it is, then, it may pose an insurmountable economic barrier.

In a common sense approach, cybersecurity needs to be enhanced for high value targets and the level of security may be increased or decreased, by choice. For example, the US President has more security personnel than the Governor of a State. The systems at the Pentagon are better protected than online systems for Ticketmaster. On the other hand, Ms Julia Roberts may be accompanied by a few security personnel when travelling to Boston but her entourage may include a few dozen security members if she arrives in Bangalore or Bahrain.

Transforming these simple scenarios to technical solutions, may not be difficult, at least in principle. For the President we could use HACMS⁴⁶ and task Galois⁴⁷ with its execution, under the watchful eyes of Kathleen Fisher⁴⁸ and John Launchbury⁴⁹. For the Governor, we may use enterprise version of ESET⁵⁰ while Ms Roberts may summon more 'bodies' if necessary. The latter may be analogous to the one layer of personal key for the hotel door versus the triple layer cascade of keys, configured by Q for Mr Bond.

The financial burden of cybersecurity and assurances for safety, may drain our resources, to the point where the actual task and function of the system may suffer, to provide for, and guarantee, security. Then there must be provision for litigation costs, if the security malfunctions or events are not covered by indemnity clauses. We may create an almost-impenetrable digital fortress, with nothing in it, of value, to be guarded.

In FY 2015, US Department of Defense spending was \$598 billion, compared to US Department of Education annual budget of \$68 billion and the US Department of Health and Human Services budget of \$77 billion. For FY 2018, the US Senate approved \$700 billion National Defense Authorization Act on 18th September 2017. The writing is on the wall.

Cybersecurity by engineering design, within the data transmission layers, may be one approach. The idea is to detect the intrusion and/or to catch the intruding agent, very early. The digital nature of the intrusion, and the digital access points the intruder must use, makes it reasonable to assume that the nefarious agent uses the same infrastructure, and same routing protocols, to reach its desired target(s). Thus, engineering security by design, using some facet of IPv6, could be helpful.

Distributing cybersecurity, in the modular approach, allows room for immense granularity. A cacophony of providers, vying for a piece of the business, must peddle its brand reputation and use different delivery mechanisms. The user will add extra layers of security, perhaps at the application layers. The strength of this approach is rooted in its diversity and may be boosted by its complexity, which must be sufficiently compromised, in order to create a breach.

Monetization of distributed cybersecurity using a pay-per-use micro-payment model may be lucrative. If 10% of the global population, uses **one** security function per day, and if you charge 1 penny (1 US cent) per use, then you earn \$2.5 billion per year. With trillions of end points in IoT networks, billions of people in the world using millions of devices, is it possible that projected earnings of \$2.5 billion per year is exaggerated?

PSA, IPSA, OPSA and distributed cybersecurity tools are not yet in our vernacular but may not be too far behind. Agent based cybersecurity is an old concept which must be re-viewed with new eyes. Dynamic composability is quintessential for cybersecurity due to volatility of environments. The *ability* to maintain a modest presence (for example, security guards at the entrance) but the *capability* to call in the cavalry, if an attack is imminent (for example, swarms of mobile agents), is the type of *push-pull optimization* that cybersecurity demands, to face future challenges. We need basic protection for a nominal SECaaS fee and pay-per-use *on-demand* security-on-steroids option, when faced with a threat, attack or intruder.

These concepts may not have a mainstream following, yet. These are not “low hanging fruits” to entice the corporate world. Harvesting low hanging fruits require low level skills. The pursuit of cybersecurity calls for brilliant, creative, and unusual, minds, and investments which can tune the engine, rather than merely polish the chrome.

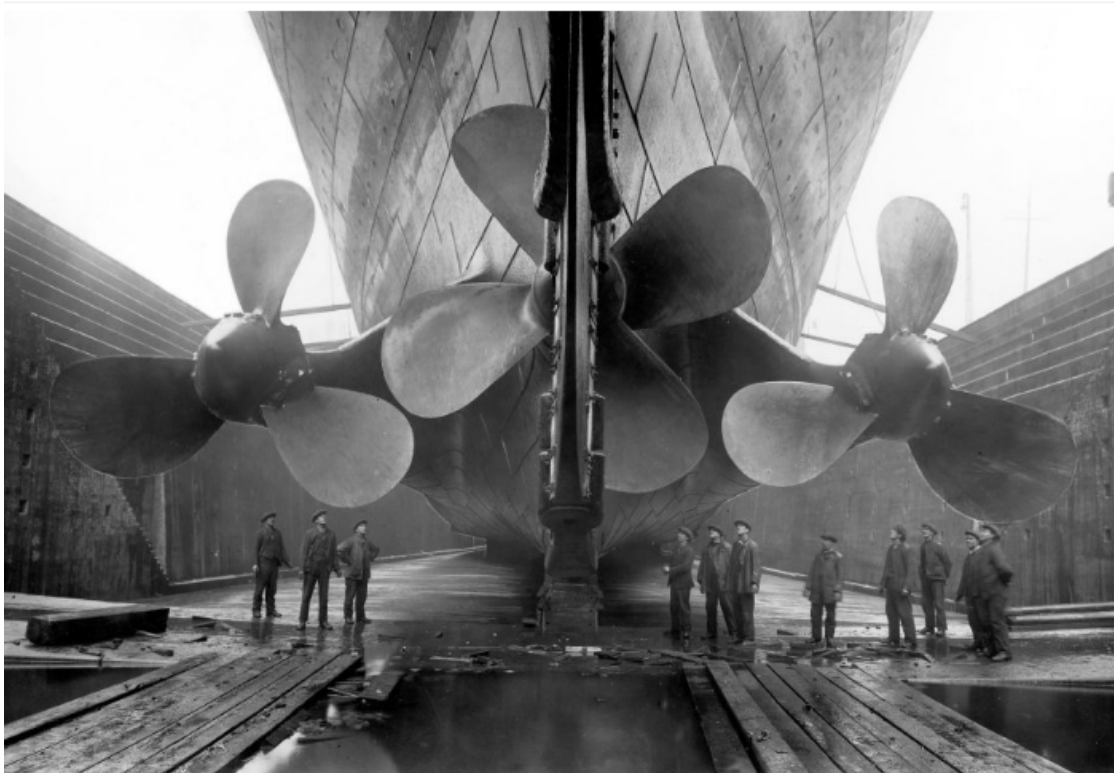


Fig 4 - Cybersecurity may be analogous to the propellers of a ship. You may not see it, but the vessel cannot move forward, without it. Security is the not-so-secret sauce for diffusion, adoption, and profitable outcomes, we expect, from digital transformation.

Notes

- ¹<https://doi.org/10.1016/j.jacc.2017.09.1107>
- ²<http://hub.dyn.com/static/hub.dyn.com/dyn-blog/dyn-statement-on-10-21-2016-ddos-attack.html>
- ³<http://www.politico.com/agenda/story/2015/06/internet-of-things-privacy-risks-security-000096>
- ⁴www.propublica.org/article/google-has-quietly-dropped-ban-on-personally-identifiable-web-tracking
- ⁵<http://bit.ly/IoT-Policy-Socio-Economic>
- ⁶<https://itu4u.wordpress.com/2014/01/06/lost-something-on-the-internet-never-again-with-new-digital-object-do-architecture/>
- ⁷http://www.cnri.reston.va.us/papers/Architectural_Evolution_Internet_17Nov10.pdf
- ⁸http://www.researchandmarkets.com/research/lght2x/global_mobile
- ⁹<http://cio.economictimes.indiatimes.com/news/mobility/tata-teleservices-enters-mobile-device-management-space-differentiates-on-unique-features/54709229>
- ¹⁰<http://www.theverge.com/2013/6/6/4403868/nsa-fbi-mine-data-apple-google-facebook-microsoft-others-prism>
- ¹¹<https://itu4u.wordpress.com/2014/01/06/lost-something-on-the-internet-never-again-with-new-digital-object-do-architecture/>
- ¹²<http://www.qmed.com/mpmn/article/teardown-look-inside-st-jude-medical-merlinhome-transmitter>
- ¹³http://www.echr.coe.int/Documents/Handbook_data_protection_ENG.pdf
- ¹⁴<http://ec.europa.eu/justice/data-protection/>
- ¹⁵<https://www.ncbi.nlm.nih.gov/pubmed/11734380>
- ¹⁶<https://openknowledge.worldbank.org/bitstream/handle/10986/20752/912490WP0Digit00Box385330B00PUBLIC0.pdf?sequence=1>
- ¹⁷<http://pubdocs.worldbank.org/en/959381434483205387/WDR16-Spotlight-on-Digital-ID-May-2015-Mariana-Dahan.pdf>
- ¹⁸<http://www.gsma.com/mobilefordevelopment/wp-content/uploads/2016/07/Towards-Shared-Principles-for-Public-and-Private-Sector-Cooperation.pdf>
- ¹⁹<http://bit.ly/NOT-NIST>
- ²⁰<https://arxiv.org/ftp/arxiv/papers/1610/1610.06467.pdf>
- ²¹<https://itu4u.wordpress.com/2014/01/06/lost-something-on-the-internet-never-again-with-new-digital-object-do-architecture/>
- ²²<http://bit.ly/DID-PLATFORM-WB>
- ²³<https://arxiv.org/ftp/arxiv/papers/1610/1610.06467.pdf>
- ²⁴<http://www.va.gov/bluebutton/>
- ²⁵http://scholarship.law.berkeley.edu/cgi/viewcontent.cgi?article=1067&context=law_econ
- ²⁶<http://www.ilvittoriano.com/>

- 27 <https://dash.harvard.edu/bitstream/handle/1/12362600/Determenistic%20Pubic-Key.pdf?sequence=1>
- 28 <http://pubs.acs.org/doi/pdf/10.1021/acsnano.5b07826>
- 29 <https://dspace.mit.edu/handle/1721.1/104456>
- 30 <https://arxiv.org/ftp/arxiv/papers/1610/1610.07862.pdf>
- 31 <http://www.acad.bg/ebook/ml/Society%20of%20Mind.pdf>
- 32 https://docs.docker.com/engine/userguide/networking/default_network/ipv6/
- 33 <http://esd.mit.edu/WPS/2007/esd-wp-2007-17.pdf> (see APPENDIX I)
- 34 <https://bitsonblocks.net/2015/09/09/a-gentle-introduction-to-blockchain-technology/>
- 35 <https://www.weforum.org/agenda/2016/06/blockchain-explained-simply/>
- 36 <http://www.mail-archive.com/cryptography@metzdowd.com/msg09959.html>
- 37 <https://bitcoin.org/bitcoin.pdf>
- 38 <http://qz.com/801640/darpa-blockchain-a-blockchain-from-guardtime-is-being-verified-by-galois-under-a-government-contract/>
- 39 <https://itu4u.wordpress.com/2014/01/06/lost-something-on-the-internet-never-again-with-new-digital-object-do-architecture/>
- 40 <https://ocw.mit.edu/courses/engineering-systems-division/esd-290-special-topics-in-supply-chain-management-spring-2005/lecture-notes/lect11.pdf>
- 41 http://cocoa.ethz.ch/downloads/2014/06/None_MIT-AUTOID-WH-002.pdf
- 42 http://cocoa.ethz.ch/downloads/2014/06/None_MIT-AUTOID-WH-001.pdf
- 43 http://cocoa.ethz.ch/downloads/2014/06/None_MIT-AUTOID-WH-003.pdf
- 44 <https://doi.org/10.1016/j.compind.2017.10.004>
- 45 <http://web.stanford.edu/class/sts175/NewFiles/Negroponte.%20Being%20Digital.pdf>
- 46 www.cyber.umd.edu/sites/default/files/documents/symposium/fisher-HACMS-MD.pdf
- 47 <https://galois.com/>
- 48 https://www.cs.tufts.edu/~kfisher/Kathleen_Fisher/Home.html
- 49 <https://galois.com/team/john-launchbury/>
- 50 <https://www.eset.com/us/>

CHAPTER 3 ▪ EMERGENCE OF DIGITAL TWINS

Abstract

Multiple forms of digital transformation are imminent. Digital Twins represent one concept, where we may use tools and technologies to “map” data (bits) from objects (atoms). It is gaining momentum because the “map” can act as a “compass” to reveal the status of atoms (things, devices, components, machines, people), process visibility and real-time transparency. Adoption of digital proxies, or digital duplicates, may face some hurdles due to lack of semantic interoperability between architectures, standards and ontologies. The technologies necessary for automated discovery are in short supply. Progress depends on the convergence of information technology, operational technology and protocol-agnostic telecommunications. Making sense of the data, ability to curate data, and perform data analytics, at the edge, or mist, rather than in the fog or cloud, is key to value. Delivering algorithm engines to the edge, are crucial for edge analytics, if latency is detrimental. The confluence of these, and other factors, may chart the future path for Digital Twins. The number of unknown unknowns, and the known unknowns, in this process, makes it imperative to create global infrastructure and organize groups, to pursue the development of fundamental building blocks. We need distinctly new ideas and unconventional research, to generate creative and innovative solutions.

1 Introduction

Being Digital (Nicholas Negroponte, 1996)¹ and *When Things Start To Think* (Neil Gershenfeld, 2000)² introduced the public to the emergence and the rise of smart machines. About a decade later, Jeff Immelt of GE started to market these ideas in the *minds and machines* campaign, claiming a future where self-organizing systems, sub-systems, multi-component subunits and modular embedded code, shall define the next generation of adaptive intelligent machines. When can we expect that “next” generation to emerge?

In 1513, the discovery of the isthmus at Panama by Vasco Núñez de Balboa triggered the idea of creating a trans-oceanic canal. Francisco Lopez de Gomara suggested (in his book, in 1552) Panama, Nicaragua, Darien and Tehuantepec as choices for a canal. Not for another 300 years, not until the 19th century, would the canal building actually commence under the leadership of Ferdinand Marie Vicomte de Lesseps, a French diplomat. Ferdinand de Lesseps (19 Nov 1805 to 7 Dec 1894) could not complete the Panama Canal and did not live to see the successful completion of the Panama Canal, in 1914, by the US Army Corps of Engineers³.

Creating intelligent adaptive machines faces a similar uphill battle. Our optimism is not unfounded but it may be burdened by the dead weight of old technology. Paving the path for new theories, new concepts and new forms of connectivity, in engineering design, of future systems, may lead to intelligent (?) machines. Perhaps, a greater challenge may be introducing cognition in systems, due to our wobbly and poor understanding of what constitutes intelligence⁴ (AI).

Companies, in quest of low hanging fruits are afraid to delve deeper. They are retrofitting existing machines by slapping on sensors to designate them as *connected*. Attaching sensors supposedly makes them *smart*. Workflow on steroids is peddled as

intelligence in analytics. Others are collecting and feeding big (noisy) data sets to existing software systems and claiming “cognitive software” in use. The tapestry of buzz words and patch-work of programs are introducing glaring gaps, generating errors, callous disregard for physical safety, and inept approach to cybersecurity⁵ in general.

One reason for the confusion, perhaps, is our general inability to ask correct questions. These are some of the questions from the field. What machines, devices and systems may be built with the tools and technologies at hand? How should we build and use them? Do we really want to just connect everything to collect big volume of data? Is it really all about data? What is data curation? How can we teach machines to achieve specific goals? Are these the correct questions to ask? *Are these the questions even worth answering?*

These and other related questions may find some answers hidden in bio-inspired design principles. Progress in bio-MEMS, bio-NEMS and molecular machines⁶ coupled with biological mimicry and cybernetics⁷ are elements which may (?) converge with AI⁸ in an over-arching strategic⁹ plan. Integrating that plan to inform engineering design is the Holy Grail. The command, control, and coordination of bio-inspired engineering design requires hardware-software synchronization, *by design* (not as an after-thought).

Time-synchronized hardware-software integration is one hallmark of cyber-physical systems¹⁰ (CPS) which is the foundation of embedded¹¹ systems. The concept of digital twins emerged from NASA, perhaps because time guarantee (concurrency) in embedded systems is critical for aero/astronautics. To advance the diffusion of the digital twin concept, we must adopt practices¹² borrowed from CPS¹³.

The current advocacy to advance the principles and practice of digital twins, from manufacturing to healthcare, calls for connectivity, by design. Systems should be able to *discover*, inherit, evaluate and share intelligence across sub-components, and coordinate to turn on/off modular code, embedded in sub-systems. We may monitor, analyze, control units (PLC) and sub-units, in real-time¹⁴ (sensors, actuation) and visualize operations not only at the system level, but, perhaps, the entire ecosystem¹⁵. The latter may accelerate the diffusion of digital transformation, using a systems engineering approach.

2 The Rationale for Digital Twins

2.1 Signal vs Noise – IoT vs Digital Transformation

The term IoT may have been coined by Peter Lewis (1985) or at the MIT Auto ID Center (1999), but the past, present and future¹⁶ concepts of IoT have been brewing for almost a century. Milestones include Isaac Asimov’s “Sally” the fictional autonomous car¹⁷, Herbert Simon’s seminal paper¹⁸ (“talk to the computer”), Hiroshi Ishii’s idea of “Tangible Bits” (People, Bits and Atoms¹⁹), Mark Weiser’s paper²⁰ “Activating Everyday Objects” as well as the 1991 article (Scientific American)²¹ and the vision²² of the “networked physical world” by Sanjay Sarma²³, David Brock and Kevin Ashton (2001). The IoT roadmap²⁴ promises to be even more dynamic in the future and scholarly discussions, including one by Alain Louchez²⁵ outlines the layers of influence.

IoT is a digital-by-design metaphor and a paradigm for ubiquitous connectivity. The value proposition rests on proper use of plethora of tools and technologies that must converge to make sense of the data. The hypothetical transparency is of little use without

the data of things, if we wish to profit from IoT applications. On the other hand, digital transformation is a cacophony of ideas open to innovation from wireless systems²⁶ as well as broadband communication²⁷ and forthcoming 5G, for time critical²⁸ operations. The latter, if combined with 8K²⁹ visualization, may catalyze robotic surgery. Masses may benefit from standard surgical procedures, such as laparoscopic cholecystectomy, appendicitis and phacoemulsification (removal of cataracts).

CNC machines, ERP, Web 2.0, fixed-task robots are examples of waves of digital transformation in business. The 2012 proposal³⁰ from Sanjay Sarma of MIT Auto ID Labs to pursue a **Cloud of Things** initiative resonated globally and the concept was promoted by others (Finland³¹, France³² and South Korea³³, to name a few). The next wave appears to be the transition from manufacturing products (items to be sold), to the creation of a service ecosystem, around the product, to sell service as a pay-per-use model. Digital transformation includes establishing a digital leash to monitor, promote, connect, track and trace, in order to monetize every point of contact in the relationship (digital CRM), not only once (sales of product), but over the life time of the customer. Hence, product lifecycle management evolves to digital PLM with quality of service (not product delivery) as the KPI, and monetization tool. Quality of service (QoS) emerges as the *readiness* metric to gauge customer satisfaction. If QoS metrics are maintained by provider(s) or manufacturer(s), then the client or customer is expected to pay for the QoS level associated with the product-service, per contractual agreement, as long as the customer is consuming the benefit, that is, the lifecycle of the user, not only the product.

In instances where the product is not an object (eg, telco) the business models are inextricably linked to “outcomes” the customer expects. Monetization of digital transformation from an outcome-based model is complex, due to the ecosystem of players and alliances. It is not easy to optimize and arrive at the point of convergence, to deliver the outcome as a seamless function, which involves end-to-end value chains, operating as a pre-agreed platform.

The task associated with monitoring each instance of engagement for micro-revenue collection, and its disbursement, is complex. We need to track each instance, and maintain a record of connectivity, in an irrefutable evidence log (eg blockchain³⁴). The latter may act as a digital ledger³⁵ to validate fractional micro-payments, due from each point of contact (PoC). The digital id of the service, delivered at the PoC, identifies the member of the supply chain providing the unit of service, at that specific instance. The latter may be a part of the *sum of services*, in the portfolio, that defines the service, and each may be weighted by a specific QoS, the customer expects. The customer pays for the final outcome (*value* in the value chain). The sum of the parts must be delivered *before* the value perishes. The duration of that value may be widely divergent (compare retail vegetables in a grocery store versus life of the data which predicts risk of diabetes).

Synthesis of the parts to act as a seamless function is the challenge. Who will build the parts of the platform, which will be sufficiently open, and interoperable, to connect with the innumerable end points, at the edge? Who will build the blocks for the digital modules? Who will build the blocks for the blockchains? The business is building the blocks is not for the faint-hearted.

2.2 Digital Twins

Scenario

Schlumberger is monitoring a drill-head in operation, on a drilling platform, in the Outer Hebrides to determine the MTBF (mean time between failure) metric, and trigger replacement (maintenance), to prevent work stoppage on the rig. The camera at the tip of the drill-head, and drill-head (drill-case) sensors (eg, vibration, temperature, gyroscope, accelerometer) transmits (wired, wireless) video, audio and other data, which must be analyzed as close to real-time as possible, with respect to object identification, precision geolocation and process linkage. AI/ML analytics updates MTBF metrics. Depending on MTBF range (80%, 90%) as decided by business logic (when to replace), the drill-head spare parts supply chain (service, fulfillment) must be connected to auto-trigger the “head” when the MTBF range is reached. Purchase orders [supplier(s)] are followed by transport and logistics for delivery, and workforce scheduling, to execute the replacement prior to breakage (payment, contracts, invoices, and accounts payable, must be connected). Data about drill-head, and lag time for each process/operation is captured by the operations management team, at a remote location, for future studies or collective evaluations. Can we visualize this entire end-to-end process as a Digital Twin, operating in real time?

In our current *modus operandi* this operation involves a plethora of operational silos (OT, drilling operation, mechanical engineering, systems, supply chain, finance, human resources), software (connectivity between locations, cloud store, cybersecurity) and hardware (not only the spare parts and drill-head but also the computational hardware, eg, servers at different locations which are essential for the IT infrastructure).

The concept of DIGITAL TWIN posits that the flow of data, process and decision (this hypothetical scenario) is captured in a software *avatar*³⁶ that mimics the operation or offers, at the least, a digital proxy.

The 3D “twin” or its “lite” version, the digital proxy, may be visualized by an analyst or manager, on a location-agnostic mobile device (iPhone, iSkin). Drilling down on a schematic illustration with the icon “drill-head” may link to the live video-feed from the drill-head camera, which opens up on a new GUI (tab or window). Data fields (features, attributes, characteristics) related to the drill in operation (pressure, torque, depth, temperature, rotations) are visible by clicking on the icon for the drill. A plot showing the data, approaching the MTBF metric, may be instantiated using a command (“plot data”). It shows the live sensor data feeding the dynamic plot, displaying the characteristics of the drill-head, and the rate at which it is approaching the MTBF. The range may be set by humans (or the system), using prescriptive and/or predictive values, based on “learned” values from machine learning tools operating in a “diagnostic” mode.

Will it allow for “what if” analysis?

Can the analyst viewing the Digital Twin, change the MTBF range and explore how downstream processes may change (see principles of <http://senseable.mit.edu/>)?

The digital proxy for supply chain should spring into action, displaying delivery lag times from different suppliers, and cost of normal vs expedited delivery. The material composition of the alloy, used in manufacturing the drill-head, should be visible. The analyst may use an *ad hoc* selection process and identify a new vendor. Can the system trigger process workflow to alert the people (roles) along the way to clear the requisition, and generate purchase order, for the new supplier? Can it auto-verify the new supplier to check credentials, inventory, cost, transportation scheduling, quality of service reports and customer reviews from prior contracts?

We are viewing Digital Twin or its digital proxy on a device. We watch the drill-head in action. A window displays real-time data/analytics approaching MTBF. Using a different app, we identify a supplier to custom-design and 3D print-on-demand a drill-head with precision fit. The supplier (www.quickparts.3dsystems.com/social-solutions/) downloads the video feed (from the cloud) of the drill-head operating in Outer Hebrides. The manager monitoring the end-to-end chain [a] selects the team of engineers who will replace the 3D printed drill using a HR menu which lists skill sets, proficiencies and years of expertise by category [b] pre-sets the command on the digital twin to actuate the replacement supply chain process, when MTBF reaches 72% because fulfilment takes 21 days, and by then (21 days later) the MTBF is predicted to reach 85% (code red: replace).

Each sub-unit provider must collaborate and synchronize (systems, standards, semantic interoperability) their role in the operation, and the *representation* of their function, in the digital proxy, or in the digital twin model, in near real-time. The plethora of system providers, suppliers, 3rd party software, analytics, cloud storage, fog providers and hardware component manufacturers - **also** - expects to be paid for the outcome.

The design of content, and connectivity between such system of systems, calls for new principles of model-based systems engineering, to integrate global standards, to anchor architectures³⁷ responsible to drive the digital-by-design paradigm. New models must inculcate the IoT digital-by-design metaphor with respect to connectivity by design, interoperability between standards by design, and cybersecurity by design. The silos of OT, IT and telecommunications must converge, to create this new digital-by-design foundation for digital proxies and/or digital twins (digital proxy plus 3D models).

In this paradigm shift, objects and things may not be baptized *after* birth to follow the digital persuasion, but will be born free of analog baggage. It may not need a path to digital transformation because they will be *born digital*.

Configuring Digital Twins: Creating the Blocks in the Blockchain

Lessons from cyber-physical systems (CPS) with respect to operational time synchronization may be key for certain forms of architecture for digital twins. Without open repositories, the process of creating (building) digital twins and the adoption of digital twins may be restricted to an industrial oligopoly. The vast majority of users cannot deploy an army of engineers to create custom digital twins. Rapid diffusion of digital twins calls for open source entity level models of sub-components (units). Think of each SKU listed in a BOM (bill of materials). Next, imagine each sub-system with unit parts, to serve as the “block” or base level unit, which needs to be created (built). The “old world” notion may have stopped at the physical manifestation - the actual unit made of tangible material. In a digital twin world, we need a digital version.

In the era of digital twins, we will call on the *source*, that is, the CAD/CAM model owner of that unit, to create, and *contribute* to a common repository (?), the software representation of the unit, replete with the physics of the material, and the engineering characteristics of its operational function. For example, the physics of the part will inherit natural laws, which governs all entities. For example, if a spare part were to fall off a table (on this planet), it will fall **down** at a rate defined by the acceleration due to gravity of 9.8 m/s^2 . The latter is an inherited³⁸ attribute from the laws of physics (characteristics forming the base in a ‘layer cake’ model).

To the informed mind, it is clear, we have encountered and entered the domain of semantics and ontologies. Digital twins of the granular units (parts), to be useful, must be connected by their relationships to the relevant data feeds from sensors/gateways. These entity relationship models and parts (connectivity) must be accessible to managers or analysts who can drag and drop the parts from the repositories on a “sense” table (device GUI). The ontology of entity level relationship models for digital twins may use bio-inspired principles. Elements³⁹ from disease models, for example, a bio-surveillance model is shown below in Figure 1.

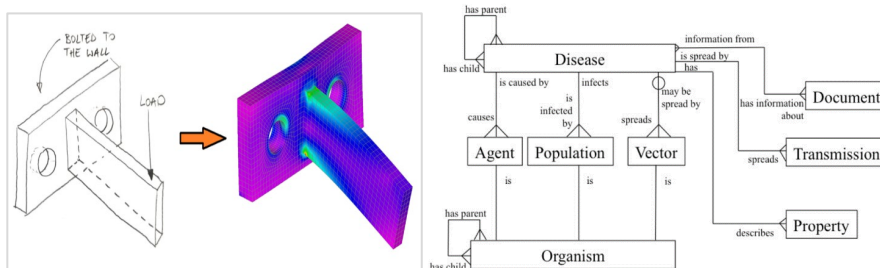


Fig. 1 - Digital twins as models of reality (left from ⁴⁰ & right from ³⁹)

To the untrained eye the cartoons may not suggest the cryptic complexity of the foundation. These foundations are “layer cakes” (eg, TCP/IP) which must be able to communicate with other “layers” (for example, semantic web⁴¹) built on other principles, concepts or ontological frameworks. It is imperative we minimize the number of such architectures, to ease interoperability between architectures (requires interoperability between standards, access to open data dictionaries, and shared ontologies).

The abstraction of the building blocks necessary for digital twins, may be similar, in principle, to the building blocks necessary to implement the use of blockchains, as a trusted digital ledger of connected instances. Who can we trust to build the blocks? This question is critical to practitioners of digital twins and blockchains. These concepts share with IoT the digital-by-design metaphor. The “block” in IoT may be the integrated platform, synthesized from subunits or blocks, containing data, of things.

The rate limiting step, which defines the functionality, is inextricably linked with, and driven by, connectivity. In order to deliver value, connectivity must span a broad spectrum of dynamic ecosystems. Implementation of such connectivity must be protocol-agnostic, location agnostic and time sensitive (maximize transmission, minimize steps), with respect to the “sense and response” latency, between the edge and the core. Since IoT is expected to connect trillions of things, scalability will be a key enabler.

Have we encountered such “block” and “connectivity” concepts elsewhere? The common answer is Agent⁴² systems. Marvin Minsky’s *brain connections* related abstraction⁴³ “**cube-on-cube**” illustrates this concept where each cube is a software Agent. It is relevant to this topic because each cube may be viewed as a “block” in the blockchain or a baseline ‘unit’ in the digital twin paradigm (digital proxy of physical entity). The origin of the concept from software Agents, emphasizes the link to semantics, ontology, and related roots, which could go as deep as neural networks, cognition and even epistemology.

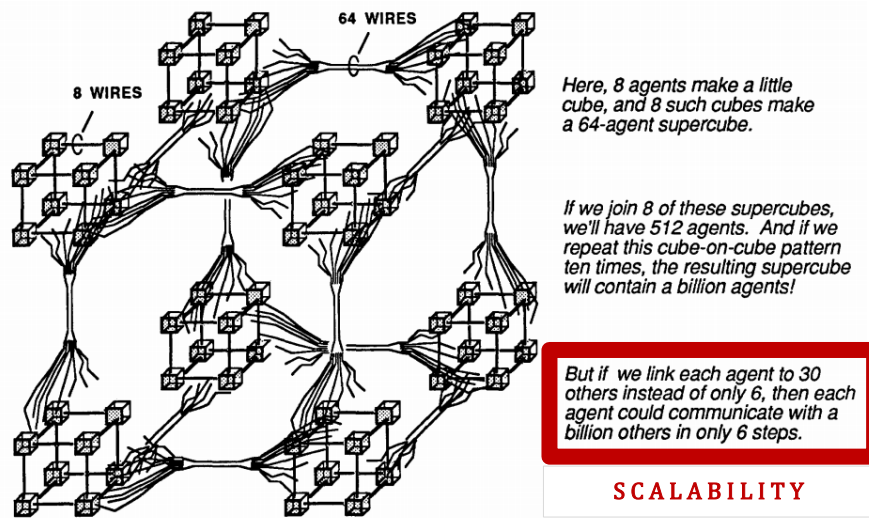


Fig. 2 - Illustration from page 315 (Appendix: Brain Connections) from *Society of Mind* by Marvin Minsky. MIT, 1985

The illustration (cube-on-cube) simplifies Minsky’s abstraction and the principle of “blocks” to represent objects, data, process and decisions (outcomes). The blocks, when connected, can synthesize a variety of entities or networks⁴⁴ joined by common digital threads. Alignment of appropriate blocks can create platforms for implementation of IoT. Parts and sub-units can be configured, to create a digital twin of any machine (drill-head). Instances and units of transactions, represented as blocks, may constitute a digital ledger of events, similar to application of financial transactions using blockchain.

For a scenario at hand, please consider the act of driving your automobile (if you can still use a gas guzzler with ICE, that is, an internal combustion engine⁴⁵) to the proximity of a gas dispenser stand, in a gas station (petrol pump).

Your car recognizes “arrival” at the gas station, correlates with low fuel reserve and unlocks the gas inlet. The petrol pump recognizes that your car is within the necessary proximity to the dispenser and recalls your choice for unleaded product. The nozzle from dispenser discovers the gas inlet, and commences fill-up, when your inlet allows, and confirms that the nozzle delivers petrol, not diesel. Once refueling completes, you see a green icon on your dashboard. You receive a SMS, indicating completion of fueling. The latter auto-triggered a financial transaction, to match the cost of fuel. Your bank confirms payment over iSkin or a smartphone app. It also informs your wife (authorized routing) that you have topped off the vehicle with gasoline (petrol).

The convergence of IoT, digital twins and blockchain is evident. The ecosystem of enterprises, when dissociated by *modular* structures and associated by function, in an operational sequence, presents a series of steps, which can be sub-divided into “blocks” which are not only things/objects but software Agents, units, processes, authentication, authorization, decisions, outliers, feedback, security, metrics and dependencies.⁴⁶

Who will build these blocks?

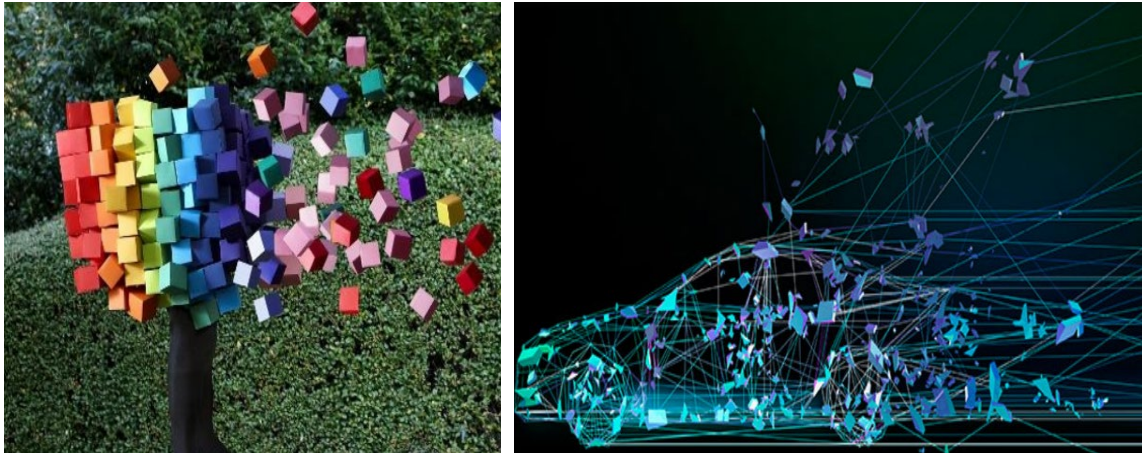


Fig. 3 - Blocks – a seamless operation represents an array of functions converging from diverse partner companies⁴⁷ (Left https://i.io.ua/img_su/small/0010/63/00106374_n1.jpg and cartoon on the right is taken from ⁴⁸)

As it is with IoT, there will not be any one industry, or company, which may claim to be the front-runner. The modular building blocks, for the many domains spanning and *overlapping* IoT, digital twins and blockchains (not limited to financial transactions) are quintessential to the global economy.

The idea of a distributed team, or teams entrusted to architect these blocks, may seem reasonable. The fractured state of the world and the intrinsic impact of natural language (in)competencies on creating semantic dictionaries and ontological frameworks introduces severe socio-technical incongruencies.

Hence, credible academic leadership of industry-government consortia, in partnership with global organizations or standardization bodies, may be a prudent option.

If a few global alliances create the blocks, and agree to establish the tools for interoperability, then we may anticipate a future global repository⁴⁹ for these digital blocks to accelerate global digital transformation. The ubiquitous need for principles and practice of connectivity⁵⁰ is salient to this discussion.

The value expected from connectivity, assumes operation of multiple ecosystems, which must *converge*, to *deliver* the value. What are the layers and components, necessary for this engineering ecosystem?

Table 1. Layers, and components for this engineering ecosystem

01	I	Infrastructure	Scaffolds which includes energy, internet engineering, telco networks
02	T	Telecommunications	Backbone of connectivity which enables location agnostic operations
03	P	Protocol	Transaction triggered response operating agnostic of protocol-specificity
04	D	Discovery	Blocks/entities must find each other in order to communicate (think RDF)
05	C	Connectivity	Glue that enables digital transformation unless restricted by boundaries
06	S	Sense	Data acquired from points of interaction to understand status / attributes
07	R	Response	Analytics driven action/actuation based on integrating diverse knowledge
08	O	Operate	Outcome as pre-determined or change direction if influenced by factors
09	A	Adapt	Ability to remain dynamic and agile by recalibrating operations (eg SCM)
10	K	Knowledge	Learnings from operation (store/delete), dissemination, update analytics

Local and global providers, who supply products and services, germane to each layer (and several sub-layers within each layer), may not practice standard operating procedures (SOP). When volatility is the norm, it is wishful to expect SOP or groups in distant corners of the world to conform.

The task of interoperability, and the ability to automate interoperability by “**discovering**” what is necessary to start communication or cross-check resources, becomes pivotal. It is a tool not yet available. Do we need this tool to *discover* and replenish the gaps, for functional interoperability to commence?

It is expected that automating interoperability, may lead to auto-generation of APIs when interfaces “discover” that they cannot “talk” between models, data holders, tables, devices. It may trigger an automated mechanism to understand *what needs to be understood* between the systems, and then obtain the “glue” (for example, creates remote function call to source a “patch” from a repository) to facilitate interoperability. APIs are *enablers* of interoperability but creating API is *not* synonymous with *instituting* interoperability between systems.

True interoperability involves the arduous task of semantic interoperability between systems, to facilitate data-driven multi-system performance optimization.

If someone speaks to me in Hebrew, I must know that I am *listening to Hebrew* before using Google translate to communicate in Hebrew. If I had a tool to *auto-detect* languages, then it could help trigger (CNN/RNN⁵¹) Hebrew translation on my iPhone. An “avatar” or Siri or Cortana or Alexa, can then, guide my exchange.

Discovery tools for auto-detection of attributes, and characteristics *between* entities, Agents, and models, are a core part of the digital-by-design metaphor, for example, IoT. In the machine tools arena, for example, if a square widget doesn’t fit a round hole, the problem must be reported in a manner that can call for a solution. In this case, the nature of discovery, may trigger the need for software as a robot. Perhaps, endowing the software with some form of mobility, to trigger the adequate response, through connectivity between diverse systems which may not be interoperable.

Research in connectivity may help develop a new generation of *digital semantic sensors* to sense (what we may not know) *what needs sensing*. The concept of “*sensing the need to sense*” must include mobility to be useful in a multitude of environments. It must also move beyond semantic detection and include certain levels of cognition. What we need is a *cognitive compass*.

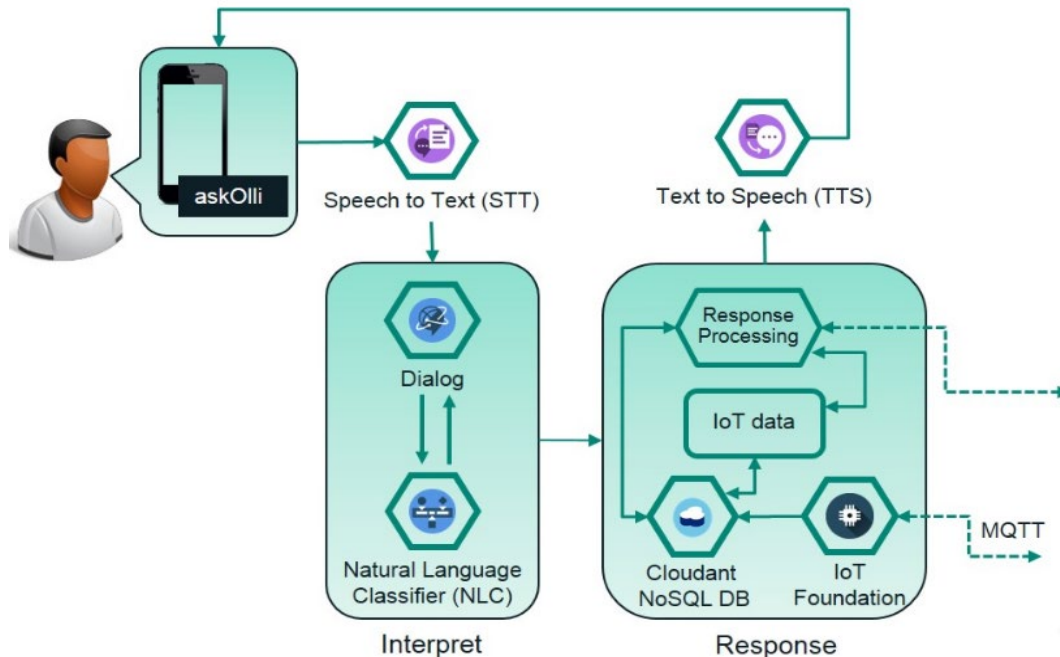


Fig. 4 - Watson Speech to text (STT) (illustration adapted from ⁵²)

The process of discovery, in addition to other elements, is a mix of semantic and cognitive modules. The inability to discover objects or identifying the wrong object or perturbing time-critical discovery (implants, medical devices) are potential pathways to compromising safety, security, privacy, authorization and cybersecurity. Intruders may be sophisticated to avoid semantic detection (5, 50 and 500, are, semantically, numbers, albeit, in different ranges). The importance of cognition and need to introduce cognitive firewalls⁵³ may be gain a wider following. Cognitive “supervisors” may be necessary to keep an eye on the semantic processes.

Thus, claims for ubiquitous computing, first, must find tools for discovery. The illusion of trillions of “things” connected via IoT are delusional, and hyperbole, marketed by uninformed publicists. Unless objects can safely *discover* each other, they may not connect (assuming that connectivity is protocol agnostic). Implementing tools and technologies⁵⁴ central to discovery, and adequate diffusion of cybersecurity as a service (SECaaS), may be required, *a priori*, to accelerate digital transformation.

Digital twins may depend on safe “discovery” using semantic properties and cognitive rules for auto-configuration (think *ad hoc* auto-configuration of mesh networks) to create the desired assembly (machine floor, medical devices attached to patient, turbines, water purification). Digital twins will inherit attributes of the physical components and physics of the system. Ontology based semantic interoperability by design depends on entity level relationships.

Distributed digital twins created by different sources, approved by cognitive supervisors, and connected by secure systems, may communicate, and form *swarms*, to help us make better decisions (one agent vs an agency or one ant vs a swarm of ants) employing the popular concepts of swarm intelligence.⁵⁵

Fraternal Twins: The First Born – Digital or Physical?

A century ago (1916), a theory about freemartins⁵⁶ (the female of the heterosexual twins of cattle) generated interest about rare monozygotic twins⁵⁷ in cattle. This led to the discovery of Müllerian Inhibiting Substance⁵⁸ (MIS). Research⁵⁹ by Patricia Donahoe⁶⁰ is beginning to unravel the role and therapeutic potential of MIS. It appears that the human genetic program is inherently female⁶¹ (which came first - male or female, the chicken or the egg). If the foetus was left to differentiate without MIS, foetal development of müllerian ducts will produce a female child. The “default” option of human genetics is programmed to produce females. Males exist due to inhibition of the development of müllerian ducts by MIS and differentiation of the Wolffian ducts by foetal testosterone. Females have evolved by design but males appear to be a modification or a by-product of evolution.

This very distant digression is intended to make the point that a fundamental plan, a base, exists in nature. The female plan is copied (duplicated) to produce the male, albeit, with modifications, catalyzed by a starter dose of MIS.

The concept of digital twins assumes we are *creating* a digital duplicate of the physical entity. But, the *born digital* metaphor may be, in reality, *digital conception*. In the industrial arena “things” may not be created without an engineering plan, technical specs and CAD/CAM models. The physical entity must be *conceived* as a digital model, before birth of the product. In the world of machines and parts, being *conceived as digital is the design*, to use a pre-natal metaphor. The physical entity is the post-natal stage.

A plethora of exceptions may prove the rule. One such case are add-ons, for example, humans (and animals), attached to medical devices⁶² in homes or hospitals. We can create digital twins of this *combined* state, to monitor their physiology, but that “twin” or digital proxy may not be referred to as *born digital*. In this instance, for medical purposes, we can think of digital twins as a combinatorial outcome, for monitoring and acquisition of data. By closing the loop and enabling feedback from medical digital twins, we can save lives, thousands, or even millions, of lives.⁶³

Think about a helicopter⁶⁴ which may not be created as a physical entity unless we have a CAD/CAM version and create a simulation (using differential equations) to test the operation (rotation of the blades for lift-off). In recent models from manufacturers (Boeing 787), the pilot is subservient to the simulated model in the auto-pilot. An image conjured by the latter generated the apocryphal statement that in an airplane of the future there may be only two creatures in the cockpit. A pilot and a dog. The role of the dog is to stop the pilot from touching the controls. The role of the pilot is to feed the dog.

If we reverse the logic of the digital twins we have discussed thus far, one might propose the digital blueprint as the primordial layer and the physical entity to be the fraternal twin (perhaps with limited mobility, if thinking about machines).

The digital blueprint and the simulated models⁶⁵ which exists today, may be rapidly engineered with data feeds from the physical operation, to approach the “live” concept of digital twins. In proposing this *modus operandi*, we move closer to the domain of cyber-physical systems⁶⁶. Time dependencies need time guaranteed software⁶⁷ which can understand the semantics of time and resist cyberthreats or time spoofing, by using cognitive firewalls, if time criticality is pivotal for its operation. For example, from (t=0) the decision to apply the brakes to the actual act of braking (t=n) to stop an automobile.

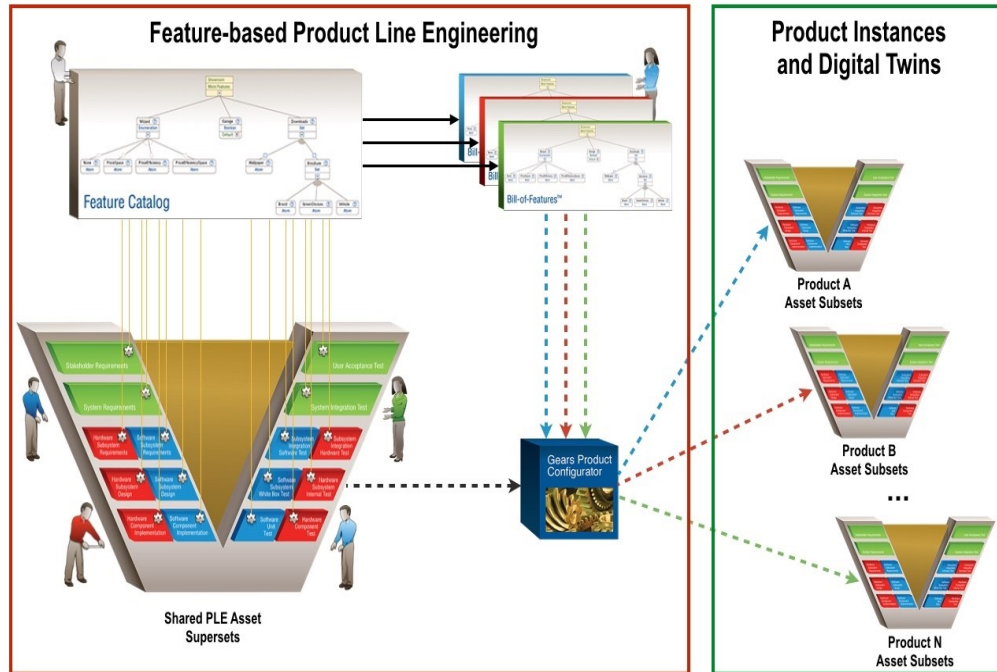


Fig. 5 – Feature Based Production Line Engineering⁶⁸

The old world of engineering V models (Fig 5), spanning requirements, design, test, to user documentation. The upper tiers of the V represent the modelling and design phases where engineers build features based on product requirements, which flow to subsequent phases of the development, and manufacturing lifecycles. Individual features of a product are represented in the software⁶⁹ as pieces of modular source code that can be "turned" on or off, allowing assets to be generated based on a particular set of features (variant configuration). This accumulation of source code-based assets provides the foundation for creating physical products, but may be leveraged simultaneously to create a corresponding digital twin.

Thus, the physical product is born digital. The digital twin can be found using unique RFID identifiers, or other forms of component serial numbers, once the device is manufactured, and may operate through intelligent PLM platforms, throughout the product's life. The latter may ensure that the digital twin or the digital proxy, is auto-updated. Standards and certifications are key to adoption of this approach.

Confluence of Swarms Through Data Fusion

The digression about the conceptual see-saw, about whose twin is it anyway, is a thread of reasoning, not a barrier. It may make it easier to create the open repositories needed in the process of digital transformation. The road ahead for digital twins, digital proxies and digital transformation is fraught with problems and also brimming with potential.

Driving fusions (please see illustrations below) through collaborative ecosystems may be one path to profit. There may not be a "winner takes it all" version in a cognitive digital twin economy.

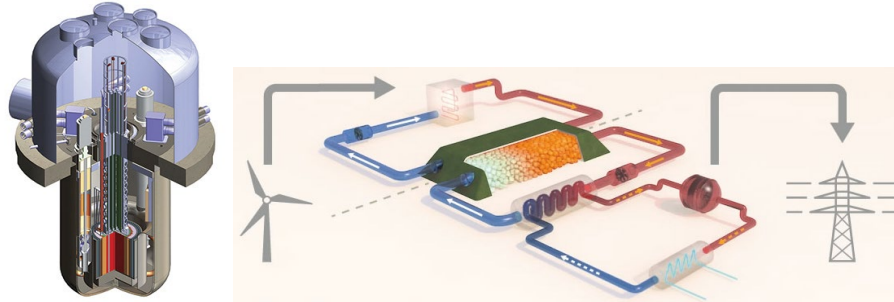


Fig. 6 – Digital Transformation: Energy Equilibrium – Elusive Quest for the Digital Mitochondria? To maintain homeostasis of energy production, distribution and load balancing. Adapting to multiple sources and types of energy obtained from diverse producers (domestic, commercial) with variable end points (homes, roadside charger, factories, mobile delivery). Left image from ⁷⁰ and right image from ⁷¹



Fig. 7 – Digital Transformation: The Transportation Alloy – Alliance of Autonomy, IoT, Telecommunications and 3D Printing⁷² (cartoon ⁷³)

To profit from fusion in the digital-by-design era, collaborative efforts⁷⁴ may be one way forward. Examples of convergence (above) may be coupled with their operational digital twins or digital proxies. Information arbitrage from a wide cross-section of similar operations (from many devices) may provide a glimpse of patterns, which were previously unobtainable, due to the focus on one or few operations.

Hence, standards are key, followed by interoperability between standards and other facilitators (converters, adapters, translators, multi-homing) to increase connectivity and reduce incompatibility. The transaction cost may increase and reduce margin of profit, incur losses and downgrade the brand, if architectural and/or structural discrepancies, continue to pose barriers to function and/or outcome, expected by the customer.

A typical laptop deals with 250 compatibility standards. About 20% of the standards are from individual companies, while 44% are from consortia and 36% from accredited standards development organizations. The complexity in laptops will be dwarfed by the variability expected for Digital Twins. The use of ICE (Internalizing Complementary Externalities) like principles may evolve to create working solutions.⁷⁵

Complementarity, compatibility and interoperability, assures us that we can expect visibility not only of one operation (which is what one industry or one team may monitor) but a group of hundreds or thousands of such operations. This massive data set may help us to understand patterns, predict faults, detect anomalies and use true “big” data, data curation and higher level metadata, to feed other functions, such as data driven policy, security threats and intruder detection using cognitive pattern analytics.

Consider the cartoon (below, left) of a physical event and assume that we have a digital twin of that operation that an analyst or manager can remotely view to “see” or monitor the physical operation in progress. What if the operation on the left is repeated?

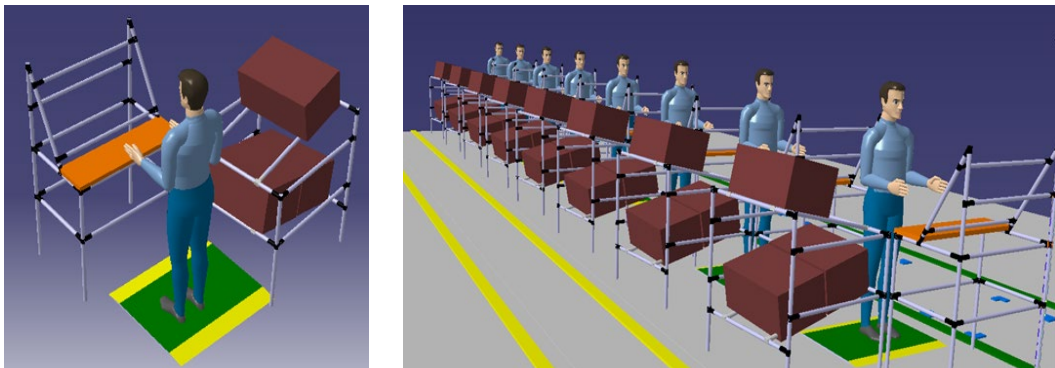


Fig. 7 – Physical System (cartoon adapted from Lego)

If the physical event (left) is not an isolated scenario, then digital duplication (right) may generate a form of digital transformation, representative of a digital swarm or flock.⁷⁶

This digital vision of aggregated events, may generate big data and metadata, from precision patterns, which may be extracted or extrapolated with respect to process, performance and profitability. Any one instance may not offer sufficient incisive insight, but applying the principles of swarm intelligence to hundreds of instances, may provide wealth of information (not only data) which could enhance decision support systems and improve the monetization⁷⁷ potential.



Fig. 8 – Robots (cartoon from ⁷⁸)

Swarms of robots (networks, connected via combination of cloud, fog, mist) are likely to generate massive amounts of data. This data, if acquired, analyzed, and used in feedback control, may optimize process, reduce waste and compress production time. Use of “intelligent” decision systems platforms, various levels of automation, and predictive analytics, may transform the concept of ‘zero’ downtime to manufacturing reality.

Data from swarms may improve detection of anomalies, predictive analytics (if equipment needs a part or replacement) and errors or *red herrings* in the swarm may indicate security threat, breach or may elicit unusual activity alerts.

The blockchain-like digital ledgers, in the backbone of the digital twins, may be useful in identifying the point of anomaly and associated objects or humans in the loop. Combined with advances in hack-proof⁷⁹ code and cognitive firewalls, this approach may add a new dimension to systems cybersecurity.

The swarm and flock approach, if applied to the developing notion of smart cities, may offer relatively precise information, from digital twin operations of scale-free networks in urban digital transformation. Monitoring digital proxies of water valves, in operation, to control or regulate water waste, water security and water pollution. From an engineering systems point of view, the digital abstraction is applicable to city-level applications. Cities are inter-dependent cascade of systems and networks⁸⁰ such as energy networks, traffic networks, sewer networks, communication networks, road networks and emergency response networks. The latter can make a difference between life and death.

The vision of network convergence may be crippled and remain impotent without architectures which are resilient, fault tolerant, and uses standards which are dynamic.

But, interoperability between standards are rather difficult when competition fuels mistrust, spurs acrimony and short-term profits are the life-blood of the industry. Digital transformations calls for confluence of ideas beyond the horizon and new roads to reach the luminous summit. Investment in scientific⁸¹ vision is often viewed with reservation, excessive caution, undue scepticism and even disdain. The latter is most unfortunate for the progress of civilization.

Digital twins, IoT, blockchains, AI and swarm intelligence may re-define our imagination and future vision of globalization. *That* sense of the future requires businesses to re-think about ROI and profits, re-configure micro-payments and micro-revenue models, but not at the expense of investment in R&D. The latter is quintessential for innovation, and a tool to catalyze the principles of digital economics, to accelerate globalization.

In part, this idea originates from Marshall McLuhan⁸² that anyone, anywhere, may consume the same information. Digital Twins are another example of how this idea may be the reality for humans and machines, at multiple levels.

For example, a manufacturing plant in China, may be operating a component or machine sub-system, (atoms), which is represented by the Digital Twin or the data model of the digital proxy (bits). The global supply chain analyst, in India, monitors the status of the part via PLM. SCM intelligent decision support can trigger a replacement part from a supplier in Tampere, Finland or the component may be 3D printed by DDM Systems in Atlanta, GA and shipped to the factory in Dalian, China.

Taking this idea one step further, if the transport cost of bits approach zero, the transport to Dalian may be replaced, by sending the bits from the 3D architect in USA, to the 3D printer in Dalian, China, to 3D print the part. Digital Twins, through the process of digital transformation, shall lead us, perhaps, to the true digital economy, which once was an idea, implicit in the trade model, proposed by Paul Krugman⁸³, 40 years ago.

3 Concluding Commentary

At the dawn of the 21st Century, the internet was viewed by different groups to serve different functions. In some cases, it served as a storage platform⁸⁴, others perceived it as a copying machine⁸⁵, and economists⁸⁶ explored its ability to reduce transaction cost (for example communication, replication, transportation, tracking, verification, search) and democratization of information, as a catalyst for global economic growth.

Digital transformation, in the 21st Century, is the ability to represent atoms, in terms of bits. It stems from the seminal work by Claude Shannon⁸⁷ which grew roots during the 20th Century (Shannon information theory).

Digital transformation is made possible by the internet. Digital Twins and its “lite” version, digital proxy, are a part of the fabric of digital transformation, likely to affect most enterprises, worldwide, willing to duplicate the physical model for remote monitoring, viewing and controlling, based on a digital format (smartphones, tablets).

It is almost justified to think about the internet as a “giant copying machine” which can “copy” physical objects (atoms), to generate corresponding Digital Twins, a representation of information about the atoms, in terms of bits. Hence, we are not dealing with entirely new concepts, just new modes of expression.

Digital Twins are akin to the “emperor’s new clothes” which are made of pre-existing conceptual yarns. We have added new vernacular and embedded the fabric with potentially new widgets (for example, the use of blockchain, as a verification tool).

In this article, we call for an open source approach, to create the “blocks” or modules, necessary to democratize the *ad hoc* and *en masse* configuration of Digital Twins, by *non-experts*. The latter may no longer limit the use and application of Digital Twins in the hands of experts, alone.

Digital Twins may evolve as a tool, unconstrained by domains, beyond the boundaries of high performing economic regions, and contribute to economic growth, through open source platforms for digitization. Economic⁸⁸ growth from such “digital dark matter” and other intangible benefits to the global economy, remains unmeasured. The impact from Digital Twins, digital proxies and digital duplicates, and cumulative benefits, may be only limited, by our imagination.

Industry must embrace change, imagine paths to reduce transaction cost, and shoulder the need to balance uncertainty, which may accompany the dynamics of digital economics. Leaders must proactively support the call for creating structures, necessary to pursue collaborative initiatives⁸⁹ through investment in massive workforce development, skills training, digital learning⁹⁰, education, research, institutional advancement and the pursuit of dignity.

Notes

- ¹Nicholas Negroponte (1996) *Being Digital*. Vintage Books
- ²Neil A. Gershenfeld (2000) *When Things Start to Think*. Henry Holt and Company
- ³www.simonandschuster.com/books/The-Path-Between-the-Seas/David-McCullough/9780743262132
- ⁴<http://bit.ly/EYE-in-AI> • <https://dspace.mit.edu/handle/1721.1/108000>
- ⁵<http://www.politico.com/agenda/story/2015/06/internet-of-things-privacy-risks-security-000096>
- ⁶https://www.nobelprize.org/nobel_prizes/chemistry/laureates/2016/popular-chemistryprize2016.pdf
- ⁷http://uberty.org/wp-content/uploads/2015/07/Norbert_Wiener_Cybernetics.pdf
- ⁸www.whitehouse.gov/sites/default/files/whitehouse_files/microsites/ostp/NSTC/preparing_for_the_future_of_ai.pdf
- ⁹www.whitehouse.gov/sites/default/files/whitehouse_files/microsites/ostp/NSTC/national_ai_rd_strategic_plan.pdf
- ¹⁰www.ieeeccs.org/sites/ieeecss.org/files/documents/IOCT-Part3-02CyberphysicalSystems.pdf
- ¹¹<http://leeseshia.org>
- ¹²<https://cse.nd.edu/seminars/cse-seminar-series-rahul-mangharam>
- ¹³https://s3.amazonaws.com/nist-sgcps/cpspwg/files/pwgglobal/CPS_PWG_Framework_for_Cyber_Physical_Systems_Release_1_0Final.pdf
- ¹⁴Lee, E.A. (2015) *The Past, Present and Future of CPS*. Sensors **15** 4837-4869
<http://www.mdpi.com/1424-8220/15/3/4837>
- ¹⁵<https://thingful.net/>
- ¹⁶<http://www.computerworld.com/article/3076213/internet-of-things/the-iot-past-present-and-future-an-interview-with-professor-sanjay-sarma.html>
- ¹⁷[https://en.wikipedia.org/wiki/Sally_\(short_story\)](https://en.wikipedia.org/wiki/Sally_(short_story))
- ¹⁸<http://digitalcollections.library.cmu.edu/awweb/awarchive?type=file&item=34057>
- ¹⁹Ishii, H. and Ullmer, B. (1997) *Tangible Bits: Towards Seamless Interfaces between People, Bits, and Atoms* in Proceedings of CHI'97 (ACM, March 1997)
<http://tangible.media.mit.edu/person/hiroshi-ishii/>
- ²⁰<http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.43.130&rep=rep1&type=pdf>
- ²¹<https://www.ics.uci.edu/~corps/phaseii/Weiser-Computer21stCentury-SciAm.pdf>
- ²²http://cocoa.ethz.ch/downloads/2014/06/None_MIT-AUTOID-WH-001.pdf
- ²³<http://autoid.mit.edu/people-2>
- ²⁴<https://www.technologyreview.com/s/601013/the-internet-of-things-roadmap-to-a-connected-world/>
- ²⁵https://www.ntia.doc.gov/files/ntia/publications/iot_rfc_june_2016_georgia_tech_cdait_alain_louchez.pdf

- ²⁶<https://www.whitehouse.gov/the-press-office/2016/07/15/fact-sheet-administration-announces-advanced-wireless-research>
- ²⁷<https://transition.fcc.gov/national-broadband-plan/national-broadband-plan.pdf>
- ²⁸http://ucsdnews.ucsd.edu/pressrelease/keeping_track_of_time_in_cyber_physical_systems
- ²⁹http://www.nhk.or.jp/8k/history/index_e.html
- ³⁰<http://news.mit.edu/2012/auto-id-cloud-of-things-big-data>
- ³¹<http://ubicomp.oulu.fi/files/cscwd13.pdf>
- ³²<https://hal.inria.fr/hal-01004489/file/city06-petrolo.pdf>
- ³³www.apan.net/meetings/Nantou2014/Sessions/IoT/Cloud-of-Things-APAN38-2014.pdf
- ³⁴<http://bit.ly/Block-Chain>
- ³⁵<https://newsroom.accenture.com/content/1101/files/Cross-FSBC.pdf>
- ³⁶<http://www.zatar.com/blog/avatars-and-iot-architecture>
- ³⁷<https://hbr.org/2014/11/setting-standards-for-the-internet-of-things>
- ³⁸MPEG <http://oxygen.csail.mit.edu/videosketching.html> • CSAIL <http://oxygen.csail.mit.edu/Overview.html>
- ³⁹<https://arxiv.org/ftp/arxiv/papers/1609/1609.05774.pdf>
- ⁴⁰<https://enterfea.com/wp-content/uploads/2017/04/A0-4.png>
- ⁴¹www.w3c.org
- ⁴² Datta, S. (2002) *Agents* - <http://dspace.mit.edu/handle/1721.1/41914>
- ⁴³Minsky, Marvin (1985) *Society of Mind* <http://www.acad.bg/ebook/ml/Society%20of%20Mind.pdf>
- ⁴⁴<http://spectrum.ieee.org/computing/networks/metcalfes-law-is-wrong> and <http://www.dtc.umn.edu/~odlyzko/doc/metcalfe.pdf>
- ⁴⁵<http://www.spiegel.de/auto/aktuell/bundeslaender-wollen-benzin-und-dieselaautos-ab-2030-verbieten-a-1115671.html>
- ⁴⁶<http://esd.mit.edu/WPS/2007/esd-wp-2007-17.pdf> and <http://dspace.mit.edu/handle/1721.1/41902>
- ⁴⁷<http://qz.com/801640/darpa-blockchain-a-blockchain-from-guardtime-is-being-verified-by-galois-under-a-government-contract/>
- ⁴⁸<https://www.sandvik.coromant.com/en-us/aboutus/lookingahead/articles/pages/a-material-revolution.aspx>
- ⁴⁹www.scientificamerican.com/article/world-repository-of-human-genetics-will-move-to-amazons-cloud/
- ⁵⁰Principles and Practice of Connectivity <https://dspace.mit.edu/handle/1721.1/104429>
- ⁵¹<https://dspace.mit.edu/handle/1721.1/101151> and <https://arxiv.org/pdf/1411.4555v2.pdf> <https://arxiv.org/pdf/1603.08270.pdf>
- ⁵²<https://www.linkedin.com/pulse/meet-olli-fusion-autonomous-electric-transport-watson-kalyanaraman/>

- ⁵³<https://dspace.mit.edu/handle/1721.1/104456>
- ⁵⁴<http://oxygen.csail.mit.edu/videoh21visit.html> and
<http://oxygen.csail.mit.edu/videomultilingual.html>
- ⁵⁵http://www.antoptima.ch/pdf/pr_harvardbusiness_0105.pdf
- ⁵⁶<https://www.jstor.org/stable/pdf/1641047.pdf>
- ⁵⁷<http://www.nature.com/hdy/journal/v2/n1/pdf/hdy19481a.pdf>
- ⁵⁸Price JM, Donahoe PK, Ito Y, Hendren III WH (1977) *Programmed cell death in the Mullerian duct induced by Mullerian inhibiting substance*. American Journal of Anatomy **149** 353–375
- ⁵⁹<http://press.endocrine.org/doi/pdf/10.1210/edrv.22.5.0445>
- ⁶⁰<http://hsci.harvard.edu/people/patricia-k-donahoe-md>
- ⁶¹<https://www.ncbi.nlm.nih.gov/pubmed/7828438>
- ⁶²<http://mdpnp.mgh.harvard.edu/>
- ⁶³<http://www.bmj.com/content/353/bmj.i2139>
- ⁶⁴<http://www.da-vinci-inventions.com/aerial-screw.aspx>
- ⁶⁵<https://www.modelica.org/>
- ⁶⁶<https://www.seas.upenn.edu/~rahulm/>
- ⁶⁷www2.eecs.berkeley.edu/Pubs/TechRpts/2008/EECS-2008-72.pdf
- ⁶⁸www.slideshare.net/ArasPLM/product-line-engineering-meets-plm
- ⁶⁹http://www.biglever.com/extras/PLE_LifecycleFramework.pdf
- ⁷⁰<http://www.world-nuclear-news.org/NN-TerraPower-brings-BandW-on-board-180214ST.html>
- ⁷¹<http://rief-jp.org/ct4/71847>
- ⁷²<http://www.theverge.com/2016/6/16/11952072/local-motors-3d-printed-self-driving-bus-washington-dc-launch>
- ⁷³<https://www.linkedin.com/pulse/meet-olli-fusion-autonomous-electric-transport-watson-kalyanaraman/>
- ⁷⁴<https://www.regulations.gov/contentStreamer?documentId=NHTSA-2014-0022-0001&attachmentNumber=1&disposition=attachment&contentType=pdf> and
<http://vistadataproject.info/>
- ⁷⁵<http://people.bu.edu/tsimcoe/documents/working/FourPaths.pdf>
- ⁷⁶Berrondo, M. and Sandoval, M. (2016) *Defining emergence: Learning from flock behavior*. Complexity **21** 69–78 doi:10.1002/cplx.21711
- ⁷⁷<http://www.icosystem.com/about-us/>
- ⁷⁸<https://www.autodesk.com/solutions/robot-programming-software>
- ⁷⁹<https://www.quantamagazine.org/20160920-formal-verification-creates-hacker-proof-code/>
- ⁸⁰<http://journals.aps.org/prx/pdf/10.1103/PhysRevX.6.011036> and
<http://dx.doi.org/10.1063/1.4962970>

- ⁸¹www.seattletimes.com/opinion/editorials/another-nobel-prize-for-uw-scientist-illustrates-value-of-pure-science
- ⁸²McLuhan, M. (1964). *Understanding Media: The Extensions of Man*.
http://robynbacken.com/text/nw_research.pdf
- ⁸³Krugman, P. (1979). A model of innovation, technology transfer, and the world distribution of income. *Journal of Political Economy*, 253–266.
<http://pioneer.netserv.chula.ac.th/~kkornkar/inter%20trade%20course/a%20model%20of%20Innovation.pdf>
- ⁸⁴<http://xml.coverpages.org/PML-MIT-AUTOID-WH-005.pdf>
- ⁸⁵Shapiro, C. and H. R. Varian (1999). *Information rules: A strategic guide to the network economy*. Harvard Business Press.
<http://faculty.csuci.edu/minder.chen/MBA550/reading/hal-varian-information-rules-chapter-1.pdf>
- ⁸⁶<http://www.nber.org/papers/w23684>
- ⁸⁷<http://www.itsoc.org/resources/Shannon-Centenary/shannon-work-legacy-paper>
- ⁸⁸Greenstein, S. and F. Nagle (2014). *Digital dark matter and the economic contribution of Apache*. *Research Policy* 43(4), 623–631.
<https://pdfs.semanticscholar.org/32ff/6098dc5d26551107935b78ef4a34f0b9aece.pdf>
- ⁸⁹http://autoid.mit.edu/iot_research_initiative
- ⁹⁰<http://odl.mit.edu/>



CHAPTER 4

Shoumen Datta

HAPHAZARD REALITY – IOT IS A METAPHOR

THIS PAGE IS LEFT BLANK


The Elusive Quest for Intelligence in Artificial Intelligence

Dr Shoumen Palit Austin Datta

MIT Auto-ID Labs
Department of Mechanical Engineering
Massachusetts Institute of Technology
shoumen@mit.edu

MDPnP Lab
Massachusetts General Hospital
Harvard Medical School
sdatta8@mgh.harvard.edu

The elusive quest for intelligence in artificial intelligence prompts us to consider that instituting human-level intelligence in systems may be (still) in the realm of utopia. In about a quarter century, we have witnessed the winter of AI (1990), being transformed and transported to the zenith of tabloid fodder, about AI (2015). The discussion, at hand, is about the elements that constitute the canonical idea of intelligence. The delivery of intelligence as a pay-per-use-service, popping out of an app or from a shrink-wrapped software or AI-as-a-Service, is in contrast to the bio-inspired view of intelligence, formed from a tapestry of events, often cross-pollinated by instances, each with its own microcosm of experiences, and learnings, which may not be discrete, all-or-none functions but continuous, over space and time. The enterprise world may not require, aspire or desire such an engaged solution, to improve its services for enabling digital transformation, through the deployment of digital twins, for example. One might ask whether the "work-flow on steroids" version of decision support may substitute for intelligence? Are we harking back to the era of rule based expert systems? The image conjured by the publicity machines offers solutions with human-level AI and preposterous claims, about capturing the "brain in a box" by 2020. Even emulating arthropods (leave alone cephalopods) may be difficult, in terms of rational AI. Perhaps we can try to focus on worms (*Caenorhabditis elegans*) which may offer what businesses may need, to *pareto-querch* its thirst, for so-called intelligent applications based on elements of AI.



Is Intelligence an Illusion in Artificial Intelligence?

It's better to keep your mouth closed and be thought a fool than to open your mouth and remove all doubt • Twain

BLANK

The Elusive Quest for Intelligence in Artificial Intelligence

Is intelligence an illusion in artificial intelligence? This essay is an academic blog. The opinions are due to the author.

Dr Shoumen Palit Austin Datta, MIT Auto-ID Labs, Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139, USA and MD PnP Lab, Massachusetts General Hospital, Harvard Medical School

PLEASE OPEN DOCUMENT WITH ADOBE ACROBAT TO ACTIVATE THE EMBEDDED HYPERLINKS

The promise, and pessimism, about AI ([artificial intelligence](#)) charts a sinusoidal path. The [questions](#) about “intelligence” in AI persists. Many [more questions](#) are meeting with fewer answers. Intelligence in AI may be an advanced form of [multi-level dynamics](#) with/without a higher order of structured [complex networks](#) or (even better) [temporal networks](#). The semantics depends on, and is colored by, one’s view of [systems](#) or interpretation of what is intelligence, what constitutes proof of intelligence, and the [nature of complexity](#).

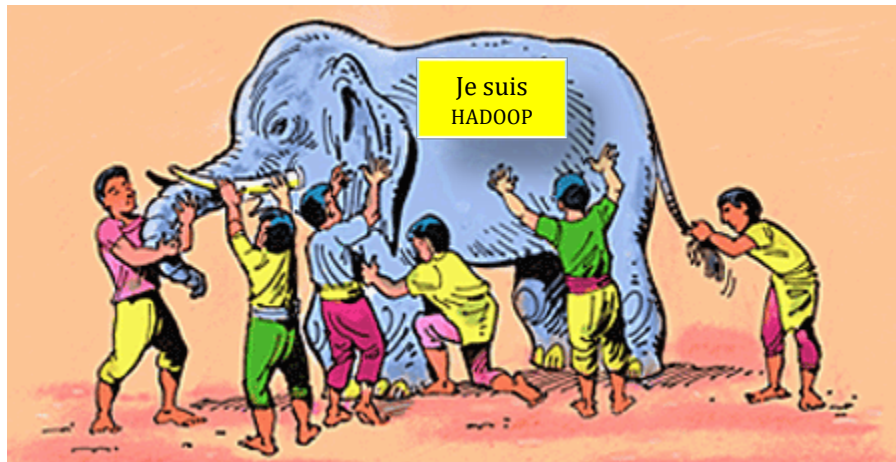


Figure 1: [The Blind Men and the Elephant](#) • John Godfrey Saxe (1816-1887)

In systems thinking a common [analogy](#) is that of [six blind men from Indostan](#) (India) touching various parts of an elephant and claiming that “elephant is a tree” (man who touched the leg), “it is like a rope” said the blind man who touched the tail. “Like a snake” (man who touched the trunk). “It is like a big hand fan” (man who touched the ear). “Like a huge wall” said the man who touched the belly of the elephant. “Like a spear” said the blind man who touched the tusk. They were misguided in describing their part and wrong about the whole picture. The definition of intelligence may be colored by the professional bias of the interpreter. Intelligence is not a point. It is a fabric or an array or collective continuum of network systems which may not be [boxed](#) with human skills, yet (the latter is by far the most ludicrous and incredible claim, at the present time, under our known circumstances).

Why this mad pursuit ?

University of Cambridge, which had done best at teaching mathematics, is the one from amongst whose graduates, have come more of the English poets. While Oxford, which has specialized in the humanities, has tended to turn out writers who have attained, on the whole, a high level of mediocrity. By the time one has discussed literature with a witty and learned professor, one knows what has been achieved, and how good it is. You become respectful, and begin to wonder, who am I to do better? (Dialogues of Alfred North Whitehead (1861-1947) as recorded by Lucien Price. Little, Brown ▪ Boston, 1954)

The [definitive treatise](#) by Stuart J Russell and Peter Norvig (*Artificial Intelligence: A Modern Approach*, 3rd edition, 2015) should suffice to discourage all amateurs (myself included) to desist from testifying about the trials and tribulations with respect to AI.

Who am I to do better ?

In this [neo-Norvig-ean](#) era of human-level AI claims, we find [LISP](#) programming language, the 2nd oldest language, since FORTRAN. It is still regarded as a powerful AI tool. Figure 1 in the first LISP paper ([John McCarthy, MIT](#)) illustrates “Representation of S-Expressions by List Structure” which takes us back to the [history of perceptrons](#) elaborated in the [seminal paper](#) by Warren McCulloch and Walter Pitts (1943) *A Logical Calculus of the Ideas Immanent in Nervous Activity* in Bulletin of Mathematical Biophysics **5** 115-133 (marks the dawn of AI).

The [perceptron algorithm](#) created by Frank Rosenblatt, was championed by the US Navy, in fueling the “intelligence” controversy, to the extent, that *The New York Times* reported (in 1958) the perceptron to be “the embryo of an electronic computer that [the Navy] expects will be able to walk, talk, see, write, reproduce itself and be conscious of its existence.” A decade later, Marvin Minsky and Seymour Papert observed (in [Perceptrons, MIT, 1969](#)) that such statements may be guilty of the wildest exaggeration. However, Minsky is no stranger to extending the euphoria, and feeding the frenzy with [predictions](#) about AI’s rosy potential. Extending the scope of intelligence in AI has always been in vogue and [continues](#) unabated.

It is well nigh impossible to over emphasize that perceptrons, decision trees, recursion functions, etc, are good topological representations and manifestations of the anatomy, which are visible, in the context of neural connectivity, and the neural networks, which we observe, for example, in worms, eg *Caenorhabditis elegans* ([Robert Horvitz, MIT; figure 3](#)).

Abstractions of these networks, eg, cube-on-cube ([The Society of Mind](#) by Marvin Minsky, MIT, 1985) and “learning” mechanisms ([The Organization of Behavior](#) by Donald O Hebb, 1949) may be building blocks of intelligence. These processes populate fields with values from the user environment which can be selectively used (*per contra* hard coded defined sets). [NEST](#) Learning Thermostat uses input values, to tune *your preferred* temperatures.

Elements of the equation/rule-based (brittle, static) structures caused the bust of expert systems. It ended the lure of *The AI Business* (Winston and Prendergast, MIT, 1984) before the rise of artificial neural networks (ANN, popularity circa 1990). Topology and (dubious) synaptic weights, in stochastic models, are suggestive of flexible infrastructure. The intent is to improve profitability from data. But, is it really an application of intelligence in AI?

Rather than partial differential equations, exploding due to increase in state functions (due to the large number of parameters), use of Agents allow each variable to be represented as a single-function entity. Collective output from an Agency of Agents improves predictive or prescriptive precision, compared to operations research applications (see Figure 2). The behavior of Agents and Agencies using “AI” concepts originated from the principles of stigmergy ([Pierre-Paul Grasse, 1959](#)) which [continues](#) to evolve.

Think Data before Thinking of AI

The recent surge in the hype associated with “big data” has navigated profitability from analytics to the front and center. Intelligence is marketed as a [commodity](#) in this scenario.

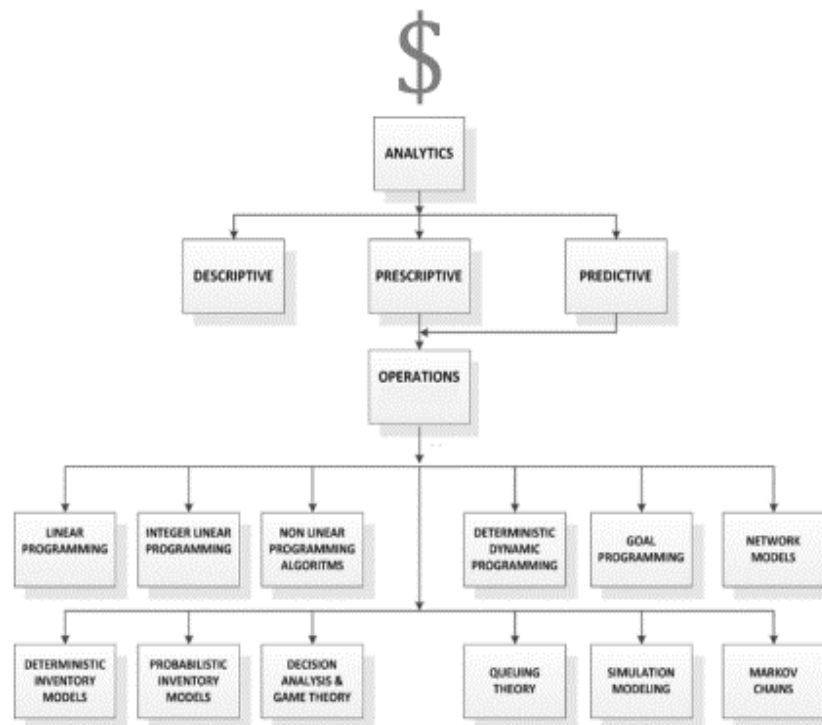


Figure 2: Pursuit of the Luminous Summit [\\$] Intelligence as a Service

In order to market intelligence as a service, the AI paradigm is being refurbished as a commodity ([brain in a box](#)), and touted to business and industry as an essential tool to reach the luminous summit [\$]. [Winning at games using ANN](#) is advocated as intelligence. [Smart](#) and [intelligence are emerging as speculative tabloid fodder](#). [Witnessing](#) the rapid transmutation of tabloid [fodder](#) from speculation to business [truth](#) is deeply troubling.

Claims about “original” thinking in [containerization](#) of data and processes are good ideas, but are concepts proposed almost half a century ago by Marvin Minsky (page 315 in the original book or search page 311 in this [PDF version of the book](#)). Connecting entities (containers) using IPv6 resonates with [ideas suggested](#) about a decade ago. However, it is reassuring that the concepts are not lost, but are being developed to advance the march of digital transformation (see Digital Twins <https://dspace.mit.edu/handle/1721.1/104429>).

Data, especially the volume of curated data, and the fundamental tools of knowledge representation (KR), are required for deploying AI and machine learning (ML) techniques. Data, AI, ML, are topics of intensive investigation, grand debates and energetic discourse, for at least half a century. However, the accelerating pace of rancor in this field, stems from marketing pundits and less informed celebrities, of a certain type.

Philosophical notions, linguistics and epistemology, in convergence with logic, ontology and computable models, fuels KR. Comprehending these principles, in combination with conventional mathematics, statistics, computer science and neurology, begins to form the foundation of AI analytics. To profit from AI applications, depth of domain knowledge must be added, to this foundation.

Those who can grasp this confluence, are converts, proselytizing about abstractions. The call for abstractions, which can hide the complexity of these principles, are essential for mass consumption of AI/ML applications. Intuitive, friendly, user interfaces (think Lego Mindstorms) which can be configured by the masses, lacking in specialized skills, are the “killer” apps, which will transform business, commerce, government, academia and *any instance, any event, any operation*, where decision may be necessary, before the next step.

Excruciatingly detailed level of minutiae are germane to KR frameworks. It remains quite inaccessible to the global population, except a few thousand computer science graduates. Minor changes in the sequence of symbols, in predicate logic (predicate calculus), can make a crucial difference in the meaning, as illustrated in the following example from John Sowa:

$(\forall x)(\exists y)((\text{woman}(x) \wedge \text{dept}(x,\text{MechE})) \supset (\text{man}(y) \wedge \text{hometown}(y,\text{Boston}) \wedge \text{married}(x,y)))$ [I]
 $(\exists y)(\forall x)((\text{woman}(x) \wedge \text{dept}(x,\text{MechE})) \supset (\text{man}(y) \wedge \text{hometown}(y,\text{Boston}) \wedge \text{married}(x,y)))$ [II]
 $(\forall x)(\exists y)((\text{man}(x) \wedge \text{dept}(x,\text{MechE})) \supset (\text{woman}(y) \wedge \text{hometown}(y,\text{Boston}) \wedge \text{married}(x,y)))$ [III]
 $(\exists y)(\forall x)((\text{man}(x) \wedge \text{dept}(x,\text{MechE})) \supset (\text{woman}(y) \wedge \text{hometown}(y,\text{Boston}) \wedge \text{married}(x,y)))$ [IV]

[I] in English and French, respectively, may read as follows:

Every woman in department of Mech Engineering married a man who came from Boston
Chaque femme du département de génie mécanique a épousé un homme venu de Boston

[II] in English and French, respectively, may read as follows:

A man who came from Boston married every woman in department of Mech Engineering
Un homme venu de Boston a épousé toute femme dans le département de génie mécanique

[III] in English and French, respectively, may read as follows:

Every man in department of Mech Engineering married a woman who came from Boston
Tout homme dans le département de génie mécanique a épousé une femme venant de Boston

[IV] in English and French, respectively, may read as follows:

A woman who came from Boston married every man in department of Mech Engineering
Une femme venant de Boston a marié tous les hommes dans le département de génie mécanique

The difference between the meaning of [I] and [IV] leaves room for social disequilibrium. The tiny change which could ignite such an immense social cataclysm may be attributed to an almost imperceptible alteration of the order of the symbols between [I] and [IV]. The latter may be obvious, only to a handful of people, in the entire world. Hence, the clamor for abstraction.

Tools for the masses must sweep these intricacies under “big buttons” which one can drag and drop, to convey their intent, through rudimentary natural language contexts. Anyone can create programs, without the faintest idea of what is a program, or any knowledge of programming, whatsoever (Lego Mindstorms). When outcome, function, and output, can be optimized by the masses, the floodgates to profit from rational AI apps, may cease to close. It will be a part of the fabric of our daily lives (quote from Herbert Simon, CMU).

Before we reach that halcyon era, we must deal with data. Data must feed algorithms, some of which, may be based on principles of AI and ML. However, most gains arise from great features, not great ML algorithms. Often, a heuristic model can solve 80% of the problem even without ML. Feature engineering is a critical skill in data science. Incorrect features will lead to irrelevant or imperfect training for algorithms. Before using a model live or exporting a model, the performance of the model must be checked using data. Anomalies in performance is an indicator of problems either with data, features or the model or all of the above. Continuous checking of the AUC (area under ROC (receiver operating characteristic) curve) is a prudent approach to validate performance of models and their suitability.

Human-level AI ?

It is hard to improve the statement from [Rodney Brooks](#), hence, here is a verbatim quote: “We have found a way to build fixed topology networks of our finite state machines which can perform learning, as an isolated subsystem, at levels comparable to these examples. At the moment, of course, we are in the very position we lambasted most AI workers for, earlier in this paper. We have an isolated module of a system working and the inputs and outputs have been left dangling.” ([Intelligence without Representation, 1991](#))

Learning triggers profound, sustained, often long term changes in our neural networks at many levels that we cannot even begin to understand, or grasp, its cognitive repercussions. Almost all assumptions made by [McCulloch & Pitts \(1943\)](#) may be violated (Appendix 1).

The “all or none” phenomena assumed by [McCulloch & Pitts \(1943\)](#) is relevant from a mechanical perspective if one assumes (perhaps incorrectly) that input data is supposed to transduce a signal, and the resultant action potential (neuronal activation), may be one form of a proof of learning. Neurologists may strenuously and vociferously take exception.

AI experts may wish adopt this view, about “learning” in the AI context. The neurological state of learning, cognition, and behavior is usually a continuous function, modulated by evolutionary weights, which are not subject, in the least, to the limitations of discrete-state machines. Application of machine learning models are often [inconsistent and incorrect](#).

Discrete systems have a finite (countable) number of states, which may be described in precise mathematical models. The computer is a finite state machine which may be viewed as a discrete system. The brain is not a computer. The neural infrastructure and networks are not finite state machines. Imposing any such model (real-world continuous systems) or ill-advised abstraction or gross extrapolation (by those not so well informed) may only perpetrate great lengths of fantasy, about intelligence, and learning, related to AI systems.

“Of the vast stream of sense data that pour into our nervous systems, we are aware of few and we name still fewer. For it is the fact that even percepta are wordless. Only by necessity do we put a vocabulary to what we touch, see, taste, and smell, and to such sounds as we hear, that are not themselves words. We look at a landscape, a rich carving and majestic architecture of a cathedral, listen to the development of harmonies in a symphony, or admire special skill in games and find ourselves woefully lacking in ability to describe our percepta. Words, as we very rightly say, fail us, either to describe the plain facts of these experiences or to impart to others, our feelings.” (G Jefferson CBE, FRS, MS, FRCS, Professor of Neurosurgery in [The Mind of Mechanical Man](#) in British Medical Journal, 25th June 1949). The [author was aware](#) of “Dr Wiener of Boston, his entertaining book [Cybernetics](#) (1948).”

Alan Turing was [cognizant](#) of the over-reach in claiming “intelligence” in AI and outlined potential objections including Godel's theorem ([mathematical objection](#)) and “Argument from Consciousness” which he reproduced from [Professor Geoffrey Jefferson](#) as a quote (from his Lister Oration, 1949) "Not until a machine can write a sonnet, or compose a concerto because of thoughts and emotions felt, and not by the chance fall of symbols, could we agree that machine equals brain. That is, not only write but know that it had written it. No mechanism could feel (and not merely artificially signal, an easy contrivance) pleasure at its successes, grief when its valves fuse, be warmed by flattery, be made miserable by its mistakes, be charmed by sex, be angry or depressed when it cannot get what it wants."

A. M. Turing (1950) Computing Machinery and Intelligence. *Mind* **49** 433-460 ([PDF](#))

Page 452 (see Appendix 2) removes any doubt that Turing had grave doubts regarding claims of intelligence in the context of computers. Turing's suggested starting point is “the child machine” (Appendix 2). Then he proposes to add the roles or processes of “evolution” “hereditary material” “mutation” “education” and “natural selection” in order to mature “the child machine” to “imitate an adult human mind” as a path forward to intelligence. To understand even vaguely what happens after “the initial state of mind, say at birth” the reader is urged to review [Patterns in the Mind](#) by [Ray Jackendoff](#) (1966) and then take into consideration the field of [linguistics](#) and [natural language](#) development (1970, PhD thesis of Terry Winograd, MIT <http://hci.stanford.edu/winograd/shrdlu/AITR-235.pdf>).

For all this to happen, we must process information encoded via developmental and environmental signals. Hence, the suggestion, research and convergence *on* the concept of molecular logic gates. The [complexity of the process](#) may help deter one from concluding that we *are* dealing with intelligence, with respect to computers, machinery or AI systems.

However, the human spirit and the fabric of scientific research cannot step away from problems, even if all available reason suggests that something is impossible, at the time. It is with this fervor the 1956 Dartmouth Summer Research Project on Artificial Intelligence (June 17 - August 16) was [proposed](#) in 1955 by a visionary group of eminent and erudite academic scholars (www.aaai.org/ojs/index.php/aimagazine/article/view/1904/1802).

The [proposal](#) (see Appendix 3) admits it is a “conjecture” but continued “that every aspect of learning, or any other feature of intelligence, can, in principle, be so precisely described that a machine can be made to simulate it.”

Great strides (Appendix 4) have been made, yet the 1956 Summer Research “conjecture” looms overhead. Progress of AI is evident from the 1145 page book by Russell and Norvig ([AI - A Modern Approach, 3rd ed](#)). We are also learning how [decisions can be made without a brain](#) in cognitive organisms (unicellular mould *Physarum polycephalum*).

Neurobiology 101

Topology and weights are the foundational underpinnings of artificial neural nets (ANN) which are the mainstay of AI systems. How reliable are these extrapolations? Are we still talking about AI? Let me reiterate what [Rodney Brooks has stated](#) but in a different vein.

Structural design of network topology aims to mimic the commonly observed *organization* of neurons. Topology based on neural organization ([small world networks](#)) may be fraught with errors, as evidenced by studies on [wiring configuration](#) and [neuroanatomical analysis](#) which reveals differences in [circuit architecture](#) and connectivity, if viewed at [mesoscopic](#) vs microscopic scale. On a mesoscopic scale, seemingly random networks exhibit consistent properties. It may be difficult, if not impossible, to extract useful/meaningful abstractions from these counter-intuitive [non-linear yet dynamic](#) structure-function complementarities.

In ANN, weights are assigned to signify connectivity strengths (the links between the perceptrons). These are arbitrary, at best, because synaptic weights between neurons and clusters are subjected to conditions not well understood. Even if one acquired neuro-physiological data related to frequency variations of action potentials (~200 Hertz), in an attempt to understand synaptic weights between neurons, the results may be inconclusive. The complexity may be compounded by the fact nerve transmissions are modified by ions, electrical threshold potential, chemical neuro-transmitters and their location in the brain.

In synaptic design, one assumes the all-or-none process ([Appendix 1](#)) and the weights are modeled based on extrapolation from “inferential changes” which are in the order of milliseconds to seconds (hence, subject to observation, data collection and extrapolation). But, the nature of the connectivity and resultant weight is also influenced by epigenetic factors (time scale – seconds to days), ontogenic factors (days to years) and phylogenetic factors, which are the result of generations or are derived from the evolutionary time scale, as noted in [Appendix 2](#). Hence, the nature of the weight deduced from “inferential” changes (primarily sense and response mechanisms) are only the tip of the iceberg. We are almost completely in the dark about the nature of the influence from these and many other factors.

Synaptic weights ascribed in stochastic models are based on heuristics. This approach may not be sufficiently informed to account for the complex distribution of spike rates, observed synaptic weights and intrinsic excitability for neurons, in different areas of the brain, for example, auditory or visual cortex, hippocampus, cerebellum, striatum, midbrain nuclei. These processes underlie neuroplasticity and the potential for continuous configuration and reconfiguration of the brain through dynamic [Hebbian Learning](#) (Donald O. Hebb).

By [definition](#), in Hebbian learning (one of the oldest learning algorithms), a synapse between two neurons is strengthened when the neurons on either side of the synapse (input and output) have highly correlated outputs. Following the analogy to an artificial system (ANN), the tap weight is increased with high correlation between two sequential neurons. Capturing this dynamic change in weights and including this change appropriately in the function of the algorithm, requires feeding the algorithm. In other words, getting the correct data with the correct features (discrete features and/or crosses) to the algorithm.

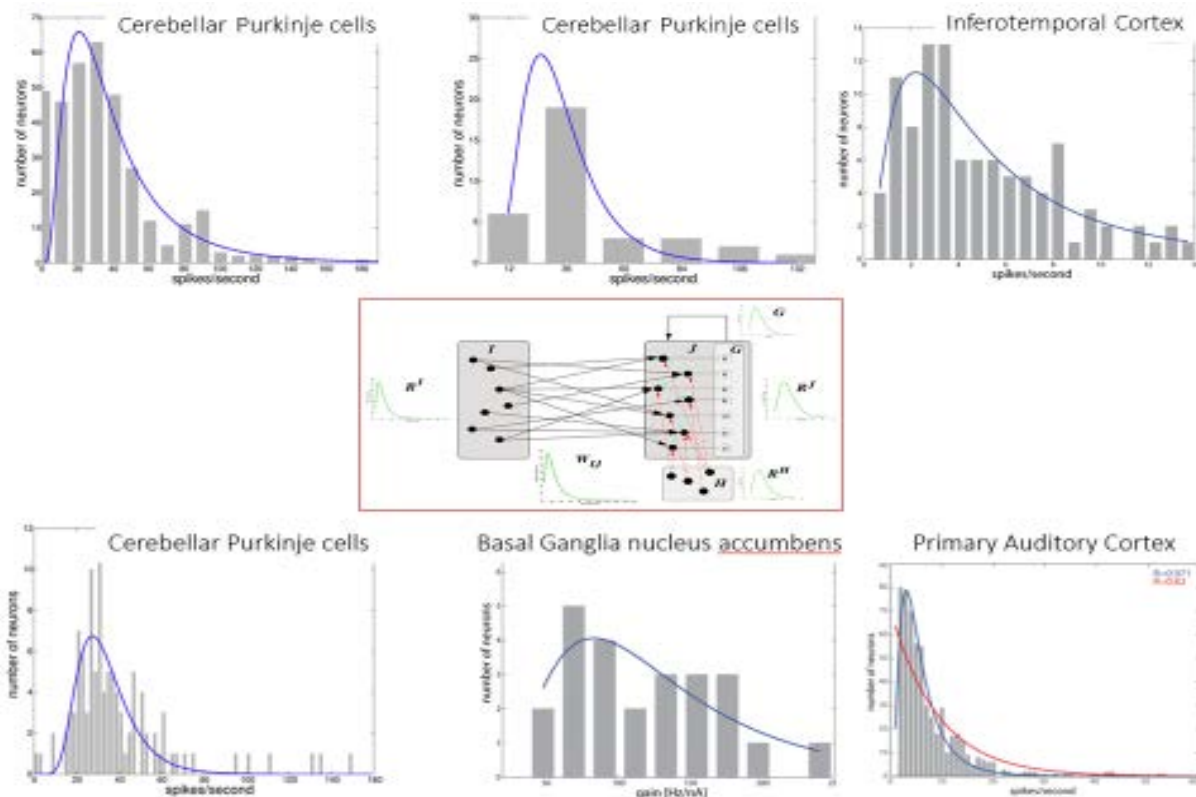


Figure 3: Distribution of neural spikes and intrinsic excitability from various parts of the brain indicate a range of responses. A representation of artificial neural network (center). Scheler, Gabriele (2017) Logarithmic distributions prove that intrinsic learning is Hebbian. *F1000Research* **6** 1222 (<https://f1000research.com/articles/6-1222/v1>)

Heuristic weights used in ANN (Figure 3, center) may not resemble reality, with respect to observed pattern of tap weights, in biological neural nets. Evidence of this discrepancy is based on observations of variability (Figure 3), central to biological processes, learning and neuroplasticity. This information may be useful when training artificial neural nets (ANN).

Untrained memory network is a structural representation (Figure 4, left panel) of a minuscule segment of the 100 trillion synapses in the (human) brain. When humans or animals learn certain behaviors, the synaptic relationship changes. A class of the latter type may be referred to as Hebbian learning (a synapse between two neurons is strengthened when the neurons on either side of the synapse, input and output, have highly correlated outputs). But, learning is not an unimodal action. Animals and humans are multi-sensory, multi-modal and multi-dimensional learners. Hence, an event cannot be mapped to change in one synapse. A simple learning, may impact a neural network, no matter how small.

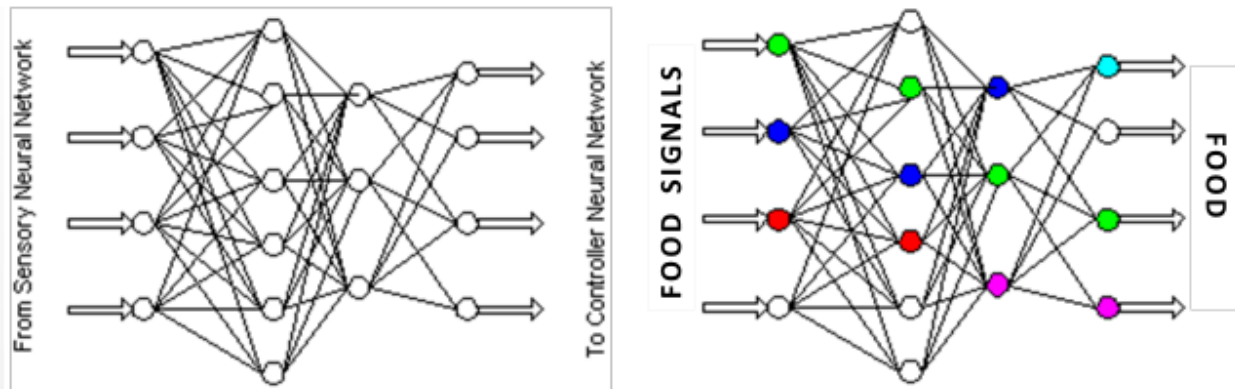


Figure 4: Untrained memory network (left panel). Trained memory network (right panel)

Re-visiting the classic example of Ivan Pavlov's dog (Spot) the “food” signal is a complex multi-sensory input. For simplicity we dissect it as follows: [1] auditory signal (Spot, Food!), [2] olfactory signal (smell of food) and [3] optical signal (sight of food). Assuming that Spot did not understand Russian or English, using the Hebbian learning principle, calling out “Spot, Food!” is just a sound, albeit emphatic, but still a sound, but it follows a specific form, a pattern, which repeats (reinforcement learning). In course of these experiments, Ivan Pavlov's dogs may have “learned” to differentiate between arbitrary background chatter and the call "Spot, Food!" by their owner. Because of the natural language ambiguity, the blue input (Figure 4, right panel) manifests as a turquoise output. The choice of the closely related colors may indicate reduced synaptic weight, and perhaps insinuate a different strength of learning in this memory circuit. However, the auditory signal (Spot, Food!), in **combination**, with other signals, sends the correct message (sounds like food) to the neural controller. The combinatorial and synergistic effects, are weighted differently, and are important determinants in memory circuits.

The blue input signal synapses with the green input signal, as if to validate the incoming olfactory signal (green cluster), since the sense of smell is a signature stimuli, for dogs. The output from the olfactory signal (input, green) is definitive (output, green) and strengthens the output message (food). The sight of food (input, red) adds to the combined output but it may be weak (output, pink, related color to red, input) because **humans** are unclear if dogs are capable of **visually** differentiating between chicken tikka masala v beef stroganoff.

I digress to make the point about “humans” understanding or not understanding. Logic, ontology and programming of computable models, is colored by the syntax and semantics of humans, their natural languages and their habitats. The same problem approached by an English, Chinese and Indian person, may produce three, related, but different outputs. This underscores the critical importance of semantics and interoperability between standards and interoperability between platforms. Hence, the role of interfaces is key to abstraction.

Returning to neural nets and weights, the point of this explanation is to convey that neural networks, naturally, lead to memory circuits. In this case, the dog's memory circuit gets trained, over time (hence, these are linked to time series) to sight, sound and smell. The training creates patterns, corresponding to the input signals feeding the network. The dynamic nature of this training is represented by colors of the neural cell clusters, with colors representing strength of connections.

The complexity of this very simple event illustrates how learning, synaptic weights and modifiers, influences memory. In this case, you can execute associative control logic by having an integrator/arbitrator neural cluster (sight and sound). The degree to which we can abstract these principles and create ANNs closely resembling natural neural nets remains an open question.

But, it should not discourage humans from trying to use bio-inspired models in developing and using ANNs to support “intelligent” decision support systems. No matter how intricate and multifactorial natural neural nets may be, humans are persevering in their attempt to create ANNs and use it as effectively, as possible, even if “intelligence” remains a mirage.

For example, you can plug in the memory network for the stimulus represented by green neural cell cluster (Fig 4) and track the memory of an event, executing the associative logic.

Similarly, we can integrate associative control clusters and create a complex of associative control logic. In Figure 5 (right), two associative control circuits are integrated. Each circuit feeds a gray memory circuit above it. The two memory circuits tie in to a control circuit (black node) that feeds into a memory circuit at the apex (gray node). This topology can execute a complex set of behavioral controls in response to a complex set of multi-source stimuli. It has an internal memory of the actions taken in response to the situation. The latter is reminiscent of human action, that is, the ability to remember actions in a given set of circumstances. The ability of humans to show restraint and the ability to “forget” are important elements which may be driven by higher level cognition. Pragmatic applications of AI are keen to capture part of this “human problem solving and processing ability” due to neural networks. It is certainly worthy of mimicry.

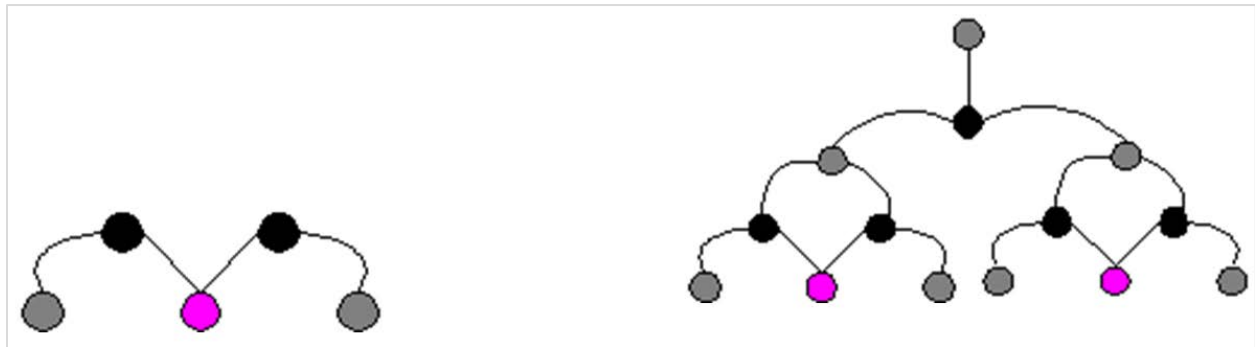


Figure 5: Simple associative control (L) and association complex with internal memory (R)

Taken together, perhaps we shall invest more thought in the design of ANNs by re-visiting assumptions which are generally incorrect because we are still significantly uninformed. Having said that, one must hasten to add, that, no matter how approximately correct the synthetic weights, may be, it may not be impossible to conceive building better ANNs with partially unsure topologies and unqualified numbers (Figure 3) using the Pareto Principle. Perhaps we can achieve 80% of the goal, using the approximations, at 20% of the cost.

Clever integration of tools and techniques (for example, Luenberger Observer, back propagation algorithms) may allow us to tune and re-tune AI systems in a dynamic data-driven manner and improve the learning, as discussed above, to generate actionable information. Over-fitting the model may cause harm, for example, in collision avoidance. Understanding the principles that govern these processes (neurobiology) may improve the thinking of analysts to use better design principles while constructing dynamic models.

Scholars [continue to discuss](#) new ways of using robots to make robots, create self-healing intelligent machines and [adaptive machines](#) to optimize up-time. Thinkers are conjuring up ways to harness the developmental foundations of neurons – *neurogenesis*. Emulation of *neural development* using computational AI systems can incorporate characteristics of natural neural systems into engineering design. Scientists are claiming that rather than *designing* neural networks, emulation of neurogenesis shall enable us to *generate* neural networks to serve dynamic and even more complex systems of the future. This emerging field of programmable artificial neurogenesis appears to call for a meta-design paradigm which may begin with components (objects?). It aims to build higher order intelligent systems which will [adapt](#) (to demands, environment, resources) without re-programming component level entities. When components are updated, the changes will be propagated, via appropriate “learning” functions, up/down hierarchies.

The great desire to emulate the grand vision latent in intelligence, cognition and the brain, works almost as an aphrodisiac. The immense powers of biology, and the ability to distil and capture even an iota of that potential, from bio-inspired systems, through convergence with computation, will continue to be a Holy Grail. Here is one example. We have about 3 billion base pairs (A-T, G-C) in the [human genome](#) (3×10^9) which codes for about 10,000 – 20,000 genes resulting in a human body with 100 trillion cells (1×10^{14}). At least [a third of the approximately 20,000 different genes](#) that make up the human genome are active (expressed) in the brain. We have about 8.5×10^{10} neural cells (there are an equivalent number of glial cells). Each neural cell connects on an average with 1,000 other neural cells to create about 1×10^{14} neural connections (100 trillion synapses). This is the natural neural network which makes us human, brews intelligence and cognition. In terms of compression ratio, the ratio approaches 10^{11} (7,000 genes creating 1×10^{14} connections). From the non-biological world, the most effective compression algorithm [CMIX](#) doesn't even come close. The [illegal 42.zip](#) bomb which unfolds to 4.5 petabytes (pb) from a 42 kilobytes (kb) single symbol zip, approaches a compression ratio of 10^{11} in an artificial circumstance devoid of intelligence. The human compression of 10^{11} offers sustainable, real, life-long intelligence.

Conclusion – [These ‘intelligent’ machines may never be intelligent in a human sense \(p339\)](#)

A quantum leap, still cryptic within the unknown unknowns, may unleash what is intelligence within AI, in the future. We must continue to explore far and wide, emulate insects and think about the Octopus. “We can only see a short distance ahead, but we can see plenty there that needs to be done.” Convergence of tools (statistics, math) with data curation ([noise](#) vs signal) is replete with promise and profitability even if it lacks (human-level) intelligence. We must continue to explore ways to profit from AI (Appendix 6).

APPENDIX – 1

Warren S McCulloch and Walter H Pitts (1943) *A Logical Calculus of the Ideas Immanent in Nervous Activity*. Bulletin of Mathematical Biophysics **5** 115-133

<http://www.cse.chalmers.se/~coquand/AUTOMATA/mcp.pdf>

A Logical Calculus of Ideas Immanent in Nervous Activity

adequate. But for nets undergoing both alterations, we can substitute equivalent fictitious nets composed of neurons whose connections and thresholds are unaltered. But one point must be made clear: neither of us conceives the formal equivalence to be a factual explanation. *Per contra!*—we regard facilitation and extinction as dependent upon continuous changes in threshold related to electrical and chemical variables, such as after-potentials and ionic concentrations; and learning as an enduring change which can survive sleep, anaesthesia, convulsions and coma. The importance of the formal equivalence lies in this: that the alterations actually underlying facilitation, extinction and learning in no way affect the conclusions which follow from the formal treatment of the activity of nervous nets, and the relations of the corresponding propositions remain those of the logic of propositions.

The nervous system contains many circular paths, whose activity so regenerates the excitation of any participant neuron that reference to time past becomes indefinite, although it still implies that afferent activity has realized one of a certain class of configurations over time. Precise specification of these implications by means of recursive functions, and determination of those that can be embodied in the activity of nervous nets, completes the theory.

THE THEORY: NETS WITHOUT CIRCLES

We shall make the following physical assumptions for our calculus.

1. The activity of the neuron is an “all-or-none” process.
2. A certain fixed number of synapses must be excited within the period of latent addition in order to excite a neuron at any time, and this number is independent of previous activity and position on the neuron.
3. The only significant delay within the nervous system is synaptic delay.
4. The activity of any inhibitory synapse absolutely prevents excitation of the neuron at that time.
5. The structure of the net does not change with time.

APPENDIX – 2

[Page 452](#)

A. M. Turing (1950) Computing Machinery and Intelligence. *Mind* **49** 433-460
www.csee.umbc.edu/courses/471/papers/turing.pdf

In the process of trying to imitate an adult human mind we are bound to think a good deal about the process which has brought it to the state that it is in. We may notice three components.

- (a) The initial state of the mind, say at birth,
- (b) The education to which it has been subjected,
- (c) Other experience, not to be described as education, to which it has been subjected.

Instead of trying to produce a programme to simulate the adult mind, why not rather try to produce one which simulates the child's? If this were then subjected to an appropriate course of education one would obtain the adult brain. Presumably the child brain is something like a notebook as one buys it from the stationer's. Rather little mechanism, and lots of blank sheets. (Mechanism and writing are from our point of view almost synonymous.) Our hope is that there is so little mechanism in the child brain that something like it can be easily programmed. The amount of work in the education we can assume, as a first approximation, to be much the same as for the human child.

We have thus divided our problem into two parts. The child programme and the education process. These two remain very closely connected. We cannot expect to find a good child machine at the first attempt. One must experiment with teaching one such machine and see how well it learns. One can then try another and see if it is better or worse. There is an obvious connection between this process and evolution, by the identifications

Structure of the child machine = hereditary material

Changes of the child machine = mutation,

Natural selection = judgment of the experimenter

APPENDIX – 3

1955 Dartmouth Summer Research Proposal

<http://www.aaai.org/ojs/index.php/aimagazine/article/view/1904/1802>

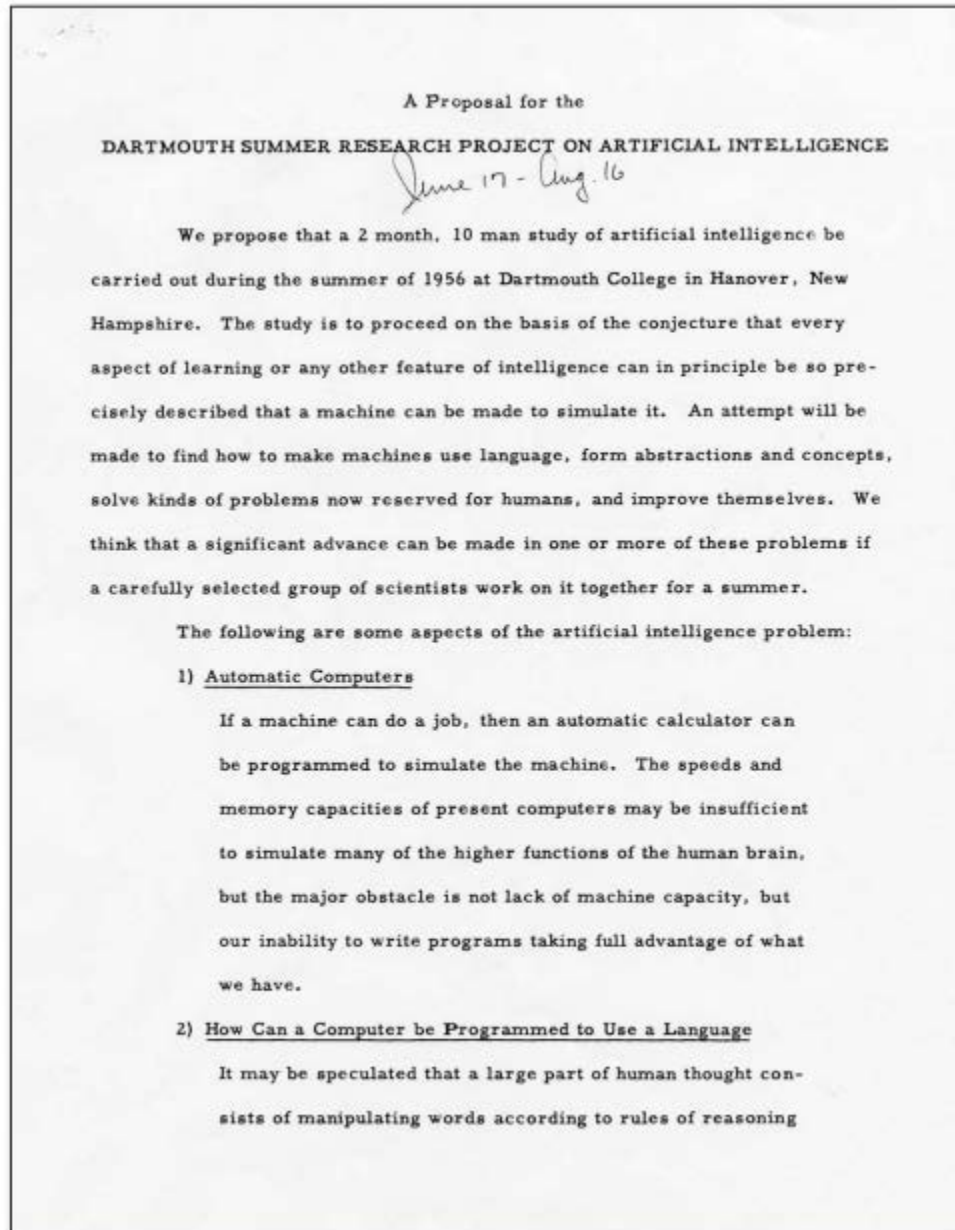


Photo courtesy Dartmouth College.

Page 1 of the Original Proposal.

APPENDIX – 4

1943 Warren S McCulloch and Walter H Pitts *A Logical Calculus of the Ideas Immanent in Nervous Activity* in Bulletin of Mathematical Biophysics **5** 115-133

<http://www.cse.chalmers.se/~coquand/AUTOMATA/mcp.pdf>

1949 Geoffrey Jefferson *The Mind of Mechanical Man* in British Medical Journal June 25

<http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2050428/pdf/brmedj03683-0003.pdf>

1950 Alan M. Turing *Computing Machinery and Intelligence* in Mind 49 433-460

www.csee.umbc.edu/courses/471/papers/turing.pdf

1955 Proposal for Dartmouth Summer Research Project on Artificial Intelligence

<http://www.aaai.org/ojs/index.php/aimagazine/article/view/1904/1802>

1960 Marvin Minsky *Steps Toward Artificial Intelligence* in Proceedings of the IRE

<http://web.media.mit.edu/~minsky/papers/steps.html>

<http://www.cs.utexas.edu/~jsinapov/teaching/cs378/readings/W2/Minsky60steps.pdf>

1966 Ray Jackendoff *Patterns in the Mind*

http://ling.umd.edu/~omaki/teaching/Ling240_Summ2007/Jackendoff94_Ch1.pdf

1970 Natural Language – PhD Thesis of Terry Winograd, MIT

<http://hci.stanford.edu/winograd/shrdlu/AITR-235.pdf>

1974 Marvin Minsky *A Framework for Representing Knowledge* in MIT AI Lab Memo 306

www.u-picardie.fr/~furst/docs/Minsky_Frames_1974.pdf

1984 Patrick H Winston *Artificial Intelligence: A Perspective*

https://mitpress.mit.edu/sites/default/files/titles/content/9780262570770_sch_0001.pdf

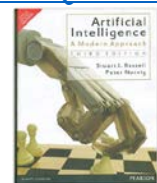
1984 Winston & Prendergast *The AI Business* <https://mitpress.mit.edu/books/ai-business>

1986 Kay Rodgers – US Library of Congress <http://files.eric.ed.gov/fulltext/ED271107.pdf>

1992 P Winston *Artificial Intelligence* 3rd <http://courses.csail.mit.edu/6.034f/ai3/rest.pdf>

2015 Stuart J Russell and Peter Norvig *Artificial Intelligence - A Modern Approach* (3rd ed)

www.amazon.com/Artificial-Intelligence-Approach-Russell-2015-01-01/dp/B0182Q542W



APPENDIX – 5 – What business needs for sustainable long term profitability

As an AI optimist, one cannot leave “AI” hanging without some form of a path forward to deploy the treasure of principles. The discussion about lack of “intelligence” in AI should not indicate the author’s lack of support for the *ideas that are represented* through AI. Informed individuals are likely to agree that human level intelligence is still utopian. A cursory reading of Chapter 1 of Russell and Norvig’s seminal work (2015) will enlighten even a pre-teen student that the flight of an air plane is not *artificial flight* which mimics birds and *artificial intelligence* or AI is not similar to human intelligence. The introduction of the term “AI” by John McCarthy during the summer of 1956 was a genius stroke of public relations and marketing coup completely unbeknownst to John McCarthy or others in 1956.

Russell & Norvig (2015) *Artificial Intelligence: A Modern Approach* (3rd ed). Page 17
Perhaps “computational rationality” would have been more precise and less threatening, but “AI” has stuck. At the 50th anniversary of the 1956 Dartmouth conference (in 2006), McCarthy stated that he resisted the terms “computer” or “computational” in deference to Norbert Wiener, who was promoting analog cybernetic devices (in the 1950’s) rather than digital computers. (Section 1.3.2)

Definitions are often useless and narrow but if one must re-define “AI” then consider this: The science and art of designing engineering tools, systems and platforms to perform tasks that generally requires human input, as a gradient of responses (segmented by simplicity or complexity) based on rational, contextual, and optimal attributes of human reasoning.

Those seeking to distill the “value proposition” of AI may consider this verbose statement: The value of AI is in performance of tasks, using one or more tools or systems, repeatedly and accurately, often, at a very high frequency, often, with immense sets of structured or even unstructured data, in various possible combinations of the features, of the data, using a dynamic selection of algorithms and solvers, from the system or platforms or several other sources (cloud, fog), in near real-time, or with negligible latency which the outcome can tolerate. The delivery of the value of AI is inextricably linked to the **strategic** value of data and/in connected networks. The value of AI analytics may be reaped at the edge or core or in sub-systems, if the outcome or output can effectively aid decision support systems, within bounded latency, to improve performance and/or actuate/execute events, without further human input, in near real time, or at the correct time, to optimize the scenario or improve profitability from the decision or outcome based on AI data analytics.

Organizations and corporations are perhaps most interested in the AI economy. Hence, the application and deployment of AI tool kits. To achieve these goals, at least in part, diffusion of the principles and practice of AI tools must precede the P&L quest for profitability. The most critical catalyst for breaking new ground is *information arbitrage*. AI is no exception.

The industry needs skilled communicators with content knowledge, those who can simplify but refrain from being simplistic, explain without dilution or downsizing the material and reach the executive core as well as practitioners without making it a journey of “billable hours” consulting. The communicators must also understand strategy and management.

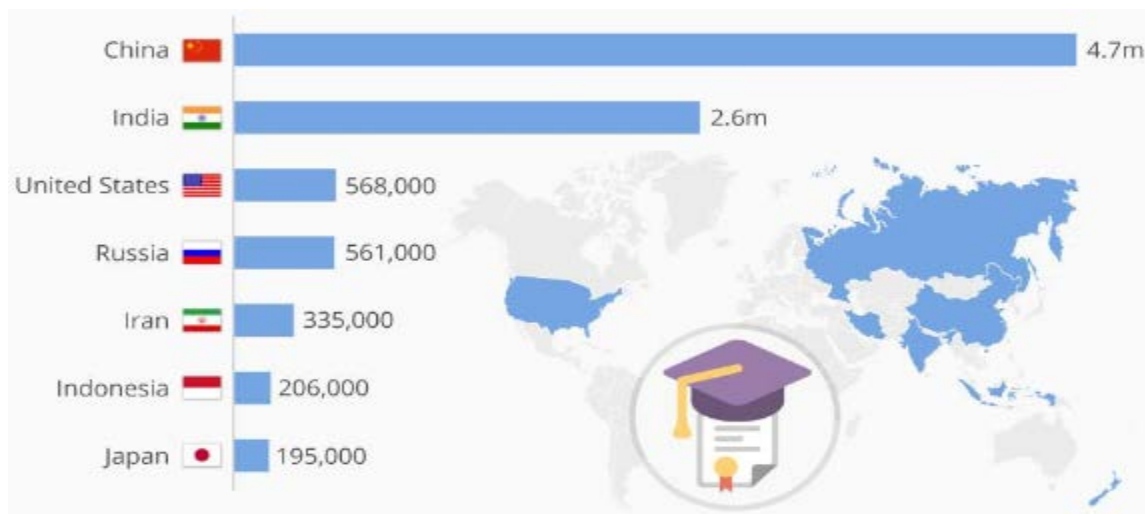
Strategic communication of the science and engineering, related to the principles and practice of AI, requires a synthesis of logic, ontology and computation. Taken together, the trinity, is the foundation of knowledge representation (KR). The abstraction of KR may be industry agnostic for certain classes and industry specific in many instances. Widespread understanding of these elements and the participation of the industry specific knowledge experts in their development, is the Holy Grail, which is essential for systems to benefit and profit from AI. The *strategic* value of this modus operandi must be in balance rather than serving AI as a one shoe fits all or a panacea for all the woes of decision support systems.

To be driven by data, AI tools cannot exclude the principles of data handling, feature engineering, data curation and how to use dynamic high volume data to extract *actionable information*. These are not apps which teenagers can build in a few hours. A most sincere concerted effort is a pre-requisite. This is a field where certain tools and standards exist. Inclusion, interoperability between standards and integration may be essential, in certain domains. The ability to cross-pollinate existing and available tools from different sectors with new, novel or unique capabilities, requires a dynamic platform, agile in its ability to adopt and adapt. These attributes are missing in certain vendors who promote their “all-in-one” package or install cryptic boundaries (example: closed data dictionaries or semantic incompatibilities between knowledge representation modules). In a volatile economy, any restriction may become a detriment to global businesses and an anathema for profitability.

These roadblocks are nothing new and are usually organizational. The general disregard for experts and academic-industry collaborations, fuels the “illusion of expertise” which often retards innovation. Evolution of digital transformation can easily fall prey to market forces which manufactures these veneers or silos. One role of the visionary leader or the entrepreneurial corporation is to recognize the mirage created by illusions of completeness and prevent the delusion from asphyxiating the transformation of vision into reality.

Businesses need intuition and imagination to inculcate vision. The leadership may invest in building the capacity to execute in a manner that catalyzes entrepreneurial innovation. The path to AI driven data analytics is calling out for leaders. Also, AI calls for confluence, even more than other broad areas. Context of AI applications are pivotal in order to reduce the *garbage-in/garbage-out* syndrome. Cloud, cybersecurity, computation and communication must converge for the data to be available, secure, analyzed and used *before* the value of the information perishes. These and other factors are critical for success of AI applications.

For businesses to stay in business it must look beyond business, for networks of innovation which will depend on the supply chain of global talent. The excitement about new tools and technologies may die a premature death in a manner similar to the hypothetical demise of the industrial revolution, if the world ran out of coal. Data is not the new coal, or new oil or new goal. Talent and education was and still remains the coal to ignite our imagination. The wealth of nations must be invested to cultivate talent through education. The US ought to be deeply concerned by the diminishing number of STEM graduates from its institutions.



According to the World Economic Forum, US produced 568,000 STEM graduates in 2016. If 1% of these students (5,680) are in the general area of AI, and if 1% of that number (568) are proficient in communicating about AI, and if 1% of the strategic experts may choose to work for your business, then the human capital you may have to promote AI education, strategy and usability in your business, amounts to less than 6 employees, if you are lucky! The supply chain of talent is the ultimate rate limiting step. Education needs an avenue to amplify its reach, increase the pool of talent, globally. The new path is digital, it is digital learning. For corporations with global ambitions, sponsorship of education, digital learning and academic-industry partnerships, are sign posts on the road, to long term profitability.

Prescription for Profit

Dr. Shoumen Palit Austin Datta

Senior Member, MIT Auto-ID Labs
Research Affiliate, Department of Mechanical Engineering
Massachusetts Institute of Technology, Room 35-203, Cambridge, Massachusetts 02139, USA
Senior Scientist, Medical Interoperability Program, MDPnP Laboratory
Massachusetts General Hospital, Harvard Medical School
Partners MGH Research Building, 65 Landsdowne Street, Cambridge, MA 02139, USA
shoumen@mit.edu, sdatta8@mgh.harvard.edu

Letter from Academia

AI is being marketed as a panacea solution or a complex “black box” by the PR spin doctors. How to profit from AI in business applications is still unclear. The lack of understanding of knowledge representation, data structures and feature engineering, are a few of the core underlying problems, devoid of easy solutions. This short guide is a note on strategy with respect to the use of AI tool kits. What is necessary for rational use and integration of AI tools with business are humans.

Keywords. AI, Digital Twins, Rational Agents, Logic, Ontology, Knowledge Representation, Data, Analytics, Computational Rationality, Neural Networks, Cognition, Machine Learning, ERP, Syntax, Semantics, Synapse, Speech, Vision, Neurobiology, Innovation, Management.

1 Pragmatic use of Artificial Intelligence

Pragmatic use of Artificial Intelligence (AI), which can catalyze corporations to profit from applications of AI, is the ultimate goal for business and industry. Academia could help industry achieve this goal, albeit in part, the rational part.

The probability of bursting the public relations bubble, and the hype about the promises made on behalf of AI, are increasing. It may be reduced if industry and management better understood why the world must opt to lower its expectations of “intelligence” as an outcome from AI tools.

The suggestions in this letter does not distract from the rational possibilities of using the principles of AI in data analytics, decision support, and even, in automation.

During 1955-56, the term “AI” rather than “computational rationality” was used to describe a “new” and “emerging” field. The difference between the terms is a matter of states because “intelligence” is continuous (core attribute of many biological processes) while “computational rationality” is a discrete process. The latter is explained by the boundaries of limited rationality which systems generate, based on computable models.

The cognitive glue, necessary to bond discrete events to form the continuum, may be a cherished objective, but remains an illusion for science, and delusion for engineers, at this time. This brings to mind the pithy words of John Searle "brains cause minds" as

if to say that a mere collection of cells (neurons, glia) will lead to thought, action and consciousness. It is true, the brain is a collection of these cells, but does that suffice to serve as a platform, to extrapolate the brain to the scope of the human mind?

To illustrate the issue on page 7 (see <https://dspace.mit.edu/handle/1721.1/108000>), I refer to (<https://link.springer.com/content/pdf/10.1007%2Fs11633-017-1093-8.pdf>) a recent paper. It starts with states (each binary bit has two states, 0 and 1) and memory storage capacity. A human brain has 1×10^{14} neural cells (100 trillion synapses) with approximately 2×10^{15} states, equivalent to a storage capacity of 500 terabytes (assume 4.6 bits of information stored by each synapse). Hence, 2×10^{15} is the number of synaptic connections in a human brain. Is this, then, the capacity of the human mind?

In our mind, cognition allows us to read, write, create, and understand language, simple and complex. Our vision can distinguish topology of objects, colors, size, depth, shades. Our five senses, in combination, can respond to an array of input, to produce a vast (unknown) number, and variety, of output. If artificial neural nets claim to “capture” the brain and if we can scientifically describe this *capture* as “brain in a box” then, this network, if etched on a “neuromorphic chip” is the sum total of “intelligence” that we may rely on, for all our activities. By this rationale, “intelligence” is governed by the maximum number of states of our synapses. That number is about 2×10^{15} and that is, by this account, the total number of instances or the magnitude of combinations of our thoughts. Is this a true statement?

As Danko Nikolic points out, an English speaker’s vocabulary has about 15,000 words which consists of 5% adverbs, 20% adjectives, 20% verbs and 55% nouns (750, 3000, 3000, 8250 words in each of the four categories, respectively). From those numbers, we can calculate the number of all combinations, of sentences, of different lengths. For four word sentences, consisting of a noun, followed by a verb and ending with a noun plus an adjective, we obtain $8250 \times 3000 \times 8250 \times 3000$ or about 2×10^{18} combinations. We have not even pondered about the semantic boundaries of the syntax in the four-word sentences. This number (2×10^{18}) is already bigger than the limit that is posed by the total number of synapses in the brain (2×10^{15}). By this reasoning, there isn’t enough memory in our brains to generate a different response even for sentences with 4 words!

At this stage, we have only considered “speech” and limited our expression to 4-word sentences. Limited by the storage capacity of the total number of synapses in our brain (2×10^{15}) we will not be able to see, hear, taste or touch, among other things. Do we still wish to continue, and support marketing campaigns, suggesting that deep neural nets are equivalent to biological intelligence, which powers AI? Hence, is there intelligence in AI?

The fact that humans possess at least five senses, and do much more than what 2×10^{15} synapses may allow, is due to the fact that this number is an anatomical representation of the number of discrete connections. This is the **structure** of the organizational aspect of the anatomy and topology of the human brain. Structure is **not** the same as **function** in the same manner that anatomy (human skeleton) is not equivalent to physiology and physiological function (human organism), even though the skeleton (structure) is quintessential for physiology (function).

It is **function** that generates the amorphous quality of intelligence and makes humans intelligent. The numbers in the structure are discrete. The numbers matter, of course.

With 302 neurons, potential structural relationships in *Caenorhabditis elegans* (worms) may not qualify to provide intelligent functions or even pattern recognition.

The function of intelligence is best perceived as a *continuous* fabric, inextricably linked with data, rules, patterns, experiences, knowledge and learnings to inform or support decisions.

The almost unlimited number of connected continuity, the underpinning of intelligent human action, is a result of 2×10^{15} synapses which are being formed, and re-formed, connected and disconnected, re-connected and re-configured, in an asynchronous, dynamic manner, in response to signals, perceived, received, in processing or being transmitted. Signals may originate from diverse sources (internal, external, autocrine, endocrine) or may be presented to sensory interfaces in a multitude of shapes or forms.

Continuity is not an attribute of a computable model. The term AI was less appropriate than “computational rationality” in 1956 and it is even less appropriate, today. But, we may use the term AI, for the sake of posterity, its magnetic image and public imprint.

The term intelligence is supposed to present a mental image relating evolution of words, objects, ideas, in terms of meaning and context. It is not a discrete, structural, one to one syntax, which can be translated. It is an *interpretation*, based on semantics, and by extension, logic, and ontology. The fact that intelligence may not be amenable to simple syntactic translation was demonstrated by the almost abject failure of the Russian to English translation during 1960s (prior to use of convolutional or recursive neural nets).

The “artificial” architecture of intelligence may have literary roots. Perhaps, a reference to *Leviathan* by Thomas Hobbes (1651) or similar, from that school of thought. Hobbes argued for "artificial animal" based on observation that the heart is a spring, nerves are strings and joints are wheels. Attempts to mimic birds and develop "artificial flight" did not lead to aviation. The right approach by the Wright Brothers was to view flight as a function of aerodynamics, which gave birth to the airline industry. Reality of flying, for human use, was not a reproduction of the fantasy of viewing birds in flight.

2 From Taylorisms to Terabytes

The movement from Taylorisms to terabytes needs AI, and its tools. Hence, AI, despite its limitations and a handicapped terminology, presents opportunities for companies to automate business processes. But, fantasy driven scenarios, about winning at GO or poker, may not suffice for integrating AI or ML applications, in the real world. While ERP implementations enhanced competitiveness, several companies also uncovered nightmares. The promised opportunity from ERP never came to fruition, for some. Do we have a sense of *déjà vu* with AI? The rain on the AI parade falls mostly on input data and the output/outcome. Unless reliably automated, the outcome requires people to do something with the information. Is it actionable? AI analytics cannot help if input data is noisy or corrupt. How do you know the data or the outcome is of poor quality?

AI and ML can augment performance. In case of AI (more than ERP) those changes create highly skilled tasks which require education, prudence and domain expertise, *from humans*. Businesses are forever in an elusive quest for “low hanging fruit” without gaining the wisdom from repeated failures. The pursuit of “low hanging fruits” require only low level skills. That *modus operandi* may not help, at all, to profit from AI.

Generating value from AI by recruiting more data scientists is an amorphous escape clause. Several domains converge under the umbrella of data science, which makes it impossible to ascribe the term data scientist, to any one individual. Data science is a team sport. Bringing the talent together, and synthesizing the unpacked problems, are tasks that few companies can execute because companies do not have, or rarely employ, strategic *cube-on-cube* thinkers.

Companies do not even know, that they do not know, that they lack trans-disciplinary cross-pollinators. Companies and HR are unable to comprehend that they need people with broad spectrum of knowledge “cubes” and a matrix of experiences, unlike those that can fit in a box. “Thinking different” is not a principle that HR departments can practice. Hence, the clamor for data scientists but lack of jobs describing the need for out-of-the-box thinkers, followed by an absence of zeal, to pursue the road not taken.

Thinkers are pivotal to assist teams to dissect problems into components, to identify the confluence of domains, and underpinnings of potential solutions. Creative thinkers are key to assist the leaders to move the fulcrum and mentor the rank and file to frame the correct questions. Hiring and allowing *cube-on-cube* thinkers to form agile, case-dependent teams, staffed with vertical experts, across silos (network of business units), may be the first step to profitability, from advanced applications, which are fueled by convergence, such as, AI, analytics, robotics and nanotechnology.

Data science must start with data. Data must be acquired, processed and curated to serve the business needs. Hence, the critical demand for domain experts, and field knowledge providers, who must help identify the obvious, common, and uncommon “features” that businesses are seeking. Then, add non-obvious relationship analyses, and garnish with unconventional wisdom. To harvest the latter, perhaps crowd sourcing may be useful.

Organized data, using the principles of knowledge representation and application of logic and ontology, is a starting point, to construct computable models/structures of the domains of interest (agnostic of industry, vertical or horizontal). In the computational phase, we can use algorithms and tools from AI including ML, DL, ANN, CNN, RNN.

The trinity of out-of-the-box thinkers, who can connect the cubes, with field knowledge providers, and computational experts, is the “secret sauce” which must be continuously stirred, shaken, configured and re-configured, to blend the correct team, case by case, to profit from AI, and use the ability of AI, in problem solving. This approach and grasp of the extended fabric, is lacking in businesses and absent within corporate leadership.

The marketing hype, which is furiously polishing the chrome, on the AI engine, may help to explode the bubble and trigger a second AI winter. Global warming will be essential to thaw the AI ice age. But, before we boil the ocean, let us try to warm up to what may be necessary, the prerequisites, what is missing, how deep is the abyss and how education may bridge the chasm. Let us imagine, we have managed to fast forward to the spring of AI. Assume, AI in the tool kit is generating probabilistic output.

As pointed out by Jeanne Ross, an AI application indicates that a lead has a 95% chance of converting into a sale, while another has a 60% chance. Should we assume the salesperson knows what to do with that information?

ML applications may help lawyers identify appropriate legal precedents, help vendor management teams ensure compliance with contracts, assist financial institutions to gauge risk. These systems use ML to perform mundane tasks. Systems can learn to

develop spreadsheets and search databases for relevant information. But, in order to generate competitive advantage from ML (AI), we may need skilled humans to process the outcome. Hence, companies must redesign accountabilities, motivate employees to deploy ML tools, when they believe it may enhance outcomes. The educated workforce of the future must possess higher order skills, capable of consuming intelligence, and trigger actions to benefit, and hopefully, profit, from the deployment of AI tool kits.

Hence, these AI tools must be capable of use by general employees. The tools may be drag and drop interfaces representing abstractions. The employee may not need to deal with the computational complexities, programming principles and Boolean operators. To use these abstracted tools and intuitive interfaces, the educated workforce, in future, must possess skills which catalyzes the *consumption of intelligence, the outcome*. The educated consumer is the best customer for the future of AI and to profit from AI tools.

This raises a critical issue concerning K-12 education and how learning must be adapted to deal with the imminent socio-economic disequilibrium. Education must address the changing face of the supply chain of talent as well as the ingredients which are necessary to future-proof workforce preparation and make the workforce future-ready.

The future is not about apocalyptic reduction of employment. It is about a refresh of skills, which must be updated and upgraded, for the humans in the loop, to play relevant roles. We need the AI tool kit to help reduce uncertainty, and better manage, volatility.

To achieve that goal, executives need to appreciate the principles of data analytics and AI. Leaders must support education, inculcate insight and remain eager to learn, before they leap to manage. Leaders must institute internal education and external learning liaisons, where thinkers are viewed as assets and not as cost centers. Leaders must stress on understanding how AI works rather than blindly purchasing “black box” solutions.

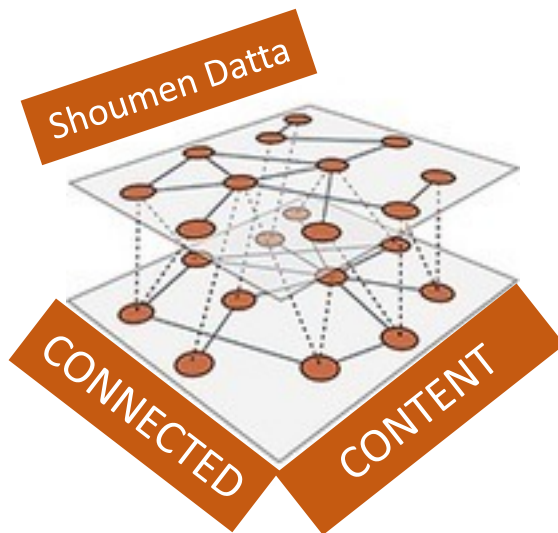
The digital world will still need to serve analog communities. AI may lead to profit, if allowed to offer reliable computational assistance to the workforce, customers, and the global ecosystem of consumers, seeking credible, rational, near real-time, and perhaps predictive, decision support.

All things considered, the path to profitability rests with the imagination and the vision of the executive management and their counterparts in academia, and government.

Corporate leaders must evolve in their leadership roles. Leaders must assume the risk of leadership. Leaders must engage to provide broader guidance, bring parties to the table (competitors) and advocate for interoperability of architectures, to enable digital connectivity. Without security, digital transformation could be annihilated. Without connectivity, without data from different systems and ecosystems, without knowledge of what is *beyond the boundary*, the ability of AI, analytics and tools such as blockchain applications, will be curtailed. The outcome will be less valuable, less actionable, less profitable.

Hence, leaders must champion digital transformation by leading, and inspiring global teams, and navigating businesses to lift many boats, not just their personal yachts.

Acknowledgments. 1) This “letter” also appears as APPENDIX 6 in the essay “03.AI” available from the MIT Library – see folder “CHAPTERS” <https://dspace.mit.edu/handle/1721.1/106496>. 2) *The Fatal Flaw of AI Implementation* by Jeanne Ross, MIT SMR (14 July 2017) served as a source of a few examples and the reference to enterprise resource planning.

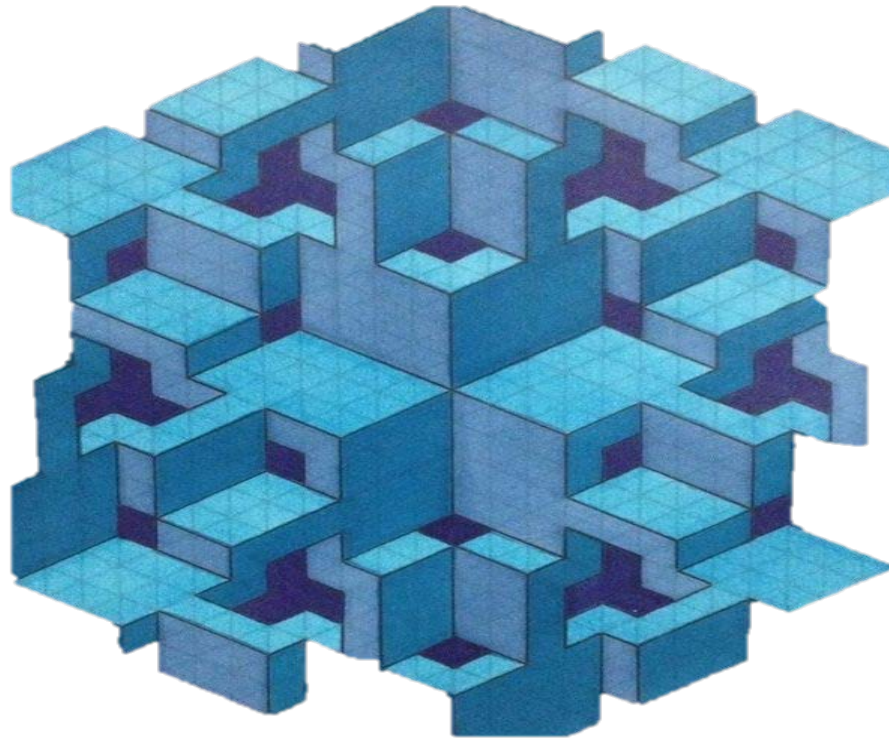


CHAPTER 5

Shoumen Datta

HAPHAZARD REALITY – IOT IS A METAPHOR

THIS PAGE IS LEFT BLANK



Digital Enterprise X.0

A blog about building blocks

Shoumen Palit Austin Datta

Senior Member, MIT Auto-ID Labs and Research Affiliate, Department of Mechanical Engineering
Massachusetts Institute of Technology, Room 35-203, Cambridge, Massachusetts 02139, USA

shoumen@mit.edu • <http://bit.ly/IOT-MIT>

Senior Scientist, Medical Interoperability Program, MDPnP Labs

Massachusetts General Hospital, Harvard Medical School

Partners MGH Research Building, 65 Landsdowne Street, Cambridge, MA 02139, USA

sdatta8@mgh.harvard.edu • <http://bit.ly/MIT-IOT>

Cover	Page 1
Table of Contents	Page 2
Preface	Page 3
Abstract	Page 3
Background	Page 4
What is the expected outcome?	Page 4
How to prepare to achieve the expected outcome?	Page 6
Building blocks of the Digital Enterprise X.0 (DEX)	Page 7
Which structural elements and connectivity are crucial for connectivity?	Page 9
Why interoperability between platforms is synonymous with performance and profit?	Page 20
Healthcare Platforms	Page 26
AI and Analytics	Page 31
Looking Forward	Page 36
Conclusion	Page 41
References	Page 44
Appendix	Page 49
End	Page 52

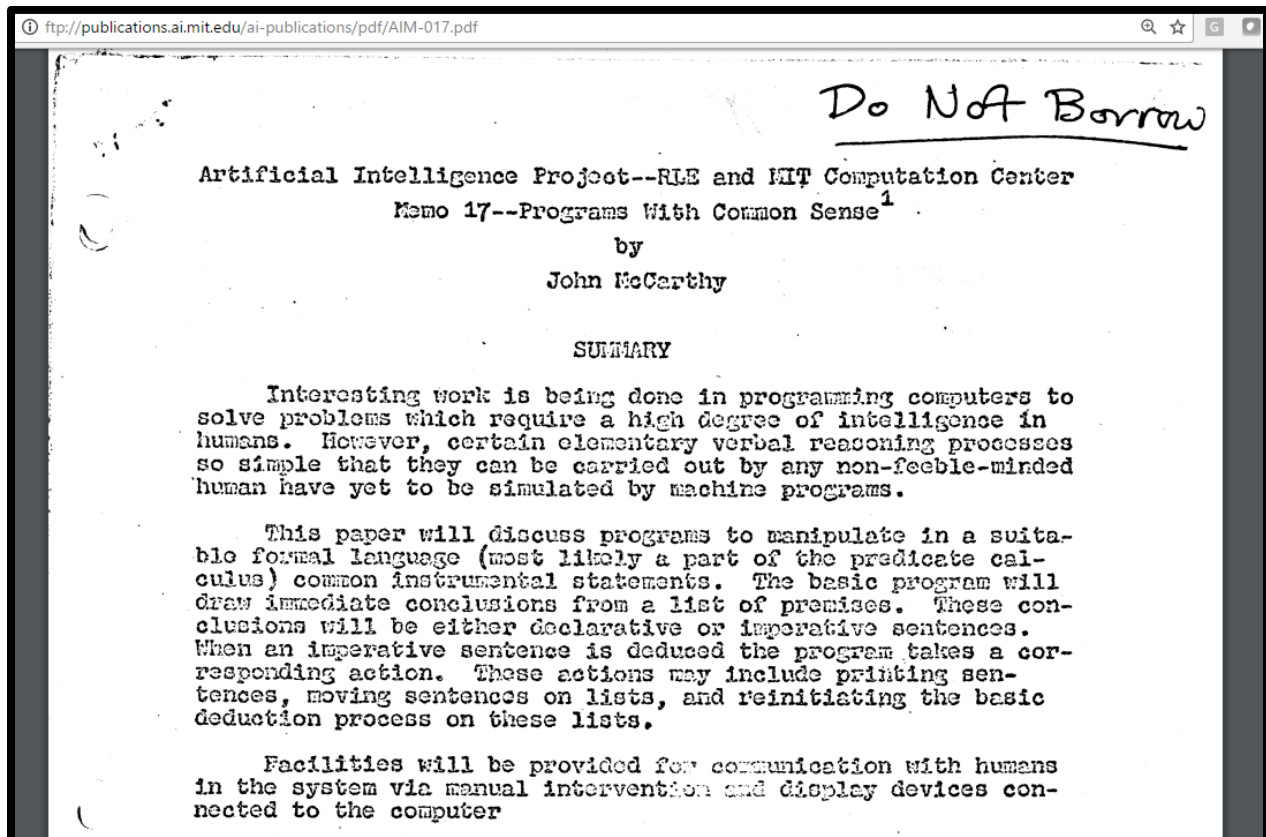


Fig 0: The fact that a program can find a solution in principle does not mean that the program contains any of the mechanisms needed to find it in practice. (1956 • MIT AI Lab Memo # 17 by John McCarthy)

Digital Enterprise X.0

A blog about building blocks by Shoumen Datta

PREFACE

Experts and non-experts have already commented that this blog is shoddy and second grade in style and content. It lacks several seminal issues indicative of the author's lack of knowledge, depth and business experience. I concur. Therefore, please proceed with caution. The intent (please see appendix) was to offer suggestions about paths that may be different or diverges from conventional wisdom or what is in vogue. The disjointed digressions are an attempt to connect the "dots" and that process may be chaotic. This is not an instruction manual, recipe or a roadmap. It is a compass. It points in so many directions because of what may be possible, the yet unseen tangled networks and the looming digital quagmire.

Aren't we all apprentices in a craft where no one ever becomes a master? from Ernest Hemingway

ABSTRACT

The approaching wave of digitalization may dwarf the immense economic consequences of what could have happened if we were to flood the Sahara Desert. In this essay, we may not even scratch the surface of convergence which is the quintessential foundation of the imminent transformational tsunami. Flooding the Sahara [¹] is a metaphor. We present vast opportunities for business solutions in terms of development and sales of services under the banner of Digital Enterprise X.0 (DEX) and its potential for global diffusion. Modular services may offer delayed differentiation using "lego bricks" or building blocks aggregated to form platforms, which can rapidly configure trillions of outcomes for billions of customer choices, using variant configuration and dynamic composition. The combinatorial efficiency may be optimized by a "menu" to select choices triggered by customer preferences. Sense-aware bots may "drag and drop" or "plug and play" Agent-based entities at mobile edge devices (or interact in a mist or fog). It may execute functions (data analytics - predictive, prescriptive, diagnostic) at the edge or in the cloud, linked to objects, processes, decisions, patterns or things connected to the internet [²]. Hence, a convergence, of enterprise systems, with IoT, a conceptual digital design metaphor. Synthesis of each element, in sequence, offers a micro-revenue harvesting potential for each creator, developer, provider of each function in each micro-service. The trans-disciplinary convergence and systems integration, necessary to arrive at the outcome, is rewarded when the end customer pays, after the value of the service is realized or the outcome is delivered. Revenue collection "at the end of the tunnel" may require a channel master, brand integrity, security and interoperability between platforms (local and global, private and public, open and proprietary). Monetization demands tools and technologies to document every event in an irrefutable digital ledger. The latter is essential for billing purposes, if the partners in the ecosystem may wish to claim their fraction of nano-earnings from each micro-payment.

BACKGROUND

Digital transformation is still embryonic and evolving. The process is punctuated by islands of hype and hyperbole [3] which makes it difficult to synthesize the fabric, in order to capture the convergence and continuum, characteristic of most enterprises. The alternative approach is to discuss discrete events, such as, tools, technologies and applications, that is, business as usual in terms of products or services. Compartmentalization of business solutions further fragments the collective use of data and diminishes the potential for profitability which may ensue from data analytics, if the interdependencies between silos, were analyzed. Static data storage may not be beneficial in this age of data driven decisions.

We are drowning in data yet suffering from poverty of information and knowledge. The classical chasm between information technology (IT) and operational technology (OT) is a reminder that the enterprise was not designed to interface or analyze external/internal data to boost efficiency, reduce waste and take advantage of risk pooling. Systems integration to promote collective “intelligence” by dissolving the archaic IT/OT boundary is not a core competency for most enterprise. Thus, supporting businesses are still creating discrete products and pushing independent domain specific business services touting their use and efficacy in a manner which resembles a hammer looking for a nail. Not every product or service is a solution and certainly one solution may not fit all. In some cases, the solution may not be a solution at all [4] but a public relations gimmick to impress the uninformed through game shows or board games and marketing chutzpah. The elusive quest for wisdom about “disruptive” [5] digital transformation from dubious management gurus [6] with a widely known predilection for self-promotion [7] is tantamount to dissemination of dead ideas [8] from live people [9].

WHAT IS THE EXPECTED OUTCOME ?

Pulling the digital thread through the eye of the needle relies on the assumption that every needle has an eye. Once threaded, we must be able to display a measurable outcome, that is, the needle must move, hopefully, in a manner which may be sustainable and supports an ethos of ethical profitability.

Neither the hand-waving about the prospects for digital transformation nor the glib PR of estimated economic growth due to digitalization [10] may be realized, even partially, unless we focus on building the foundation, at the systems level. We have to make sure that there *are* “new eyes” in every system, if the process of digital threading is expected to succeed. Convergence of digital threads are quintessential to the systems integration process, which in turn, is key to linking the systems of systems, at the heart of the enterprise, both analog and digital. Solutions are likely to incorporate elements, we have seen, or what already may exist. Innovation germinates from imagination, and thinking, what no one else has thought [11], by visualizing creative juxtaposition of blocks or bricks, to create new designs or patterns, and to implement them for systemic improvements. A catalyst for entrepreneurial economic growth is not so much to obtain novel facts or delve into research, but to uncover unique ways of thinking about existing facts, data, tools and technologies, percolating them in “various speeds” in a matrix of unusual or imaginative combinations. Frequent departures from conventional wisdom, creative destruction of existing rules and application of the principle of non-obvious relationship [12] are vitamins for progress.



Fig 1: Partial view of one of the floors of a NY Times printing facility (1 NY Times Plz, Flushing, NY 11354)

Imagine standing in front of a machine on the floor of a New York Times printing facility (Figure 1). You take out your smartphone and click on the app marked DEX. What you expect is the software avatar of the hardware, ie, machine, in front of you (aisle 8A in Figure 1). You see a blinking icon in a network diagram displaying other connected machines (8A, 8B, 7A in Figure 1). You tap the blinking icon to focus on the digital duplicate of 8A, that is, the Digital Twin ^[13] of the paper-cutting and sorting machine (8A in Figure 1). You tap on the parts icon to drill down to the details, for example, performance (blade speed), wear and tear (MTBF of blade), lubrication of the hydraulic cutting arm (oil pressure), temperature inside the press which holds down the paper stack (to optimize performance of the blade) and conveyor belt surface aberrations (data from mounted camera under the belt analyzed using optical recognition).

This scenario is part of an expected **outcome** relevant to, for example, **efficiency**. We need **metrics** to measure the **value** of key performance indicators (**KPI**), for example, down-time, based on the **data** (outlined in above paragraph as blade speed, MTBF of blade, oil pressure, temperature, belt health) and **data analytics**, to understand the **meaning** of the data, in terms of **information**, related to efficiency.

The data thus converted into information can update and inform the status of the machine (8A in Fig 1). Individual machine data, when combined, can further inform the KPIs for the entire machine floor or the entire operational system. Instead of one machine, we can acquire data and analytics from a **swarm** of machines and rather than understanding the status of one machine, we optimize the entire **operation**.

The **transaction cost** ^[14] to obtain each piece of data can be **aggregated** and the monetary value of the information is deduced. To perform comparisons, we model and run “what if” **simulations** to compare the operation with and without data, with respect to the sequence of events in the cascade or the final outcome (may be affected) of this operation, due to an unplanned failure of a machine (preventable).

If two machines shut-down due to over-heating without an alert (absence of temperature sensor data) what will be the impact on the operation? Will decreasing the output affect distribution or logistics or the supply chain? Can it impact quality of service for delivery and customer satisfaction? Will it damage brand image? Will the ripple effect influence the ecosystem of partners? Can it reduce EVA (economic value added) parameters? Each event in this multi-pronged process may have a value or can be assigned a weight in addition to transaction cost (positive or negative). Comparing the simulated transaction cost between [a] acquisition of data/information to inform and alert vs [b] operation running without these tools, may provide the rationale and justification to invest in digital transformation or not.

HOW TO PREPARE TO ACHIEVE THE EXPECTED OUTCOME ?

This discussion must begin by reiterating the obvious - no one solution or architecture or strategy may suffice to address the needs of Digital Enterprise X.0 (DEX). Complete disregard for archaic or monolithic approaches (for example, IBM DB2, SAP R3) may be a bit unwise. Salivating for new tools (for example, Google Spanner, IBM Watson) may be replete with copious shortcomings.

The disturbing efforts by some behemoths claiming “brain in a box” by 2020 [15] can only amplify hype through yellow journalism. AI apocalypse is a marketing [16] attempt devoid of scientific foundation. For example, engine wants to reduce NOx emissions [17] without increasing carbon dioxide. The outcome depends on a plethora of parameters which must be optimized, such as, controlling multiple points of injection of the fuel, how to determine efficiency by balancing fuel composition, temperature, humidity data from hygrometer, etc. It is difficult for humans to monitor, adapt and regulate NOx emissions to the lowest level because the optimization requires too many experts to learn, observe, agree and predict the thresholds and the range, before each equation can be solved and the results applied to the process. A portfolio of algorithms and solvers using the principles of machine learning (ML) may be used. Is this AI or artificial intelligence at work? This is ML at work using contextual higher order reasoning (CHOR) in real-time. Publicists call it AI. This is the crux of the discontent, over-selling of what is intelligence [19].

A portfolio of solvers [18] is not equivalent to intelligence. What is intelligence [19] if we are discussing actions at the level of a worm or an ant? Solvers rely on data but forced fitting data to models is fitting noise. Processed data may be denuded of its informational content just as processed food can lose its nutritional value. Just because the data was smoothed does not mean that the data is smooth. Hence, curation of data through a data “forge” and then harvesting the data based on feature engineering [20] is a prelude to composing better models. But, models *per se* are fraught with problems. Most models are incapacitated in the face of dynamic change in data or fails to be useful if the rules or patterns in the data may change, indicating the need for feature engineering re-design [21].

Automatic code generation based on models [22] continues to be a useful tool for equation based models (EBM) but may lack the dynamic attributes increasingly important due to the volatility of digital transformation. Modularity, dynamic composition and mathematical models to drive the best outcome in face of uncertainty are the general principles of rational Agents and multi-Agent systems. The latter is essential for enterprise architecture as a key component of AI and will enable us to profit from use of AI.

Hence, we propose introducing Agent based models (ABM) with EBM. Meta-modeling principles from model driven engineering [23] could be useful in digital transformation if the meta approach may be better tuned to accommodate dynamic changes expected in the future. Knowledge representation and symbolics, for example, in feature engineering for data analytics, will be avoided in this blog. Rather we shall focus on interoperability and connectivity between platforms and applications. Convergence of various cyberphysical systems (CPS) or CPS SoS (system of systems) with time sensitive networking will present even more complex challenges [24] where interoperability between platforms may solicit more attention. However, tuning the engine vs polishing the chrome, may continue to haunt us. It is difficult to find the balance, coalesce teams, adapt and/or adopt with respect to state, context and dynamic composability needs, at present and in the future. Examples of progress may be found in GE Predix, Siemens MindSphere, Hitachi Lumada and IBM Bluemix, in addition to other less known IoT platforms.

BUILDING BLOCKS OF THE DIGITAL ENTERPRISE X.0 (DEX) – A BRICK BY BRICK ACCOUNT OF DEX

The preparation necessary to substantiate the introductory level of Digital Enterprise X.0 (DEX) outlined under “expected outcome” in the preceding section, offers the grand potential for new lines of business.

The evidence from GE’s Predix suggests that GE may use this platform for its own business units and sell the platform as a service. This is the new business. The scope and reach may be far greater than what appears to be on offer from any vendor, at this time.

This solutions space is analogous to fractals [25] or Minsky’s cube-on-cube paradigm [26] rather than point or line. It will evolve and change as the semantic context of DEX adapts to diverse domains, from manufacturing to medicine to mobility, serving different needs in Memphis, Maputo and Mumbai.

The vision, investment and determination necessary to create this new line of business may be uncommon. Few companies possess a portfolio of operations where DEX systems may be developed, evaluated and implemented. The customer and supplier base of these companies may be the first users. Hence, expect a network boost from creating the business of DEX.

Not all components of DEX may be created *de novo*. DEX needs to tap into applications (start-ups) and potential advances (academia). Commodity tools (sensors) and services (cloud, storage) are likely to be procured. Foresight is crucial to converge and orchestrate near-term needs, profitability and long-term sustainability of the vision.

If the expression “low hanging fruit” creeps in early discussions, that is an ominous sign and the plight of DEX may be compromised. It is abundantly clear that incremental gains must be a part of this journey but such gains may not be “low hanging” from the onset of this process.

Slapping a sensor on a machine to harvest vibration signals from a pump is not indicative of digital transformation. Similar mistakes [27] were made at the dawn of the 20th century with electrification [28]. It was repeated [29] two decades ago when retailers thought affixing a RFID tag offered transparency and the digital supply chain was a *fait accompli*.



Fig 2: Digital Twin of a pump showing virtual (VR) sensor. The context of a pump within the operation (water purification, air recirculation, oil flow) is key to the value of data vs information. Including sensors to identify pump metrics is perhaps an incomplete approach, incongruent with the convergent vision of operational efficiency in the context of the customer (pump is one asset in the operation of the plant).

Convergence of the need for data with acquisition tools to harvest data (for example, from RFID, sensor) is step one in a systems approach. Subjecting the data to appropriate analytical tools may help to make “sense” of the data in step two. Extracting actionable information or knowledge makes the data valuable (sense and response) to the supply chain network or partners. The architecture and systems engineering principles must converge with the business process and the context of the data, with respect to the operation, where the information may be actionable.

Latent in the “preparation” is the need for organizational vision which must sufficiently percolate within senior leadership. They must be imbued with the spirit to grasp beyond their reach and embrace innovation uncertainty with a pledge to proceed beyond proof of concept to large scale implementation. The rationale for the latter is based on the principle in Young’s double slit experiment conducted by Akira Tonomura [30] in HCRL, Kokubunji [31]. There must be a consensus to move mountains and remain cognizant of the fact that there are *mountains beyond mountains* [32]. The action plan may commence by acknowledging **convergence** is as important as **connectivity** between digital threads.

How to connect the entities to drive the “outcome” is a key question. This is a convergence issue which manifests as systems integration, has many moveable parts which may rapidly change. Components may become relics within the time span of implementation due to short half-lives. Functions often may not scale and non-linearity is the norm. Response or lag time in proof of concept (PoC) may not extrapolate in large scale implementations due to non-deterministic real-world variabilities which one may not capture in deterministic models used for PoC. These known unknowns behaves poorly at the systems level (Figure 3). Early attempts to create systems to generate tangible outcomes [33] resulted in the “Store of the Future” in 2002 [34]. The PoC may be best described as a successful failure.

The complexity of the components, which are systems within systems, and integration with data and analytics, remains challenging. It may have inspired Amazon GO, the no-checkout convenience store of 2017. GO is wobbly, incomplete and still a PoC, on steroids. But, Amazon’s “Store of the Future” is still not yet good to go [35].

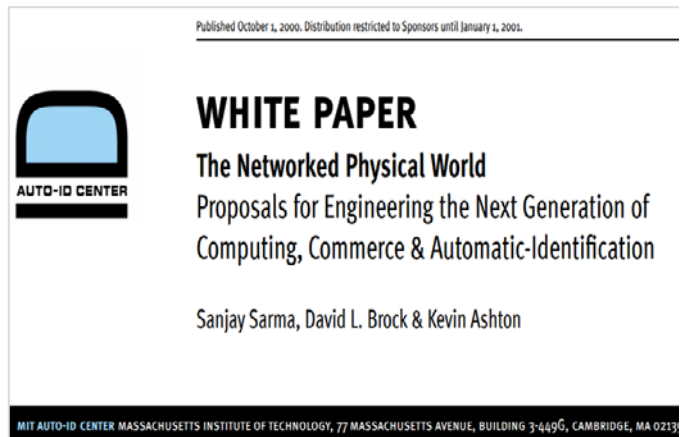
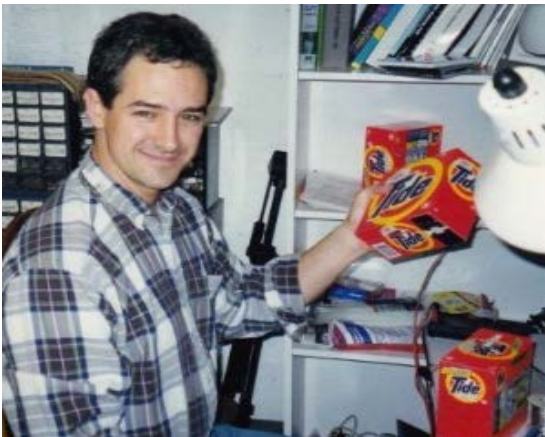


Fig 3: Dr David Brock attaches RFID tags to objects (1999), at the MIT Auto ID Center, which created part of the vision (*The Networked Physical World*) and further catalyzed digital transformation and DEX [36].

WHICH STRUCTURAL ELEMENTS AND COMPONENTS ARE CRUCIAL FOR CONNECTIVITY ?

Over the past half century we have made progress in connecting various software modules with a host of different interfaces. In a simplistic form, we would like to connect processes and data in a manner that it can use the outcome (decisions) to inform and improve the process (classic feedback loop). Process and data must stay decoupled but encapsulating process and data in software “wrappers” may generate myriad of different forms. Perhaps the most useful are functional modular representations or “lego” blocks, which can be used for complex combinatorial creations, to develop layers of successively higher order functions, subject to rapid assembly, dis-assembly and dynamic re-assembly, if necessary.

The Agent Network Architecture proposed by Patti Maes [37] was based on a 1989 proposal [38]. Some of the ideas [39] are still germinating at the hands of Google, Apple, Microsoft and others [40]. The potential revolution cryptic within the vision of Agent Network Architecture (ANA) was recognized by experts [41] and gained academic momentum [42]. However, its use in industry [43] may be still sluggish [44], at best.

Agents based architecture provides the tools critical for interface components. These tools are key to facilitate connectivity and interoperability between the blocks or modules or units of Agents. Thirty years later, Agents are still struggling to cross the bridge to the business world. There weren’t any “low hanging fruits” then and there may not be any “low hanging fruits” now. The myopia prevalent in the business world leads to the stampede for “low hanging fruits” but without the understanding that “low hanging fruits” require low level skills. The rational Agent based approach is the underpinning of AI.

Development, deployment and diffusion of ANA and other Agent architectures are pregnant with solutions [45]. Skills necessary to design, evaluate and implement these architectures are neither trivial nor automated. The “winter” of AI [46], the resurgence of AI hype [47] and the lack of CS graduates [48] are hampering the arduous tasks which must be undertaken if the so-called fourth industrial revolution, characterized by ubiquitous connectivity, is expected to yield actual profit. It appears that these discussions are increasingly part of corporate marketing budgets rather than R&D or education investments. All things digital, IoT and AI, in particular, is prime tabloid fodder and electrifies cocktail banter at the gatherings of glitterati in a highly secure winter chalet, feeding the frenzy of paparazzi [49]. AI is rather useful if we may think less of human level intelligence and more of higher order reasoning.

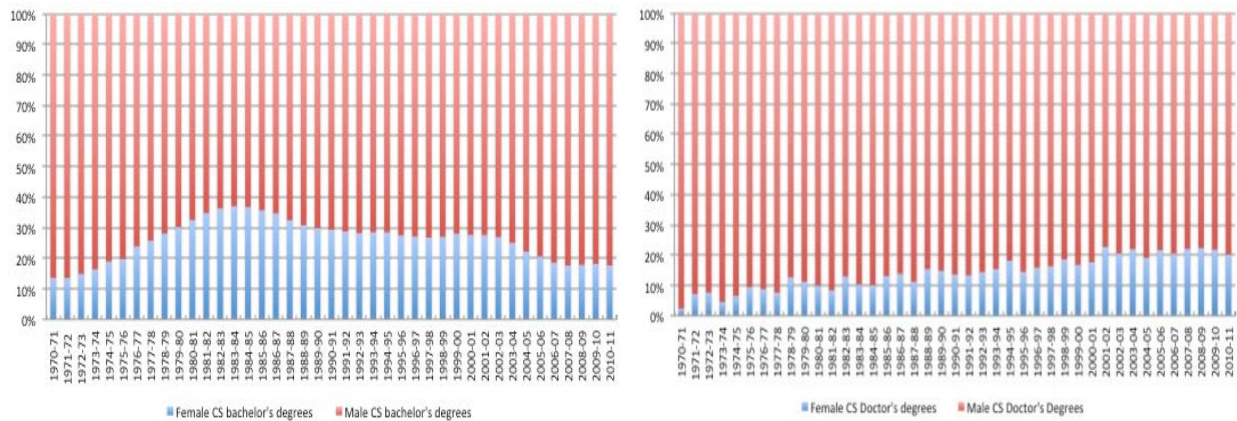


Fig 4: BS (L) & PhD (R) degrees in CS (computer science) from US universities [50]. Too few in numbers to supply the workforce necessary to catalyze convergence (IoT, AI, ML, Agents, Robotics, Data, AR, VR).

Connectivity by powerpoint (Fig 5, left) is witnessing exponential growth [51]. But dissecting these “boxes” and reducing each to its basal functional granularity may reveal multiple layers in each “box” and each with its own multi-dimensional matrix (but not always) representing complex interactions, dependencies and potential for interactions between building blocks and function modules (Fig 5, right).

In Agent based architecture, each function is encapsulated as an Agent with interfaces which can connect to other Agents encapsulating other functions (process, decision, location, data feed, sensors, analytical engine, edge parameter, cloud store). Each unit or block or box may comprise of multiple Agents in accordance with the “layers” of functions that each represents. Each Agent or a collection of Agents (referred to as an *Agency*) within a “box” may serve as a module capable of executing one function. It can be used independently (1 Agent) or as a collection of function-specific Agents (Agency).

Thus, Agents and Agencies (representing these “boxes” at the level of desired granularity) can be mixed and matched without the need to re-tool or re-structure or re-program the entire function or operation. In equation based models (EBM), the interrelationships and dependencies are refractory to dynamic adaptability because they are hard-coded. Hence, addition or deletion of functions (boxes) alters the equation and renders it useless or incompatible unless re-programmed or re-structured or re-designed.

In contrast, in Agent based models (ABM), dynamic composability is normal since each Agent or Agency can interact with any other Agent or Agency as long as the Agent interface enables the communication. The Agent interface can control the connectivity, because it can be configured by design to regulate the nature of data sharing process, by differentiating between sharing data vs information. The Agent acts as a “wrapper” within which the decoupled modules of process definition (feature) and data co-exists in separate sub-modules. They can function as 1 entity for data/information sharing or differentially parsed based on business or security logic. If a bot pings your location, your PSA (personal security agent) may trigger *selective permeability* (Figure 8). The Agent shares information “not in the office” but protects your actual GPS location data because of your *selective* privacy settings in the Agent interface layer [52].

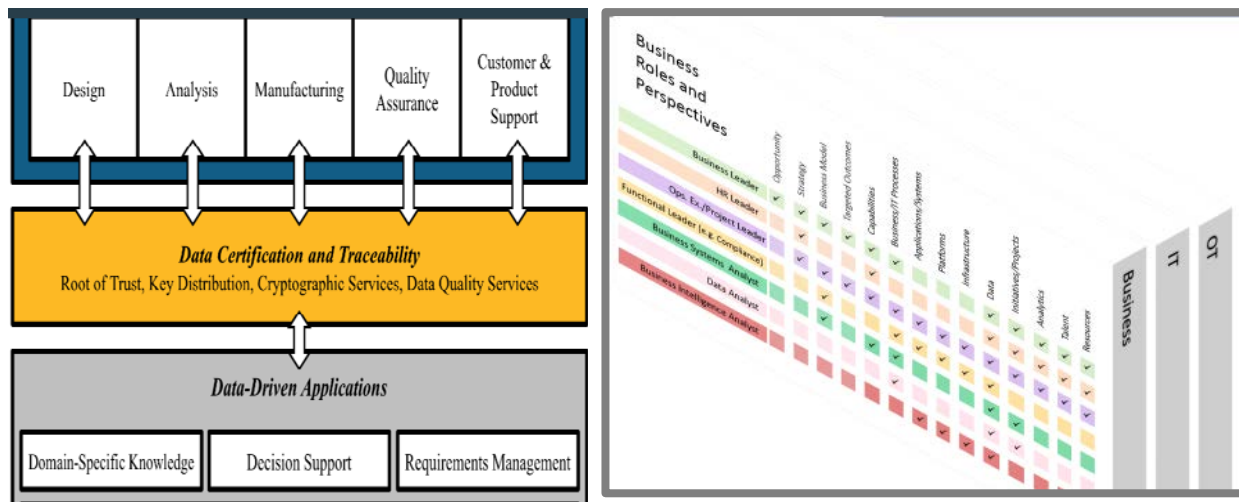


Fig 5: Connectivity by design require architectural modularity and interoperability between the modules. Elements are available from object-oriented analysis and design principles [53] and related advances [54]

Is this *modus operandi* applicable to all enterprise architectures in order to align businesses with DEX? Unlikely. As previously stated, digital transformation must be a value-driven process guided by metrics including transaction cost analysis. But, most businesses lack granular transaction cost information. The economy, as a whole, still considers Agent based models [55] as an academic [56] storm in a tea cup [57].

In preparing to augment connectivity, businesses must undertake an analysis of the structural elements in their existing software architecture, especially the interfaces (API), which influences system behavior and collaboration between elements (within the existing architecture framework).

Enterprise architecture [58] was not created for digital transformation or DEX. It is critical to understand which structural elements can be or should be changed to Agent based architecture (ABM) to augment connectivity between elements. Which elements are likely to provide the alignment necessary to adapt between static, dynamic and real-time events in the age of 5G, GIS, AI, ML, M2M, IoT and industrial IoT?

This is a powerful analysis and should be documented as a template for business process engineering or re-design (BPR). The template may be a key learning and form a part of the service provided through the new line of DEX business, as a part of the business solutions arm of the corporation (how GE created the new business of GE Digital as a part of the GE conglomerate). DEX will offer new services to move the rest of the business world (SME) on the road to digital transformation through DEX implementations.

Interfaces to and from data sources and sinks, as well as analytics at the core and the edge, are increasingly commonplace in domains as diverse as finance and fashion. Interoperability between elements and interfaces (both internal and external) shall determine system behavior and interaction between ecosystems or platforms. Assigning a priority and value to interfaces, with respect to stability and security, may reduce or balance the risk of innovation. Risk is implicit and may be omnipresent in transformation from a product-based ERP state of mind to a service driven economy, which is “always-on” and mobile, digital and connected, fragmented yet linked to a plethora of partners, regulators, influencers, customers and constantly bombarded by digital environments and ecosystems (Figure 6).

	Google	amazon	f	Apple
IT & Infrastructure	Google fiber	amazon web services fulfillment amazon	Aquila	Apple SIM
Artificial Intelligence	Google Assistant	amazon alexa	Jarvis	Siri
Hardware Devices	Pixel Chromecast Home nest	amazon fireTV amazon kindle amazon echo	oculus	iPhone iPad WATCH etc.
Communication & Messaging	Google+ Allo		Whatsapp facebook Messenger workplace	Message
Digital Media & Entertainment	Google Play YouTube	amazon Prime music video	facebook.com/gaming	iTunes Apple TV MUSIC
Connected Car & e-Mobility	android auto	amazon alexa Alexa integration	-Integration (Transportation)	CarPlay
E-Commerce & Retail	Google Shopping 'Purchase on Google'	amazon.com etc. amazon Prime	Facebook 'Buy-Button'	iBeacon store
FinTech & Payment	Google Wallet pay	amazon payments	-Integration (Friend-to-Friend Payment)	Apple Pay
Navigation & Location services	Google Maps	Amazon Maps API, MAPS.ME integration		Apple Maps
Advertising	Google AdWords AdSense doubleclick AdExchange	amazon associates amazon advertising	Facebook Business, Instagram Business	Apple Search Ads

Fig 6: The global digital environment is faced with and reacts to these captivating influencers. Can B2B and B2C interactions adapt to and adopt the *de facto* standards of communication and connectivity?

Preparing to transform the architecture to enable DEX is just one part of progress. It may be useful to use a “bill of materials” (BOM) approach in evaluating key expected outcomes relevant to the operation (for example, manufacturing, water purification, retail, commodities) or business services (logistics, supply chain, finance, business solutions). What do you wish to change or improve or make more efficient or reduce waste or increase productivity? Which nodes, if improved, may lead to decreased uncertainty, better margins, less waste, higher quality of service and will aid greater brand recognition?

Once these targets are identified, that is, each outcome you expect to influence profitability, the task begins to create process maps of dependencies and network of layers which may have an impact on the outcome. For each dependency and/or sub-layer and/or sub-node, it is vital to map its data/analytics flows/engines and the metrics associated with the input/output of data/decisions to measure and determine the performance of that dependency/sub-layer/sub-node with respect to a part or the entire operation, that is, the network of layers/dependencies/nodes, each in its appropriate semantic context.

This approach may benefit from principles of business dynamics using structured analysis in terms of systems engineering thinking and convergence with system dynamics [59]. Software tools (SyntheSim, iThink, Powersim) may help in creating models [60] and may make the tasks less onerous. Classical SD (system dynamics) may still be relevant in the age of DEX. But, the practitioner must be creative and innovative in applying SD to model development for DEX purposes. Blind use of SD as a recipe may be incongruous in view of the EBM infrastructure of classical SD versus the need to move to a digital by design strategy. The latter is volatile by nature and data drivers are often subject to network effects.

In addition, models must be able to simulate adaptability to dynamic situations which oscillate between closed-loop/open-loop with variable feedback control loops, if any, and may be subjected to networks of inter-dependent/inter-related, asynchronous, non-linear and decentralized dynamics. Perhaps we need to determine [1] which nodes, sub-nodes, instances, can perform as modular structural elements in Agents based models (ABM), [2] the interface with legacy systems and [3] dynamic co-existence between ERP/EBM systems versus ABM.

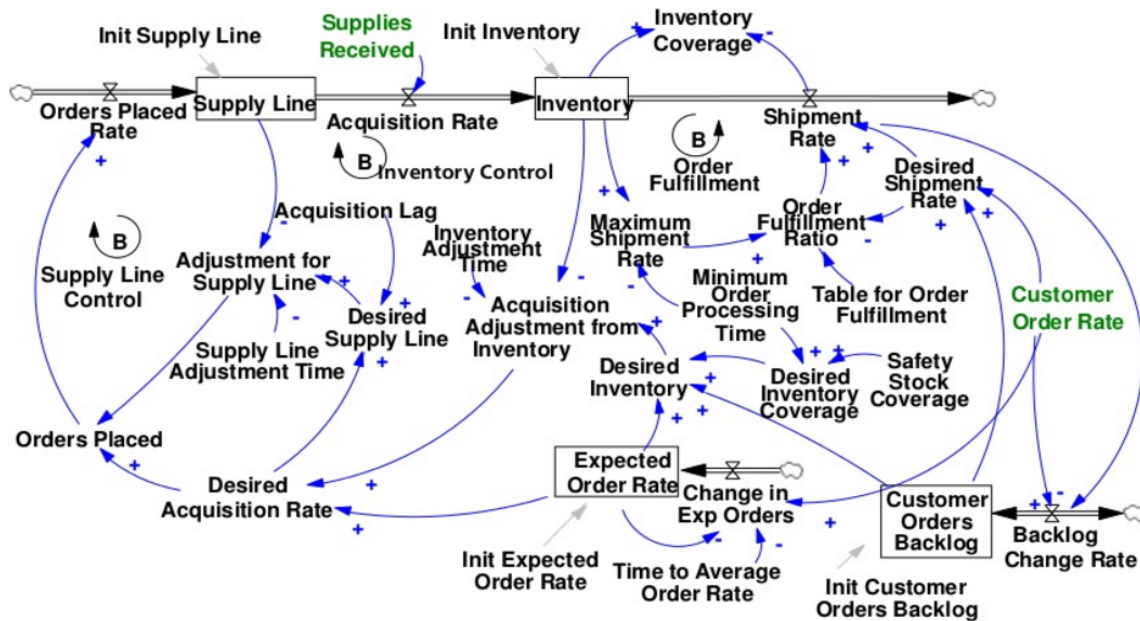


Fig 7: Use of SD (system dynamics) modeling [58] to understand dependencies and networks which may influence outcomes. SD is in need of creativity to adapt to DEX, the digital enterprise, by including, for example, data flow, information streams, analytical engines, dynamic composition, risk and security.

Connectivity between structural elements in the architecture of business solutions will continue to pose challenges due to multiplicity of legacy systems built on different principles. Continuation of mainframe servers may serve as an example and reminder of the dead weight of old technology that still co-exists. How has the processing of payroll changed due to the digital onslaught? Externally, the change is the medium of delivery - paper checks vs electronic transfers. The processes for payroll including payment cycles and deductions may not have changed significantly since the first GE data processor in 1959 [61].

Connectivity between structural elements, old and new, must be able to respond to and interface with the network. Connectivity between layers, domains and external systems becomes more crucial in the age of DEX. The drum roll about connectivity has reached a fever pitch in the context of IoT and IIoT. The tools and connectivity between tools and interfaces between software and hardware must continue to evolve and are subjected to rapid replacement/substitution/upgrade based on customer demand. If the customer wants to know the price of gasoline in 3 different zip codes, the app or service provider must connect the data streams, design the visualization appropriately and work within the telecom standards, protocols and latency boundaries to deliver the user experience capable of capturing a critical mass of repeat customers. The important principle here is interoperability between systems.

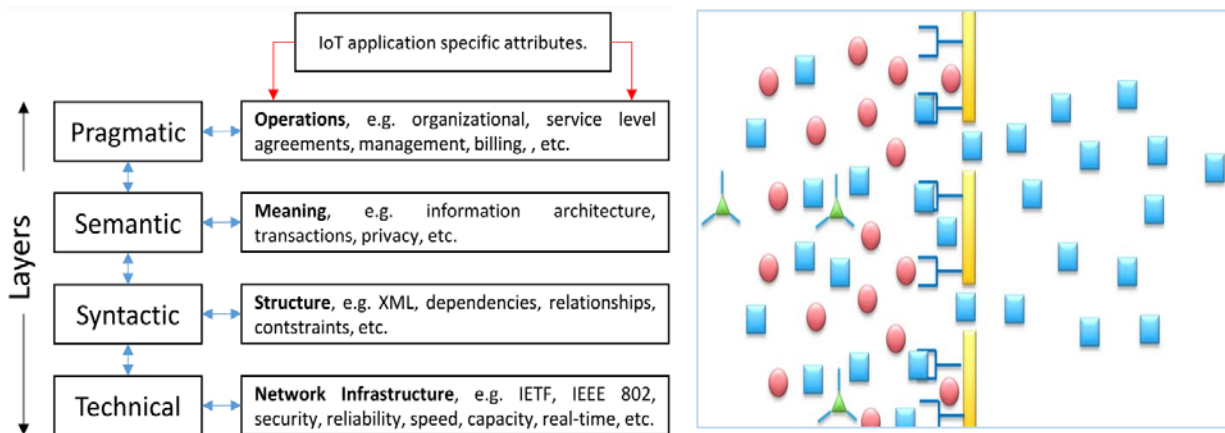


Fig 8: Architectural components must evolve and serve syntactic, semantic and pragmatic demands [62]. Selective permeability (cartoon, right) may be necessary for data security and privacy between layers.

The nature and reach of connectivity, and its interactions with the ecosystem, is so crucial for the final customer-facing outcome that the new line of business solutions and DEX leaders cannot be constrained by lack of interoperability, between domains, including third party API and systems on-demand. Evolving open platforms or platforms that are partially open (for example, GE's Predix) are indicative of a future trend. Interoperability between platforms and systems are driven by interfaces (API). Agent based interfaces are interoperable by design and may be selectively permeable for security. EBM products using specific software languages or closed data dictionaries or specifically designed to restrict semantic interoperability (for example, Epic electronic health record systems) are road blocks on the path to global DEX. The digital tsunami may annihilate closed approaches, especially in the emerging markets.

Connectivity between the (hardware) physical machine in aisle 8A (Figure 1) and its digital (software) representation is a part of the “liquid” interface of DEX as outlined in “expected outcome” segment of this article. If every piece of hardware - that is, every machine manufactured by a different equipment factory - were to use proprietary interfaces for its data port (for example, data from sensors) then interfaces for data analysis may be incompatible. Software and hardware are likely to be poles apart in aligning their product interfaces for data communications unless they belong to the same club [63].

An Agent model of the machine (hardware) may be interoperable with a number of Agent-based software data and analysis tools. The Agent model of the machine is not one Agent but an Agency made up of many Agents representing each discrete component in the machine (parts, sensors, belts, ball bearings, gears). The software representation (this Agent model) of the hardware is the Digital Twin concept [13]. Digital Twins are not restricted to machines but can represent humans. For example, a human may be uniquely identified on the smartphone screen, of a RN or MD in a hospital who can view and monitor real time data about the patient’s heart rate, oxygen saturation, end tidal carbon dioxide and blood glucose level from sensor data or diagnostic devices [64].

Without the type of connectivity and interoperability described above, the “expected outcome” with reference to Figure 1 may be difficult to achieve. The modularity of the Agent infrastructure - bricks and blocks - can be combined to create components in manufacturing plants, bridges, turbines, airplanes, automobiles, EKG machines, pulse oximeters, mammography, sensors, oil pipelines, water pumps, satellites, violins and agricultural machinery. Access to digital object repositories [65] may enable a “drag and drop” tool to create any machine or object or tool as a duplicate or Digital Twin [13]. Activating the software to connect the data from the object or machine with the Digital Twin or avatar calls for a plethora of other interfaces and telco components which must “discover” [66] the hardware (machine), “discover” the sensor data stream from that specific machine (in a shop floor of thousands of machines) and connect it to the specific software model on the smartphone or tablet of the user. The pivotal role of “discovery” and the tools for automatic identification and secure communication of data must converge to fuel the digital convergence, in order to accomplish the “expected outcome” for DEX.

The hype about trillions of objects connected to the internet (in IoT and industrial IoT) is oblivious of the fundamentals [1] that a connection to the internet is not equivalent to a function and [2] that IoT is not a solution or a tool or technology but rather a design metaphor. Functional value of connected objects depends on **discovery** [67] of the appropriate objects in context of the operation and relation to the data streams. Taken together, it may create an *ad hoc* dynamic composition of objects which offer value when constituted as a function and the ensuing network of things [68] provides an outcome. An analogy is the *ad hoc* creation of a mesh network [69] which also highlights the role of standards and interfaces. Connectivity of objects offers limited value unless the connectivity is in the context of an operation. For example, the efficiency of pumps is important to the manufacturer but the customer who buys the pump to execute an operation prefers information on the whole operation in terms of all the key performance indicators, not just the motors or the pumps [70]. The outcome economy is less interested in tools and more interested in the final outcome. DEX is also interested in performance and outcome.

Components of connectivity have been discussed *ad nauseam* in millions of technical and business publications but a few other issues deserves to be mentioned.

Telecommunication standards are immensely critical in bridging domains. It must be flexible to switch between protocols as IP applications (software) move from closed to open to hostile environments (PLC in boiler room of a plant) and interacts with multitude of objects, data and processes using diverse modes of communication. It is the central theme of application dependent networks which posits that applications will trigger how the network will respond because the application is the focus or the master (it is the monetization node) while the telecom network is a medium (slave) for delivery. The network must respond to the needs of the application, by switching to appropriate fixed or wireless or hybrid technologies, for example, multi-protocol label switching (MPLS) network.

It may be obvious that the application running on the Digital Twin of the machine in aisle 8A (Figure 1) will be deemed inefficient if the sensor data from the machine failed to populate the Digital Twin sensor database with the pressure or temperature data. One reason for such inefficiency may be the nature of the telecommunication signal on a shop floor densely packed with machines spewing exabytes of data. If the communication link suffers from interference (WiFi or Bluetooth or VPN or controller area network, LPWA) or transmits null data signals (occurs with RF data in a dense data environment or if reflected by metal in the infrastructure) then the Digital Twin application fails to provide the desired outcome.

Connectivity in the age of DEX, therefore, requires new thinking in design, construction and utilization of telecommunications networks to prioritize network applications and service demands. DEX expects significant application-efficiency gains for networks to ensure robust connectivity adhering to the QoS with respect to latency, bandwidth and data rates.

To respond to these targets, over the past few years application triggered systems (for example, ACI from Cisco, ADN from Huawei) are trying to meet future application demands, especially for 5G, for example, by decoupling the services plane. Applications do not need to know the underlying network complexity, which must be navigated, in order to deliver the service – the application.

Not everything is about high data volume, broadband and zero latency. There are a growing group of functions in the IoT/IIoT domain where proprietary low-power wide-area (LPWA) networks are providing services for very low bandwidth, very low data, very low power and very low cost devices.

In preparing for the digital transformation tsunami, it goes without saying that reliability of connectivity will be paramount in a DEX environment because we are increasingly reliant on data driven decision support systems. The medium of telecommunications is the principal conduit for acquisition of data. If this medium shows “cracks” and the data falls through these “cracks” then the analytical engines will view data streams or data flows with missing data sets. The analysis by the analytical engines will be based on data presented to the algorithms. The outcome or prediction will be flawed to the extent of the significance and context of the missing data (machine shop vs pediatric cardiology ICU in a hospital).

If the flawed data is for a MTBF (mean time between failures) value then the outcome may be an unanticipated machine downtime due to fractured blade or rotor or spindle. The flaw in data acquisition may be due to network traffic congestion, inconsistencies or interference from other signals or time [71] spoofing (systems security breach). If the missing data pockets were for heart rate from a pediatric patient in the ICU, with cardiac arrhythmia, then the outcome may be fatal and a funeral, bit too soon.

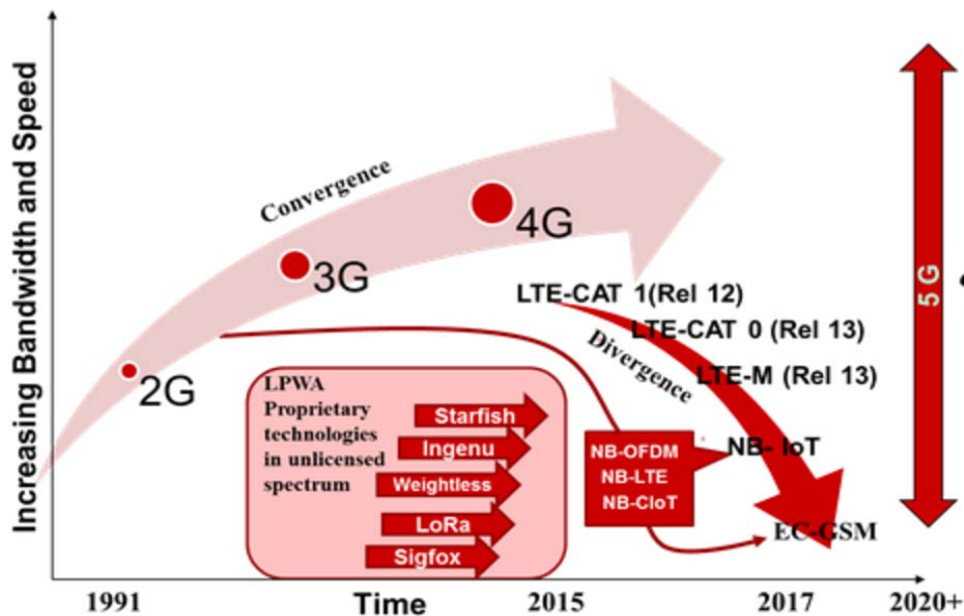


Fig 9: Niche IoT applications use low-power wide-area (LPWA) networks using proprietary products [72]

The complexity and variety of network evolution follows the new uses of networks for different types of applications which may be created in remote corners of the world and/or crowd sourced. Traditional voice communication relied on hierarchical network architecture and follows a Poisson distribution model because phone calls are likely to remain at a constant frequency and duration, over time. But internet (IP) communications follow power-law distribution model [73] where most users connect via central nodes. Machine-to-machine (M2M) communication, which may be in progress in the scenario depicted in Figure 1, may be comprised of many different cases, each with a different need.

For example, autonomous vehicles and robotic surgery both demand near-zero latency, extreme bandwidth and ultra-high reliability. The environment for a vehicle rapidly changes as it moves on a crowded street lined with tall buildings or inside a tunnel or a bridge or climbs the Twin Peaks. The environment for robotic surgery may be an urban hospital from where the surgeon is “performing” a laparoscopic cholecystectomy (gall bladder surgery) on a patient in Petit Bois Island, Mississippi.

These scenarios emphasize that connectivity demands are very diverse. To meet these demands we must be able to slice, dice and splice dynamic programmable network-agnostic networks on top of fiber, copper, wireless, LTE and future 5G, using open source platforms and protocols, for example, software defined networking (SDN) and network function virtualization (NFV). Network flexibility is vital. It is enhanced by dividing the network and using open source software, as far as appropriate, to manage the decoupled data plane (traffic forwarding), control plane (devices) and services plane (applications). If a connected vehicle needs software download or must upload sensor data, the customer expects the outcome to be download/upload. In the outcome economy, the customer will not care if it is a wired or wireless connection, SDN or NFV. Implementation must offer complete connectivity for the customer.

For the telecommunication industry the concept of monetizing the “pipe” is increasingly irrelevant because the revenue is realized only when billions of end customers access or use the services. It is hard to differentiate “pipes” which must adhere to standards and protocols that are globally accepted. The value-added portfolio for telco may be in real-time data analytics, which is not their core competency. Hence, it is important for progressive telecoms and OEMs [74] to create partnerships across a diverse cross-section [75] of other component providers [76] in order to multiply their sources of partial revenue (micro-payment, nano pay-per-use). The service will only earn revenue when delivered to the end user.

Sharing fractional micro-payments may require new tools for micro-event billing segmented by micro-sequences which may include micro-services [77] and require seamless convergence to deliver the end service (outcome). The modularity of micro-services and use of software-oriented architecture [78] may be better suited to Agent based architectures. SOA may enable harmonious co-existence of Agent-based models (ABM) and equation-based models (EBM) to optimize dynamic composition when serving the on-demand service request (application triggered). Services in each layer may have a different provider. Each provider in the ecosystem will claim a fraction of the end-revenue which is earned only when the service is delivered at a satisfactory quality of service level. A potential scheme for this approach was suggested [79] and if analyzed, it resembles, at least, in principle, a digital ledger or blockchain [80].



Fig 10: Who will build the blocks? New lines of businesses may emerge in the domain of DEX blocks which are not limited to enterprise architecture could include cybersecurity [81] and Digital Twins [13]. Both instances are influenced by AI and the rational Agent approach may be the common building block.

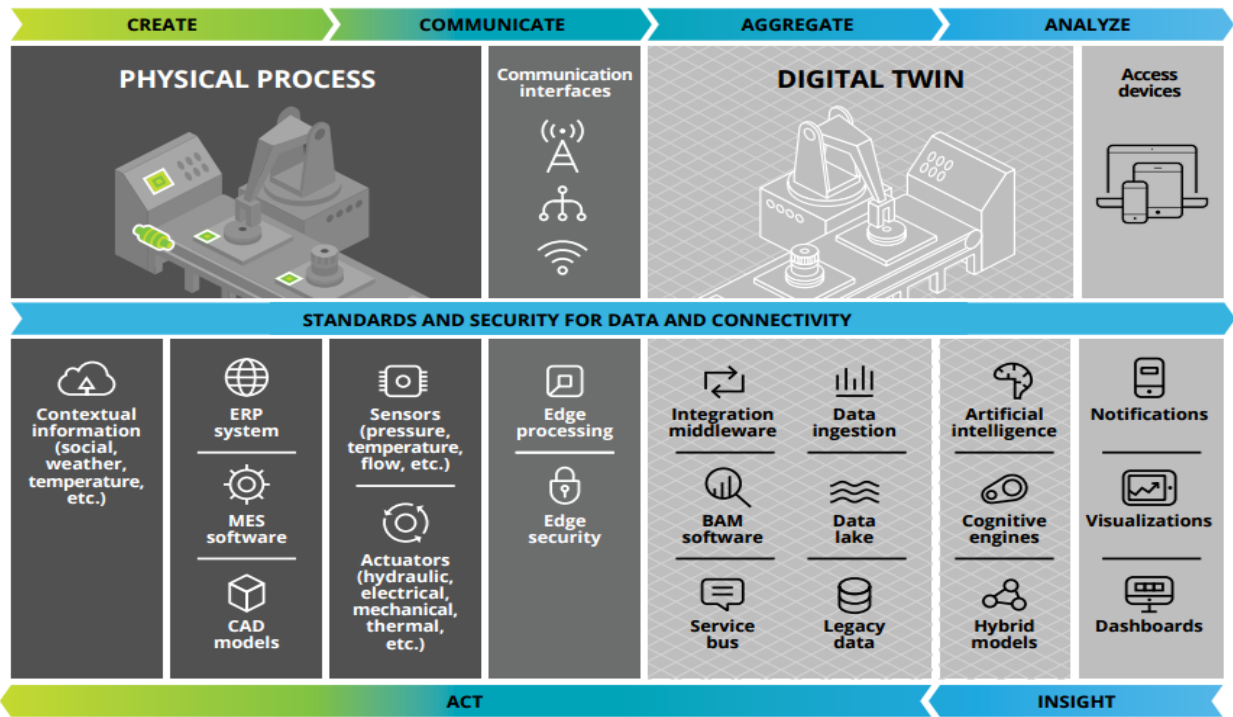
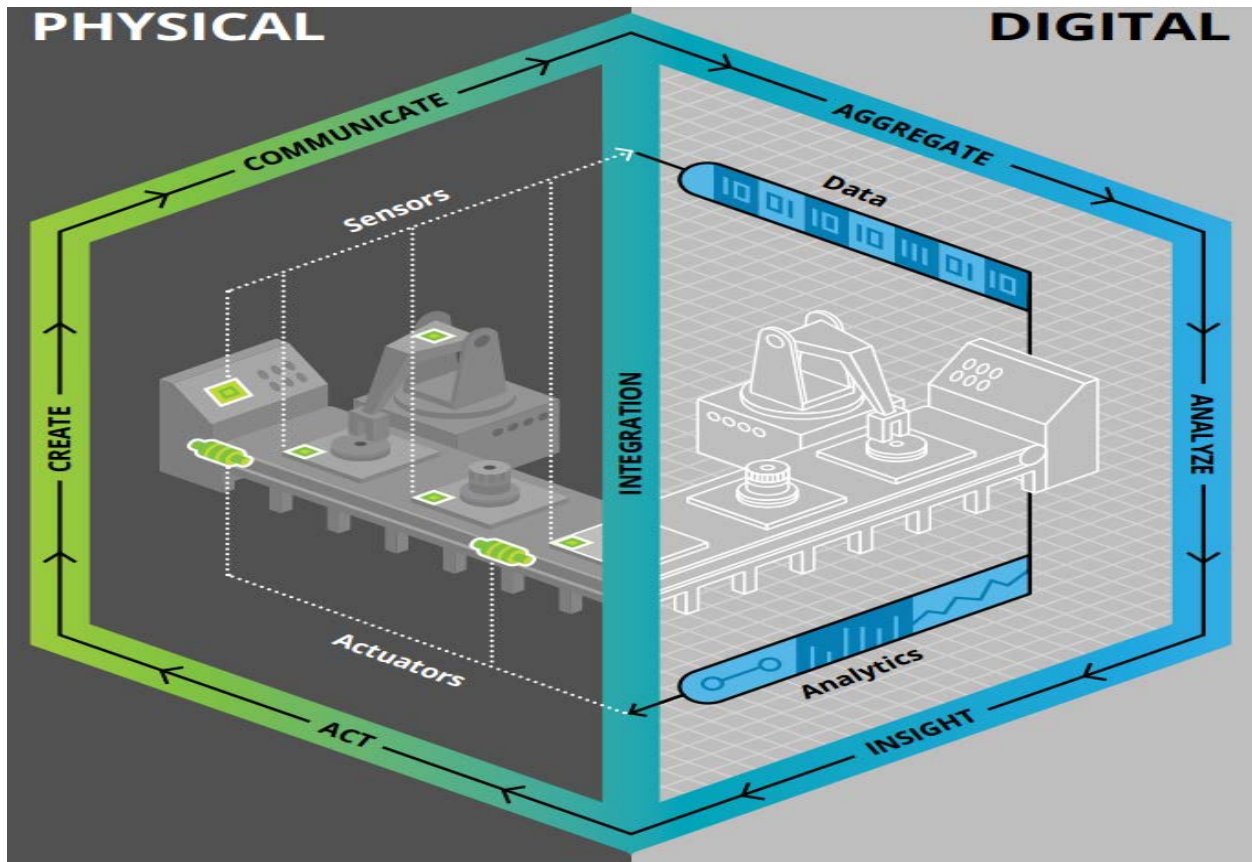


Fig 11: Digital Twins are within our reach? Cartoon from article by Aaron Parrott and Lane Warshaw, Deloitte [82]

WHY INTEROPERABILITY BETWEEN PLATFORMS IS SYNONYMOUS WITH PERFORMANCE AND PROFIT ?

A challenge for open platforms providers is that open is synonymous with free in the digital economy. A quandary for open platform providers is the lack of monetization systems integration, that is, seamless convergence between micro-billing tools, digital ledger of micro-service delivery confirmation and time guarantees for time sensitive networks or real-time events. The ecosystem is strained when seamless functionality is compromised due to lack of interoperability between services or platform (assuming that connectivity is not punctured and the data flow is agnostic of the protocols and the telecom networks).

The sketch (Figure 12) outlines the diverse domains that must interact through the mobile platform to provide the service you demand (the expected outcome). The plethora of service providers include hardware and software vendors, telecom, security systems, asset owners (airline, car, garage, hotel, restaurant, wearables) and other public/private agencies (map, traffic, news, weather). Each provider wants a share of the revenue. The customer only pays when the end-to-end connectivity offers value.

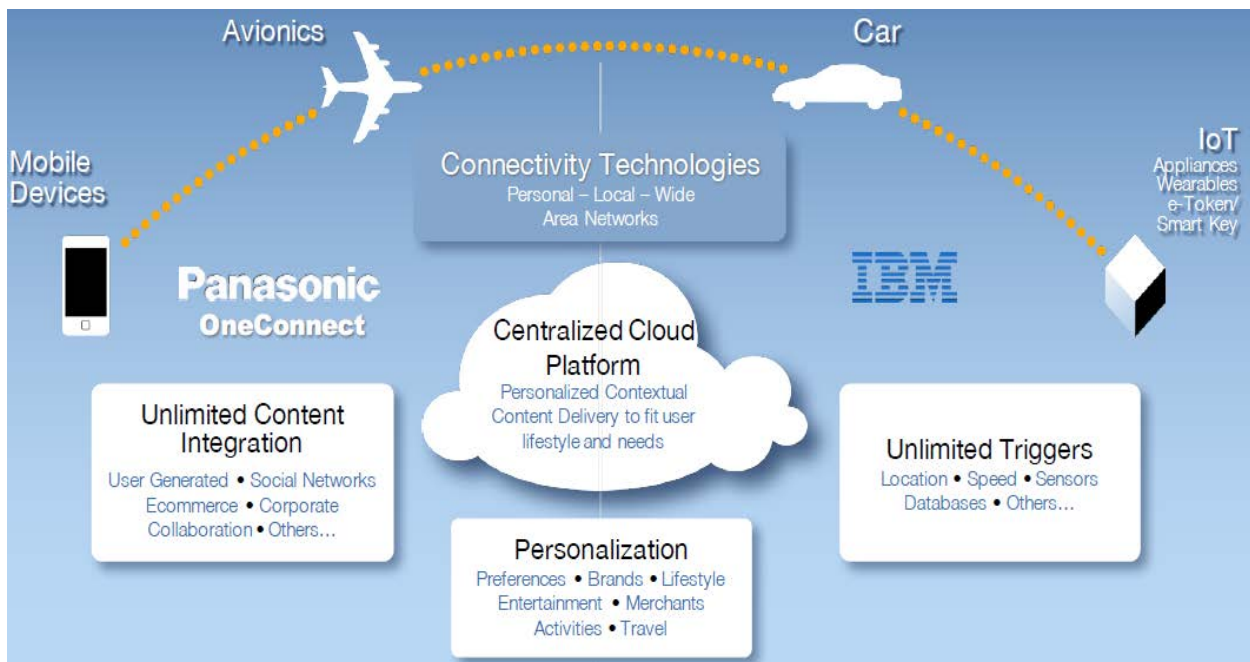


Fig 12: Your mobile device [1] receives update from your calendar [2] flight/terminal arrival/departure data from the airlines [3] informs your car rental agency that your flight is delayed [4] confirms that your checked-in bag is arriving soon on the conveyor belt [5] unlocks the car door [6] displays the map to the destination [7] cautions about excess traffic on Memorial Drive [8] informs the mobile device of the person you are meeting about your estimated time of arrival [9] guides you to the parking garage space [10] offers you choices for dinner reservations [11] confirms the dinner reservation [12] checks you in at the Le Meridien at Cambridge [13] unlocks your hotel room door [14] calls your lovely wife at 9pm EDT [15] merges your OneNote [16] syncs the FitBit [17] sets the wake-up call [18] checks the weather.

The consumer centric IoT-esque illustration in Figure 12 contains the essential structural elements also common in B2B or intra-enterprise scenarios. Convergence of Agents-based micro-services, ABM, EBM, data, connectivity, analytical engines and decision support “sense & response” systems augmented with security and higher order reasoning tools (ML, DL, AI) are at the core of Digital Enterprise X.0 [83].

Modular units encapsulating core functions, processes or data holders, which can be sourced from a common services (SaaS) repository (across multiple verticals or business units) may offer benefits in terms of risk pooling, reducing waste and re-use or recycling of software components. Once identified, the units may be connected through interoperable, configurable and adaptable interfaces. The resultant architecture can be recombined with other units to increase the combinatorial potential which may be essential to capture and map the process cascade, in terms of functional outcome. These units must be capable of “discovery” and amenable to be “discovered” when interacting with and between platforms.

How the modular units/blocks will be combined, to create the higher order structures, which maps to the process or the platform, is a rate limiting factor. The compilation (drag and drop) may be slow if humans are necessary to create these units per process maps or events/data flow. Automating this process and creating a “supervisory” Agent to guide the process, when triggered, is an option. The ability to use natural language descriptions as a trigger will facilitate the process and empower non-technical users to create appropriate outcomes (Figure 13) by selecting and stitching the components using verbal commands and logic operators (using set operators to specify epistemic constraints).

For example, a non-technical TSA employee encounters an individual and wants to know if that person was in pre-recorded photo bank. To set up the search parameters, the program requires defining what algorithm based facial recognition application may be used. To select the algorithm based app, one must understand the parameters that makes the algorithm useful. The TSA employee is unable to perform this task and sends the request to the technical desk to search for a match with the person the TSA employee encountered. The delay in arriving at the outcome was sufficiently long. In the interim, the person of interest had ample time to board the aircraft and depart.

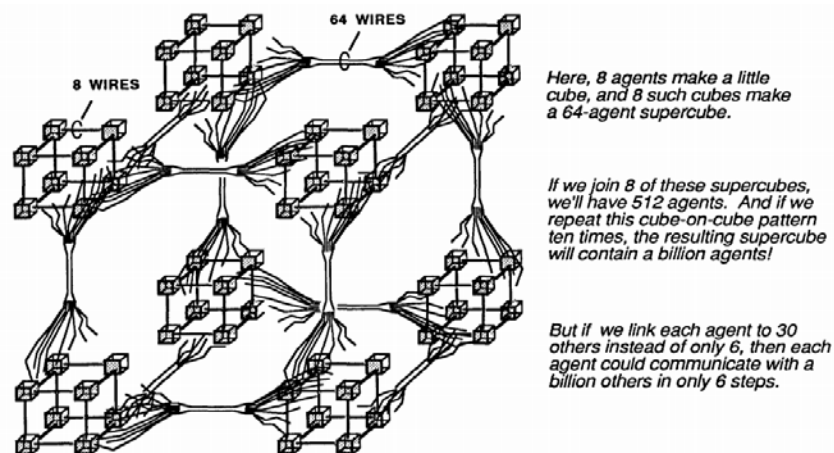


Fig 13: Connectivity between cubes [82] or modular units (blocks, bricks, Agents) can contain functions with multiple variables and create higher order Multi-Agent networks which can converge on platforms.

One solution is programming abstraction [84]. If the program understands (semantics) natural language descriptions, then, it concludes from the natural language query that the TSA agent wants to find a match of the person within the pre-recorded material. The program solves for the required algorithm parameters, processes the request and provides an output, which may be instrumental for airport security. Software automation by implementing programming abstractions may be useful to configure dynamic architectures on demand. Interoperability between programming interfaces will catalyze seamless connectivity between cubes [85]. The hype about AI bots in automation [86] is just that - hype. Programming abstraction is a tool defined by the rigors of computer science and software engineering.

Platforms may be viewed as higher level structures to aggregate, converge and synthesize digital building blocks. Modular units shuffle and re-shuffle within dynamic transformation processes where decoupling and recoupling may design, re-design and optimize the structural elements that can deliver the expected outcome. This layer is closer to the customer’s expectation of the digital experience at the edge. The interaction at the edge favors, and often demands, pay-per-use models rather than stoic contracts. Connecting to the platform is the bridge the customer chooses. If the customer selects to cross the bridge then the possibility of monetization increases. The transaction cost to access, use and re-visit the platform (if satisfied) will drive and define service diffusion [87], create markets, predict market penetration and may be indicative of the potential for sustainable ethical profitability [88].

Digital transformation is hard at work to convert products to services. For example, Rolls Royce may no longer sell jet engines but “uptime” services which offers engine performance as the outcome [89]. The pay per performance metric eliminates the multi-million dollar price tag for the engines. By lowering the barrier to entry, Rolls Royce engines can serve low cost airlines. Reducing barriers to entry in emerging markets requires different strategic perspectives. US management gurus often insist on chanting the same mantras from an analog world, burdened with the dead weight of old technology, and affordable to less than 10% of the world’s population. Digital tools may help us leapfrog the old world inhibitions.

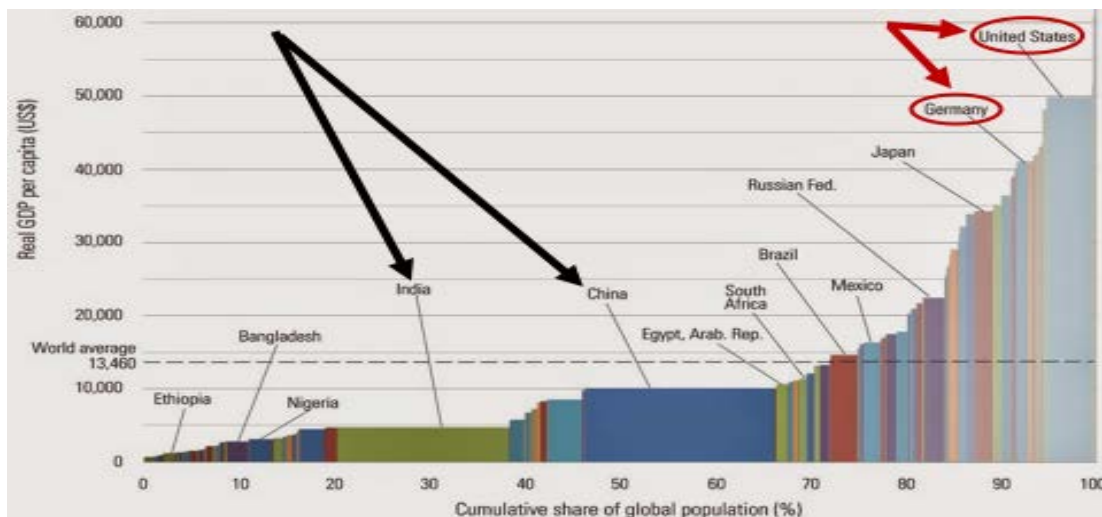


Fig 14: Strategy and management ideas used in US and EU unlikely to help the emerging economies.

The platform principle enables service aggregation from any person or behemoth or small or medium enterprises, if the services and tools are designed to interface with one or more open templates. For example, assume the pump manufacturer Grundfos is still living in an analog world of products but anticipates charting a digital transformation path to embrace DEX. Pumps are one component in a plant where the outcome may be purified drinking water. Creating a digital twin of the plant with its share of pumps and various other equipment is one way to create a new line of business. Analytics may predict which equipment may need service or replacement. Predictive analytics coupled with supply chain improves efficiency and reduces downtime. The outcome is a steady supply of clean drinking water. In the analog model, the pumps and data from pumps may be the sole focus of the pump manufacturer. In the digital paradigm, the contribution of Grundfos to create the digital twin of the plant and monitor its pump for optimum efficiency may lift many boats. It will earn the customer's trust. The customer can rely on "Grundfos Digital" to monitor the entire plant operation using Digital Twins. Isn't that a new source of revenue? Will Grundfos still continue the old world *modus operandi* of charging for pumps and maintenance? Can Grundfos think different and envision the global challenge of the digital tsunami? Can it transform its revenue model to reflect micro-earnings based on service/performance related to the outcome? Why not make the product "free" but charge a penny per gallon of clean water leaving the plant? Is this a new idea? Not at all. Please ask the telecommunications and the telephone industry.

Thinking different is applicable to existing platforms which must change if the platform wishes to serve the masses. Nano-satellites [90] are using different tools and technologies [91] which are clashing with the multi-million dollar satellite industry by lowering unit costs (to thousands of dollars) for satellite service. Innovation in education, using credibility as a platform to build technical services, is the hallmark of edX, developed by MIT [92] and Harvard. Massive open online courses (MOOC) are evolving [93] and often are disastrous [94]. But, it discovers students determined to benefit from available academic wealth [95]. By lowering the barrier to entry, MIT is accelerating the diffusion of excellence, usually at no cost to the student. For example, the microMasters program in Supply Chain Management [96] is free unless you want a credential. It costs \$1,350 for the entire program. Successful candidates who may earn the credential can apply to MIT for a Masters in Engineering (M. Eng) degree in Supply Chain Management (SCM). Credit from the online program makes it possible to complete M. Eng in SCM in one term at MIT at half the cost [97]. The full-time residential program lasts for 10 months or two full terms at MIT.

The edX platform running the MITx microMasters program [98] is capable of harvesting the crème de la crème students who may further bolster the credibility, reputation and prestige of the program and the institution. In the recently completed SCM microMasters, around 200,000 students registered and 2,000 sought a credential (\$2.7 million in tuition fees). In the absence of the SCM online program, the capacity for accepting students into the residential program at MIT is about 40. Student tuition is \$71,000 for the full 10-month residential program (M. Eng in SCM). If 40 paying students attended MIT then they would pay \$2.84 million to MIT. By reducing the barrier to entry from \$71,000 (full time) to \$1,350 (credential), the program earned \$2.7 million. Was it a financial loss? Perhaps. But, the edX microMaster's strategy identified the best of the best brains. Later, during Fall 2017, about 40 students from the 2,000 cohort will join MIT and complete M. Eng in SCM at half the cost of residential tuition (plus living expenses).

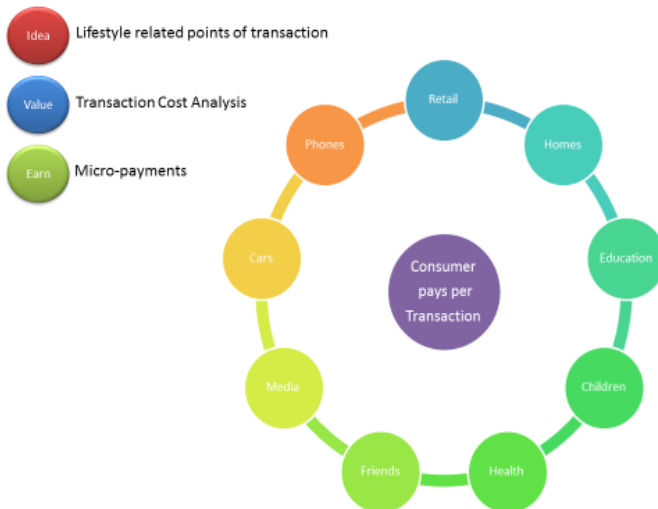


Fig 15: Pay-per-use micro-revenue model is digital by design. It touches every facet of an user everyday in a manner that is distributed over time without making time to access create a barrier to entry. For example, if an educational course is distributed in unit packages and if the charging tool operates are per unit (each unit may be 5 minutes in duration) then even full-time employees can complete a course in many steps by accessing and learning a few units, between breaks or when they have some spare time. Instead of an upfront payment of \$100 for an online course of 1000 units, the user pays \$0.10 per unit. Using a pay-as-you-go self-paced system converts almost all individuals to potential students if they have access to mobile device, telecom infrastructure and an incentive leading to economic growth.

Perhaps counter-intuitive but profitability of platform providers may be directly proportional to the open source strength of the platform. In other words, if platform vendor(s) offer “almost free” access to the platform then the potential for profit increases dramatically and sustained over the long term. The logic behind this apparently illogical statement is firmly rooted in the principle of micro-payments. If tier two and tier three providers can create touch points to the platform without high licensing costs then the ecosystem of function providers and app creators, from all over the world, will exponentially flock to associate with the “channel masters” platform. Consider Amazon’s network of other vendors who use Amazon’s brand to market their products (especially the category of used/new book sellers). The global diffusion of the platform and its connectivity with providers from all around the world also unleashes the creation of new markets all around the world, naturally. The more end users and customers use the services and touch the platform, the greater is the market penetration, hence, more trips to the bank.

If each pay per transaction is affordable and within reach of 80% of the population, both in terms of cost and services they actually need and use, (health, insurance, security, education but not flamboyance, ie, wardrobe matching, luxury cruise, LVMH), then every point of contact is a potential point of sale, hence, a point of revenue, even if it is only a penny per transaction. This is a profitable idea [99]. Micro-earners include PayPal, PayTM, Amazon Pay, Apple Pay, Google Pay, Samsung Pay, Ali Pay, Citi Pay and others. It goes without saying that DEX platforms and access must be essentially global and truly mobile [100].

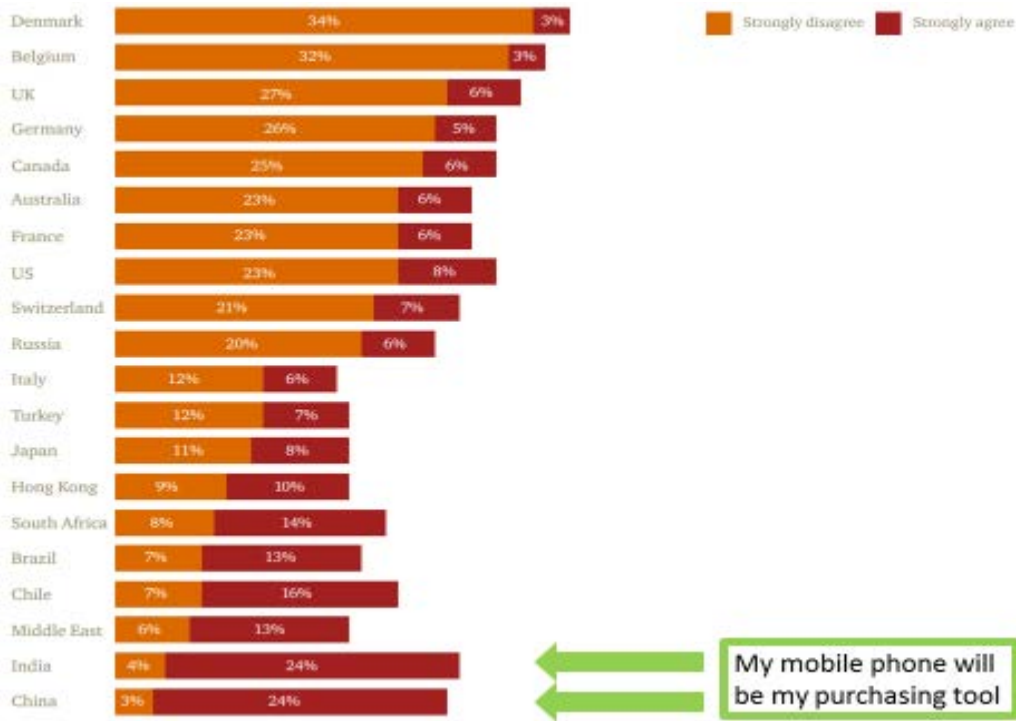


Fig 16: Pay-per-use micro-revenue model is mobile by design. Emerging economies are the markets [97]



Fig 17: Rationale for “Miss Money penny” paradigm: Pay-per-use micro-revenue model at a penny per transaction may be an ethical profitability model. It may work due to volume of transactions [101] which may continue to increase [102] and already proven to be quite lucrative for the financial sector [103].

HEALTHCARE PLATFORMS

The corner of the world referred to as South-east Asia, stretches from Pakistan to Philippines. It is home to about 80% of the world's population and enjoys a certain market envy. It may be the testing ground for the Miss Money penny paradigm (Figure 17). If businesses can use platforms as service delivery tools or engagement points and if pricing per access is limited to one or two pennies per transaction, it is likely to become feasible. The South-east Asian market of 5.5 billion is poor in several pockets and many still earn around \$1.90 per day [104]. Two pennies per day is more than 2% of their daily earnings. This is a context that is front and center of businesses in India, China and Africa. This is why it is necessary to abandon the strategies developed and disseminated in US and EU (Figure 14) as paths to profitability.

Providing health and healthcare access using pay-penny-per-use platforms will test the art of the possible. Healthcare does not discriminate between the wealthy, poor or the impoverished [105]. It is the access to healthcare by the poor and from impoverished nations that is limited. 10 million children die annually due to preventable causes [106] and 3 million neonatal deaths are due to pre-term births [107].

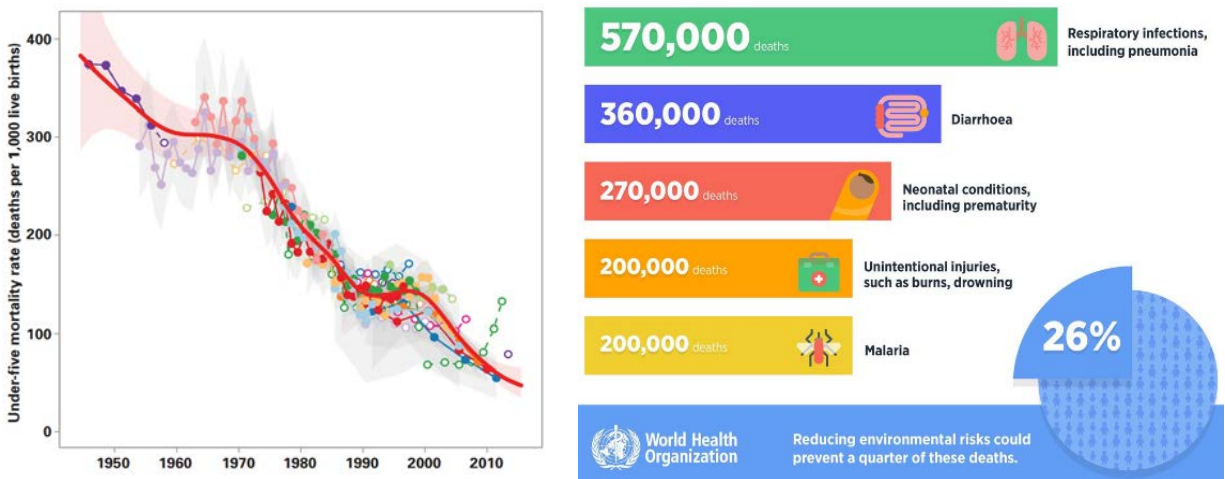


Fig 18: Good downward trend for child mortality [108] but overall access to healthcare is still infinitesimal.

Healthcare is in need of solutions where technology can help to keep platforms open yet find routes to ethical profitability for the vendors via value added services. The deep complexity of security [109] and privacy infrastructure in healthcare creates quagmire. It discourages technology innovators. But, health workers are unlikely to disrupt this impasse. Innovation is expected from the technology leaders, but in convergence with people and processes that must be compliant with the ethics and ethos of healthcare.

Platform as an aggregator is the lowest common denominator in this discussion. The vast landscape of healthcare makes any discussion abysmally incomplete. Preventive medicine may serve as a simplistic use case where low cost sensors or gateways may be used in combination with mass produced low cost non-invasive devices to monitor certain vital signs, *if* they have access to the devices and mobile phones, perhaps with hot swappable bio-nano-sensor arrays on "sticks" connected via micro-USB interfaces [110].

Indicators such as heart rate [111], blood glucose [112], hemoglobin [113] and urine analysis [114] may be useful. Data uploaded to a common platform, when analyzed, may create a molecular metabolomics profile, which may be instrumental in molecular diagnostics, if necessary [115]. Pattern changes in these data sets may be indicative of physiological malfunction. Depending on the sensitivity of the sensor data [116] and analytical precision, early detection, diagnosis and intervention may reduce morbidity and mortality. It may reduce acuity and hence the cost of healthcare from emergencies and hospitalization.

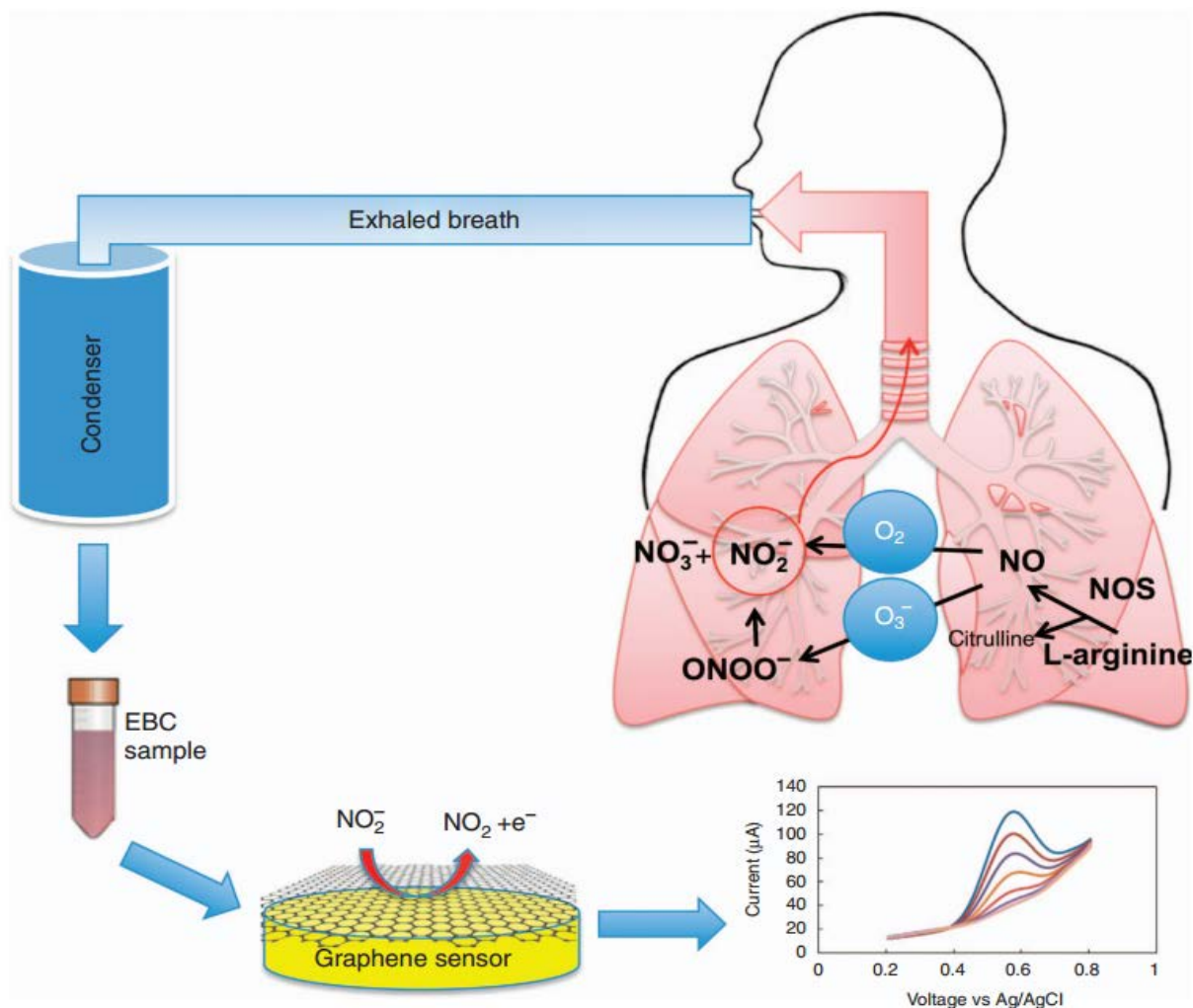


Fig 19: Exhaled breath condensate (EBC) is collected. Nitrite content is measured electrochemically using graphene oxide sensor. Increased levels of nitrogen oxides (NO) are associated with inflammatory disease states such as asthma, chronic obstructive pulmonary disease (COPD) and cystic fibrosis (CF). The increased level of exhaled NO in asthma may be due to an increased expression of inducible NO synthase (iNOS) in bronchial epithelium. Given the relative stability of nitrite in EBC, it is a promising biomarker of chronic respiratory inflammation. The nano-sensitivity of probe-free/label-free sensor for the detection of nitrite in EBC enables early detection and reduces cost of hospitalization [117].

The transition from classical sensors [118] to nanowire and graphene [114] sensors [119] may increase sensitivity for sensing changes [120] in disease [121], microbiomes [122], and water [123]. The latter is a medium of transmission for many pathogens. Some of these tools and technologies are nearly two decades old. What is lacking in healthcare is an informed vision and the convergence of technical tools on platforms. The leadership for systems integration is suffering from paralysis by analysis. The situation may be similar to use of RFID in retail stores which lacked ignition [124] circa 2002 vs the 2017 “back to the future” attempt to re-invent the past through Amazon GO, the new no-checkout grocery store [125].

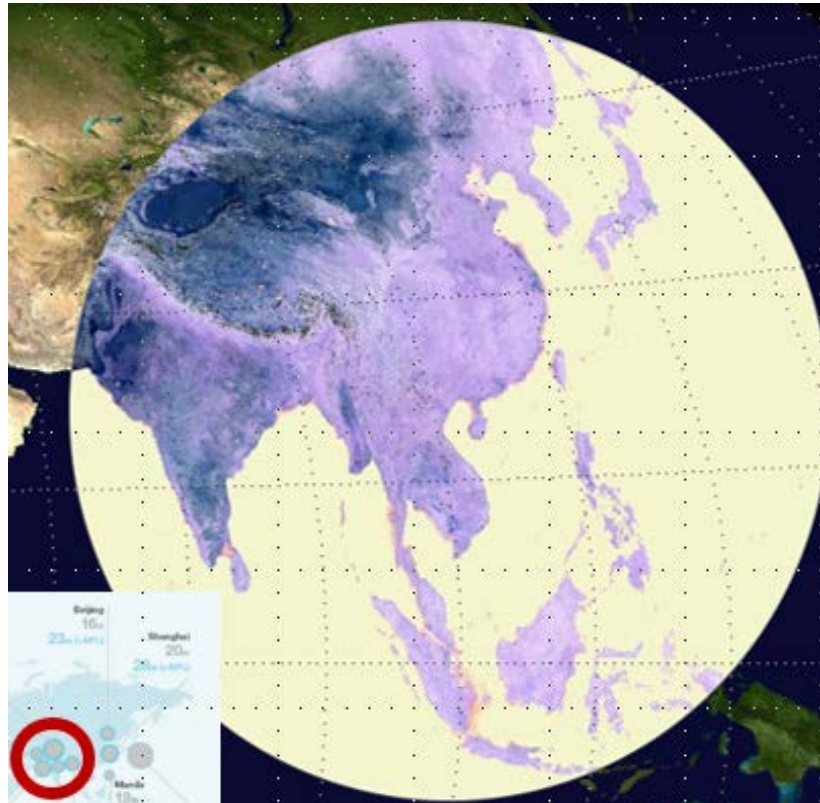


Fig 20: More people (about 5+ billion) live inside this circle than anywhere else in the world. Five cities (small red circle) represents a market of 100 million (Dhaka, Calcutta, Mumbai, New Delhi, Karachi).

If convergence of healthcare platforms were a reality, the long-term profitability seems to be immense. Consider New Delhi, with an estimated population of 40 million by 2030. Assume 10% of the population subscribes to health platforms. The platform vendor earns \$0.01 per day as a micro-payment from the customer to access/upload data/analytics through the platform. That translates to an annual revenue of US\$14.6 million for *one point of contact on the platform from one city*. If 1% of the 5.5 billion people in SE Asia paid \$0.10 per event per day then the platform revenue soars to US\$2 billion per year. This is not a “low hanging fruit” and seeks an astute visionary with a penchant to make a difference to create the convergence for healthcare, for the underserved. Hence, the “Amazon” of healthcare is still out there.

Convergence in healthcare requires thinking of healthcare as a fabric rather than as a visit to the doctor. Healthcare vendors start the thinking with billing codes. Hence, it is hard to realize that a 30 minute hospital visit, after a patient survives a myocardial infarction (heart attack), leaves the patient at risk for 99.999% of the time. Where is the system to monitor the patient? We have tools but not the systems because the businesses in the business of systems integration know precious little about health. The healthcare industry still cannot find the “billing code” for remote monitoring of a cardiac patient in order to prevent future emergencies or reduce re-hospitalization. Emergency visits [126], hospital stay, diagnostic procedures [127] and unnecessary routines [128] are profit centers for US healthcare industry.

Healthcare platform innovation may not germinate from Accenture (systems integrator) or CVS Health or McKesson. Electronic health/medical record (EHR/EMR database) providers are not promoting global platforms but poster perfect for epic greed [129], skilled in information blocking [130] by developing closed systems and preventing semantic interoperability, deliberately, by design. For healthcare information technology (HIT), the inability to access EHR/EMR information is often fatal [131] but continues unabated.

Perhaps it is hard to change systems from inside. Tesla and Google changed the auto industry rather than GM or Toyota. YouTube and Facebook re-invented media, not ABC, NBC or BBC. Space exploration entered a new era with SpaceX and Virgin Galactic, not through Boeing or Airbus. Retail giant Wal-Mart is struggling to catch-up with innovator Amazon. Hence, the elusive quest continues, for a leader to rise and implement micro-payment based systems innovation for healthcare as a service, for the rest of us. Is it going to address all healthcare woes? No, but, it may be helpful to billions. The near complete lack of such tools and lack of EHR/EMR in most of SE Asia makes it a fertile ground for “open” platforms. The immense scale of implementation may be unsettling to providers who may think in terms of US and EU.

The ecosystem of device manufacturers and their convergence with platform providers through mobile infrastructure to acquire, deliver and distribute data, in a manner that is safe and secure, is a tall order. The open source movement is generally focused on access to data. Lack of data or inability to combine data to extract information is one reason why medical errors are a leading cause of death in the US [132].

Enabling access to data from devices is an anathema for manufacturers. It results in interoperability issues [133] and asphyxiates open source approaches [134] vital for healthcare. Lack of medical device interoperability issues are more pronounced in the affluent nations (US and EU). The inability of emerging economies to afford US-based EHR/EMR systems (Epic, Cerner) is a blessing and a catalyst for open source integrated clinical environments [135] to improve healthcare and safety.

Justifiably, monetization of the open source model deserves attention. Data acquisition from devices, the data model and interfaces, are some of the essential “open” elements. Safety, security and privacy must be demonstrated in the open model. Authorized access to raw data must be kept open and almost free for patients, hospitals, healthcare workers and anybody else who may be legally permitted to use.

A simplistic analogy is a person calling a bank or checking the online statement to find out what is the balance in the checking account. This data (balance in the account) cannot be “closed” to the account holder. If the account holder asks how to optimize her rate of interest or investment, ie, seeking advice (analysis), then the bank can charge a consulting fee for an appointment to discuss individual needs. For access to data in terms of bank balance, the bank can charge 10 cents each time a customer calls or a nano-payment of 1 cent each time the customer wishes to query the balance through the online portal.

In the open source healthcare platform model, the vendor may not restrict the data but may impose a micro-payment for accessing the platform to access the data. Customers may understand that there is a cost to develop, implement, maintain and secure the infrastructure which enables these transactions.

It may be a quantum leap forward if the healthcare industry is able to obtain raw data from devices and use an open platform model as a tool for convergence. If it is your data, then, you should be able to access your health data, anytime, anywhere. But, perhaps, there will be pay-per-access nano-payment.

If the person observes that the blood glucose level is 139mg/dl and wishes to know what it means, then it triggers a different application, which may require the services of an analytical engine to process the data and respond to the query. This analytical engine may be provided by the platform vendor or may be sourced from a third party, similar to Apple/Google app stores. Access to this app is not free and the query may cost the customer 10 cents each time. If 1% of the world’s population (~7.5 billion people) asked one question each month then it could generate \$90 million in annual revenue from 1 question.

The monetization model distributes fractional micro-payments to the app creator, platform host, telecom provider and other micro-service vendors. If the system required thirty different vendors to converge for the systems integration to answer that question then each vendor may receive 1/30th of the \$90 million revenue or \$3 million per annum (if revenue was shared equally among the partners).

Dynamic pricing of queries may be based on the complexity of the question. Dynamic composition of micro-services, analytical tools, algorithm engines or portfolio of solvers must be sourced, aggregated, activated and executed in order to respond. It may not be difficult to understand why the structural elements of this architecture must be modular, blocks to be “discovered” if necessary, interoperable, agile, compatible, perhaps capable of natural language processing and preferably Agent based tools.

Platform analytics will evolve as a key tool for monetization for open platforms and medical internet of things (MIoT). Security [¹³⁶], privacy and data de-identification may play pivotal roles. The question of “intelligence” in analytics and how the platform will address **context** of input data remains a challenge. Reasoning (erroneously referred to as AI) must occur in a specific context for specific goal(s). Medical expert systems accepting list of symptoms as input and generating output (most likely diagnosis) ignores the basic tenets of medicine: hypothesis-directed gathering of information, complex task of interpreting sensory data (obtain uncertain indicators of symptoms) and the goal of curing the patient. The latter may involve treating less likely but potentially dangerous condition rather than likely but harmless ones.

AI AND ANALYTICS – THE BREAD AND BUTTER WITH JAM FOR FUTURES, NEAR AND FAR

Artificial intelligence (AI) is a potent tool but may be an unfortunate yet **very** attractive choice of words to capture the public imagination. Reference to intelligence in AI is due to its use of the phenotype of neural networks, with input and output (I/O), as a core [82] feature of artificial neural networks (ANN). The lack of erudition in AI was mimicked when an AI program was requested to name colors (Figure 21). However, the world has embraced AI and etched it in its psyche. AI appears to possess that Midas touch. All things AI sells faster than hot scones with clotted cream. For a few, witnessing the transmutation of tabloid fodder from speculation to truth may be deeply troubling because there is no “intelligence” in AI [137] with respect to human intelligence. It was never there, may not be there now, or in the near future.

Yet, the tools of AI are critical in the connected global economy to catalyze growth, reduce inefficiencies, make sense of data. Collectively AI presents immense potential to increase profitability for practitioners.



Fig 21: I gave the neural network a list of about 7700 paint colors along with their RGB values. (RGB = red, green, blue). Could the neural network learn to invent new paint colors and give them attractive names? The invention of paint by numbers may not be bad [138] but the names are less desirable.

Yet it is an egregious error of judgement when venerable corporations manipulate the media [139] in the name of AI. IBM spun a story how IBM’s AI flagship Watson could improve cancer treatment [140]. It was unsuccessful yet PricewaterhouseCoopers walked away with \$23 million for the project, which, despite contractual stipulations, was not implemented at the M D Anderson Cancer Center, University of Texas.

If we can look beyond the name and the fake publicity, the tools (Figure 22) collectively referred to as AI, are indeed extremely useful. Higher order reasoning is indeed necessary for digital transformation and is an important monetization tool for analytics in DEX, the digital enterprise, made up of rational Agents.

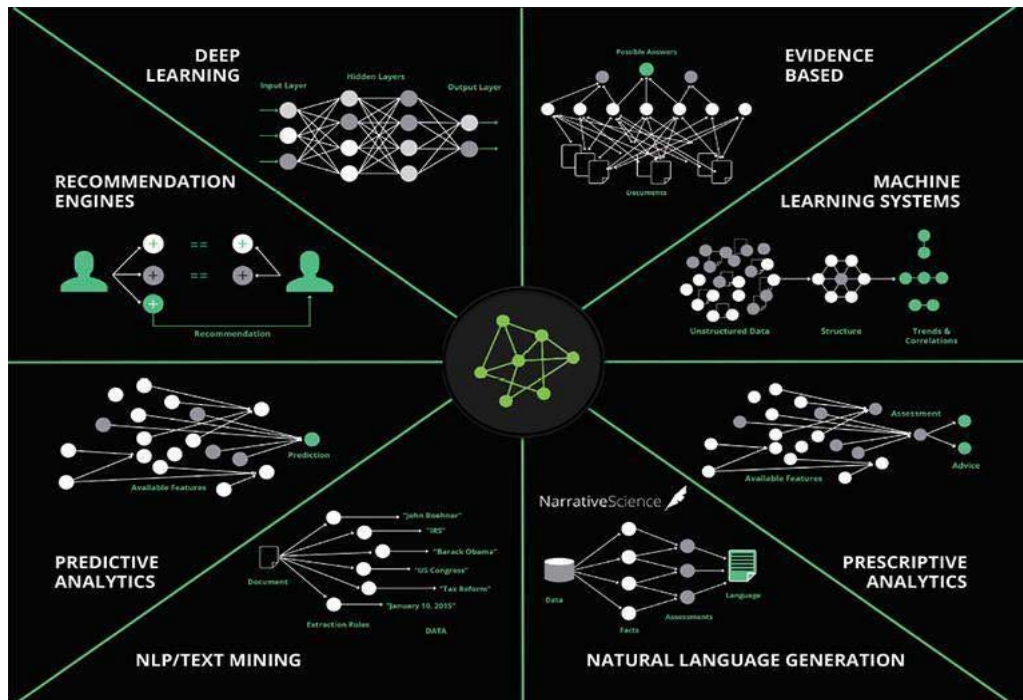


Fig 22: The combination of tools which are collectively referred to as AI by the media and businesses.

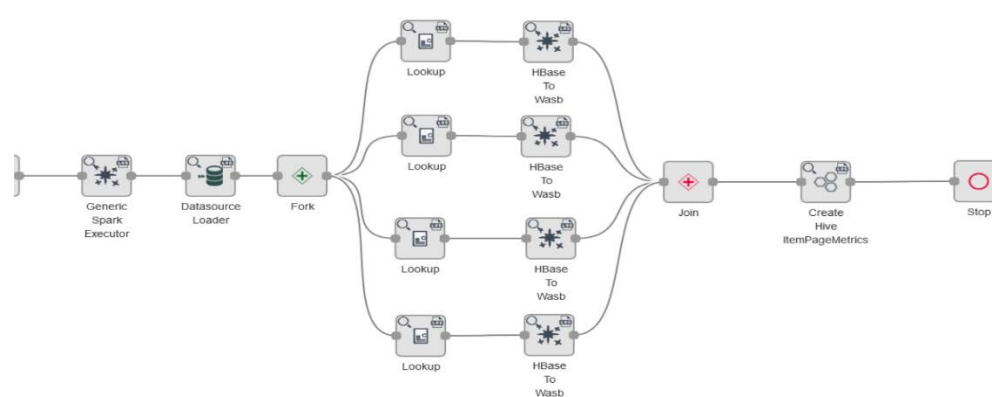


Fig 23: So called augmented intelligence [AI] in this diagram is rather pedestrian quality workflow [141]. Converting “work packages” (box) to multi-Agent systems may enable us to profit from principles of AI.

The scholastic effort in this field over the past half century or more has resulted in breakthroughs that makes it possible for systems and computers to process speech and recognize photographs, among other advances. The field has progressed from rule based expert systems [142] to pattern recognition systems which uses artificial neural networks [143] and/or statistical methods [144]. Unfortunately, the exaggerated views verging on narcissistic stupidity [145] appears to be more fashionable (Figure 25).

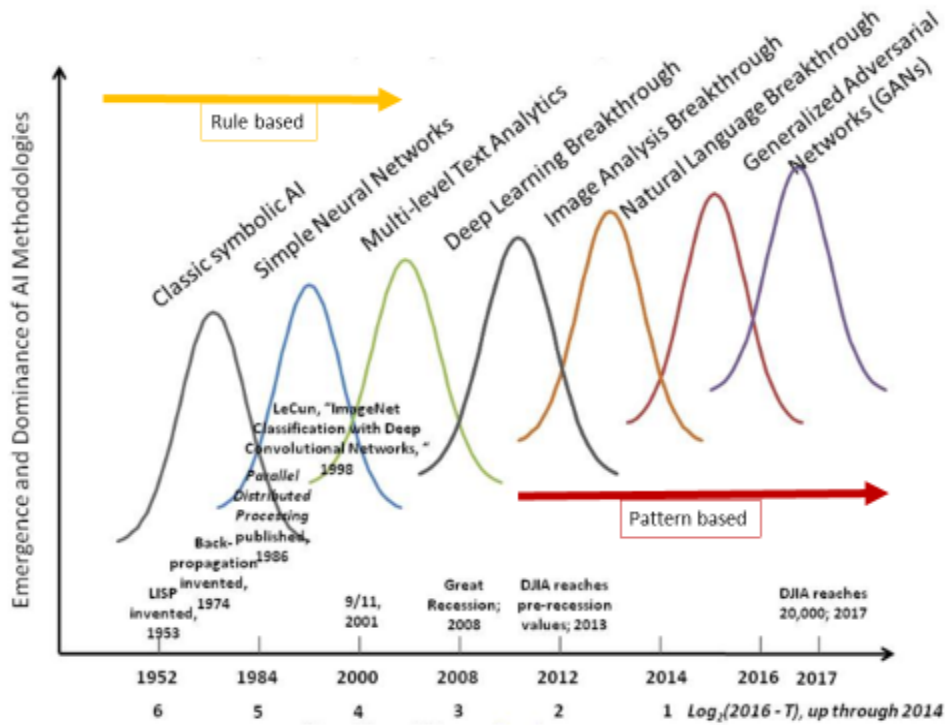


Fig 24: Brief History of AI – The evolution of rule based systems and pattern recognition [146] by ANN

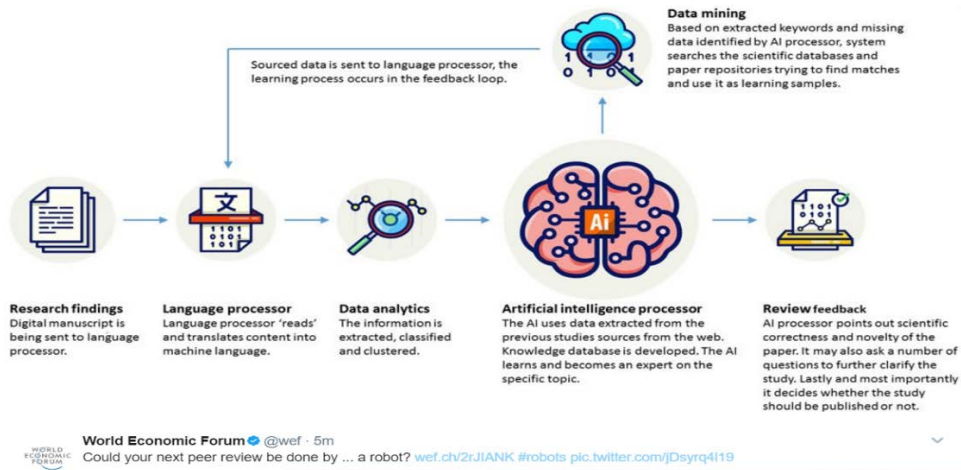


Fig 25: Sensationalism is a hard habit to resist for marketing, even if it is a form of misrepresentation.

Perhaps we can use this AI awareness that has gripped the global imagination. It seems that almost everything in the business world strives to be laced with AI or shrewdly insert AI in the folds (Figure 26). We have moved from hot dog eating contests as spectator sports to watching numbers creep up on AI acquisition charts (Figure 27). Perhaps there is a silver lining. Maybe school students dreaming about six figure starting salaries will be inclined to take a deeper look at Khan Academy [147] or edX or MOOCs [148] to understand that mathematics, computer science, linguistics, epistemology, neurology, engineering and basic science are indeed salient to understanding the foundation of AI and learn how to apply AI.



Fig 26: Why is AI missing in this ad? Not really. It is carefully concealed to stir the viewer's imagination.

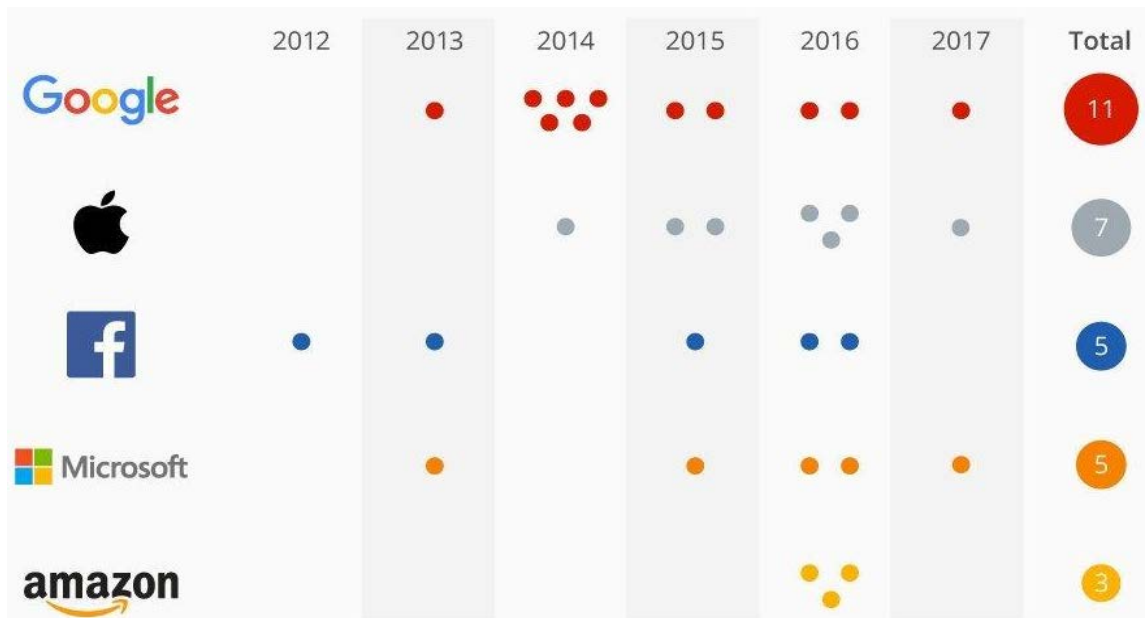


Fig 27: Number of AI start-ups acquired [149]. Like watching balls jump up the tube in a lottery drawing.

Contextual higher order reasoning (CHOR) sounds insipid compared to the magnetism of AI and unlikely to become a household name. Artificial neural network (ANN) tools, including convolutional neural networks (CNN) and recursive neural networks (RNN), in combination with predictive analytical tools (ANN and statistical techniques) drives machine learning (ML) analytics. Speech, NLP and vision are components necessary for many industries and image analysis is integral to medical diagnostics.

These tools are expected to be part of analytical engines or apps [150] associated with the open data platform for healthcare (for example, openICE [131], the integrated clinical environment). These tools may or may not be created by the platform lead but sourced from contributors including crowdsourcing. Verification and validation [151] of these solvers and apps may be performed for the channel master (platform lead) before they are uploaded. Who will choose the correct solvers or apps? If the consumer does not know how to choose, the importance of programming abstraction (page 22) increases. NLP can guide these choices by extracting information from user’s speech, if the platform is quite sophisticated.

Monetization of apps [152] and sharing micro-dividends from micro-payments, harvested by app stores or app creators for crowdsourced apps, will present financial challenges that must be addressed. Apps with “security badges” “pre-validation” “five star reviews” are likely to be “preferred” and will rise to claim profitability, if the monetization model of the ecosystem is approved and online. At a systems level, nano-payments for micro-services is a horizontal need for Digital Enterprise X.0, or any version of digital transformation, in an economy where the exponential clamor for blockchain may be justified.

Platforms for remote monitoring, telemedicine and in-hospital care, are in need of open source tools to aggregate data, structure and function. Without decision support and predictive analytics, healthcare platforms may be impotent to serve as the conduit for contextual connectivity and convergence.

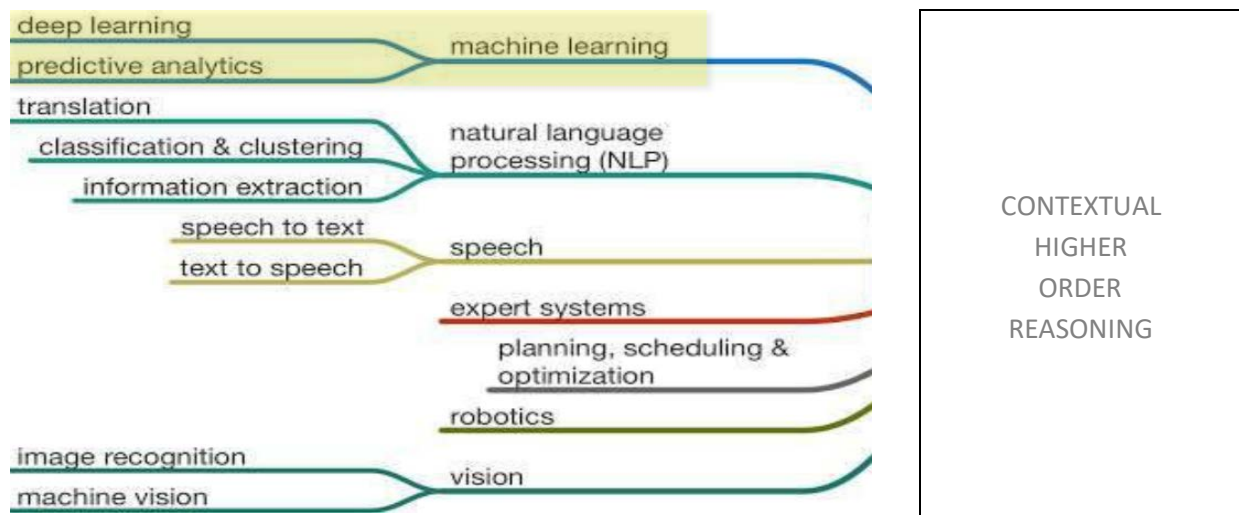


Fig 28: Contextual Higher Order Reasoning (CHOR) as another name for Artificial Intelligence (AI) may never see the light of the day. Decades ago, knowledge representation was introduced (it is pivotal for enterprise architecture) and the term “intelligent reasoning” [153]. Is CHOR akin to *intelligent reasoning*?

LOOKING FORWARD

The illustration below is "Rue Future" (Future Street) from Eugene Alfred Henard's (1849-1923) article, "The Cities of the Future" (1911). Henard (architect of Paris and from 1880 a life-long employee and advocate of public works in Paris) looks into the future and sees movement towards underground (or enclosed) vehicular traffic, "smart" buildings, pneumatic tubing for vacuum cleaners ("almost sure to come into general use"), an improvement in the system for water delivery and removal, replacing coal with natural gas. His ideas, if implemented in Paris, would cost \$420 million, then, \$15 billion, today [154].

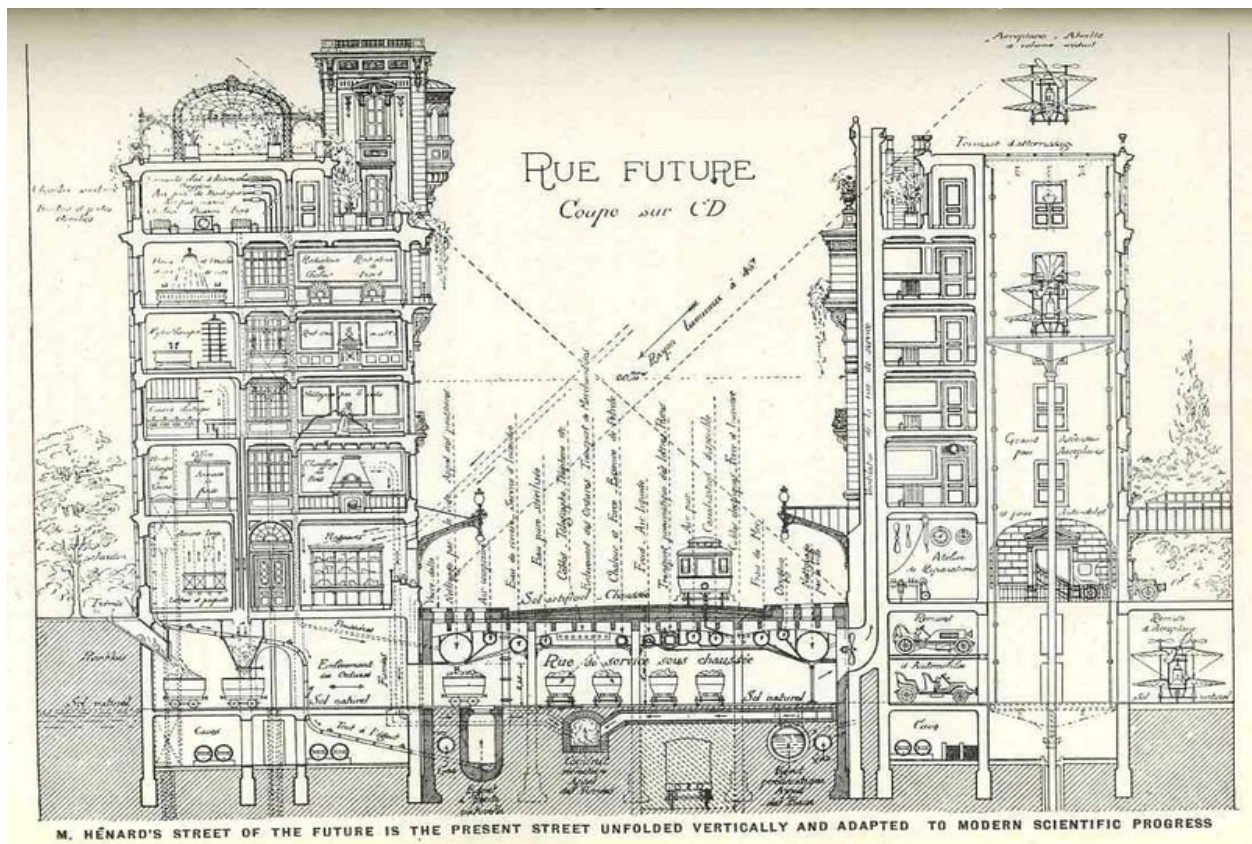


Fig 29: Size, scale and vision of "Rue Future" is comparable to the Digital Enterprise X.0 (DEX) proposal.

DEX is comparable to the foresight in Rue Future. Hence, it is difficult to conclude any discussion of DEX and its building blocks because we haven't even started the journey, in earnest. Digital transformation must be viewed in the context of demand, demographics, markets, economic trends in the context of the socio-cultural milieu. Digital enterprises must embrace digital twins, optimize security and mobility. The challenges of DEX may not be solved by yesterday's thinking or today's solutions. Opportunities for the diffusion of DEX may arise from unexpected quarters, uncharted waters and may even unleash untapped potential.

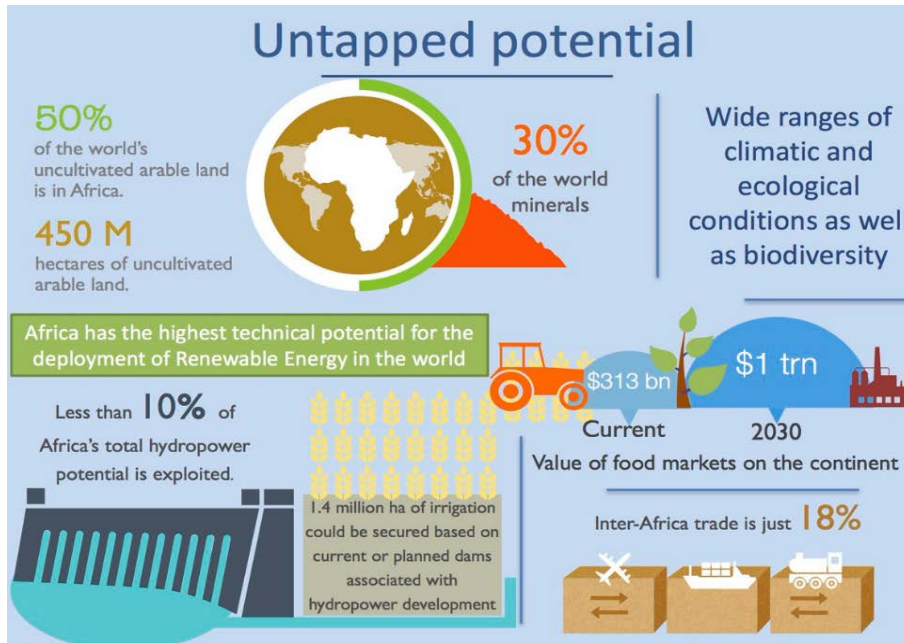


Fig 30: Flooding the Sahara Desert could have changed Africa. Technology should serve humanity.

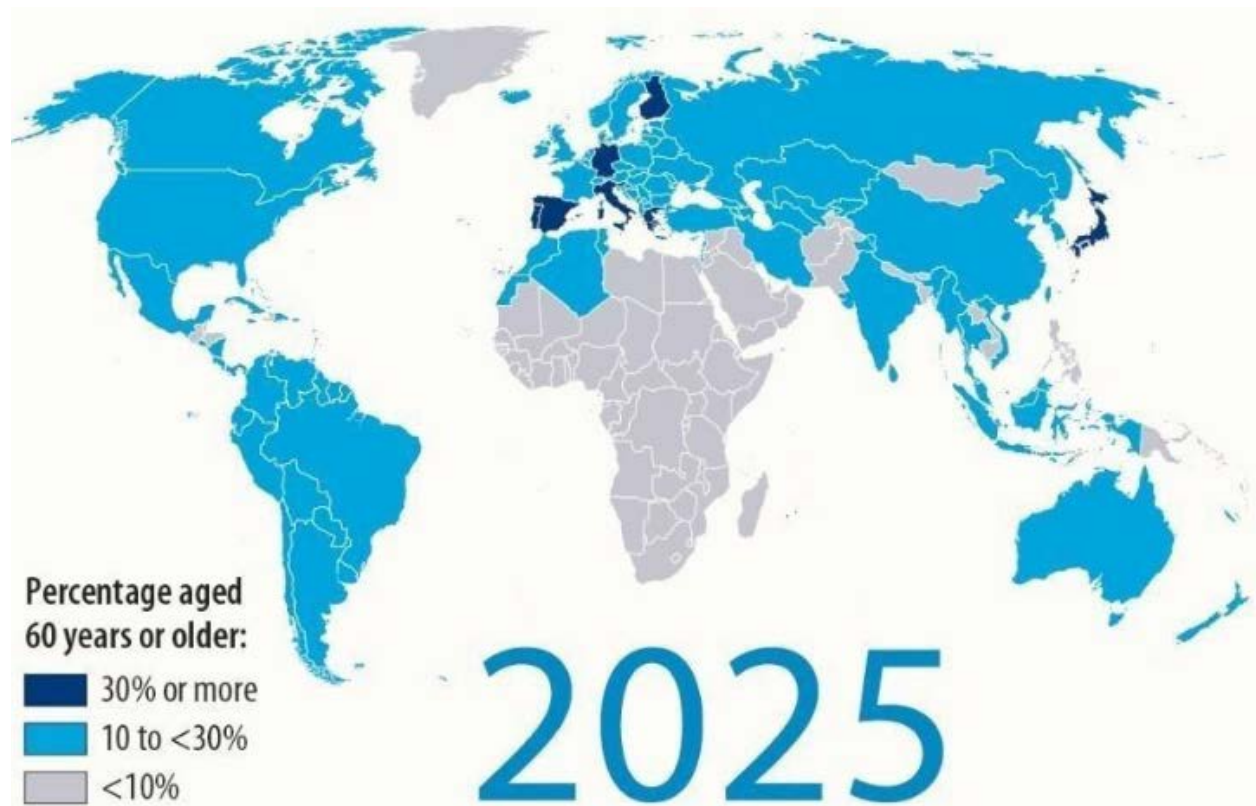


Fig 31: Testament of Youth [155]

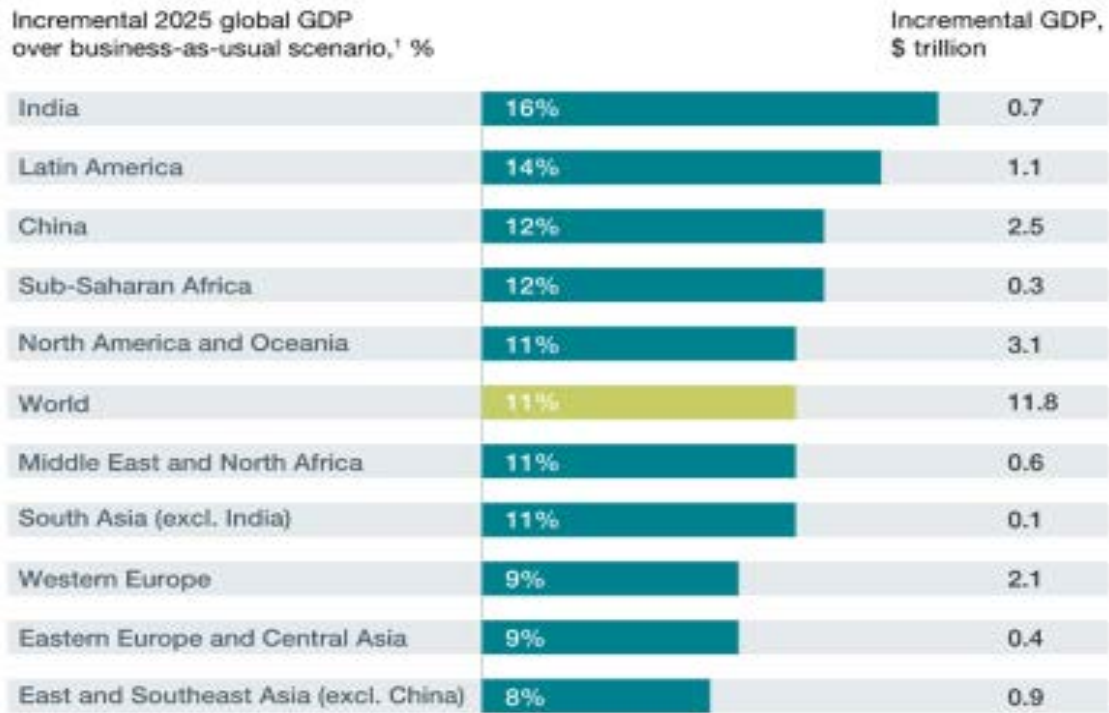


Fig 32: Money left on the table? Gender parity may increase GDP up to \$12 trillion in 2025 [156]. The education of women and gender parity at the workplace is an economic no-brainer to increase profit.



Fig 33: In 1920, Goddard outlined how a rocket might reach the moon. NY Times wrote he “lacked knowledge ladled out daily in high schools” and argued thrust was not possible in a vacuum [157].

paper). The uncanny innovator in Mr Jobs has extracted the service model through iTunes and may be poised to compete with the likes of Nokia or NTT DoCoMo. Skype-like features in an IPv6 enabled iPod will come with built-in 802.11g, 802.15.4 and 802.16 features (WiFi, Zigbee, WiMax) but aesthetically engineered to expose the crème de la crème of human-machine interface that is central to Apple's innovation. Wave your iPod.femto at a Marks & Spencer store to compare the price of the "collezione" charcoal grey pure cashmere scarf that you saw at Tie Rack, buy petrol and pay for groceries at Tesco or pause "Sleepless in Seattle" if Mum is Skype-in mode to you.

(see figure 26) when the iPod evolves as your secure-car operation platform.



Fig 34: Apple employees Jeff Robbin and Bill Kincaid developed iTunes in the 1990's but left Apple to market it as SoundJam (1998). Apple bought SoundJam and re-introduced it as iTunes in 2000. In 2001, the debut of iPod in the US catapulted the concept of micro-payment based crowd-sourced apps on a platform. Combining the concept of iPod and the almost parallel release of i-mode (2001) platform by NTT DoCoMo in Japan, it wasn't hard for the public to predict that the iPod may also serve as a mobile device and phone, as suggested in a 2005 article reproduced above [158]. The control of objects using a mobile device was a concept introduced around 1999 in the form of IoT by the MIT Auto-ID Center. The concept of IoT with that of a mobile device linked to telecom was one rationale for the suggestion (cartoon above) that in future we will control automobiles with a phone. The figure shows the potential of "plugging in" or inserting a "stick" in the automobile. This concept was not elaborated in the 2005 article because it was too far out as science fiction, at that time. The concept of inserting a "stick" to control the automobile was based on ideas surrounding metastable hydrogen which proposed the potential of hydrogen to behave as a metal [159] and hence "packaged" as a source of energy for hydrogen powered objects, for example, the hydrogen powered automobile model showed in the cartoon (above). The disclosure of this idea at this time is appropriate because the presence of metastable hydrogen hypothesized by Eugene Wigner in 1935 has been confirmed to exist [160]. It is a first step by graduate student Ranga Dias at Harvard University [161] on the road to driving an automobile or flying an airplane using a highly compact USB thumb drive type "stick" as shown in the cartoon from 2005 using the iPod form factor. The future stick may be no larger than a thimble or perhaps similar to a credit card sized pack of energy. This form factor may change the automobile industry which will no longer need solar fuel cells or batteries which weigh thousands of kilograms and reduces range. Taxicabs and auto-rickshaws can use credit card size energy packs and swap the energy cards in retail stores or convenience stores when depleted [162]. Mobility of atoms and its connection with bits (data, information) is a catalyst for the untethered but networked physical world - a digital by design metaphor suggested by Sanjay Sarma [163] and others, as a conceptual basis for diffusion of IoT.

In our excitement to engage with the explosion of emerging advances, tools, ideas, IoT, and applications, we have devoted less attention to the foundation of semantic interoperability [164] necessary to make sense of the data. Meaning of the data drives its value and extracting actionable information is the Holy Grail. At the heart of this process is the convergence of data, which is essential for relevant analysis, but that cannot happen unless we optimize connectivity between data holders (streams, lakes, fog, cloud), which must understand (cognitive tools?) the context of the data, in order to select, channel or curate the data, before subjecting it to associations, algorithms and analytics. Cross-pollination and information arbitrage depends on semantic interoperability between modules, building blocks, systems, ecosystems and end-user facing applications (where the *rubber meets the road* in terms of revenue, profit and loss).

We will be handicapped if we fail to “look forward” in addressing the ontological basis of semantic interoperability between entities. Agent based architectures are one approach. A global discussion between standards bodies, ontologists, linguists, business user groups, developers and enterprise architects are essential to improve systems interoperability, if and where Agents may fear to tread [165].

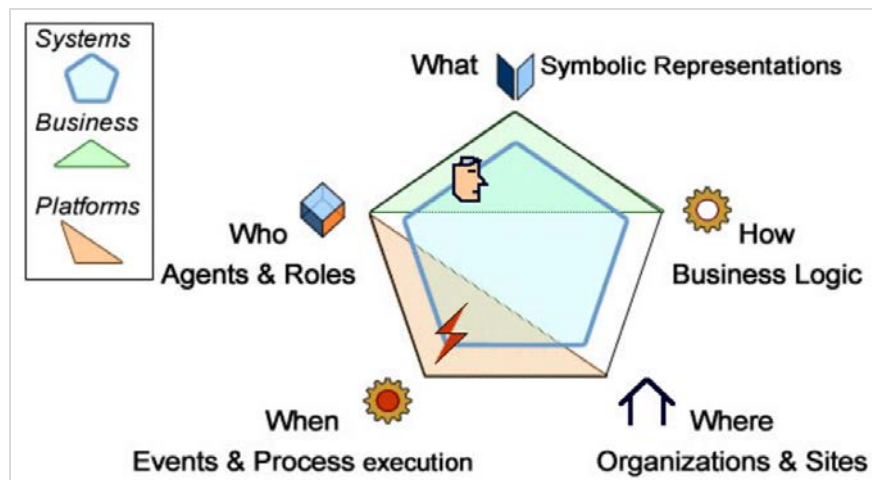


Fig 35: In 1987 John A. Zachman, an IBM researcher, proposed the Zachman Framework, a concept of what is involved in information system architecture [166]. Organizations may not have one architecture, but a range of diagrams/documents representing different aspects or views and/at different stages [167].

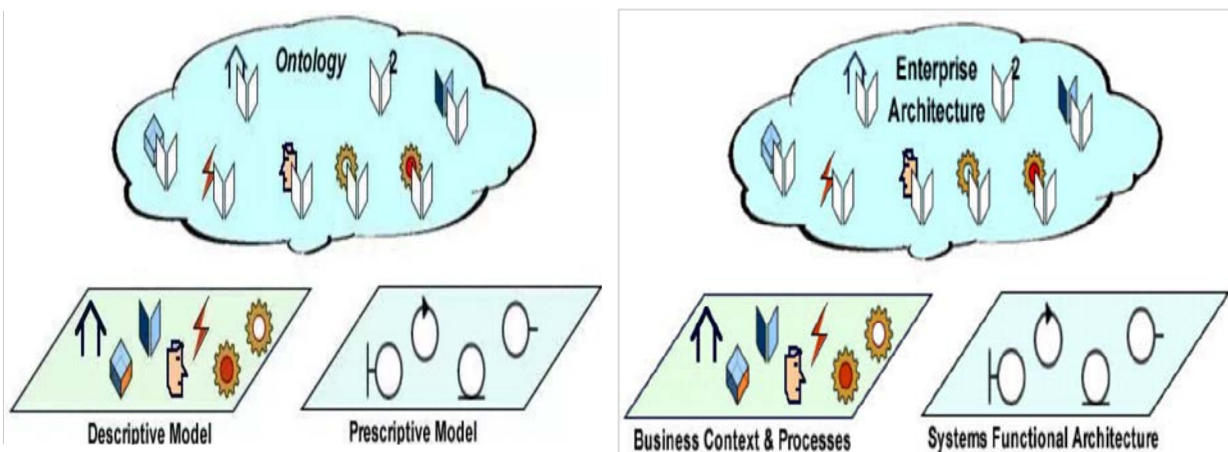


Fig 36: Models sub-layers to ontologies. Enterprise architecture as an ontology of symbolic systems [168].

CONCLUSION

It is possible the transformational tsunami will wipe out the need or significance of DEX. The discussion about forward looking thoughts may be wishful thinking. Quest for open source [169] may be stunted. The academic discussion what constitutes intelligence may be obliterated by the market forces driving AI. The financial muscle behind market driven AI (Figure 37) can crush dissent and defund dissenters.

However, it is reassuring that AI leaders in some of the corporations are exceptionally brilliant engineers (for example, Peter Norvig, Andrew Ng) who are aware of the deep shortcomings of intelligence in AI and they pay attention to neuro-scientists (Tomaso Poggio). Yet, the marketing machines keep churning out chest-thumping tabloid fodder, as if it were the truth. In the middle-ages “artificial flight” attempted to mimic birds. The Wright brothers turned to wind tunnels and aerodynamics, which removed “artificial flight” from our vernacular and gave birth to the aviation industry. AI will generate deep reasoning (DR) and profitable analytics but not intelligence. But, truth always lags behind, limping on the arm of Time (Baltasar Gracián y Morales). Is the truth in AI for a few? Is this discussion about AI a storm in tea cup? Will it suffice if the market acknowledges this is not intelligence or AI but DR or deep reasoning?

Why AI is devoid of intelligence may be unintelligible to individuals without knowledge of neurology or the desire to understand what does it mean to sense or taste or hear. The various aspects of neurology essential to grasp the concept of intelligence, even in its rudimentary form, may include anatomy and physiology of the nervous system and a comparative perspective of neural systems (octopus vs worms). As discussed elsewhere [47], the physical representation of neurons in our brain is not representative of the *functional* outcome. This is the single most crucial factor in this debate. Just because computational systems can create neuro-morphic structures, does not mean it can re-create the function or pass the Turing Test. Cryptic and deep in the functional context are states of intelligence, intuition, perception and characteristics that makes us, humans, intelligent. Harnessing the amorphous attributes are beyond engineering systems because the biology still remains undiscovered and our elusive quest continues.

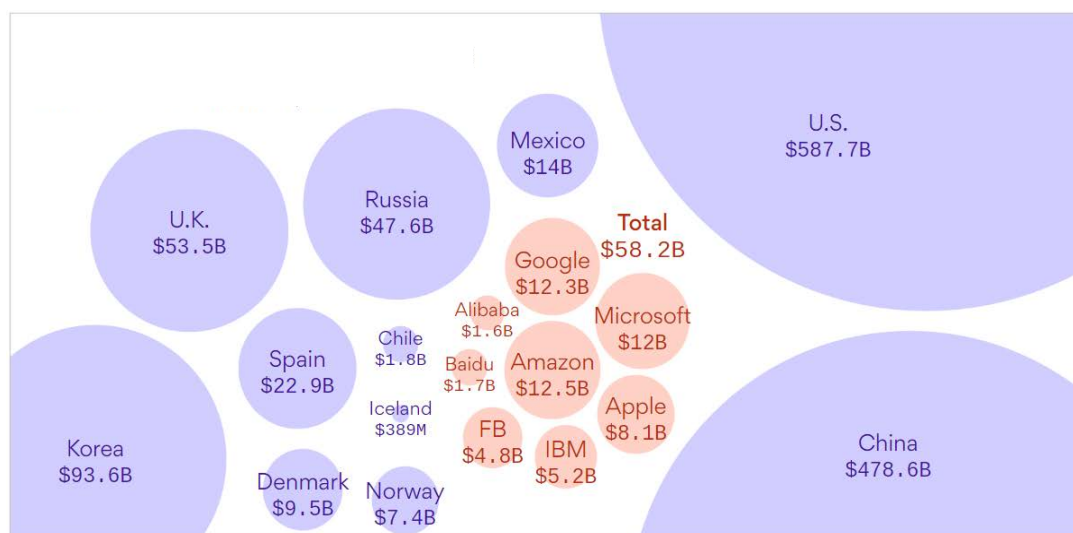


Fig 37: R&D budgets of AI-intensive firms and select countries (OECD, 2015). Bubbles brewing trouble?

MEMORANDUM

August 28, 1963

Memorandum To: Messrs. A. L. Williams
T. V. Learson
H. W. Miller, Jr.
E. R. Piore
O. M. Scott
M. B. Smith
A. K. Watson

Last week CDC had a press conference during which they officially announced their 6600 system. I understand that in the laboratory developing this system there are only 34 people, "including the janitor." Of these, 14 are engineers and 4 are programmers, and only one person has a Ph. D., a relatively junior programmer. To the outsider, the laboratory appeared to be cost conscious, hard working and highly motivated.

Contrasting this modest effort with our own vast development activities, I fail to understand why we have lost our industry leadership position by letting someone else offer the world's most powerful computer. At Jenny Lake, I think top priority should be given to a discussion as to what we are doing wrong and how we should go about changing it immediately.

TJW, Jr:jmc

T. J. Watson, Jr.

cc: Mr. W. B. McWhirter

Fig 38: Innovation abhors conventional wisdom and driven by vision reflecting confluence of ideas

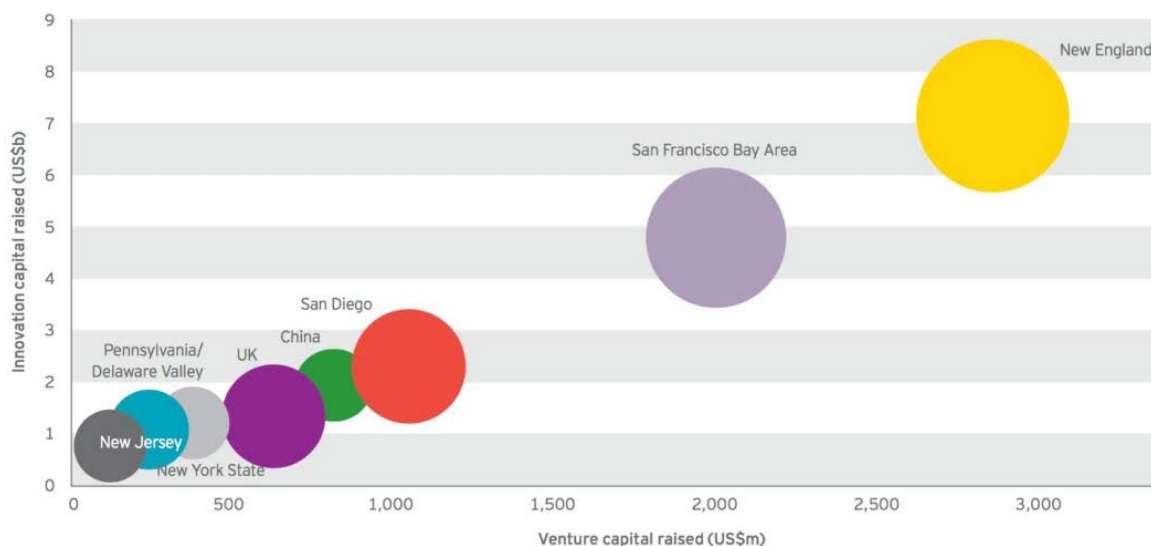


Fig 39: Geography of biotech innovation (Ernst & Young, 2016) proportional to research and education?

Quantum leaps are integral to progress of science (Galileo Galilei) and society (Leo Varadkar). The revelation “what is intelligence” may be breaking news, tomorrow on BBC, from Corina Logan. Hence, paradoxes may be converted into paradigms. What is heresy today may be in harmony, tomorrow. We must view the past (Fig 38) with the present (Fig 39) and accept change (Fig 40) in our future (Fig 41). But, it is encouraging to observe the diffusion of change, even if they are only in illustrations (Fig 42). Things that we may not wish to change are our norms of respect, égalité, and a sense of dignity [170].

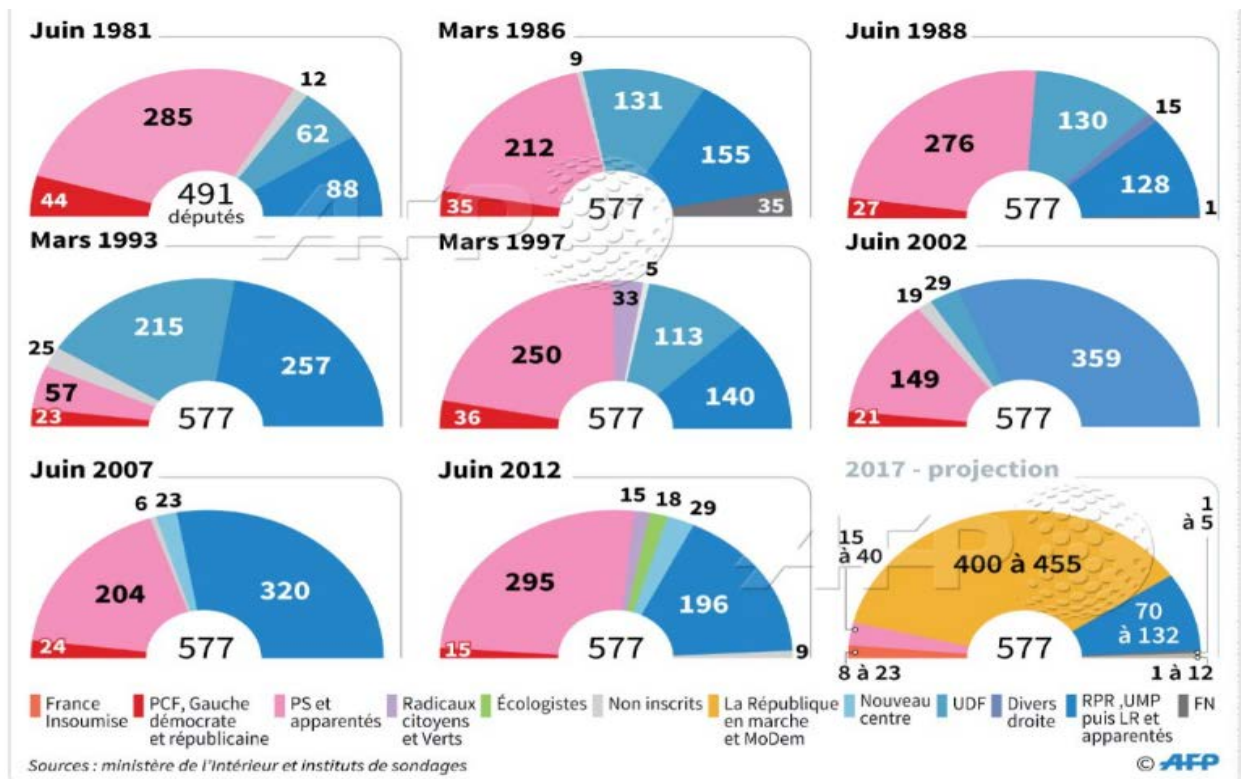


Fig 40: French Revolution 2.0 (La deuxième partie débute environ deux cents ans plus tard).

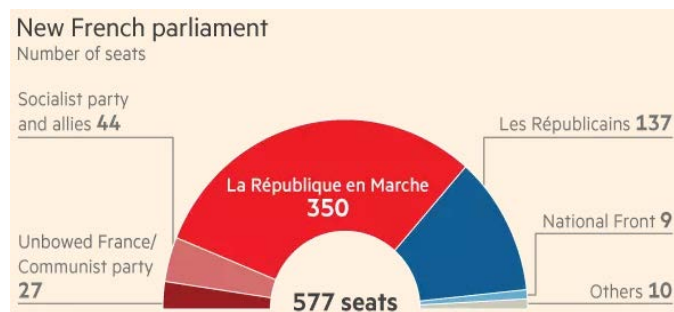


Fig 41: Le parti naissant du président français Emmanuel Macron La République en Marche et son modèle d'allié centenaire sécurisent 350 des 577 sièges à l'Assemblée nationale. Macron réfute Voltaire? En 1741, Voltaire [171] écrit "sans la voix de la le Maure, & le canard de Vaucanson vous n'auriez rien qui fit ressouvenir de la gloire de la France." Macron voudrait différer. N'est-ce pas?



Fig 42: The manufacturing enterprise illustrated by Deepesh Nanda suggests convergence of digital threads in DEX.

REFERENCES

- ¹ <https://ia902205.us.archive.org/23/items/floodingsaharaa01mackgoog/floodingsaharaa01mackgoog.pdf>
- ² <https://tools.ietf.org/html/draft-lee-iot-problem-statement-04>
- ³ <http://callingbullshit.org>
- ⁴ <https://www.healthnewsreview.org/2017/02/md-anderson-cancer-centers-ibm-watson-project-fails-journalism-related/>
- ⁵ <http://www.newyorker.com/magazine/2014/06/23/the-disruption-machine>
- ⁶ <http://www.economist.com/node/11848432>
- ⁷ <https://hbr.org/1993/07/building-a-learning-organization>
- ⁸ <https://1.cdn.edl.io/ewMbRRD0v8rfiYEBfRNJ4JnsbvgPQ2g28N1oGvi9HYX2s0mC.pdf>
- ⁹ <http://www.economist.com/news/business/21711909-what-martin-luther-did-catholic-church-needs-be-done-business-gurus-management?>
- ¹⁰ <http://economictimes.indiatimes.com/tech/internet/nearly-3/4th-of-internet-of-things-projects-are-failing-cisco/articleshow/58821949.cms>
- ¹¹ <https://arxiv.org/pdf/1602.08194.pdf>
- ¹² <http://cass-mt.pnnl.gov/docs/ia3-2013/brockman.pdf>
- ¹³ <https://dspace.mit.edu/handle/1721.1/107989>
- ¹⁴ <https://msuweb.montclair.edu/~lebelp/CoaseNatFirmEc1937.pdf>

-
- 15 www.foxbusiness.com/features/2013/08/22/after-watson-ibm-looks-to-build-brain-in-box.html
- 16 <http://time.com/3614349/artificial-intelligence-singularity-stephen-hawking-elon-musk/>
- 17 <https://www3.epa.gov/region1/airquality/nox.html>
- 18 <https://arxiv.org/pdf/1111.2249.pdf>
- 19 <https://www.gatescambridge.org/news/towards-smarter-definition-intelligence>
- 20 http://groups.csail.mit.edu/EVO-DesignOpt/groupWebSite/uploads/Site/DSAA_DSM_2015.pdf
- 21 <https://docs.microsoft.com/en-us/azure/machine-learning/machine-learning-data-science-create-features>
- 22 <https://arxiv.org/pdf/1701.04217.pdf>
- 23 <ftp://ftp.inf.ufrgs.br/pub/simoo/papers/mompes10.pdf>
- 24 <https://pdfs.semanticscholar.org/db9/0595ab3ccefabf5b8e7b2c1a21cc38a732fc.pdf>
- 25 <http://www.fractal.org/Bewustzijns-Besturings-Model/Fractals-Useful-Beauty.htm>
- 26 <http://web.media.mit.edu/~minsky/papers/PR1971.html>
- 27 <https://www.economics.ox.ac.uk/materials/papers/2269/33DAVID4.PDF>
- 28 <http://www.siepr.stanford.edu/workp/swp04008.pdf>
- 29 https://eml.berkeley.edu/~bhhall/e124/David90_dynamo.pdf
- 30 https://www.youtube.com/watch?v=PanqoHa_B6c
- 31 http://www.physics.rutgers.edu/~steves/501/links/double_slit_experiment.pdf
- 32 <https://archive.org/details/MountainsBeyondMountains-LifeOfDoctorPaulFarmer>
- 33 <https://www.forbes.com/global/2002/0318/092.html>
- 34 <http://www.rfidjournal.com/articles/view?399>
- 35 <http://www.cnbc.com/2017/03/27/amazon-go-reportedly-isnt-a-go-for-now-as-retailer-postpones-opening-of-convenience-stores.html>
- 36 http://cocoa.ethz.ch/downloads/2014/06/None_MIT-AUTOID-WH-001.pdf
- 37 doi.org/10.1145/122344.122367
- 38 <ftp://publications.ai.mit.edu/ai-publications/pdf/AIM-1180.pdf>
- 39 <https://aaai.org/Papers/AAAI/1993/AAAI93-069.pdf>
- 40 <https://www.nature.com/articles/s41598-017-02910-x>
- 41 <http://repository.cmu.edu/cgi/viewcontent.cgi?article=1682&context=robotics>
- 42 <http://www.msl.ri.cmu.edu/publications/pdfs/isrr99.pdf>
- 43 <https://pdfs.semanticscholar.org/d3d9/16ef99addf63f0161d3086d34415460f587b.pdf>
- 44 <http://dx.doi.org/10.1080/09537280410001662529>
- 45 <https://dspace.mit.edu/handle/1721.1/41914>
- 46 <https://www.inf.ed.ac.uk/teaching/courses/irm/mcdermott.pdf>
- 47 <https://dspace.mit.edu/handle/1721.1/108000>
- 48 https://nces.ed.gov/programs/digest/d12/tables/dt12_318.asp
- 49 <https://www.weforum.org/focus/the-fourth-industrial-revolution>
- 50 <http://www.computerworld.com/article/2474991/it-careers/women-computer-science-grads--the-bump-before-the-decline.html>
- 51 Hedberg T, Jr., Feeney A, Helu M, Camelio JA. Toward a Lifecycle Information Framework and Technology in Manufacturing. *ASME. J. Comput. Inf. Sci. Eng.* 2017;17(2):021010-021010-13. doi:10.1115/1.4034132 http://ws680.nist.gov/publication/get_pdf.cfm?pub_id=920885
- 52 <https://dspace.mit.edu/handle/1721.1/107988>
- 53 <http://www.informit.com/store/object-oriented-analysis-and-design-with-applications-9780201895513>
- 54 www.ibm.com/developerworks/rational/library/content/03July/1000/1251/1251_bestpractices_TP026B.pdf
- 55 http://eos.cs.princeton.edu/ChrisChan_IW_2008_Part2.pdf
- 56 <http://ebusiness.mit.edu/research/papers/124%20Poggio%20Lo,%20Agent-based%20Models.pdf>

57 <http://cbcl.mit.edu/cbcl/publications/memos-reports.html>

58 <https://pdfs.semanticscholar.org/7de2/0692c774798016e06d2eb0ade959c61df350.pdf>

59 <http://web.mit.edu/sysdyn/sd-intro/D-4165-1.pdf>

60 <http://scripts.mit.edu/~jsterman/docs/Sterman-1992-SystemDynamicsModeling.pdf>

61 <http://archive.computerhistory.org/resources/text/GE/GE.150.1959.102621675.pdf>

62 <http://ubiquity.acm.org/article.cfm?id=2822533>

63 <https://www.arm.com/markets/internet-of-things>

64 www.mdnp.org and www.openice.info

65 <http://www.cnri.reston.va.us/k-w.html>

66 <http://ubiquity.acm.org/article.cfm?id=2822529>

67 <http://www.eurecom.fr/en/publication/4716/download/cm-publi-4716.pdf>

68 <https://www.nist.gov/news-events/news/2016/07/nists-network-things-model-builds-foundation-help-define-internet-things>

69 www.open-mesh.org

70 <http://in.grundfos.com/industries-solutions/industries/wastewater-treatment.html>

71 <http://www.ieee802.org/1/pages/tsn.html>

72 http://www.lightreading.com/iot/iot-strategies/how-iot-forked-the-mobile-roadmap/a/d-id/720262?image_number=1

73 <https://arxiv.org/pdf/0706.1062.pdf>

74 <https://www.ucsf.edu/news/2014/02/111976/samsung-ucsf-partner-accelerate-new-innovations-preventive-health-technology>

75 <https://www.business.att.com/enterprise/Family/internet-of-things/iot-healthcare/>

76 <http://www.lightreading.com/data-center/data-center-infrastructure/huawei-partners-with-global-switch-to-build-modular-data-centers-supporting-smart-oandm/d/d-id/731936>

77 <https://opensource.com/resources/what-are-microservices>

78 <https://msdn.microsoft.com/en-us/library/bb833022.aspx>

79 <https://dspace.mit.edu/handle/1721.1/41902>

80 <https://www.blockchain.com/>

81 <https://dspace.mit.edu/handle/1721.1/107988>

82 <https://dupress.deloitte.com/dup-us-en/focus/industry-4-0/digital-twin-technology-smart-factory.html>

83 <http://www.cio.com/article/2886389/enterprise-software/digital-buzzwords-are-obscuring-real-business-strategies-and-value-creation.html>

84 <http://ieeexplore.ieee.org/document/1649428/>

85 <http://www.acad.bg/ebook/ml/Society%20of%20Mind.pdf>

86 <http://www.mckinsey.com/business-functions/digital-mckinsey/our-insights/digital-blog/burned-by-the-bots-why-robotic-automation-is-stumbling?>

87 www.jbs.cam.ac.uk/fileadmin/user_upload/research/centres/india/downloads/report_talwara.pdf

88 https://books.google.com/books/about/Good_Profit.html?id=Kp_GBgAAQBAJ&source=kp_cover

89 <https://hbr.org/2016/06/manufacturing-companies-need-to-sell-outcomes-not-products>

90 https://www.nasa.gov/mission_pages/station/research/experiments/1326.html

91 <http://www.accion-systems.com/team/>

92 <http://odl.mit.edu/>

93 http://media.proquest.com/media/pq/classic/doc/3389125941/fmt/ai/rep/NPDF?_s=wUTlu9wjfAltqKUqmHEHxqi6w5E%3D

94 https://harvardx.harvard.edu/files/harvardx/files/reich_reconsidering_moocs.pdf

95 <https://www.edsurge.com/news/2017-02-22-the-flip-side-of-abysmal-mooc-completion-rates-discovering-the-most-tenacious-learners>

-
- ⁹⁶ <http://scm.mit.edu/micromasters>
- ⁹⁷ <http://scm.mit.edu/admissions/faqs>
- ⁹⁸ <https://micromasters.mit.edu/>
- ⁹⁹ <https://www.gfmag.com/global-data/economic-data/26gzj8-payments-volumes-worldwide>
- ¹⁰⁰ www.pwc.com/gx/en/retail-consumer/retail-consumer-publications/global-multi-channel-consumer-survey/assets/pdf/total-retail-2015.pdf
- ¹⁰¹ <https://www.worldpaymentsreport.com/#non-cash-payments-content>
- ¹⁰² www.fr.capgemini-consulting.com/resource-file-access/resource/pdf/world_payments_report_2015_vfinal.pdf
- ¹⁰³ www.mckinsey.com/~media/mckinsey/dotcom/client_service/financial%20services/latest%20thinking/payments/global_payments_2015_a_healthy_industry_confronts_disruption.ashx
- ¹⁰⁴ <http://www.worldbank.org/en/topic/poverty/overview>
- ¹⁰⁵ <https://dspace.mit.edu/handle/1721.1/107893>
- ¹⁰⁶ [http://www.thelancet.com/pdfs/journals/lancet/PIIS0140-6736\(03\)13779-8.pdf](http://www.thelancet.com/pdfs/journals/lancet/PIIS0140-6736(03)13779-8.pdf)
- ¹⁰⁷ <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3828585/pdf/1742-4755-10-S1-S2.pdf>
- ¹⁰⁸ www.childmortality.org/files_v20/download/igme%20report%202015%20child%20mortality%20final.pdf
- ¹⁰⁹ <http://cra.org/ccr/resources/ccr-led-whitepapers/#infrastructure>
- ¹¹⁰ <http://venturebeat.com/2016/09/02/a-brief-history-of-googles-ill-fated-modular-smartphone-project-ara/>
- ¹¹¹ <https://dspace.mit.edu/handle/1721.1/32706>
- ¹¹² <https://www.google.com/patents/US5028787>
- ¹¹³ <https://www.google.com/patents/US5377674>
- ¹¹⁴ https://sinolandtrade.en.alibaba.com/products/showimg/60477597513-803823402/Urine_analysis_equipment_Portable_Urine_test_analyzer.html?spm=a2700.8304367.0.0.b9GOfq
- ¹¹⁵ http://www.fasebj.org/content/31/1_Supplement/767.8.short
- ¹¹⁶ <http://www.sciencedirect.com/science/article/pii/S1367593108001245?via%3Dihub>
- ¹¹⁷ <https://www.nature.com/articles/micronano201722.pdf>
- ¹¹⁸ <http://pubs.acs.org/doi/full/10.1021/acscentsci.7b00021>
- ¹¹⁹ http://cmliris.harvard.edu/assets/Nanomedicine_1_51.pdf
- ¹²⁰ <https://www.nature.com/articles/n-12342922>
- ¹²¹ <http://science.sciencemag.org/content/356/6341/938>
- ¹²² <https://www.nature.com/emm/journal/v49/n5/pdf/emm201736a.pdf>
- ¹²³ <http://pubs.acs.org/doi/pdf/10.1021/acs.nanolett.7b00442>
- ¹²⁴ <https://risnews.com/case-study-metros-future-store>
- ¹²⁵ <https://www.forbes.com/sites/ronaldholden/2017/05/22/amazons-no-line-no-checkout-groceries-are-still-in-beta/#70bca23569ed>
- ¹²⁶ <http://onlinelibrary.wiley.com/doi/10.1111/acem.12625/abstract>
- ¹²⁷ <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2653931/pdf/823.pdf>
- ¹²⁸ <http://www.newyorker.com/magazine/2015/05/11/overkill-atul-gawande>
- ¹²⁹ www.motherjones.com/politics/2015/10/epic-systems-judith-faulkner-hitech-ehr-interoperability/
- ¹³⁰ <https://assets.documentcloud.org/documents/2461137/onc-report-to-congress-on-health-information.pdf>
- ¹³¹ <http://www.healthcareitnews.com/news/deaths-by-medical-mistakes-hit-records>
- ¹³² <http://www.bmj.com/content/353/bmj.i2139>
- ¹³³ www.mdppn.org
- ¹³⁴ www.openice.info
- ¹³⁵ <http://www.docboxmed.com/>
- ¹³⁶ <http://ubiquity.acm.org/article.cfm?id=2822883>
- ¹³⁷ <https://dspace.mit.edu/handle/1721.1/108000>

-
- ¹³⁸ <http://lewisandquark.tumblr.com/post/160776374467/new-paint-colors-invented-by-neural-network>
- ¹³⁹ www.healthnewsreview.org/2017/02/md-anderson-cancer-centers-ibm-watson-project-fails-journalism-related/
- ¹⁴⁰ <https://which-50.com/cover-story-watson-cancer-story-ibm-doesnt-talk/>
- ¹⁴¹ <http://science4data.com/>
- ¹⁴² <http://www.sciencedirect.com/science/article/pii/S0004370282900388>
- ¹⁴³ Bishop, Christopher M. (1995). *Neural networks for pattern recognition*. Oxford University Press. http://cs.du.edu/~mitchell/mario_books/Neural_Networks_for_Pattern_Recognition_-_Christopher_Bishop.pdf
- ¹⁴⁴ <http://ieeexplore.ieee.org/abstract/document/824819/>
- ¹⁴⁵ <http://www.singularity.com/KurzweilFuturist.pdf>
- ¹⁴⁶ <http://www.aliannajmaren.com/>
- ¹⁴⁷ <https://www.khanacademy.org/>
- ¹⁴⁸ <https://www.inc.com/linkedin/sramana-mitra/billion-dollar-unicorn-udacity-leans-industry-giants-sramana-mitra.html>
- ¹⁴⁹ <https://www.statista.com/>
- ¹⁵⁰ <http://jaha.ahajournals.org/content/5/7/e003428.short>
- ¹⁵¹ www.mobihealthnews.com/30219/ucsf-samsung-to-validate-and-commercialize-digital-health-tools
- ¹⁵² <http://ieeexplore.ieee.org/abstract/document/7067022/>
- ¹⁵³ <http://groups.csail.mit.edu/medg/ftp/psz/k-rep.html>
- ¹⁵⁴ <http://longstreet.typepad.com/thesciencebookstore/2015/10/a-small-note-on-the-future-of-the-future-1911.html>
- ¹⁵⁵ www.un.org/en/development/desa/population/publications/pdf/ageing/WPA2015_Report.pdf
- ¹⁵⁶ <http://www.mckinsey.com/global-themes/employment-and-growth/how-advancing-womens-equality-can-add-12-trillion-to-global-growth>
- ¹⁵⁷ <http://astronauticsnow.com/history/goddard/index.html>
- ¹⁵⁸ <https://dspace.mit.edu/handle/1721.1/56251>
- ¹⁵⁹ <http://dx.doi.org/10.1063/1.1749590>
- ¹⁶⁰ <http://science.sciencemag.org/content/early/2017/01/25/science.aal1579>
- ¹⁶¹ <https://www.nytimes.com/2017/01/26/science/solid-metallic-hydrogen-harvard-physicists.html?mcubz=1&r=0>
- ¹⁶² <https://qz.com/1001518/indias-electric-vehicle-revolution-will-begin-with-auto-rickshaws-running-on-swappable-batteries/>
- ¹⁶³ www.technologyreview.com/s/601013/the-internet-of-things-roadmap-to-a-connected-world/
- ¹⁶⁴ <https://dspace.mit.edu/handle/1721.1/41903>
- ¹⁶⁵ Forster, Edward Morgan. (1905) *Where Angels Fear to Tread*
- ¹⁶⁶ http://www.omg.org/mda/mda_files/09-03-WP_Mapping_MDA_to_Zachman_Framework1.pdf
- ¹⁶⁷ <https://caminao.wordpress.com/overview/thread-ea/>
- ¹⁶⁸ <https://caminao.wordpress.com/open-concepts/ontologies-models/>
- ¹⁶⁹ <https://julialang.org/>
- ¹⁷⁰ <https://obamawhitehouse.archives.gov/the-press-office/2015/07/28/remarks-president-obama-people-africa>
- ¹⁷¹ *Oeuvres Complètes: Recueil Des Lettres De M. De Voltaire*. T. 3 **81** 1739 – 1741 (Sanson, 1792)

Disclaimer - The author is solely responsible for the opinions and comments. Views are not attributable to any organization with which the author is affiliated at present or was affiliated in the past. Names are used without permission and does not imply endorsement of ideas, products or promotion of companies.

APPENDIX I



The Great Wave at Kanagawa, 1829 by Katsushika Hokusai (modified)

Digital Tsunami

The objective of this blog is to suggest tools and structures that businesses may use or develop in order to benefit from the tsunami of digital transformation, create new lines of business and venture into new global markets. The task is immense and as a consequence any cohesive synthesis is vastly imperfect, as indicated in the “preface” on page 2. Despite its critical shortcomings, the appendix (this section) will try to provide a context for individuals who may be less acquainted with the current wave of digitalization.

Imagine a well-built grand highway.

Now, re-imagine a well-built grand highway but in the middle of nowhere!



Consider that within a few miles from this highway there are people living in the area. You are here to sell Tesla Model 3. By now you have grasped the conundrum. Haven't you? Your potential customers near the highway are strongly suggesting that if you wish to sell cars, please help them to build roads.

But that is a different task, the job of building roads. Other potential customers are taking you (on their horses) to show some of dirt roads and even stretches of ill-maintained paved roads which are peppered with pot holes. Can you help them repair pot holes or can you sell them faster horses, instead of Tesla?

In the analogy to digital transformation, imagine the highway to represent the digital platform of convergence. The car is your application or transaction or enterprise, on that platform, which enables you to connect to the ecosystem, using the platform (that is, you travel from A to B to C and may engage in commerce, if the highway was connected to the people and businesses via roads, lanes and bridges).

The job of building roads and repairing pot holes, dampens the thrill of driving the Tesla down the highway. Digital transformation projects are failing or pilots are struggling to break away from small scale implementations because we are interested in the exciting aspects of the digital revolution, IoT and AR/VR. We are less interested to help bridge the gap from legacy, devices and monolithic systems.

This blog suggests that decomposition of the enterprise into modular blocks and enabling connectivity between the building blocks to synthesize the customer facing outcome may be a multi-step and tedious process, but one that is mandatory, if we expect to profit from the vast potential of digital enterprise.

To profit, the customer facing outcome must be the reverse of what is mentioned in the last paragraph. Customers are seeking solutions to their problems not just “patches” or information about the problem when unpacked and reduced to tractable sub-problems. Dissection is quintessential but the customer will reward (pay) the value provider who can synthesize a “systemic” solution not just install a tool or technology as a contribution to the “whole” solution. Hence, “tool” providers (Intel, Cisco, Microsoft, Oracle, SAP, IBM) are all consulting companies. Tools are not produced in the context of the enterprise but externally with guidance from knowledge experts. The demand from system integrators (Accenture, Deloitte, KPMG, Wipro, Infosys, TCS) is to “stitch” the “patches” from “tool” providers and expect a harmonious and functional “quilt” to serve as a solution. Exception to this model are conglomerates like GE, Siemens and Hitachi. They are evolving from manufacturing and finance to systems companies recognizing the underpinning of data, information and knowledge which is at the core of profitability in a connected world. The creation of GE Digital and its software evolution through Predix, is one example. It reflects a thinking about systemic solutions approach to problems rather than depend on vendors or system integrators. Both are essential in the ecosystem but business solutions from businesses may offer a different flavor because they view the whole “elephant” rather than look at it in parts.



[The Blind Men and the Elephant • John Godfrey Saxe \(1816-1887\)](#)

In systems thinking a common [analogy](#) is that of [six blind men from Indostan](#) (India) touching various parts of an elephant and claiming that “elephant is a tree” (man who touched the leg), “it is like a rope” said the blind man who touched the tail. “Like a snake” (man who touched the trunk). “It is like a big hand fan” (man who touched the ear). “Like a huge wall” said the man who touched the belly of the elephant. “Like a spear” said the blind man who touched the tusk. They were misguided in describing the part they touched and as a consequence their interpretation is incorrect about the whole animal.

The illusion of expertise peddled by vendors and integrators are true in the context of their “part” of the solution. The latter was not unsuitable for an analog world where the company had no idea of what happened to the product once it left the manufacturing plant. In the service paradigm, connectivity is the bread and butter. Customer experience is king. The ubiquity of digital transformation has the potential to constantly communicate and harvest outcomes from each user layer or machine or device. The inability of the system to use that data or extract the information is directly proportional to its profitability or lack of it.

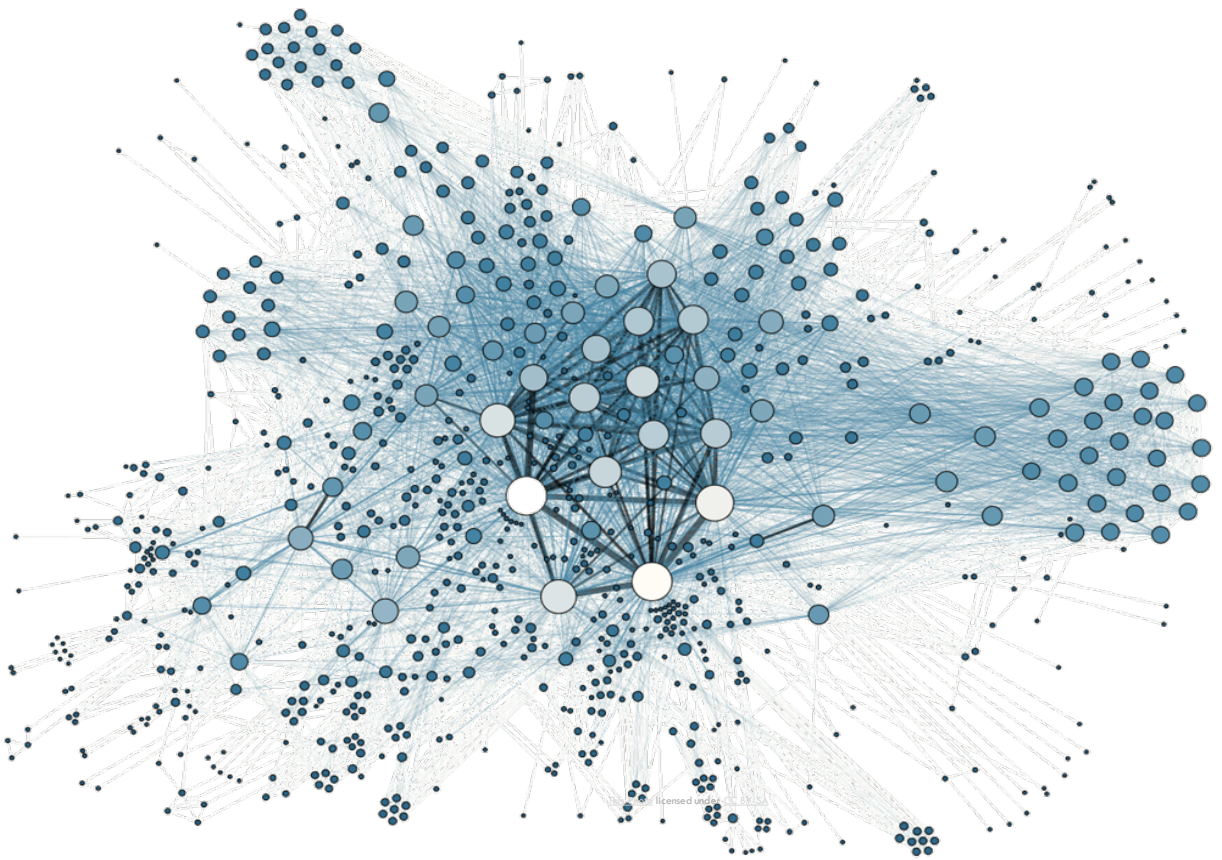
Hence, the “illusion of expertise” which was once suitable and sufficient for discrete analog enterprises, is now a chronic recurring challenge which handcuffs systemic innovation. The vast complexity of business evolution in its always connected digital transformation *modus operandi* is an entirely new playing field. There is plenty of room for conglomerates to profit from unleashing *intrapreneurs* and supporting unconventional entrepreneurial innovation to splice with conventional wisdom. Leaders must recognize the illusions (and delusions) in traditional business as usual and help to remove those roadblocks to spur real transformation, that is, the whole “elephant” is your customer.



The whole “elephant” is the customer. An “analog” approach to “parts” may be insufficient to increase profitability when continuous connectivity of service, and “intelligent” decision support systems in near real-time, are desired outcomes and key performance indicators (KPI) expected from digital enterprises. The metaphor of building blocks in this blog now must help build the metaphorical elephant which is a connected system, a biological enterprise. One cannot use the mouse as a model to build an elephant.

APPENDIX II

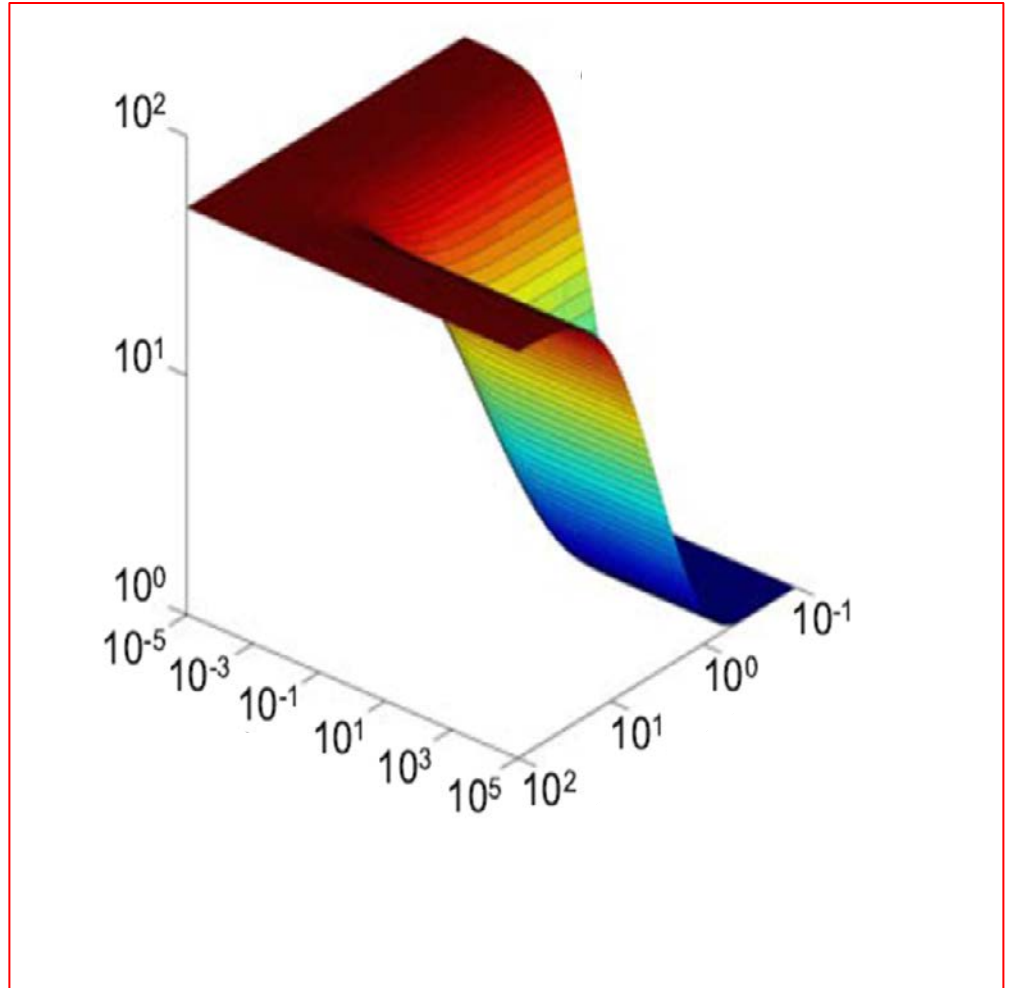
Physical+Digital



Synergistic Integration Platform for Sense and Response Paradigm

SIPSAR

Shoumen Palit Austin Datta
Email - shoumen@mit.edu



Platform for Synergistic Integration of Predictive Maintenance of Machines with Maintenance and Repair Supply Networks: Virtual Mobile Dashboard for Near Real-Time Transparency and Operations Management Optimization

Shoumen Datta, Auto ID Labs, Massachusetts Institute of Technology and MDPnP Lab, Massachusetts General Hospital, Harvard Medical School

PREFACE

In the US, a quarter million patients die each year due¹ to preventable medical errors. One leading cause is the lack of medical device interoperability² and the lack of data integration platforms. The latter is quintessential to treat the patient, as a whole. The widespread practice of viewing stand-alone data from multiple medical devices, attached to the patient, manufactured by different medical device equipment companies, increases the risk of fatal errors, due to the reliance on medical professionals, who must integrate all the data, in order to actuate treatment.

The human heart, as an example of a machine, may be deconstructed into parts and components. Hence, a bill of materials (BOM) may be prepared and various parts/components may lend itself to monitoring using signals and sensors. Reconstructing the signals on a common “heart health platform” may reveal the state of heart health. The knowledge, dependencies and case logic, embedded in the platform, may remain cryptic to the point-of-care end-user. But, the *combined* outcome, based on analytics of the data, from signals and system of sensors, from various medical devices, may aid in the precision and accuracy of the decision support system (DSS). Humans in the loop may use the outcome to design preventive measures, recommend maintenance (for example, valvuloplasty) or prescribe medication (for example, statins, a class of lipid-lowering drug which is a HMG-CoA reductase inhibitor).

The thrust of this position paper is to recommend that we pursue an analogous approach for all machines and devices, to maintain the health of machines. We may create an open source approach to synergistic integration of data, using “plug-n-play” modular platforms, running analytical engines to extract information, from system of sensors. Promoting interoperability between platforms may unleash the potential for diagnostics using real-time data. Taken together, it may mitigate mechanical risks due to usage, reduce uncertainty of operational downtime, prevent energy waste, optimize output efficiency, catalyze savings from economies of scale and use of big data.

The application of this *modus operandi* is scalable for manufacturing, through integration with legacy manufacturing execution systems (MES), product lifecycle management (PLM) systems and advanced planning and optimization (APO) routines, commonly found in classical enterprise resource planning (ERP) systems. Shop floors with a few or a few hundred machines, are equally capable of harvesting the value from synergistic integration. We can extend this approach to [1] a collection of diverse machines, for example, farm equipment, [2] different devices, for example, home health monitoring, wearable body sensors for wellness and healthcare, [3] transportation network of vehicles, combined with traffic data, [4] optimize load balancing in energy distribution using smart grids.

Our suggestions are neither unique nor novel. The strength of this proposal is grounded in an *open-source, modular* approach, which can support scalability, interoperability and real-time communication for transparency, with suitable data protection (cybersecurity, privacy, identity and authorization). Proprietary platforms often retard productivity by reducing economies of scale, may exclude outlier events which could influence performance and increases TCO or total cost of ownership (for example, capital expenses, cost to operate) for global operations, if multiple types of platforms, which may lack interoperability, give rise to local silos or cannot “talk” between regions. Open-source optimization for customer-centric value is not synonymous with corporate profit-centricity. Hence, transforming this vision into reality, albeit in parts, requires a PPP (public-private partnership) framework with pre-competitive collaborators from industry and users (customers), along with academia and government agencies, to fund this initiative, and enable large scale implementations. Monetization of open source platforms, and the service supply chain of data acquisition tools (sensors, communications), are quite common. To accelerate global diffusion, a pay-per-use, micro-revenue business model, may lubricate market entry, and amplify, long term, ethical profit.

¹ <https://doi.org/10.1136/bmj.i2139>

² <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5052027/>

FRAMEWORK

The conceptual structure, of the synergistic integration platform infrastructure, may be loosely illustrated by the old telephone switchboard (Fig 1). The “plug-n-play” input resembles the potential to aggregate data streams from sensors, actuators, RFID tags and other tools. In the logic layer background, the nature or type of data may trigger *data-dependent selection* of one or more tools, for example, analytical engines, “containers” with algorithms for data-driven micro-services³ and other virtual machines, which may be on-site or sourced, *ad hoc*, from clouds, fog, or mist computing repertoires. Automated programming⁴ and feature engineering⁵ may be included with ML.



Fig 1: The old telephone switchboard may be conceptually analogous to future ‘plug-n-play’ integration platforms.

The analytical output may feed decision support systems, and/or actuators, and/or executable software programs, to act/modify physical systems (for example, cyberphysical systemic control of valves based on rate/flow). The visualization of the data on a mobile device (smartphone) may resemble the cartoon in Fig 2. The illustration is adapted from an agent-based inventory monitoring⁶ example which used RFID data. For our current discussion, each component from the BOM which can be sensed, may be attached with a sensor (vibration, temperature, pressure). The sensor data will be transmitted to an Agent system where one dedicated software agent will be responsible for acquiring the sensor data and feeding it to an ‘agency’ which will converge inputs to trigger alerts or execute action.

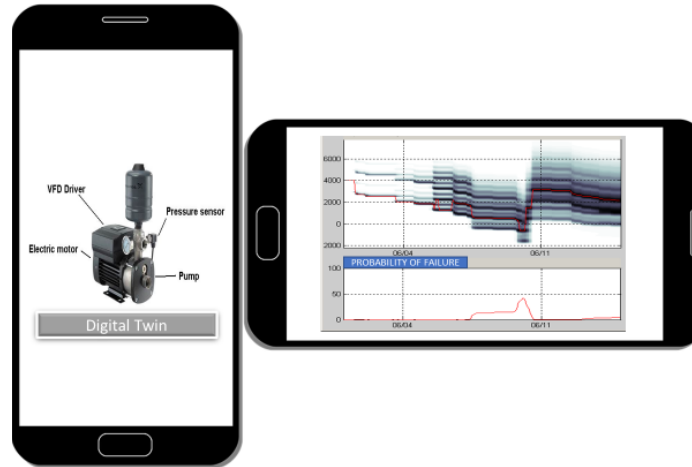


Fig 2: Monitoring mean time between failure (MTBF) from sensor data on a mobile smartphone. With decreasing residual lifecycle (upper panel) the probability of failure (broken part may precipitate unplanned downtime) increases (lower panel). Just in time spare parts supply chain coordination with maintenance, using MTBF data, prevents potential machine failure. Probability of failure drops to “zero” (lower panel) when the part at risk is replaced. This example of an agent-based system uses MTBF metrics and ML to guide preventive maintenance.

³ <https://ieeexplore.ieee.org/document/7506647/>

⁴ <https://arxiv.org/pdf/1807.02816.pdf>

⁵ https://www.featurelabs.com/wp-content/uploads/2017/12/DSAA_DSM_2015.pdf

⁶ <http://dSPACE.mit.edu/handle/1721.1/111021>

IMMENSE SCOPE

Data from sensors integrated into⁷ sensing-compatible components of machines (for example, hoses, seals, belts) can transmit data about operating conditions (temperature, pressure) as well as micro- and macro-system wear, as a measure of system health. In principle the ‘sense & response’ paradigm may not be restricted to devices, machines, and energy. The scope of *sense & response* can embrace much more than manufacturing (eg Wabash), farm operations (eg Fair Oaks Farms) and robotics (eg Automotive Robotics). The scope may extend to system of systems including machines, buildings, roads and emergency response systems. In other words, this synergistic integration platform (SIP) can distribute the sense & response (SAR) paradigm to gauge the real-time “health” of the university campus, community, city, county, state and a bird’s eye view of the networked society (cartoon⁸ below).

SIP SAR is driven by the mantra of connectivity, the primary barrier preventing the implementation of the scope. Lack of communication between systems, loss of data due to absence of interoperability, and the chasm between manufacturing processes and products, are all remediable injustices, yet they are still holding back global productivity. However, tracking money and financial transactions⁹ are making better use of connectivity.

One purpose of this proposal is to identify gaps which may be addressed through research to improve connectivity and, in turn, productivity. In parallel, with a greater priority, this proposal expects to coalesce PPP to deliver very large scale implementations of SAR (sense & response paradigm), which has been popularized by the metaphor of internet of things (IoT). IoT is a digital by design approach, which encapsulates the connectivity of the networked physical world¹⁰ where the duality of the physical, and the digital, converges into a fluidic continuum.

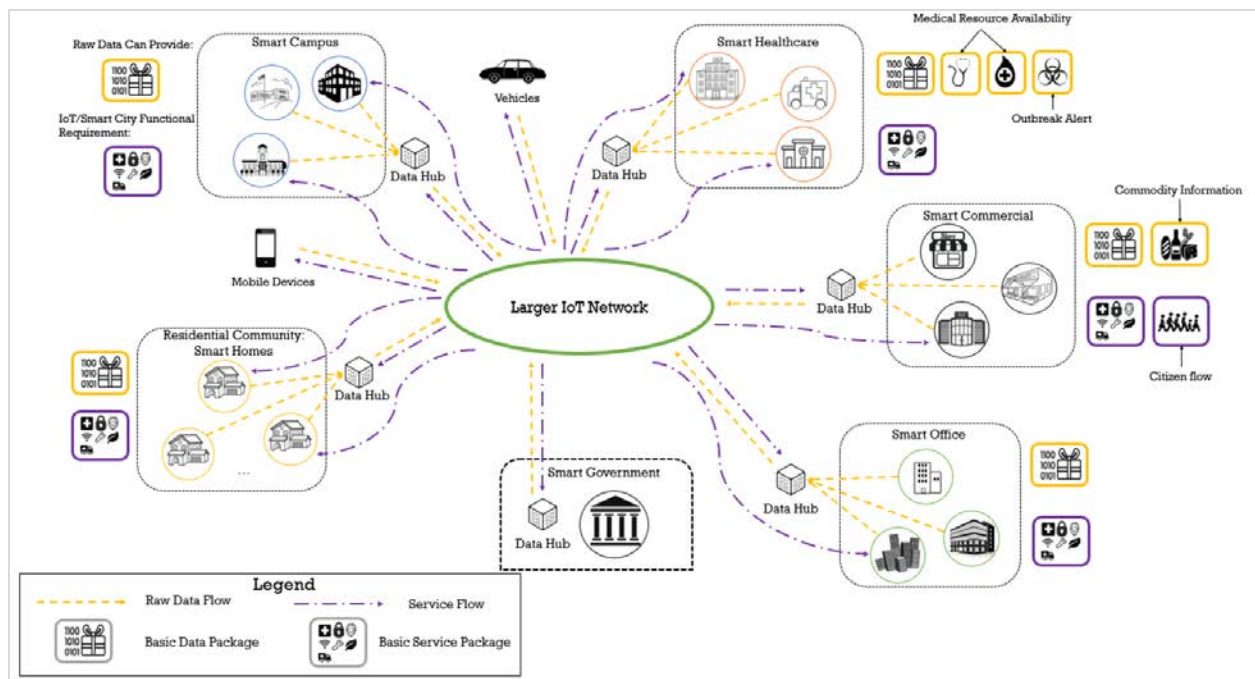


Fig 3: IoT is a metaphor without borders. It represents⁸ a continuum made up of discrete objects, decisions, processes and outcomes, each of which, in turn, impacts and influences, man and machines, life and living.

⁷ <https://dl.acm.org/citation.cfm?doid=3131672.3131702>

⁸ <http://bit.ly/CDAIT-IoT>

⁹ <https://newsroom.mastercard.com/press-releases/mastercard-introduces-mastercard-track-to-make-the-business-of-doing-business-easier/>

¹⁰ http://cocoa.ethz.ch/downloads/2014/06/None_MIT-AUTOID-WH-001.pdf

CYBERMANUFACTURING

Connectivity and chemistry, in combination, presents the next emerging challenge to the *status quo* of manufacturing. The quantum leap for material science is a rags¹¹ to riches story¹² which has the potential to change almost everything in classical manufacturing and usher in cyber-manufacturing as well as the future digital foundry.

Additive manufacturing of metals, composites, biomaterials (joints, prosthetics), will re-form the supply chain using distributed additive manufacturing on-demand and replenishment (**DAMODAR**). The inclusion of “replenishment” signifies the profound supply chain disruptions, and business discussions, that distributed on-demand direct digital manufacturing (cyberphysical) systems, is poised to usher. The “distributed” local physical presence, will benefit from the confluence of ideas from global digital connectivity (*metaphor of IoT-by-design*). Digital design tools (cyber component) may harvest “best of breed” outcomes from experts and benefit from location-agnostic convergence of deep knowledge. The best parts can be printed in Mongolia and Mogadishu (as well as, on a military¹³ aircraft carrier). Thus, in combination, it may influence the context, quality, metrology, and performance, of local physical manufacturing (3D printed additive manufacturing products (**DAM**) as a service).

3D printed objects with integrated sensors¹⁴ presents the next opportunity for precision in detection, diagnostics and advanced analytics. Imagine a 3D printed hip joint using metal-ceramic composites or other metal alloys¹⁵ that may be a partially hollow mesh integrated with sensors (gyroscopic sensor, glucose sensor, CTx-1 collagen sensor¹⁶ for bone loss) and room for cancellous bone (spongy bone) containing hematopoietic precursors (forms blood cells). Therefore, direct digital manufacturing brings us back to where we started. Cyber-manufacturing can work as a catalyst to democratize healthcare. Using distributed additive manufacturing, the advanced hip joint may be printed on-site for fortunate folks in Anchorage as well as the less fortunate people in Addis Ababa.

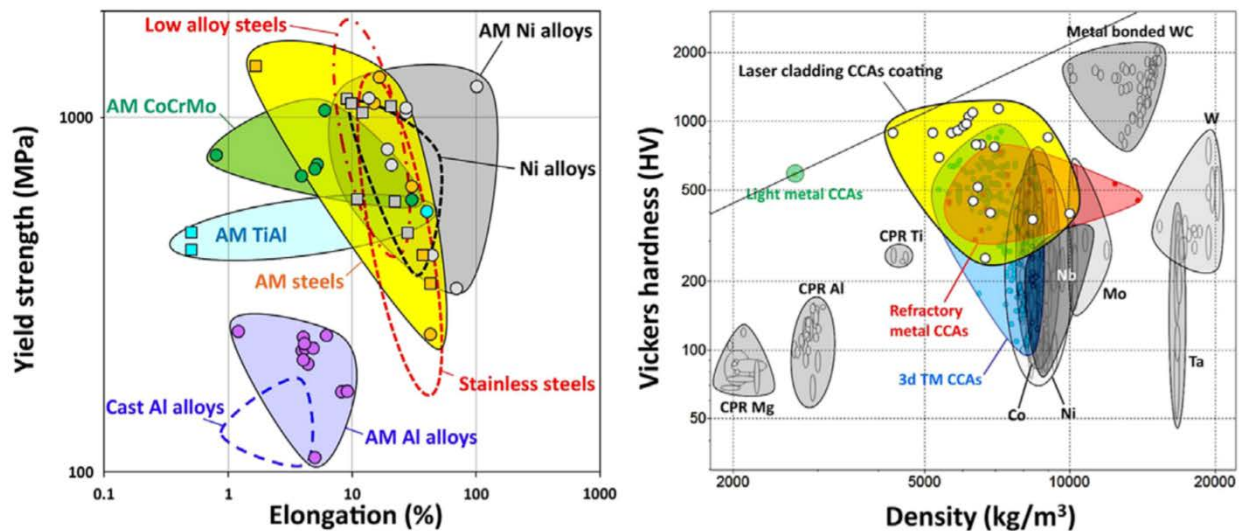


Fig 4: Mechanical properties of additive manufactured alloys¹⁵ compared to conventionally processed counterparts.

¹¹ <https://bases-brevets.inpi.fr/fr/document/FR2567668/publications.html>

¹² <https://patents.google.com/patent/US4575330>

¹³ https://www.darpa.mil/attachments/DARAPA60_publication-no-ads.pdf

¹⁴ <https://pubs.acs.org/doi/10.1021/acsami.8b06903>

¹⁵ <https://www.tandfonline.com/doi/full/10.1080/14686996.2017.1361305>

¹⁶ <http://www.mdpi.com/2224-2708/7/1/10>

SIPSAR is Appendix II in Chapter 5 of the book 'Haphazard Reality - IoT is a Metaphor' available from the MIT Library.

<http://dspace.mit.edu/handle/1721.1/111021>

TRANSCENDENTAL CONNECTIVITY



Chadwick (the discoverer of the neutron) was a student of Rutherford (discoverer of the proton) who was the student of Thomson (the discoverer of the electron).

CHAPTER 6

Shoumen Datta

HAPHAZARD REALITY – IOT IS A METAPHOR

THIS PAGE IS LEFT BLANK

Digital in 4D

COMBINE

Telecommunications (COM) + Bio (B) Info (I) Nano (N) Ecology-Environment (E)

Shoumen Palit Austin Datta

This blog is dedicated to the memory of Mrs Sheila O’Sullivan. If diagnosis and treatment of her breast cancer, had access to these tools, there would be so much reason to celebrate her life, rather than her death anniversary, on 25th September.

Detection, Data, Diagnosis, Decision

Digital in 4D • Transformation of Public Health, Environmental Health, Healthcare & Preventive Medicine

Dr Shoumen Palit Austin Datta, Massachusetts Institute of Technology (MIT) and Massachusetts General Hospital, Harvard Medical School (HMS)

PREFACE

The ideas and suggestions in this blog are not uncommon. This is neither an unique proposal nor a report about a new widget or novel technology. The strength, and purpose of this blog, is to seek convergence. Suggested scenarios, highlights the synthesis and confluence of tools, without any new inventions. The suggestions offer room for innovation, social business, economic progress, plethora of entrepreneurial opportunities, ways to improve quality of life and lift many boats.

Suggestions in this blog may not provide any final solution, it is a compass to create solutions, far beyond the scope of this discussion. The primary focus is on detection and orders of magnitude we may gain, in terms of sensitivity of detection, from micro-arrays vs nano-arrays. Unless we can detect, we can neither measure nor diagnose. Unless we detect long before the event precipitates, the actions and analytics necessary to trigger predictions for prevention, may be moot and sterile.

PROBLEM SPACE - SOLUTION PORTAL

US DHS CBP officer at Boston Logan Airport Global Entry kiosk hands me a tube, and instructs me to spit inside the tube, *after* I take it over to the attendant, in the holding area. I am returning back to the US, after giving a talk at the Internet Forum in Goma, DRC. During the event, I lodged at the Lake Kivu Serena Hotel in Gisenyi, Rwanda. To re-enter the US, I must be tested for Zika virus, first detected in 1947 in the Ziika forest, Entebbe, Uganda, near Lake Victoria. The forest is more than 500km east of the locations I visited. Goma and Gisenyi, are both located on the shores of Lac Kivu, but in different countries, Democratic Republic of Congo and Rwanda, respectively.

My sputum is diluted, and a miniscule drop is applied (using a micropipette), on a flash drive with a micro-USB. The attendant hands me the flash drive and suggests I insert it in my phone, *after* activating the DHS Global Entry app. The app display reveals a distinct red button. The dialog box prompts me to insert Foreign Agent Detection (FAD) flash-sensor drive. I insert the flash drive. In about 30 seconds, the red button turns blue. It reads: "SUCCESS! Foreign agent was not detected. Welcome to the United States of America." I return the drive. On inquiry, I learn the assay^[1] used gold nanostars conjugated with antibodies to detect Zika non-structural protein 1 (NS1). The sensitivity to the biomarker was improved using surface enhanced Raman spectroscopy (SERS). The assay did not detect NS1 in my sputum. Hence, I was free to walk out of the secure area. A DHS agent re-checks my app for the blue button. I proceeded to baggage claim to pick up my bag.

ABSTRACT

This blog analyzes tools and technologies, to collect data, and the convergence, to transform this scenario (above) to reality. This is one of many potential^[2] applications in healthcare. However, 'detection' is useful in agriculture, security, environment, manufacturing, etc.

INTRODUCTION

The public health scenario, in practice, may prevent epidemics and pandemics. It may help identify the point of origin, pattern of dissemination and spread of infection, due to a pathogen.

The sensor, in the scenario, can sense any material which can be engineered^[3] and detected, within the limits of what can be sensed, if the limits of sensitivity, are useful for the purpose. Detection of air-borne pathogens^[4] or toxins^[5], arsenic^[6] in water, pesticides^[7] in soil^[8], bacteria in food^[9], methane^[10] from animals, gas^[11] in the environment, nerve agents^[12] in conflict zones^[13], chemical^[14] pollution and glucose^[15] in blood^[16], are a few, of the many use cases.

Transmission of the outcome (data resulting from action of the sensor) must generate a wireless signal^[14], which can be captured^[11] in an app^[17], is essential for connectivity and communication. It allows us to thread the “digital needle” in order to move the needle, and take advantage of the wave of digital transformation, and benefit from the imminent tsunami of digital economics^[18]. Various efforts target only part of this end-to-end scenario (detect, connect, transmit, decide).

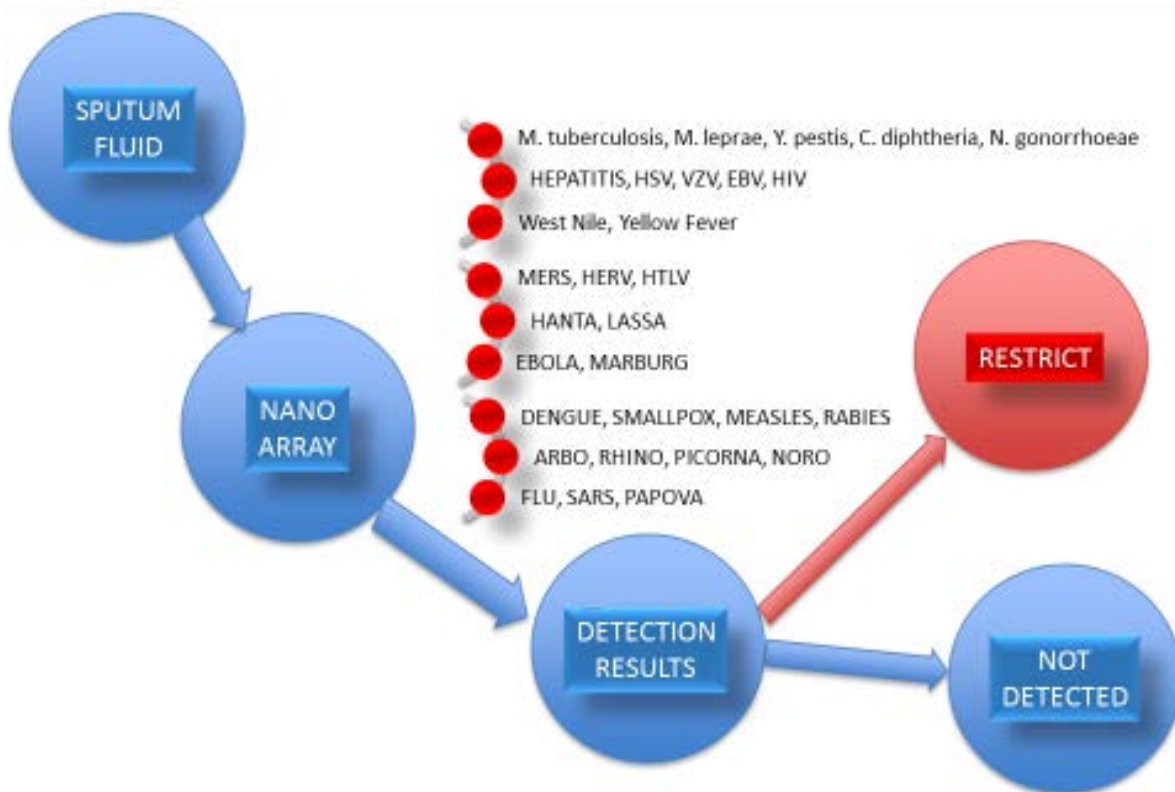
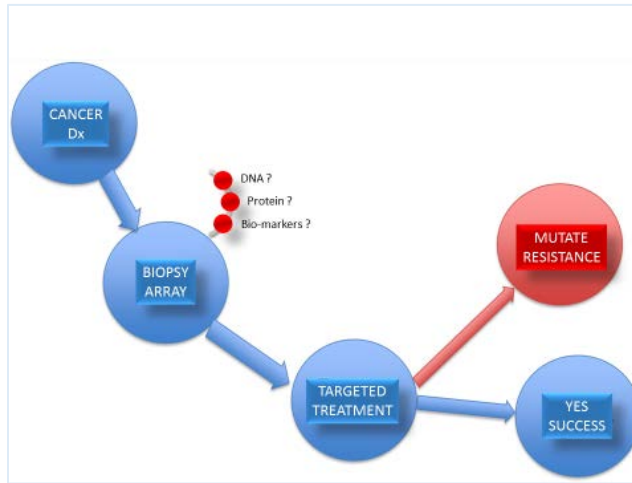
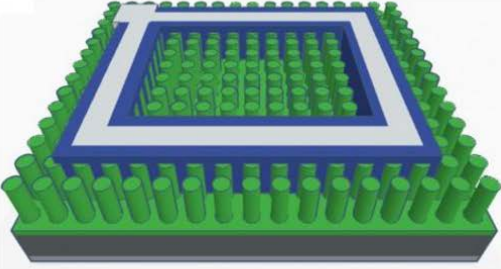


Figure 1: Simple illustration of public health application. The basic research, in principle, and the tools to connect the data, to an application, on a mobile device, are available. What are the key barriers to implementation? Growth in air travel and shipborne trade, are reasons for appearance of communicable disease pandemics, disease vector invasions, vector-borne disease movement^[19] and infected people. A risk mitigation strategy, without emphasis on detection, is blasphemous.

APPLICATIONS – INDIVIDUAL STUDIES



Secure | <https://ftoor.lab.uiowa.edu/research>



Silicon Nanowire based Optoelectronic Biosensors

Current cancer detection methods are insufficient for early detection; at present, cancer detection is performed using a combination of physical examination and CT scans or MRIs. Early detection both lowers the cost of treatment and increases survival rates. Nanowires (NWs) are effective sensing structures due to their large surface area to volume ratio. However, contacting the NW arrays is challenging. Our silicon (Si) NW optoelectronic biosensor is made by a bundle of vertically oriented NWs, allowing us to electrically contact millions of NWs per cm² simultaneously, compared to 10's of NWs in other state-of-the-art NW biosensors.

The project is in collaboration with a Massachusetts-based start-up, Advanced Silicon Group, and Professor Aliasger Salem's lab at Ulowa, and funded by the National Science Foundation STTR and I-Corps programs.

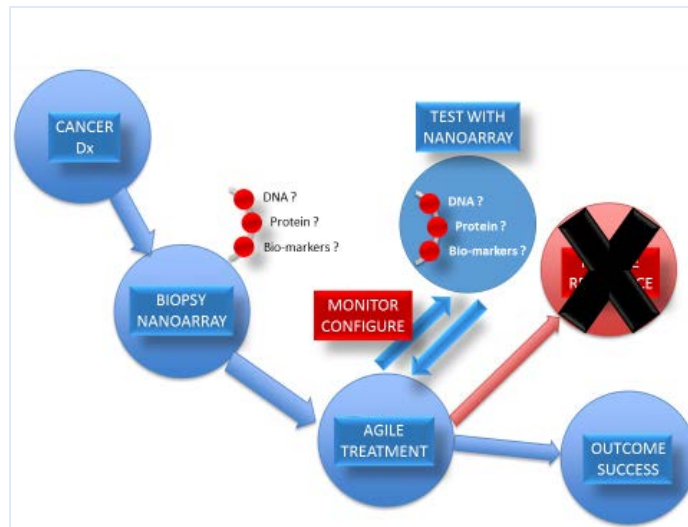


Figure 2: Monitoring bio-markers may help prevention, and treatment, in progress. Prediction of potential risks can reduce morbidity and mortality due to common diseases (stroke, congestive heart failure, COPD). What often happens during cancer treatment (upper panel) may be reduced by monitoring biomarkers with high sensitivity nano-arrays, to alleviate multi-factorial resistance.

APPLICATIONS – POPULATION STUDIES

If Twitter (Figure 3) can be used as a crowdsourcing app to map hate^[20], imagine the immense benefit to public health (and epidemiology) if we can crowdsource sensor data, about air-borne pathogens or arsenic in water (for example, Bangladesh). Using the appropriate sensor, attached to a mobile device (microUSB flash drives with swappable slots for analyte-specific sensors), one can generate global maps of analyte distribution, and track and trace, any molecule, anywhere, anytime, if the sensor and signal transmission is compatible with smartphone microUSB platform.

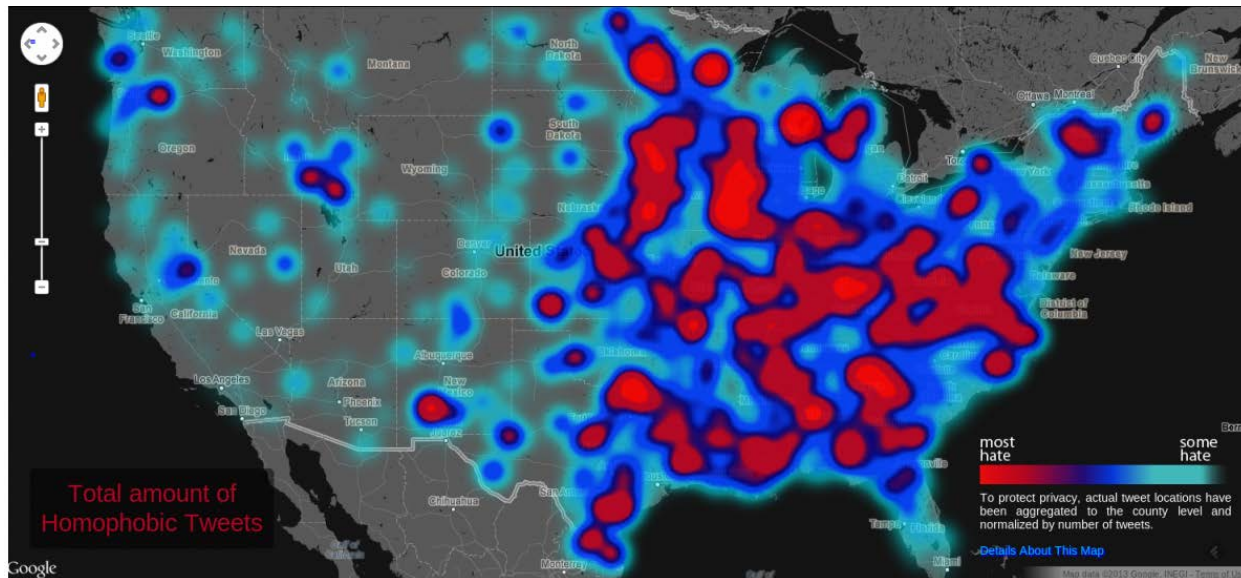


Figure 3: Potential of crowd-sourced sensor data, in convergence with GIS, to map harmful agents.



Figure 4: Converge: crowd-sourced data and swarm^[21] intelligence^[22] for data analytics?

LOCAL DECISIONS USING GLOBAL PLATFORMS: SENSE-TRANSMIT-COMMUNICATE-RESPOND

Project Ara from NK Labs^[23] (Cambridge, MA), failed to ignite the spark, at the hands of Google^[24] but its potential, if viewed with 'new' eyes, may be innovative for sensor applications.

The swappable modular architecture may be the preferred "housing" infrastructure for the sensor and serve as a platform. The form factor of this **housing platform** is a standard (USB) connector based flash drive-like unit which can transmit, compute and communicate with smart devices, for example, phones, tablets, automobiles, cameras, lawn mowers, refrigerators, washing machines. For mobility applications, the device must be mobile, but for stationary monitoring, any widget, with a connector, may be adequate, as long as it is functional, within the end-to-end ecosystem.

Computational requirements within the housing platform may need tinyOS (operating system), tinyDB (database), tinyAPI (application programming interface). Seminal work by David Culler^[25] and Howard Shrobe^[26], among others, are available for innovators, to introduce these functions, within this form factor (housing platform). Security, identity, authorization, verification and data privacy are cybersecurity^[27] issues which depends on data de-identification.

Identification of the housing platform, and creating an unique identification of the test subject, in combination with the tool (drive), may use RFID EPC code plus the IPv6 address of the device or combine with biometric id. This may be relevant for travel and immigration.



Figure 5: Any analyte, or pathogen, can be sensed, anywhere. If the sensor, and smartphone, can capture the data, it may be transmitted, anywhere. One assumes the transmission infrastructure exists, is protocol-agnostic and connects or uploads between wired or wireless, nodes or gateways. Examples of molecular diagnostics, illustrated, are benefits from medical internet of things (IoT). It may help preventive medicine, and diffusion of healthcare tools, to remote places in the world.



Figure 6: Arsenic contamination of water^[28] leads to severe morbidity, for many, in Bangladesh.



Figure 7: Pioneering work by Nokia. Connecting sensor data, for detection of Arsenic in water, with communications, may be rejuvenated in the era of IoT. Digital transformation, and detection of Arsenic, can help to improve the quality of life for inhabitants of Bangladesh. Millions of people may use a mobile phone, with attached sensor, to test any water, they encounter. The data can be uploaded to the cloud. Dynamic data analytics may provide precision maps of the areas to avoid. It may trigger measures for water safety^[29], calibrate purification^[30] and preventive healthcare.

Unless we can make sense of the data from sensors, in near real-time, the value of detection may be zero. Hence, the importance of telecommunications in this end-to-end ecosystem. Nokia's entry into "digital water" was not triggered by altruism but due to the business case, based on pay-per-use micro-payment business model (discussed in "Digital Enterprise" which is a part of "Digital Transformation" here <https://dspace.mit.edu/handle/1721.1/111021>). Telco standards and interoperability between protocols, may help or hinder adoption of solutions, in different areas.



Figure 8: Sense and response systems (in discussion) must transmit data to centers or to the edge.

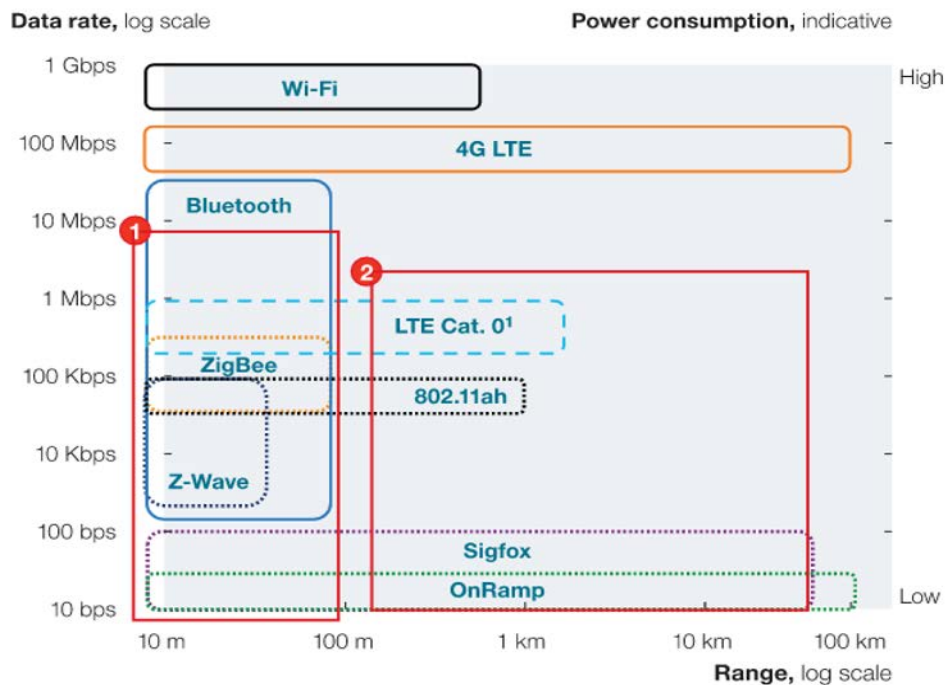


Figure 9: Competing standards and protocols in the short range (1) are an increasing problem. This is the telco segment where "detection" tools are likely to be used. Hence, compatibility and interoperability between protocols and standards, is a pre-requisite for function. The longer range (2) is used for other purposes, eg, smart grid, where there is less competition and more regulation.

Open standards and use of global standards, for example, Open Systems Interconnection (OSI) model, are important elements in the solutions approach. OSI (Figure 10) characterizes and standardizes the communication functions of a telecommunication or computing system. Its goal is the interoperability of diverse communication systems with standard protocols (Figure 11). The 7-layered OSI design is due to Charles William Bachman III (December 11, 1924 – July 13, 2017). Aspects of the OSI design are similar to ARPANET^[31] and related networks, in other countries.

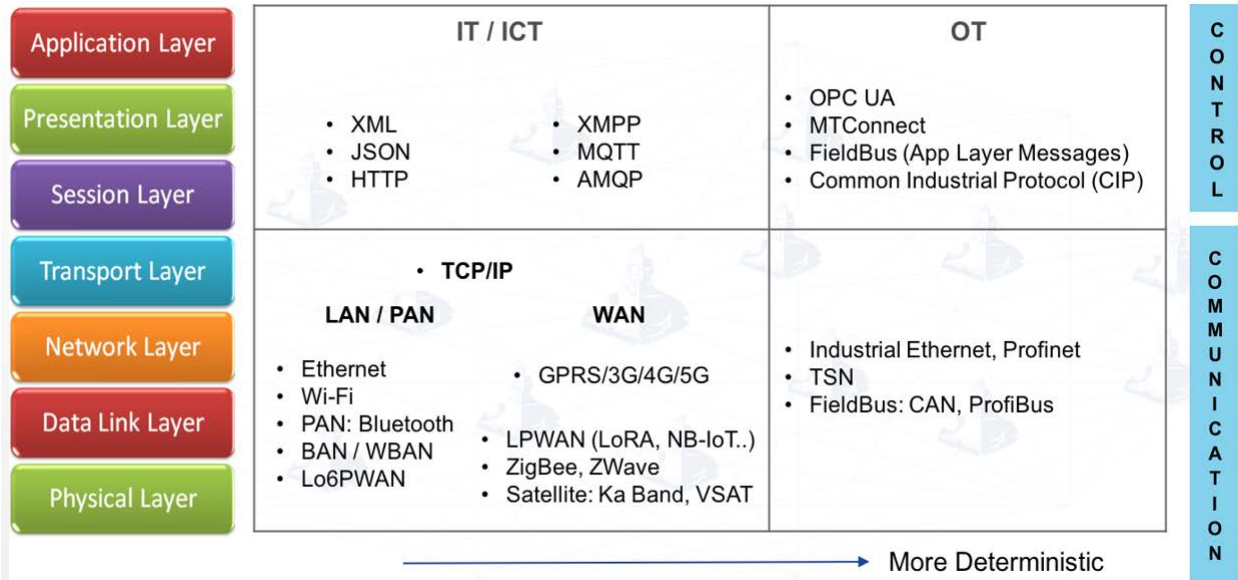


Figure 10: OSI model. ICT WAN (information communication technologies wide area network) standards are bifurcating to high-power/high-bandwidth and low-power/low-bandwidth segments. Most ICT WAN protocols aid in sensing (not in actuating). Operational Technology (OT) is not directly relevant to this discussion but it is an integral part of the 7-layer OSI model.

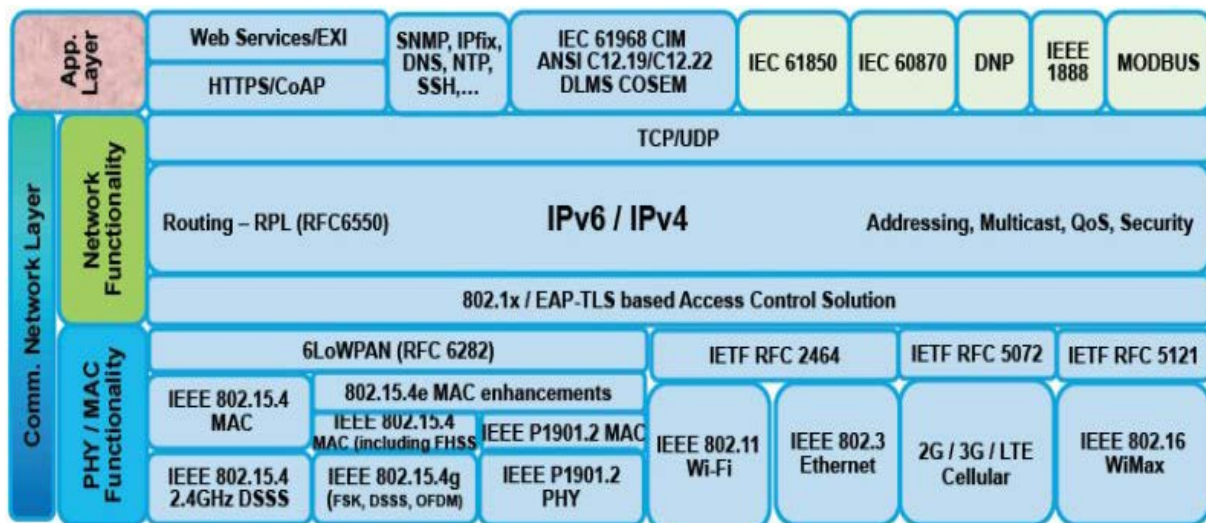


Figure 11: Standards relevant to OSI model. Open standards reference model from David Culler^[22]

REVIEWING THE COMPONENTS OF THE SYSTEM – EXPLORING THE ROOM FOR INNOVATION

The scenario presented at the beginning of this blog starts with

- [1] fluid (sputum) applied to
- [2] sensor (FAD flash-sensor drive)
- [3] which communicates via an app (data).

The sample containing the analyte or pathogen or bio-marker is the natural product, to be tested. Innovation is not applicable to this phase. Selecting alternate fluids may not be an innovation, for example, if an invasive test, involving blood were to be used, instead of the non-invasive sputum.

Signal detection, data transmission, storage, transport and visualization through an app, may not be as direct as procuring the components, in the bill of materials (BOM), from an “off-the-shelf” catalogue. However, these steps are used in millions of processes. Information is available for configurable components (for example, tinyOS and tinyDB). Communication systems must use standards and protocols. Apps, APIs, GUIs are generic software products. Taken together, it must converge to generate the result – the data – which must be analyzed, “intelligently” if possible^[32].

Data analytics is of paramount importance. It is fertile grounds for innovation, to fuel decisions, following detection, and diagnosis. Unlocking actionable information from data is the Holy Grail. Data, analytics, AI, and platforms, are brimming with hype. Examples of how the cookie^[33] can crumble^[34] are cautionary tales. Even if you have a hammer, does not mean everything is a nail.

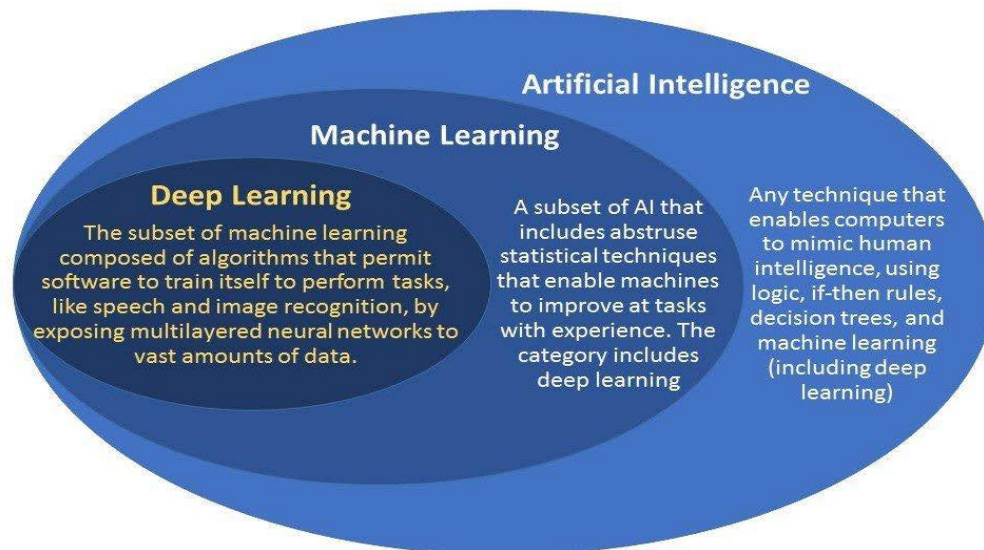


Figure 12: Making sense of data, with respect semantics and context^[35] of data, is crucial to obtaining useful information. Data must deliver value to justify the investment in the system. The application of AI (artificial intelligence) algorithms, and its various manifestations, are a part of the portfolio of approaches to data analytics. Choice of algorithms, the type of solvers and models which may be used in analytical engines, may evolve with the application, or the application may trigger functions based on context, an old idea^[36], reincarnated through SDN^[37]. The nature of the data, transmission speed, bandwidth and the latency the data can tolerate, (before the data or information perishes, in value), may dictate whether the analysis, and response, may occur via the cloud, the fog or mist or at the point of contact^[38], that is, at the edge (as in the DHS scenario).

ROOM FOR INNOVATION ?

We are left with the actual sensor. This is a critical point of convergence and demands fusion of transdisciplinary domains. Generating viable analyte-responsive sensors require orchestration of medical parameters, biology of molecules, chemistry of molecules and material, material science, biomedical device engineering, and manufacturing processes necessary to produce sensors.

There is plenty of room for innovation but one must start with asking correct questions. What are we planning to detect? This is where the depth of science, and knowledge about the subject area, is critical. The sensor will be worthless, unless identification of the target is unambiguous, and is relevant, from the perspective of biology and medicine (if applicable), in terms of function.

The next question is the knowledge about the complementarity of the detection process. For example, if we wish to detect an antigen or an epitope of an antigen, then its specific antibody must be available and presented, as the immobile component, on the surface of the sensor.

How many immobile components will be available for interaction on the surface of the sensor? This is where the “game changes” as we move from micro-arrays^[39] to nano-arrays, which may owe its origin to the principle of nanowires^[40], but modified, over the past quarter century. The move to nano will increase the surface area but will that result in a concomitant increase in the sensitivity of detection? Detection ability of novel nanowire sensors are in the picogram per milliliter (pg/ml) range and at a 100x reduction in cost compared to other manufacturing processes for silicon nanowire sensors (Marcie Black, Advanced Silicon Group, *personal communication*).

Sensitivity of detection, is one reason why nano-wire sensors (nanoarrays) could change the face of public health and preventive medicine. Coupled with digital transformation, and IoT, as a digital by design metaphor, the scope of digital health, and medical IoT are, truly immense.

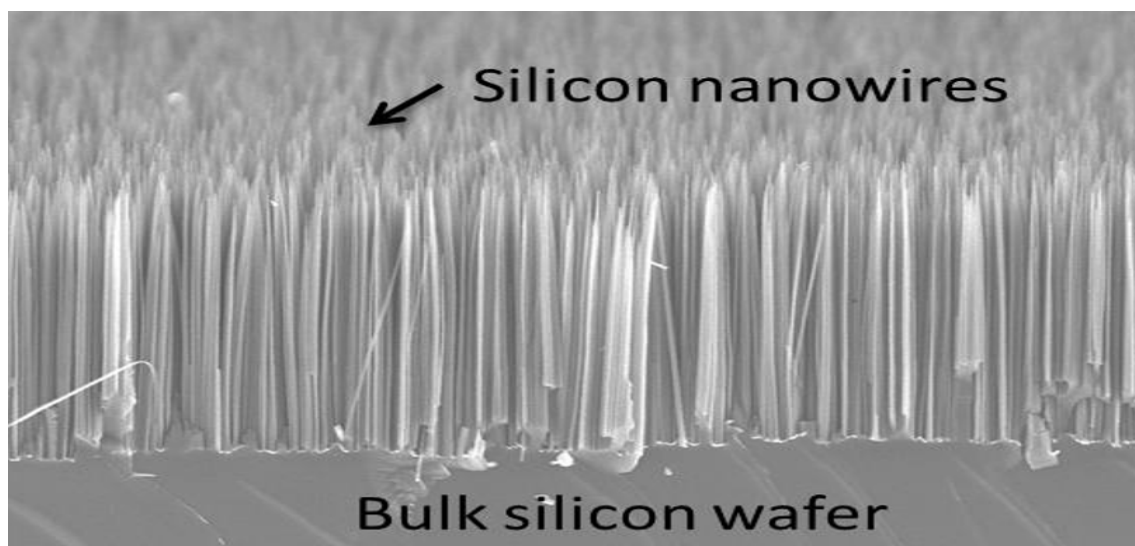


Figure 13: The revolution in detection due to nano-arrays using silicon nanowires. Compare 5-10 molecules on other forms of nanowire devices versus this configuration (above) which has the potential to be far more sensitive due to >1 million nanowires per device (six orders of magnitude increase, per sensor surface). Theoretically, each nanowire can serve as an anchor for an analyte.

The biochemical challenge is *retaining the functional viability* after attaching the analyte to the nanowire. An assay to measure the amount of attached analytes cannot be used to extrapolate the gain in *sensitivity* due to nanowires. To estimate the gain in sensitivity, we must reproducibly assay the percentage of the attached molecules which are functionally active to detect the target. What is the tolerance for variability in assay conditions with respect to functional sensitivity? Is the nano-sensor suitable for multiple uses or single use? Will the complex formation (necessary for detection?) auto-dissociate to rejuvenate the nano-sensor for another cycle? In the absence of auto-dissociation, can the nano-sensor return (treated to return?) to basal or ground zero state? What is the nature of false positives? Is error correction and/or data curation/cleansing required to obtain the result? What is the detection signal when the analyte detects the target? In what ways this signal can be modulated? How is the signal converted to data? Attempting to answer these and other related questions, provides ample room for innovation in biology/biochemistry.

Can we create standard operating processes (SOP) for nano-arrays, using a modular approach? In this vision, the components, except the target, are pre-fab “kits” from vendors (for example, New England BioLabs). Democratization of the nano-array tools, beyond specialized labs to any clinic or industry, may benefit other domains, for example, exploration of microbiomes^[41].

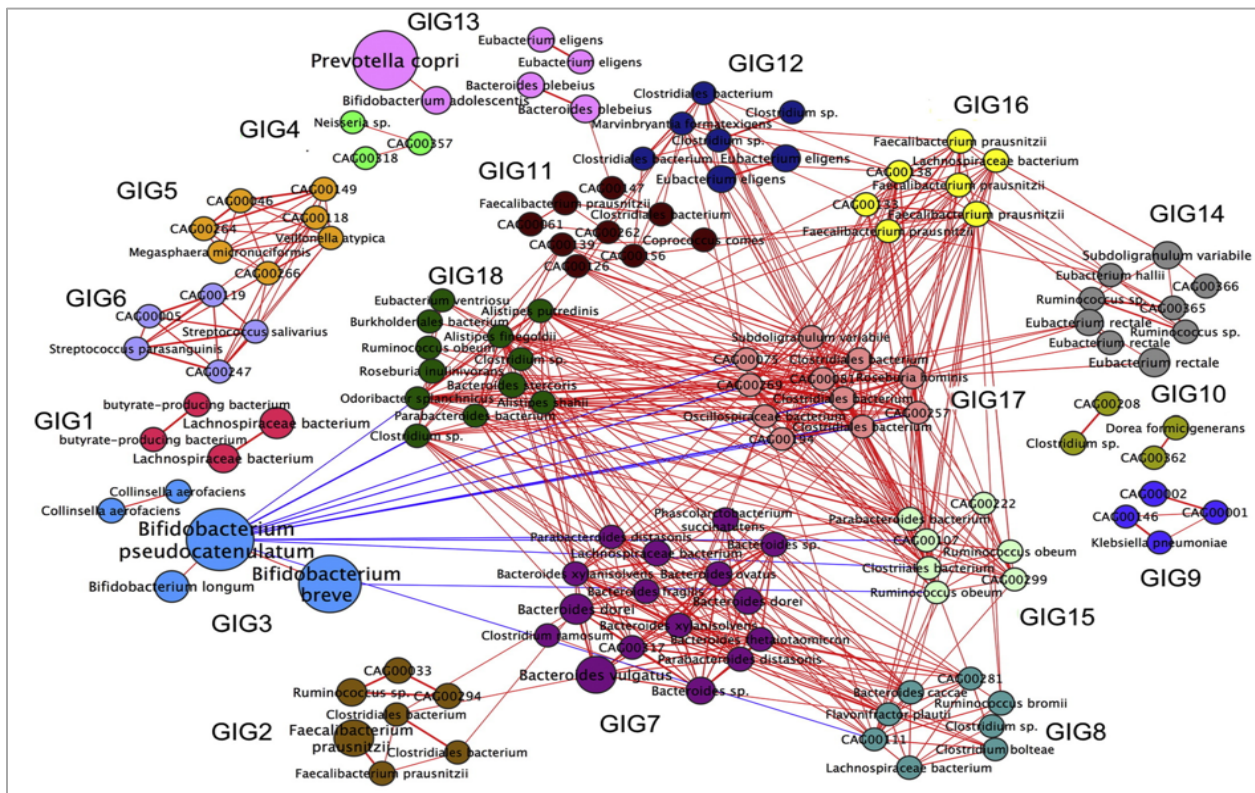


Figure 14: Network of interactions between gut microbiota in obese children^[35]. With low cost, routine nano-metabolomic assays, out-patient or primary care clinics, may detect molecules of interest, while they are still below the threshold (picogram or femtogram per milliliter) of disease or dysfunction. Nano-arrays for prevention, in home test kits, can use non-invasive body fluids (sputum, urine, feces) to detect target molecules, in a manner similar to pregnancy tests or blood glucose strips, available from pharmacies (CVS, Walgreens, in USA). Nano-kits may be purchased from brick-and-mortar stores or ordered online (WalMart, PetSmart) or delivered-by-drone to your door-step or window-sill (Amazon, Alibaba), in the near future.

CONFLUENCE OF IDEAS

The vast room for innovation, in optimizing sensitivity of detection of analytes, will determine the ultimate power of, and benefit from, nano-arrays. Availability of home nano-array kits in gas stations and convenience stores, can reach far corners of the world, where availability of medical professionals may not need a miracle, but is as rare as a solar eclipse. What was not feasible with microarrays may be possible with nano-arrays in the detection of agents for flu, cholera, plague, TB, malaria, leprosy, meningitis, diabetes, myocardial infarction and so many other diseases, which affect the rich and the poor. If detected, before the threshold, millions of lives can be saved.

Digital transformation catalyzed data collection, enables quantitative measurements, establishing metrics, changing the rigidity of “the model mind set” and driving key performance indicators. In the data driven economy, KPIs must be guided by the *context of the problem* or the environment, rather than feeding models from antiquity, limited by the scope of their equation based structure. In the digital era of near real-time data, the dynamic composability of agent based models and its modular components (parameters, features), must be continuously constructed, de-constructed and reconstructed, to keep pace with the volatility of data. The data must not be made to *fit* the model. The model must fit the observed data, to be useful, at least per the Pareto principle. Data from detection is no longer the “Epic of Gilgamesh” available to the Queen. Digital transformation can make this data accessible to anyone, anywhere and we may access that *same* information (please see page 5 in “Digital Transformation” here <https://dspace.mit.edu/handle/1721.1/111021>).

Data repeatedly re-appears to be at the heart of decisions. Suggestions in this blog are “obvious” as well as data dependent. Mobile phones analyzing sensor data can detect tremors related to Parkinson’s disease^[42] and display in apps. In the near future, the smartphone, which you plug in the car, to charge, while you are driving, can also inform you if the tire-pressure is low or the car needs wheel balancing – without the automobile’s sensor. *Sensors in phones* (accelerometer, gyroscopic sensor) can “sense” the operation and use machine learning (ML) to predict status. Sensors can upload real-time data about emissions and record reduction of pollution by EVs.

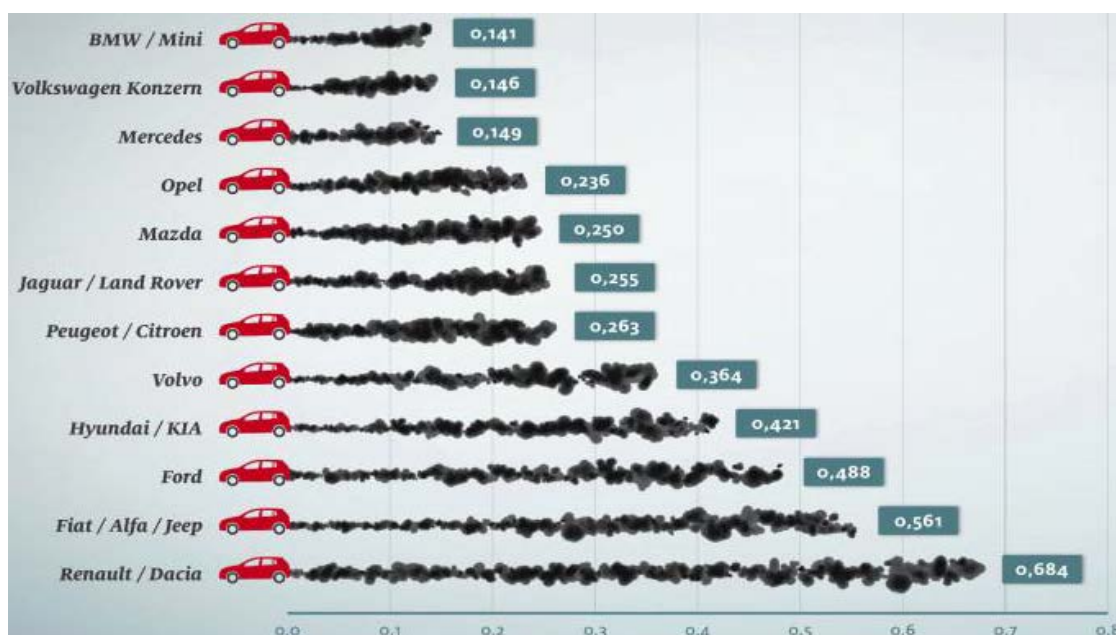


Figure 15: We do not need nano-array sensors to detect NOx (g/km). EU data from diesel cars^[43]

The ability to connect the data to health monitoring or healthcare systems, unleashes multiple benefits, for the patient, individuals, families, local community, national governments and global organizations (PIH, WHO, MSF). Data and data analytics are essential elements in the closed loop abstraction, that is, cycle of data and analytics feeding the decision, and data from implementing the decision, feeding the next round, of the dynamic decision process. Data and contextual analytics, at the right time, may reduce [a] the 43 million cases^[44] per annum, worldwide, due to medical errors, [b] 99,000 deaths per year due to healthcare related infections and [c] 770,000 injuries and deaths due to problems with medication. The outcome, hospital readmission, costs^[45] an estimated US\$17 billion, each year. This is the immense value, from connected data.

How do we collect data, how do we communicate it, how we store it, how we transmit it, how to query it, and what to do with it, in order to extract value for the decision process, with or without humans, are questions that must be addressed, case by case, because it is not formulaic. We have come a long way from the stethoscope of 1816. In about 200 hundred years, we can use a mobile smartphone, which can connect to an USB flash drive, with a sensor. It is a sign of the times.

The type of sensors suggested in this blog, are able to track and trace analytes, related to health and environment, among other things, using nano-wires for ultra-high sensitivity nano-arrays. Anybody who doubts “if” it will happen, may wish to pay attention to recent developments in chemistry. Two groups from the same department at the University of Manchester, Chilton & Mills^[46] and Richard Layfield^[47], have reported a dysprosium molecule [⁶⁶Dy] with switchable magnetic properties, single-molecule magnet (SMM), with the ability to store a single bit of data.

The stunning chemistry of the dysprosium molecule runs parallel to the thrilling potential for advancing information technology. Molecular data storage using SMMs could handle about 30 terabits of data per square centimeter, or more than 25,000 GB of data (>3 terabytes), on a device the size of a flash drive. That is about 10-fold more than the current (256GB) data storage capacity of Apple’s latest iPhone 8, which relies on magnetic nanoparticles.

Cross-pollination of multi-disciplinary approaches, and innovation, may guide us to create new vistas, to analyze analytes, in an attempt to inform the processes, which may improve the health of animals, humans, plants, and the collective health of the interconnected environment.

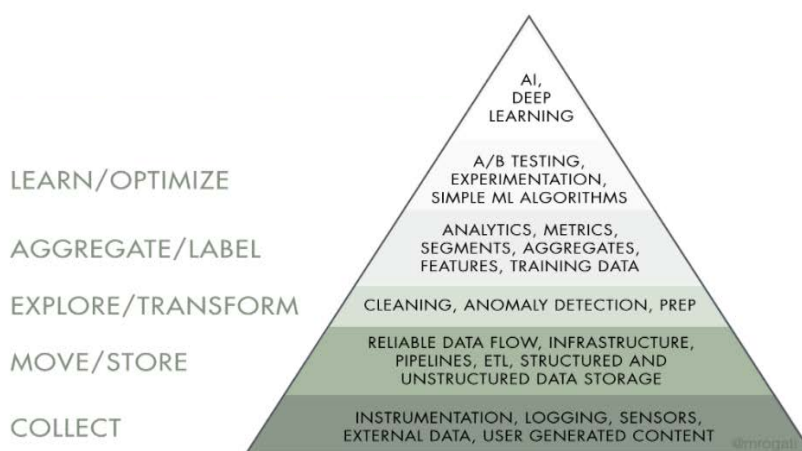


Figure 16: In this blog we have focused on the bottom of the pyramid. “Detection, Diagnosis and Decision” needs data. Nanosensors and mobile devices are tools we may use for collection of data.

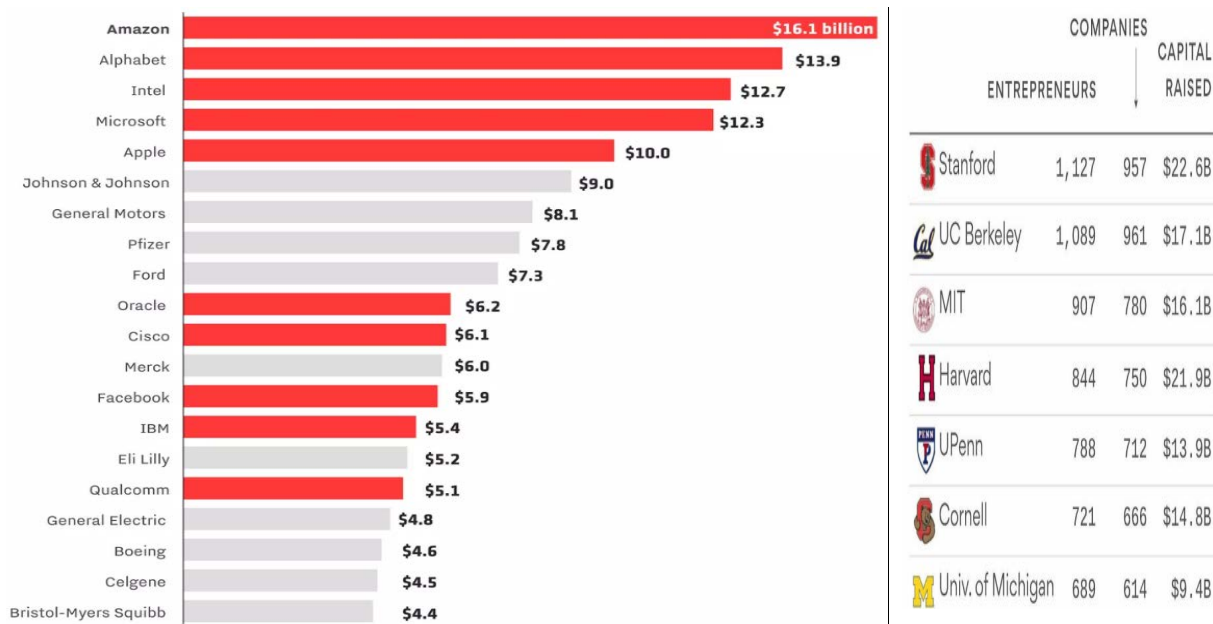


Figure 17: US corporate R&D budgets. Tech companies (red bars) in the Top 20 list, by R&D spending, invested almost US\$100 billion in research and occupy 5 out of the Top 5 positions^[48]

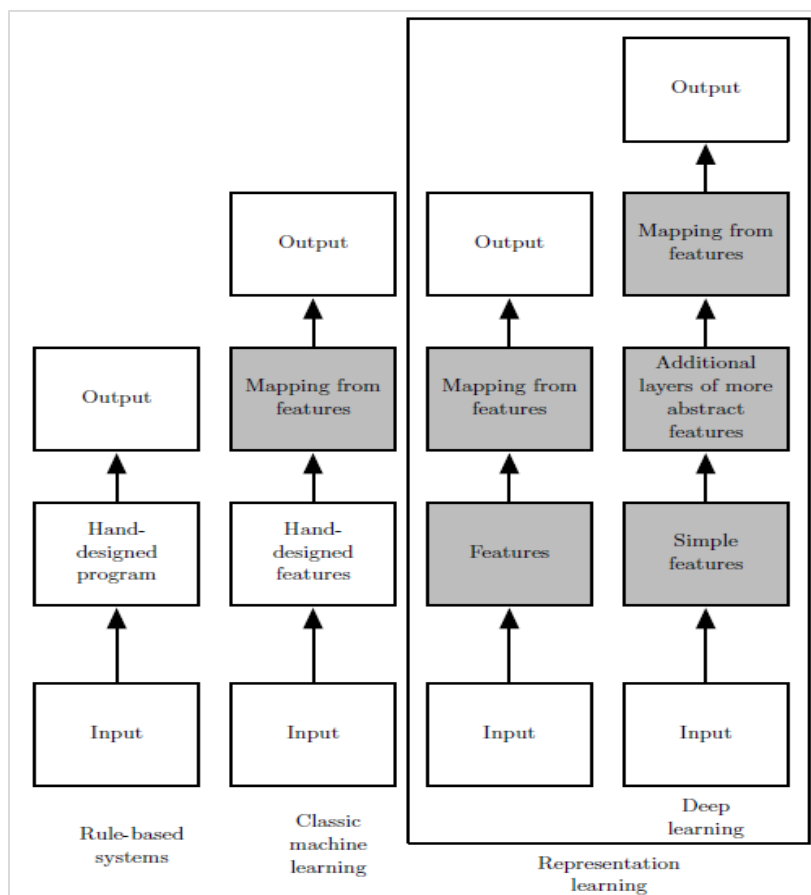


Figure 18: Feature engineering is key to AI. Insufficient, noisy, unstructured data, with respect to features, renders these tools impotent. From^[49] Ian Goodfellow in *Deep Learning*. MIT Press. 2016

CONCLUDING COMMENTARY

Science and engineering are at the heart of this blog. The identification of biomarkers and analytes, as molecules of interest, is fundamental. Scientists who can transform these ideas into reality, may not care much about the end-to-end qualitative scenario, outlined in this blog. In other words, majority of scientists will not consider reading a “blog” by a non-expert. Engineers who can fabricate the material, to create the nano-wires, will follow in the footsteps of scientists. The engineers in telecommunications, architecture and systems connectivity, will disregard the blog because it deals with “biology” or medicine. The computer scientists and the data scientists (we used to call them statisticians), will ignore the blog because there is “nothing in it about actual data” to discuss. Most business folks and investors will roll their eyes, because they are interested in ROI and business models, not in analytes or nano-wires or tools to save millions of lives. Foundations and “angels” will ignore this blog due to its lack of focus. Publishers of august journals will point out that there aren’t any new advances, in this blog. Other publication outlets will ask who is the intended audience, what is the target market? There are so many, so justified, and so good reasons, why this blog was a waste of time and considered junk mail, in in-boxes.

Ian Goodfellow, answering a question from the audience, remarked that the reason why those who tend to delve into deep learning are not sufficiently informed in neurology, and those who are in neurology, are not engaged with AI or deep pursuits in computer science, due to the fact that mathematics is not a priority in biology and biology is not a priority for artificial intelligence. He went on to add, computer scientists abhor learning declarative facts and prefers developing processes from first principles. But, neurology or biology, emphasizes the learning of facts. The chasm between the groups, and the fact that we may be at the level of arthropods (insects, bees), in terms of understanding neural networks, makes the process of AI and representational learning almost entirely, and precariously, dependent on trial and error. The science of AI is still an art.



Figure 19: The panel on the left attempts to fit data and reveals, once again, that common sense is uncommon. Extending that idea to neural networks, the right panel, shows how artificial neural networks (ANNs) are highly vulnerable due to their linear nature. In this example^[50], applying a very small perturbation (+ 0.007) to the dataset (panda image recognition with 58% confidence), can dramatically change the output and emphasize an incorrect answer with very high confidence (image suggests gibbon with 99% confidence). This is due to the linearity of ANN, which is the principal tool for ML, DL and AI. Linearity is an artifact of ANN and not an intrinsic property of neural networks. From the perspective of human neurology, humans are well equipped to “think back” and go “back” in thought and thinking, often in the presence of significant perturbation. Back propagation is difficult yet back propagation algorithms are used in training deep models.

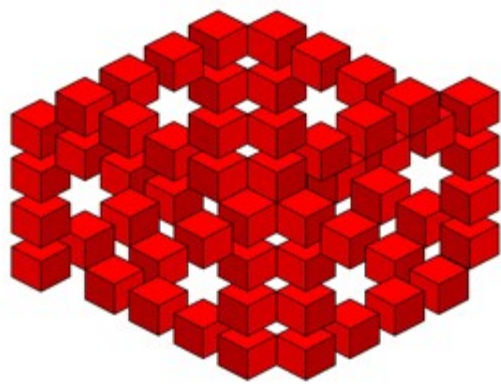
In the ANN model, data perturbation by an input of 0.007 completely changed the output, and sharply increased the confidence of the result. Imagine what could happen to medical diagnosis! If using an AI tool for diagnosis, minor perturbations in cerebral metabolic rate (CMR) or GABA (gamma amino butyric acid, a neuro transmitter) or tissue plasminogen activator (tPA), may lead to a diagnosis of idiopathic epilepsy^[51], when a normal person or animal, was suffering only from anxiety or stress due to duress. AI is useful but how can it be trusted without humans in the loop?



Figure 20: Home delivery-by-drone of nano-array kits. Arriving soon on a window-sill, near you? Measuring Arsenic in Bangladesh or Mercury^[52] in Colombia or CEA in cancer, can save millions.

One expected outcome (illustrated in Figure 20), is not impossible, because we do not have to break any rules of physics, to make it happen. The barriers are due to the rules of finance and economics. An investor commented that it will take a major catastrophe in a wealthy nation to mobilize the detection tools, drive the convergence, and for industries, to seek the end-to-end solution. The fact that eleven million children die, annually, due to mainly preventable causes, is not sufficient reason to catalyze the convergence. About 70% of the deaths are attributable to six causes (diarrhea, malaria, neonatal infection, pneumonia, preterm delivery, and lack of oxygen at birth). The fact these deaths are concentrated in 10 countries, mostly, in Sub-Saharan Africa, is the fly in the ointment. If that “fly” from Bamako could fly and trigger a public health havoc in Boston, then, try to prevent angels from investing or foundations from opening the funding gates.

1 <http://pubs.acs.org/doi/abs/10.1021/acsinfecdis.7b00110>
2 www.usda.gov/media/blog/2016/11/30/nanostructured-biosensors-detect-pesticide-help-preserve-environment
3 <https://swagroup.mit.edu/nanowire-chemicalbiological-sensors-status-and-roadmap-future>
4 <http://www.nuwavesensors.com/products/lumair-lu45>
5 https://ll.mit.edu/publications/journal/pdf/vol17_no1/17_1_3Petrovick.pdf
6 <http://pubs.rsc.org/en/content/articlelanding/2016/ew/c5ew00276a#!divAbstract>
7 <https://www.elsevier.com/books/new-pesticides-and-soil-sensors/grumezescu/978-0-12-804299-1>
8 http://www.mdpi.com/journal/sensors/special_issues/sopsawf
9 <https://swagroup.mit.edu/janus-emulsions-detection-bacteria>
10 <https://swagroup.mit.edu/wireless-oxygen-sensors-enabled-feii-polymer-wrapped-carbon-nanotubes>
11 <https://swagroup.mit.edu/organocobalt%E2%80%9393carbon-nanotube-chemiresistive-carbon-monoxide-detector>
12 <http://onlinelibrary.wiley.com/doi/10.1002/anie.201604431/abstract>
13 <https://swagroup.mit.edu/chemiresistor-devices-chemical-warfare-agent-detection-based-polymer-wrapped-single-walled-carbon>
14 <https://swagroup.mit.edu/integrated-gas-sensing-system-swcnt-and-cellulose-polymer-concentrator-benzene-toluene-and-xylenes>
15 <http://care.diabetesjournals.org/content/40/1/63>
16 <https://swagroup.mit.edu/quaternized-polymer%E2%80%9393single-walled-carbon-nanotube-scaffolds-chemiresistive-glucose-sensor>
17 <https://ubicomplab.cs.washington.edu/pdfs/biliscreen.pdf>
18 <https://dspace.mit.edu/handle/1721.1/111021>
19 <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3145127/pdf/ukmss-35894.pdf>
20 <https://www.technologyreview.com/s/514816/researchers-create-hate-map-of-the-us-with-twitter-data/>
21 https://www.intechopen.com/books/swarm_intelligence_focus_on_ant_and_particle_swarm_optimization
22 https://users.info.uvt.ro/~dzaharie/ma2016/projects/techniques/FireflyAlgorithm/Yang_nature_book_part.pdf
23 <https://www.nklabs.com/>
24 <https://venturebeat.com/2016/09/02/a-brief-history-of-googles-ill-fated-modular-smartphone-project-ara/>
25 <https://people.eecs.berkeley.edu/~culler/>
26 <https://people.csail.mit.edu/hes/>
27 <https://dspace.mit.edu/handle/1721.1/107988>
28 <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4772235/pdf/ijerph-13-00215.pdf>
29 <http://news.mit.edu/2016/faculty-profile-rohit-karnik-0901>
30 <http://web.mit.edu/karnik/www/home.htm>
31 <https://en.wikipedia.org/wiki/ARPANET>
32 <https://dspace.mit.edu/handle/1721.1/108000>
33 <https://www.energymanagertoday.com/how-ge-plans-to-make-billions-with-predix-0127475/>
34 <https://ca.reuters.com/article/businessNews/idCAKCN1B80CB-OCABS>
35 https://www.nature.com/polopoly_fs/1.12413!/menu/main/topColumns/topLeftColumn/pdf/494155a.pdf
36 <http://www.cs.columbia.edu/~feiner/courses/mobwear/resources/schilit-mcsa94.pdf>
37 <https://www.cisco.com/c/en/us/solutions/software-defined-networking/overview.html>
38 http://www.rle.mit.edu/eems/wp-content/uploads/2016/11/everiss_jssc_2017.pdf
39 <http://www.pnas.org/content/94/6/2150.full.pdf>
40 <http://science.sciencemag.org/content/261/5126/1316>
41 [http://www.ebiomedicine.com/article/S2352-3964\(15\)30064-5/pdf](http://www.ebiomedicine.com/article/S2352-3964(15)30064-5/pdf)
42 <https://www.newscientist.com/article/2123459-super-fast-parkinsons-app-will-track-symptoms-more-closely/>
43 <https://www.adac.de/infotestrat/tests/eco-test/default.aspx>
44 <http://qualitysafety.bmj.com/content/ghc/22/10/798.full.pdf>
45 <http://www.nejm.org/doi/pdf/10.1056/NEJMsa0803563>
46 <http://www.nature.com/nature/journal/v548/n7668/full/nature23447.html>
47 <http://onlinelibrary.wiley.com/doi/10.1002/anie.201705426/full>
48 <https://www.recode.net/2017/9/1/16236506/tech-amazon-apple-gdp-spending-productivity>
49 <http://www.deeplearningbook.org/>
50 <https://arxiv.org/pdf/1412.6572.pdf>
51 <https://www.ncbi.nlm.nih.gov/books/NBK28033/>
52 <http://mercury2017.com/program/technical-program/4c/> (WO-069) PARTICIPATORY MONITORING AND COMMUNITY PROTECTION FROM MERCURY POLLUTION GENERATED BY ARTISANAL GOLD MINING IN COLOMBIA (Dr Eric Mclamore, University of Florida, Gainesville, FL)



CHAPTER 7

Shoumen Datta


HAPHAZARD REALITY – IOT IS A METAPHOR

THIS PAGE IS LEFT BLANK


Healthcare

Shoumen Datta

Julian Goldman



This is the true joy in life, the being used for a purpose you consider a mighty one, the being a force of nature rather than a feverish, selfish clod of ailments and grievances complaining that the world will not devote itself to making you happy.



George Bernard Shaw

Digital Transformation of the Healthcare Value Chain: Emergence of Medical Internet of Things (MIoT) and an Integrated Clinical Environment (ICE) as a Platform

Table of Contents

Cover	Page 1
Table of Contents	Page 2
Abstract	Page 3
Background	Pages 4-7
In Praise Of	Page 8
Introduction	Pages 9-11
Problem Space	Page 12
Solution Space	Page 13
Innovation Space	Pages 14-15
Digital Transformation of Healthcare	Page 16
Medical IoT (Internet of Things)	Pages 17-24
Beyond Errors	Pages 25-27
The Pragmatic Horizon	Pages 28-30
Near Future	Pages 30-35
Global Public Health	Pages 36-39
Nano Tools	Pages 40-41
Temporary Conclusion	Pages 42-43
References	Pages 44-57

Digital Transformation of the Healthcare Value Chain: Emergence of Medical Internet of Things (MIoT) and an Integrated Clinical Environment (ICE) as a Platform

Shoumen Palit Austin Datta, PhD

Senior Member, MIT Auto-ID Labs and Research Affiliate, Dept of Mechanical Engineering
Massachusetts Institute of Technology

Senior Scientist, Medical Interoperability Program, MDPnP Labs

Massachusetts General Hospital, Harvard Medical School

shoumen@mit.edu or sdatta8@mgh.harvard.edu (additional info <http://bit.ly/IOT-MIT>)

Julian M Goldman, MD

Medical Director, Biomedical Engineering, Department of Anesthesiology

Director, Medical Interoperability Program, MDPnP Labs

Partners HealthCare System, Massachusetts General Hospital, Harvard Medical School

jmgoldman@mgh.harvard.edu (additional info <http://www.juliangoldman.info/>)

ABSTRACT

The complexity of the healthcare ecosystem and the trans-disciplinary convergence which is essential for its function, makes it difficult to address healthcare as one domain. Divided in various stages for ease of management, healthcare is quintessentially a continuum which commences at birth and may cease at death. In this paper, we have attempted to take a broad view but it still isn't broad enough. We have focused on issues, such as, data and interoperability, yet it scratches only the surface of these sub-domains. For the specific problem at hand, we propose an "http" approach to adopt open standards to enable medical equipment and devices to share and synthesize data using ICE (integrated clinical environment), a medical device interoperability platform. ICE may help reduce deaths due to preventable medical errors. Thinking about the future of data in personal healthcare, we propose creating an ecosystem which contributes data from multiple health related domains. Data curation and analysis of the information may boost our health related knowledge. Improving infrastructure, increasing connectivity and decision support apps for communication, may help, among other things, to uncover facts, synthesize data and observations which may influence the future of global health. In our plight for lofty ideas, we must not forget that 11 million children die each year and about 70% of the deaths are attributable to six causes (diarrhea, malaria, neonatal infection, pneumonia, preterm delivery, and lack of oxygen at birth). The majority are preventable. Health care at homes and huts may profit from systems integration and mobility due to internet of things (IoT), especially, medical IoT.

BACKGROUND (US-CENTRIC)

The legendary editor of the august New England Journal of Medicine, Arnold S Relman (1923-2014), offered an incisive perspective when he delivered the 171st Annual Discourse at the Massachusetts Medical Society on May 21, 1980 [1].

“According to an article in the *Wall Street Journal* of December 27, 1979, the net earnings of health-care corporations with public stock shares rose by 30 to 35 per cent in 1979 and are expected to increase another 20 to 25 per cent in 1980. A vice-president of Merrill Lynch appeared a few months ago (prior to this article) on "Wall Street Week," the public television program, to describe the attractions of health-care stocks. According to this authority, health care is now the basis of a huge private industry, which is growing rapidly, has a bright future, and is relatively invulnerable to recession. He predicted that the health business would soon capture a large share of the health-care market and said that the only major risk to investors was the threat of greater government control through the enactment of comprehensive national health insurance or through other forms of federal regulation” [1].

The sluggish progress of the US national health insurance initiatives [2] and the pugilistic powers in action [3] are indicative of the pugnacious influence of private health-care industries on national health policy. A broad national health-insurance program, with the inevitable federal regulation of costs, is an anathema to the medical-industrial complex, just as a national or global disarmament policy may be to the military-industrial complex. President Eisenhower was concerned about the unhealthy aspirations of the military-industrial complex and emphasized “*we must guard against the acquisition of unwarranted influence*” in his farewell address [4]. A similar admonition is applicable to the healthcare industry. Today’s medical-industrial complex is replete with aggressive enterprises vying for global dominance of epic proportions and maximizing profit taking at every step.

The transmutation of healthcare, once guided by the ethos of the Hippocratic Oath [5], to a commodity guided by the free market economy to improve efficiency and quality, is deeply flawed. Application of business values [6] and operational optimizations are uninformed efforts by well-intentioned bean counters. Patients are not “consumers” or “clients” and doctors are not “partners” or “service providers” in the classical context of Adam Smith [7]. However, business relationships and “best practices” may be applicable when a hospital or a clinic is purchasing bathroom tissue or contracting for janitorial services or outsourcing valet parking. The latter is an operational function but cannot be referred to as healthcare.

Hence, tools of operations management, for example, supply chain management, are useful only to a limited extent to things, equipment, objects or facilities, which are very likely to

be less uncertain in their use or application because the goods or inventory, usually, are uninfluenced or unrelated to the practice of healthcare. These observations, however, have had little impact on the vast cost of consulting fees extracted from the healthcare industry by major firms [8] who continue to pontificate about business best practices to healthcare.

Patients who are sick, or worried that they may be sick, generally, are neither capable of understanding their physiological status nor inclined to shop around for bargains. The value of life often far outweighs the consideration of cost. Patients and their families seek and demand the best care they can get irrespective of the price. Hence, the classic laws of supply and demand are ill suited because healthcare “consumers” may not subscribe to the usual incentives to be prudent, discriminating and frugal in their decision. This “decision” is not about profit and loss, even if glib management consultants may view it as a *purchase*.

Health care is neither synonymous nor interchangeable with “medical marketplace” because the canonical rules of competitive economic equilibrium [9] are unlikely to be applicable. The tireless pursuit of the for-profit business process consultants to inflict the so-called supply chain principles from the “marketplace” on to healthcare is fraught with problems. It exhibits a flagrant disregard for the foundational distinction that must choose value over cost in the practice of medicine or the effort necessary to save even a single life. Economies of scale or risk pooling are not always applicable or even desired in health care.

The root of the disequilibrium in healthcare is the heavy, often total, dependence of the patient (irrationally referred to as the consumer) on the medical practitioner (nurse or physician, viewed in the business framework as a service provider).

The business consultants, administrators and software packages peddling the operational principles extracted from retail stores or grocery chains or manufacturing plants may not be fully cognizant about the seminal work by Kenneth Arrow referred to as information inequality [10]. The latter catalyzed more in depth analysis of markets with asymmetric information pioneered by George A. Akerlof, A. Michael Spence and Joseph E. Stiglitz [11].

It is interesting to observe that few business students, middle managers and corporate executives are able to connect the fact that the Forrester Effect [12] which later morphed as the Bullwhip Effect [13] is partly due to information asymmetry [14]. The resurgence of RFID [15] to ignite the digital supply chain [16] has had limited impact on the reduction of information asymmetry. The reasons may include dead weight of old technology, lack of an engineering systems approach [17], inability to evolve out of the organizational “silo” frameworks and punctuated connectivity. Taken together, productivity gains, if used as a (key) performance indicator (KPI), remains a paradox [18] while limits on our data driven prediction abilities [19] makes predictive analytics more of an art and less of a paradigm.

The incisive foresight available from the application of the principles of information asymmetry to healthcare may explain why the usual assumptions about competitive free markets do not apply. There aren't any known mechanism to the bridge the chasm of medical knowledge between the patient and physician in order to generate "equilibrium" through the establishment of "symmetric" information. The patient does not choose the plethora of medical tests or the regimen of procedures or plan for medication. Physicians decide the course of action. Hence, it is the physician who will influence 70% or 80% of all the expenditures associated with healthcare.

The potential for financial abuse, therefore, is obvious, when private for-profit companies enter the market. Private healthcare companies can conspire to influence the decisions of the physicians to maximize profit [20]. The physician is a profit center – actively engaged in the business of the *medical marketplace* which is a service industry. This scenario may fit the corner service station at the intersection of Happy and Healthy, serving gas on demand.

In *Goldfarb vs Virginia State Bar*, the US Supreme Court [21] handed down a landmark decision that found that the business activities of professionals were properly subject to antitrust law. Today, we are dealing with increasingly caustic consequences of that decision, as astutely pointed out by Late Arnold S Relman [22] in his 101st Shattuck Lecture at the Annual Meeting of the Massachusetts Medical Society in Boston on May 18, 1991 [23].

It would be a heresy to temporarily conclude this sketchy US-centric background without mentioning the influence of physicians and the organizations they champion (for example, the almighty AMA or America Medical Association). The forbidding political landscape in US healthcare reform was shaped, in part, by the physicians and their refusal to include government health insurance in the 1935 Social Security Act. In 1945, the AMA lobbied against President Harry Truman's proposed universal health insurance program and delivered the fatal blow. In 1965, much to the chagrin of the AMA, it met with partial defeat when President Lyndon Baines Johnson created Medicare, a federal health insurance program for the elderly, and Medicaid, a combined federal-state program for the poor. President Bill Clinton's failure was, in part, due to the opposition party who may have bullied the US Chamber of Commerce into withdrawing its support, as published by a senior member of the healthcare reform team, Paul Starr of Princeton University [24].

The timbre of compromises, tempered success and the catastrophic victory of President Obama's Affordable Care Act on 23 March 2010 [25] capped a struggle for US healthcare reform that commenced even before 1935. The legal name of "Obamacare" is The Patient Protection and Affordable Care Act. One cornerstone of PPACA is patient protection. This paper and our mission is focused on patient safety. Without patient safety, it may be well-nigh impossible to adequately address what is necessary to ensure patient protection.

Quote from: *The Health Care Industry: Where Is It Taking Us?* by A. S. Relman [23]

Physicians can no longer act collectively on matters affecting the economics of practice, whether their intent is to protect the public or simply to defend the interests of the profession. Advertising and marketing by individual physicians, groups of physicians, or medical facilities, which used to be regarded as unethical and were proscribed by organized medicine, are now protected - indeed, encouraged - by the Federal Trade Commission.

Advertisements now commonly extol the services of individual physicians or of hospital and ambulatory facilities staffed by physicians. Most of them go far beyond simply informing the public about the availability of medical services. Using the slick marketing techniques more appropriate for consumer goods, they lure, coax, and sometimes even frighten the public into using the services advertised.

I recently saw a particularly egregious example of this kind of advertising in the *Los Angeles Times*. A freestanding imaging center in southern California was urging the public to come for magnetic resonance imaging (MRI) studies in its new "open air" imager, without even suggesting the need for previous examination or referral by a physician. The advertisement listed a wide variety of common ailments about which the MRI scan might provide useful information — a stratagem calculated to attract large numbers of worried patients whose insurance coverage would pay the substantial fee for a test that was probably not indicated.

Many respectable institutions and reputable practitioners advertise in order to bring their services to the public's attention. But in medical advertising there is a fine line between informing and promoting; as competition grows, this line blurs. Increasingly, physicians and hospitals are using marketing and public relations techniques that can only be described as crassly commercial in appearance and intent.

Before it was placed under the protection of antitrust law, such advertising would have been discouraged by the American Medical Association (AMA) and viewed with disfavor by the vast majority of physicians. Now it is ubiquitous, on television and radio, on billboards, and in the popular print media. Of course, not all medical advertising is as sleazy.

IN PRAISE OF OTHER IMPERFECTIONS

Four common [26] approaches are (a) private-sector (USA, Switzerland), (b) national health service (UK), (c) provincial government health insurance (Canada) and (d) social insurance (France, Netherlands, Germany). Founded in 1883, by Otto von Bismarck, Germany's Statutory Health Insurance (SHI) program insures about 99.9% of the country's population and is administered by private not-for-profit organizations, authorized by law to wield power on behalf of payers and providers. The federal government intervenes in the interest of public goods if the broader interests of society are neglected [27]. The SHI Health Care Structures Reform Law, passed in 2012, created a third care sector called integrated ambulatory specialist care [28]. The latter (IASC) and other efforts (in 2004) are an attempt to mitigate the negative impact on integration due to previous segregation of ambulatory and hospital care delivery. The segregation dates back to a 1931 decree by Chancellor Heinrich Brüning, which granted physicians in private practice a monopoly on ambulatory care and essentially prohibited hospitals from providing outpatient care (the emergency decree was a direct result of a physician strike).

Economist Robert J Evans posits that the ethos of equality in the provincial healthcare system of Canada reflects a principle similar to equality before law [29]. The Canadian system is an imperfect hybrid of public funding (government taxes), private providers and universal coverage which is comprehensive in scope, affordable, single-payer, provincially administered yet works as a “national” healthcare system. It reflects political compromises, in face of powerful opposition [30].

The lofty idealism in the Canadian system is but a poisoned chalice to the US medical-industrial complex. Big pharma, manufacturers and insurance companies poured more than half a billion US dollars to lobby US politicians [31] and even more was invested to commission studies with “alternative facts” to advocate that a US national health insurance scheme modeled on the Canadian system would not work. An excess of a quarter billion US dollars went into the coffers of political parties [32] to convince Americans that they will get inferior health care coverage and fewer choices with a Canadian system [33].

The US political momentum toward the lowest possible common denominator is a tool to preserve corporate interests in healthcare, for example, the lucrative dialysis business [34]. Measures and medication to reduce the need, cost and deaths due to dialysis [35] are often subjected to the vagaries of obfuscation or appears to be mired in chronic controversies [36] orchestrated with Machiavellian shrewdness. Public illiteracy of science and medicine goads forward profit optimization routines. Those who know and can shed light on these unscrupulous practices are failing to sustain their opprobrium and silence fuels repetition.

INTRODUCTION

The ills of the US medical-industrial complex are not unique to the US. Many of the medical equipment manufacturers [37] are global. The product-driven manufacturing business model prevalent in the equipment and device sector is nuclear. The product is supposed to spell profit for companies and any attempt to share parts, feature or information about the equipment or device is viewed as detrimental for profitability. This is a general observation and not a specific behavior exclusive to the US medical-industrial complex.

This is also where medical manufacturing must distinguish itself from other industry verticals. The equipment and devices used in medical and healthcare system must be optimized for performance which, generally, may focus on one physiological function and can be used on one individual or one patient, at a time. A heart rate monitor cannot multi-task and monitor Jane and Joe, simultaneously. Hence, the principles of business (best practices, risk pooling, supply chain, economies of scale and similar operational lessons) from most other domains are relatively sterile, since the end point of the activity for the medical manufacturer is the well-being of an animal or one human being, at a time.

The human being is not the patellar disc, myocardial infarction or glomerular nephritis. A human being may have one or more of those symptoms, syndromes or afflictions but the entire person or the “whole” patient must be the focus of health care (albeit, there may exist different stages of acuity, which may or may not be applicable in this scenario).

Safety is of paramount importance. Safety is about the status of the patient, as a whole.

Surgical wizardry may save the life of a person involved in an automobile collision. Yet the post-operative patient may succumb to patient-controlled over-dose of analgesia in an ICU.

These deaths due to errors are often due to lack of integration of patient safety processes at the level of the medical devices, several of which may be attached to monitor each patient.

Each device or equipment is usually dedicated to monitor one function and can be used for one patient at a time. The physiological functions, essential for monitoring, make up a long list and each function may require a specific device manufactured by a specific corporation. Several different corporations are supplying these devices and equipment. The functional integration of data from devices which can reflect the physiological “status” of the “whole” patient at the point of care (nurse, physician) is not a competency within the domain of device manufacturers. OEM's are not experts in physiological status integration. Hence, perhaps, it is unfair to expect device and equipment manufacturers to bear the moral burden of integration, necessary for physiological status.

The physiological “sum” of data, from different devices, taken together, can make a significant difference between saving a life or death.

Errors leading to death of patients include errors arising out of lack of patient safety processes. A key element of patient safety is related to unintegrated device-level data. Devices are designed by manufacturers to present a pre-set, time-dependent, single function data point but usually lack integration with other single function monitors. This data segregation introduces (often, fatal) medical errors by preventing physiological status updates about the patient, as a whole, in a hospital or nursing facility or in private homes.

In the US, deaths due to medical errors (Figure 1) are the third leading cause of death [38]. That is equivalent to one or two passenger-filled jumbo jets (B747) crashing every day.

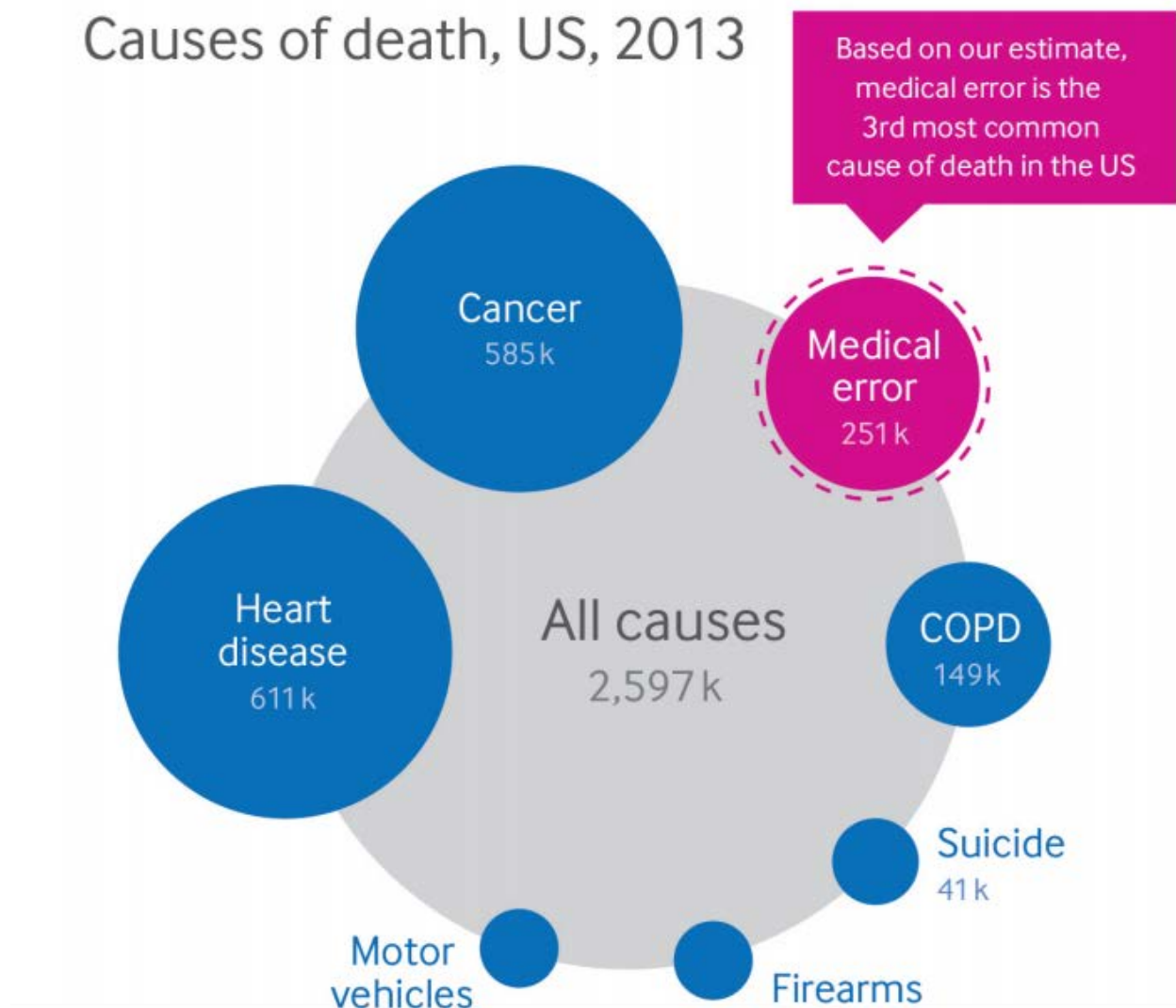


Fig 1: An estimated 220,000 – 440,000 patients die due to medical errors in the USA [38]

Deaths due to medical errors appear to be less documented in OECD nations. The relative virtues of the private Swiss system may be due to its demographics (population 8 million) and economics, 4th highest GDP in the world [39]. UK National Health Service data about adverse incidents is shown in Figure 2 [40]. Grouped as accidents under the leading causes of deaths in different geographies [41], deaths due to medical errors are unclear [42].

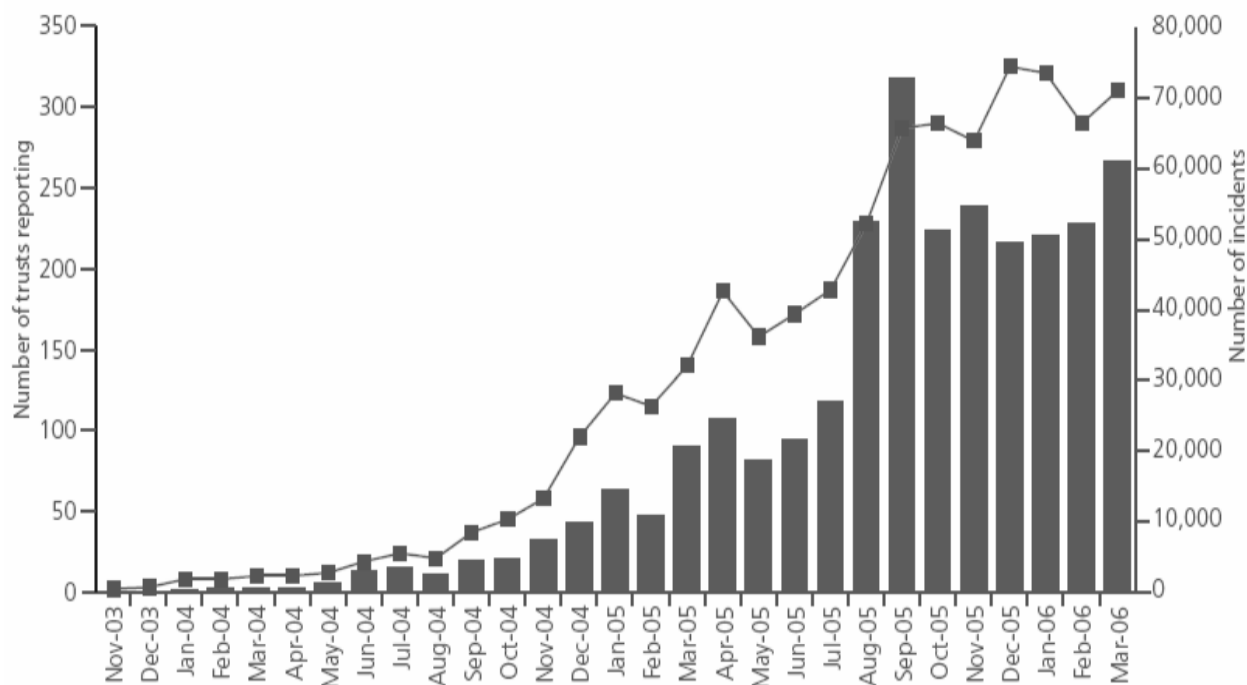


Fig 2: UK NHS Reporting – Trusts and Number of Incidents (bars) in the National [40] Reporting and Learning System. NRLS is a database where adverse incidents are reported.

Rank	Israel	EU-15 countries	USA	Canada
1	Malignant neoplasms	Malignant neoplasms	Heart disease	Malignant neoplasms
2	Heart disease	Heart disease	Malignant neoplasms	Heart disease
3	Cerebrovascular disease	Cerebrovascular disease	CLRD	Dementia
4	Diabetes	CLRD	Dementia	Cerebrovascular disease
5	Septicemia	Dementia	Cerebrovascular disease	CLRD
6	Kidney disease	Accidents	Accidents	Accidents
7	CLRD	Pneumonia & Influenza	Alzheimer's disease	Diabetes
8	Dementia	Diabetes	Diabetes	Alzheimer's disease
9	Pneumonia & Influenza	Alzheimer's disease	Pneumonia & Influenza	Pneumonia & Influenza
10	Accidents	Kidney disease	Kidney disease	Kidney disease

Table 1: Leading Causes of Death as published by the Ministry of Health, Israel [41]

PROBLEM SPACE – Preventable Fatalities due to lack of an Integrated Clinical Environment

A patient had a laparoscopic cholecystectomy [gall bladder removal] performed under general anesthesia. At the surgeon's request, a plain film x-ray was taken during a cholangiogram [bile duct x-ray]. The anesthesiologist stopped the ventilator for the film. The x-ray technician was unable to remove the film because of its position beneath the table. The anesthesiologist attempted to help but found it difficult because the gears on the table were jammed. Finally, the x-ray was removed and the procedure recommenced. At some point, the surgeon glanced at the EKG and noticed severe bradycardia. The ventilator was not restarted by the anesthesiologist. The ventilator is typically paused for 20–60 seconds to prevent motion-induced blurring of the image. The patient expired [43].

Cardiac (heart) surgery typically requires the use of cardiopulmonary bypass (CPB). During CPB, the CPB machine takes over both the pumping function of the heart and the ventilation function of the lung. Therefore, during CPB, the anesthesia machine ventilator is usually not needed, and is turned off to prevent unnecessary ventilation-induced lung movement that can interfere with surgery. During this period, physiological respiratory and circulatory monitors can be turned off or their alarm signals inactivated to prevent nuisance false alarm signals. At the conclusion of the CPB period, the heart resumes pumping blood, and the CPB machine pump is stopped. Lung ventilation must be resumed prior to discontinuation of CPB to prevent circulation of non-oxygenated blood which can cause organ damage. The anesthesia/surgical team has to remember to resume ventilation and manually re-start the anesthesia ventilator. Patient injuries and deaths occur when the team forgets or delays resumption of ventilation. This is a longstanding problem that continues to occur. Immediately following CPB, the heart and other major organs can be especially susceptible to injury from poorly oxygenated blood [43].

A 49-year-old woman underwent an uneventful total abdominal hysterectomy (removal of uterus and cervix through an abdominal incision) and bilateral salpingo-oophorectomy (removal of both sets of fallopian tube and ovary). Post-operatively, the patient complained of severe pain and received intravenous morphine sulfate in small increments. She began receiving a continuous infusion of morphine via a patient controlled analgesia (PCA) pump. A few hours after leaving the PACU [post anesthesia care unit] and arriving on the floor of the general ward, she was found pale with shallow breathing, a faint pulse and pinpoint pupils. The nursing staff called a "code" and the patient was resuscitated and transferred to the intensive care unit on a respirator [ventilator]. Based on family wishes, life support was withdrawn. The patient expired. A case review affirmed death due to PCA overdose [43].

SOLUTION SPACE – Improved Patient Safety due to an Integrated Clinical Environment

An elderly patient with end-stage renal failure was administered a standard intravenous (IV) insulin infusion protocol to manage her blood glucose, but no glucose was provided (oral or intravenous). Her blood glucose dropped to 33mg/dl and then rebounded to over 200mg/dl after glucose was administered [43]. The fluctuation is harmful for the patient.

The extreme swings of hypoglycemia and hyperglycemia should be avoided. A patient receiving IV insulin infusion must be continuously monitored for blood glucose level. An integrated platform using a workflow may automatically adjust the IV syringe pump rate to deliver the insulin according to the real-time blood glucose levels provided by the glucose monitor (mobile data dashboard also available in real-time at point of care). Integration of active device data with other patient specific data (perhaps from electronic health/medical records, EHR/EMR) may optimize the physiologically desired patient-centric maintenance of blood glucose values. The patient-specific target range integrates in the decision process the patient's record for weight, target glucose range, typical insulin dosage range (and correction factors, if any), glucose responsiveness to meals (insulin-to-carbohydrate ratio, glucose tolerance test data) and continuous assessment of vital signs (temperature, pulse oximetry, end tidal carbon dioxide, electrocardiograph, blood pressure, respiratory rate).

Hence, an integrated system will host a physiologic closed-loop control (PCLC) system algorithm to monitor and analyze the data from multiple devices as well as relevant health records in order to use an evidence-based (perhaps intelligent) decision tool to regulate the delivery of IV insulin to maintain the blood glucose values within the clinically desired range for this specific patient. To maintain homeostatic glucose levels within the target range, the system can also change/modify the glucose infusion rate using the integrated system-hosted algorithm. The IV insulin and glucose infusion changes can be automated and the system can execute changes to maintain physiological homeostatic balance without human intervention but will issue alarm/alert concomitant with the change (to mobile phone or point of contact nurse/physician) in case the medical situation warrants a medical professional to override the automated decision of the PCLC system algorithm.

The integrated system and algorithm can also trigger a software defined acuity-based ***contextual*** alarm and alert app, if patient safety was deemed at risk either for engineering reasons (device malfunction, null data, interface error) or medical causes (patient is at high risk for myocardial infarction). Hence, the maintenance of glucose levels and/or resultant physiological issue may reach beyond the design/scope of the PCLC bounded algorithm-driven decision process. The embedded logic may no longer effectively and safely manage the patient's (homeostatic) outcome by adjusting IV insulin dose or glucose infusion [43].

INNOVATION SPACE – The Unstoppable Tsunami of Ubiquitous Digital Connectivity

Making sense of sensors, sensor data and reflected radio frequency waves could lead to life-saving solutions. US reports indicate that nearly half a million patients may be dying each year due to preventable medical errors. One source of error is our lack of knowledge about the physiological status of the patient. Healthcare systems are sluggish in their progress and zeal to synthesize the data in order to provide the necessary information. Taken together, we are swimming in sensors and drowning in data yet slow to integrate the systems on a common platform to alleviate the burden of death due to errors. The common notion that such integration may be prohibitive in terms of cost is not supported by studies which claim that improved patient outcomes can be delivered within acceptable cost [44].

The importance of being frugal in healthcare carries a substantially heavy moral burden but ignoring fiscal reality and affordability may not be prudent [45]. In our haste to be penny-wise, we are often pound-foolish and court disasters. Suggestions in this paper are tainted by our lack of data and scenarios from other parts of the world but it may not be entirely callous to generalize [46] that elderly individuals are often rushed to emergencies due to falls. Accidents and emergencies are hemorrhaging [116] the healthcare system of its resources. Falls lead to hip replacements and brain injuries which are cost intensive [47].

It seems reasonable, therefore, that prevention of falls should be quite high on the list of priority for individuals over 65 years of age who are covered by Medicare and Medicaid in the US. Is it? In the US alone, more than 25,000 deaths [Figure 3] were reported in 2014 due to unintentional falls. The cost of treatment for falls in the US exceeded \$31 billion in 2015. Millions are treated in emergency rooms and thousands hospitalized, each year [48].

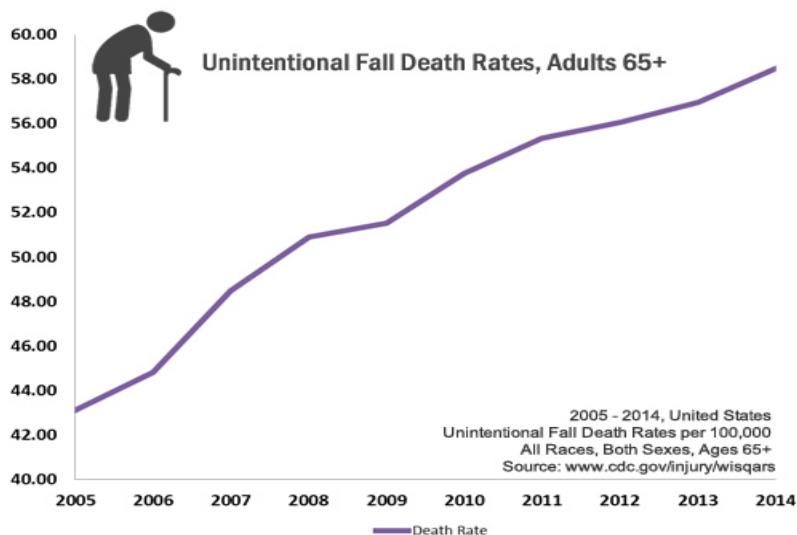


Fig 3: Mortality and morbidity due to unintentional falls may be preventable [48].

Prevention of falls is one example where integration [49] of medicine with innovative technologies [50] offers solutions. The latter is driven by principles of convergence [51] through collaborations between engineering [52] and medicine [53]. Confluence of ideas in advancing healthcare must include the entire spectrum including prevention, primary care, accidents and emergencies, palliative centers, hospices and dying with dignity [54].

Monitoring individuals in homes, hospitals and nursing facilities using reflected (RF) radio waves [55] eliminates the need for sensors. Eliminating the need to wear a tag or sensor or transponder or any object on the body is helpful to elderly people who may be forgetful or suffering from neural afflictions. Analysis of reflected radio waves may predict (Figure 4) if a person is likely to fall. Reducing the time from the instance of the fall to medical attention is key to reducing long term brain damage, hip replacements and fatalities. Today, we have the tools to prevent mortality and morbidity due to unintentional falls, albeit, in part. As soon as an event (fall) occurs, the system can connect with ambulatory services and alert care-givers [56]. Integration of the patient's existing medical data with the patient *en route* to the hospital, may reduce delays in the emergency room and improve quality of care.

The principles and practice of connectivity, when taken together with an integrated clinical environment (ICE), may enable the system to combine device data in hospitals as well as data from home, wearables, edge devices, nutrition indicators and wellness monitors. A tsunami of change is imminent in preventive care, healthcare decision support systems and the medical-industrial complex. Science and engineering [57] are catalyzing tools and technologies to advance medical [58] cyber physical systems [59] and fueling an explosion of the medical internet of things [60] which can save lives and deliver some form of healthcare to billions [61]. Decision support apps in real-time may help to prevent escalation to high acuity states by enabling a temporary "bridge" to deliver limited medical function a PoC.

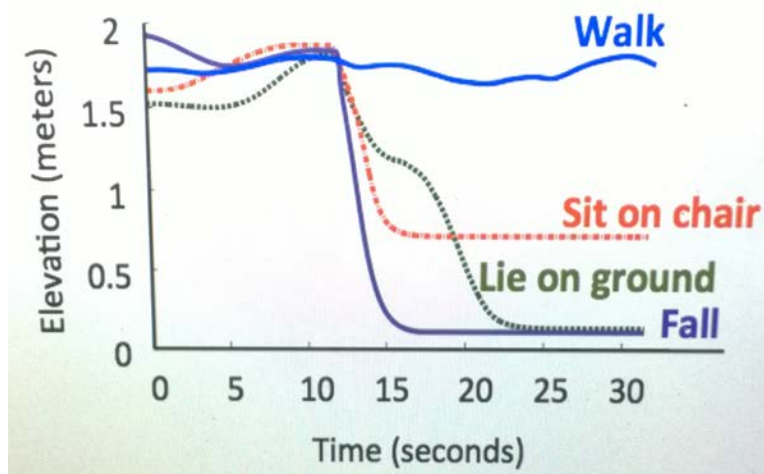


Fig 4: Predict the possibility of fall by analyzing the data from reflected radio waves [55]

DIGITAL TRANSFORMATION OF HEALTHCARE – Connected Value Chain of Medical IoT

The grand challenge implicit under the umbrella term medical internet of things is the ability to have an open mind and rise above the restricted view of medical IoT as a new thing or technology. IoT is a digital by design metaphor. By extension, medical IoT is a design metaphor, too. Why IoT is a design metaphor may be better understood if traced back to its roots in a seminal paper [62] and recent publications, in 1991 [63] and 2000 [15]. The design principle is not limited to healthcare or the medical domain. It is applicable to a vast number of domains [64] including manufacturing [65], transport [66] and energy [67].

The digital by design paradigm is made possible due to rapid diffusion of ubiquitous connectivity. The principle of connectivity, when transformed into practice, for example, Integrated Clinical Environment (ICE), is applicable to medicine and healthcare. As defined by ASTM F2761-09 standard [43], ICE is an architectural framework (work in progress) for integrating the clinical environment. It is a step toward enabling interoperability which is key to implementation, not only for medical IoT but anywhere we can apply IoT by design.

The global appeal of IoT as a design metaphor is based on the potential of IoT to spur economic growth [68]. Since hype is the main driver for public relations, the bombastic megalomaniac projections [69] are not predictions but perhaps clues to half-truths.

What appears to be true is the ability of the IoT as a design to reduce transaction cost [70]. The robust principles of transaction cost economics [71] when viewed in the context of IoT appears to support the definitive trajectory of IoT as a conceptual tool for global digital transformation expected to reshuffle prevalent trends and create new markets [72].

Observing the mere mundane fact of comparing prices of goods using your smart phone and then opting to buy the product you choose from the comfort of your home is a form of e-commerce. It is retail IoT as well, because connectivity may allow you to explore your purchase and your trigger to purchase may be due to the embedded IoT functions.

Use of medical IoT in the prevention of falls may reduce a portion of the \$31 billion direct costs for treating unintentional falls in the US. Research driven entrepreneurial innovation created economic growth [73] and even a modest (10% - 20%) reduction in direct costs will save billions for US tax-payers. Taken together, medical IoT will reduce transaction cost.

Transaction cost in the value chain of ecosystems drives the cost of creating end to end connectivity. Digital solutions are rarely vertical and engage diverse supply chain partners. Digital transformation will morph classical models and supply network strategies. Services which offer data, value, information and knowledge synthesis, are preferred over products.

MEDICAL IoT – INTEGRATED CLINICAL ENVIRONMENT (ICE) – Information Synthesis

The lack of integration of data in the context of medical devices is a major contributor to lapses in patient safety in the US [74] and worldwide. Lack of granular data from and interoperability between medical devices (attached to a patient in a hospital or from remote monitoring at home) are factors which compromise patient safety. In the absence of appropriate data analysis and synthesis, the ability to produce actionable information relevant to the collective status of the patient must depend on medical professionals to combine the data at the point of care. In this context, integration and interoperability may improve efficiency, safety and security. It is anticipated that it will lower the rates of preventable medical errors and signal a significant improvement in quality of patient care.

The grand challenge of the medical internet of things (MIoT) is to sufficiently enable the deployment of patient-centric and context-aware networked medical systems in all care environments, ranging from hospital floors to operating rooms, intensive care units to home care units. Heterogeneous devices in each care environment would effectively share data (efficiently, safely and securely) to minimize preventable errors often introduced by humans.

Mobility of medical devices between different care environments or from patient to patient presents challenges. While in transit, they must remain secure yet “open” for “discovery” by other devices in much the same way that consumer IoT accessories, for example, Amazon Echo Dot, pairs with your smartphone or the laptop when it is in the cone of connectivity. Once discovered, the devices must self-organize and form the *ad hoc* mesh network of devices, specific to the patient. They need to interoperate with, verify and execute safe, authorized and compliant operational profiles.

This generic *modus operandi* is far from the norm. To transform this simple procedure to reality, we need common or standard architectures which will optimize and prioritize the necessary balance between utility, reliability and safety with those of accuracy, security and privacy. Unless widely adopted, reference architectures, blueprints or standards are sterile, impotent and quite useless [75].

The Integrated Clinical Environment (ICE) framework, as defined by the ASTM F2761-09 standard [43] is a step toward enabling the interoperable MIoT vision. ICE is an architecture for a medical data and device interoperability platform [76]. The debate rages on about open [77] vs partially closed platforms [78]. Platform is a new word for the conceptually similar “common bus” in computers [79]. ICE is a platform where devices may connect via standard interfaces or API’s in order to contribute, select or analyze data. Actionable information relevant to the patient can be updated, shared, published or routed. OpenICE is the reference implementation of this platform vision. The medical community may access OpenIce (www.openice.info/ and www.mdnpn.org) and adapt and/or adopt for their use.

Layering ICE with a variety of engines for distributed data acquisition, data curation and data analytics (dynamic composition of engines based on the nature of data), crowd-sourcing open apps to innovate using available (de-identified) data, introducing novel algorithms for non-obvious relationship analysis (correlations) and semantic data dictionaries, are sign posts for future development. We are keen to find unknown and uncharted paths beyond the horizon. Integrating cybersecurity, security, privacy, device discovery, authentication, standards, interoperability and data de-identification [61] are a few of the more immediate tasks. Security for interconnected and dynamically composable medical systems are a priority not only because they are critical to patient safety but also because they are mandated by HIPAA, the Health Insurance Portability and Accountability Act of 1996 [80].

In most environments, physical objects – the medical devices – are likely to be mixed and matched in an *ad hoc* fashion to serve the patient (dynamic system composition). It may be a conceptual stretch but compare it to an assembly of Lego blocks where the patient is the “base” to which the blocks are connected, either directly (device) or indirectly (printer or screen) or remotely (wireless heart rate monitor). In the rush to create a working solution for a patient in an emergency room, medical staff may “grab” what is available at first sight depending on the need (infusion pump, sphygmomanometer, plethysmograph, ventilator).

Did they verify the security mechanisms and authorizations which are configured on these devices? How will they support automatic verification that the system components being used are as intended in the correct clinical context? How will they determine that the components are authentic and authorized for use in that environment? Where can they log in to confirm that the devices are still approved by the hospital’s biomedical engineering staff and certified to meet regulatory safety and effectiveness requirements?

In the long term future, as soon as a staff touches a medical equipment or a device, an automated association will be instantiated on her/his mobile device and/or in a control device which will serve as a digital footprint connecting a specific human with a specific object (for example, a baggage handler wearing a RFID and sensor embedded hand glove picks up a piece of luggage tagged with a “smart” label). The association can extend to other humans (in this case, nurses, physicians, patients) or objects (equipment, devices). In this manner, the staff rushing around to gather the devices and connect them to a patient is free to do her/his job while the “digital twin” evolves [81] to capture the patient, team of medical professionals and the devices connected to the patient. Each team member will receive a copy of the “digital twin” on their smart phones. The questions in the preceding paragraph will be digitally queried and unsatisfactory outcomes could trigger alarms or alerts (for example, app triggers message and the app is activated for all individuals in the decision support value chain to help change device or charge equipment or re-boot EKG machine).

The “digital twin” will capture the network of activities in progress in real-time, monitor for errors, serve as an active virtual assistant (avatar) to the team and store a continuous log of events. Currently, none of the above is available but digital twins [79] are slowly emerging.

Today, as far as medical device communication is concerned, few of the existing or proposed standards, for dynamically composed and interoperable medical devices and information systems, include sufficiently comprehensive or flexible security mechanisms to meet current and future safety needs. There are gaps between required security properties and those that can be fulfilled even by combinations of currently standardized protocols [44]. Safety considerations in these standardization efforts are effectively incomplete due to a lack of appropriate security analysis.

Regulators are also noting the importance of incorporating security for safety and privacy in the medical domain. The FDA is calling for medical device manufacturers to address cyber-security issues for the *entire* lifecycle of the device. It begins with the pre-market stage [82] from initial design through deployment and end-of-life or post-market stage [83]. FDA may use these draft guidelines as a basis for clearing medical device submissions [84].

Imminent fears of regulatory hurdles, associated with security, further discourages device manufacturers from delving deeper into installing security which may be subject to approval by the FDA [85] for US markets. Elsewhere, the considerations may be different.

The device-centric view of security as a company-specific endeavor may be the primary barrier in this traditional hospital-focused effort which excludes the distributed network-centric view which is rapidly evolving [86]. Cybersecurity, security and privacy related to any device and its data is a patient-centric issue and no longer a company or device-centric issue. Each device and its data is critical yet one part of a larger, distributed, temporal aggregate of a network of devices, data, decisions, events and records, linked over time, to a person and/or patient. It is a time series of events. The demand for total security and pervasive cybersecurity to ensure that privacy is not punctuated remains to be analyzed.

Solutions may evolve from alliances, organizations or groups working as a team bounded by goals which must rise above the mantra of amplifying shareholder values and take into account social responsibility to promote stakeholder values. The question without a good answer is the amount of security and privacy which is enough or is sufficient or is needed. Pervasive security and cybersecurity may be an illusion and costs may be truly prohibitive. Funding for pervasive cybersecurity may kill the patient by draining away the resources necessary for medical purposes. Perhaps passengers and drivers in body armors may have a lower risk of injury or fatality in case of an automobile accident but as a society we have decided to limit our sense of safety and precautions to safety belts and air bags in vehicles.

An analogy of punctuated security and privacy is the use of a tire pressure sensor that you bought online to monitor your car's tire pressure using an app on your iPhone. A hacker went into the control system of your BMW using the external (not factory installed) tire pressure sensor and disabled your brakes. The shield of cybersecurity was punctuated. Similar events using other IoT devices were predicted in June 2015 [87] and massive attacks were observed on 21 October 2016 [88]. Healthcare is not immune from such attacks [89].

Healthcare is no longer bound by the traditional medical institution and it is no longer in complete control of the flow of health information. Hence, security considerations must be regarded and regulated as public goods. The new and fractured state of health, wellness and emergencies are distributed problems. It cannot be solved by hospitals, alone.

How much of which data must be protected or should be kept private will change in a dynamic manner depending on personal preferences and health coverage in different nations. Travel and tourism makes it imperative that humans receive treatment when outside their countries.

Taken together, issues of interoperability, dynamic composability, variant configuration and levels of operational flexibility are all important. These factors call for different thinking about principles, infrastructures and tools which can be globally deployable yet subject to local optimizations [90], for example, the *cognitive firewall* (J Siegel and S Sarma).

However, no single solution can act as a panacea for all scenarios and applications. We need to balance new approaches with the old [91] in an effort to converge healthy idealism with doses of pragmatism. Fear of short term vulnerabilities may, justifiably, evoke resistance to reduce the dead weight of old technologies even though pockets of conviction exist about the value of distributed agent-based approaches [85] as a robust long term prescription for digital transformation.

The ICE framework, as defined by the ASTM F2761-09 standard [43] provides an approach for integrating heterogeneous medical devices and coordinating their activities to automate clinical workflows. Medical devices that conform to the ICE standard, either natively or using after-market adapters, may interoperate with other ICE-compliant devices regardless of their manufacturing origin.

A similar paradigm exists in the computing and communications domain, leading to an explosion of devices supporting WiFi, LiFi, USB, Bluetooth, LoPAN, LTE, 5G and other telco standards. It is useful to think of ICE architecture, ICE standard and OpenICE reference implementation as foundational as the "http" or hypertext transfer protocol [92]. The global impact of the non-proprietary, open standards based http, needs little over-emphasis. The mission of ICE is similar to that of http for medical equipment, devices and any object used for healthcare. There is a time and place to exercise protectionism. This is not one of them.

ICE standard will enable dramatic improvements to patient safety because cross-vendor inter-device communications may significantly reduce preventable medical errors. Examples include patient transfers from the Operating Room (OR) to Intensive Care Units (ICU) and reducing false alarms or deaths due to Patient-Controlled Analgesia (PCA). In both of these examples, synthesis of data from diverse range of medical devices may enable the generation of real-time actionable information from the system to a point of care physician/nurse to prevent medical errors and reduce patient mortality and morbidity.

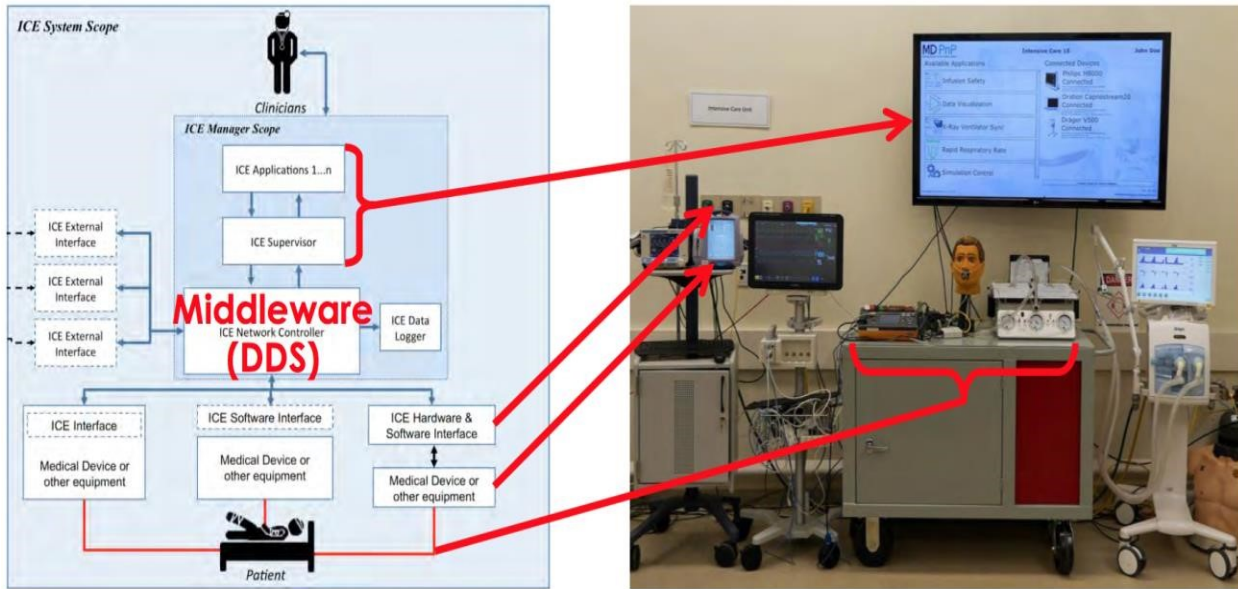


Fig 5: General architecture of ICE and an instantiation of it in a test setup at MD PnP Lab

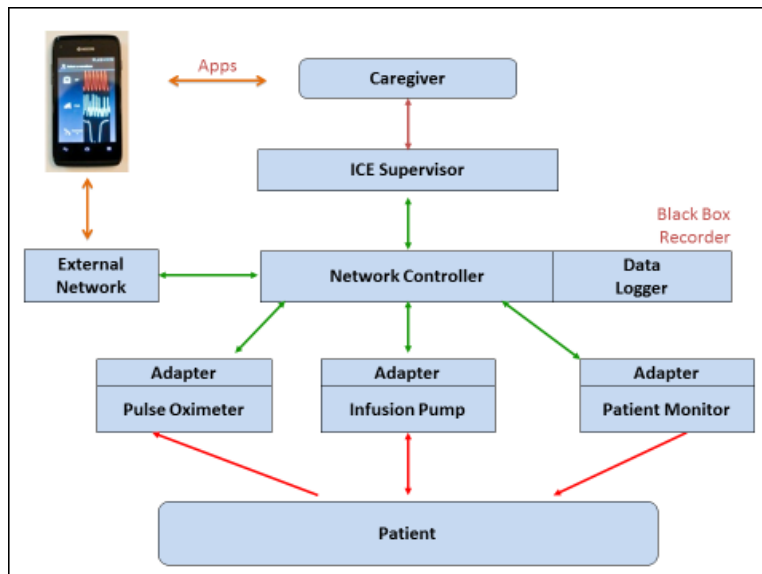


Fig 6: Overview - Components of the ICE System (apps can connect distributed functions).

The *ICE Network Controller* is a high-assurance middleware that forwards data or commands to or from ICE applications and devices, ensures communication related quality-of-service and is agnostic as to the intended use of the clinical apps that it may support. It also manages the **discovery** and connection protocol for devices that wish to connect to the system.

In view of its central role in ICE communications, it is imperative to install high-performance and context-aware security support in the ICE network controller. The major functional security requirements for the ICE network controller are:

- [a] authentication mechanisms for validating the identity of devices and apps, vouching for their provenance and ICE compliance,
- [b] dynamic and flexible yet user friendly mechanisms for defining and enforcing access control policies for various ICE configurations in different environments,
- [c] mechanism for secure device and app discovery,
- [d] secure auditing mechanism and
- [e] tools to guarantee the integrity, freshness (perishability) and confidentiality of data.

Functional requirements should minimize negative impact on non-functional requirements such as performance, availability, robustness and ease of use for clinicians and developers.

Safety considerations in standardization efforts are incomplete due to a lack of appropriate security analysis. To address this, we developed a prototype of ICE based on DDS or Data Distribution Service middleware [93] as the ICE Network Controller (please see Figure 5).

DDS is a communications API and an interoperability standard that provides a data-centric publish-subscribe model for integrating loosely coupled real-time distributed systems. DDS is data-centric. DDS separates state [94] management and data distribution from application logic and supports discoverable data models. This exposes data model to communication middleware, enabling DDS middleware to reason and optimize the performance of data movement within the system. To customize run-time behavior and achieve desired performance profile, DDS allows publishing and subscribing entities to express several quality-of-service (QoS) parameters. The offered versus requested QoS requirements of the participating entities are matched before any communication can proceed.

The *ICE Supervisor* provides separation/isolation-kernel-like data partitioning and time partitioning. It makes sure that the information cannot inadvertently leak between apps and apps cannot inadvertently interfere with one another. It provides real-time scheduling guarantees that the computation in one app cannot cause the performance of another to degrade or fail. It also provides a console that allows a clinician to launch apps, monitor their progress and provide user input during app execution. The ICE Network Controller and Supervisor may be incorporated together and deployed as a standalone ICE Manager.

ICE Applications are programs that accomplish a clinical objective by interacting with one or more devices attached to the network controller. As each app executes in the supervisor, it defines the intended use of the current ICE configuration. ICE medical devices never interact directly with each other (for safety and security reasons). All interactions are coordinated and controlled via the ICE apps. It is crucial that ICE apps exactly correspond to the specified task for which they were designed.

ICE Equipment Interfaces declares the functional capabilities of the device (for example, format of its data streams, commands to which it responds) along with non-functional properties of the data such as the rate at which data elements are streamed from the device. It is crucial that ICE Interfaces (and apps) are designed with considerations for usable security, for developers and clinical end-users.

ICE Data Logger is dedicated to logging communication and other important events within the ICE Network Controller and ICE Supervisor. Data logger should also record all security related events. The data logger can be used by medical professionals to re-create the events and actions.

It may also serve to protect against institutional vilification and indemnify the professionals in case of charges of death due to malpractice or insurance claims/payments. Physiological networks can interact and cross-react in many unpredictable ways which could lead to a cascade of deleterious events without human intervention (human is not a fault). In a very litigious society, as in the US, such incidents are often followed by “see you in court” tweets. Thus, the burden is on the medical domain to provide verifiable evidence of the sequence of events and identify each human associated with each stage of that process. Without the ICE data logger, this becomes a network reconstruction problem and network reconstruction remains an outstanding challenge [95] even in the absence of physiological complexity. ICE data logger can offer time-stamped series of the sequence of events which may exonerate the medical institution and professionals, if no human / preventable error was involved.

The concept of a *cognitive supervisor* and *cognitive firewall* has been proposed by Joshua Siegel and Sanjay Sarma (unpublished work; Joshua Siegel, PhD thesis, MIT 2016). The implementation of cognition is fraught with difficulties but the concept is perfectly logical. If the ICE Data Logger records multiple commands over a short time in a manner that might deplete a resource (battery life) or induce a DDoS (distributed denial of service) attack then the “cognitive firewall” springs into action by limiting the function or the performance or triggers an intruder detection or malfunction alert. The “cognitive supervisor” sits atop a pyramid of functions and monitors the functions or activates the cognitive firewall if and when necessary. The rationale and logic of the cognitive functions can be hard coded using known ranges and use of machine learning algorithms can extract lessons and store in a repository (memory) to use if an event appears to lie outside the hard coded boundaries.

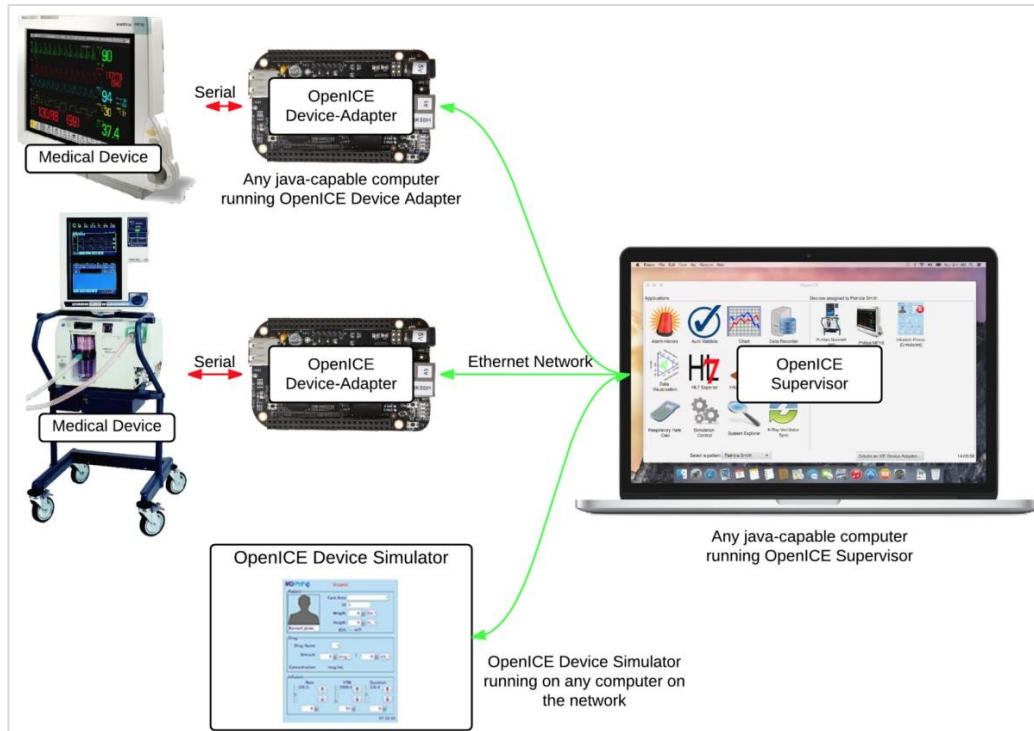


Fig 7: OpenICE from MD PnP Lab enables connectivity between various types of devices.

Standards-based medical device interoperability can also provide real-time comprehensive population of a patient's Electronic Health/Medical Record (EHR/EMR). It will permit the creation of integrated error-resistant medical systems and support advanced capabilities such as (a) automated System readiness assessment, (b) physiologic closed loop control of medication delivery, ventilation and fluid delivery, (c) decision support using machine learning and/or rudimentary artificial intelligence applications, (d) safety interlocks, (e) monitoring of device performance, (f) plug-and-play modularity to support "hot swapping" of replacement devices, (g) selection of "best of breed" components from competitive sources and (h) innovations to improve patient safety, treatment efficacy and workflow efficiency.

The vision of data synthesis and data interoperability depends on adoption of these (ICE) standards by healthcare delivery organizations and medical device manufacturers as well as endorsement by organizations (eg AMA) and regulatory bodies (eg FDA). Medical Device "Free Interoperability Requirements for the Enterprise" or MD FIRE [96] is a guide to coalesce the ecosystem necessary to create a critical mass which may initiate the steps to reduce preventable medical errors. The pursuit of ICE as a standard and interoperability between other ICE-like global standards are essential. ICE advocacy by organizations and adoption of ICE by choice or regulation will enhance patient protection and patient safety.

BEYOND ERRORS – The Opportunity and The Need

The problem of preventable medical errors is, at least in part, created by the penchant for profit. Proprietary semantic data dictionaries, locked data interfaces and upselling services are tools of the trade used by the medical-industrial complex. Adoption of open standards and open platforms [97] may partially ameliorate this dysfunction. But, the corporate need to monetize is also necessary to spur economic growth and incentivize innovation. The balance between idealism and pragmatism is crucial for our path to (ethical) profitability.

The far bigger opportunity in seeking better quality of EHR/EMR is not limited to potential for integration with data from devices and home monitors or inclusion of wearables. There are other sources of data in a fractured state or uncollected. Data from transcriptomics, genomics, proteomics, metabolomics, imaging, and pathology may reveal patterns or interplay between morphogens and morphogenesis or factors that influence immune responses [98] or eliminate pathogens [99] or analytes which predict heart failure [100].

This vast resource of data, if collected, combined and analyzed (if made available from an open repository) will aid systems biology to uncover clues cryptic in networks of proteins or genetic circuits or cellular signals. These signals connect, converge and collude in a myriad of ways to promote health or cause disease. Elucidating the elusive paths taken by these target molecules may be one part of the future progress of precision medicine [101]. The toilet in our bathroom may become our best ally [61] in preventive medicine.

Transforming these target molecules to prognostic tools may open the Pandora's Box on population genomics and populations at risk. Global medicine must find ways to address health and healthcare issues for billions. Moving from expensive micro-arrays to very low cost nano-sensor [102] arrays or nano-wires [103] to detect single molecules may hold promise for diagnostics. However, the ability to detect is only a part of the equation. Reusability is a key driver to reduce cost. Analyte association is as important as dissociation to replenish and recycle the detection tool. The time, duration and circadian rhythm of the signal is pregnant with information. An "always-on" transmission is required to capture any signal, anytime. The form factor and stable vs unstable location (topical, epidermal, subdermal, subcutaneous, ingestible) will influence efficacy, accuracy and adoption. Invention [104] and innovation of new technologies [105] may be necessary to detect, transmit and capture signals *in vivo*.

Data leading to diagnostic tools and data logging of transmitted signals to identify patterns will need a variety of tools as well as new thinking and re-visiting old ideas. We will need

data curation, pattern analysis, non-obvious relations, chemistry, engineering, computer science, nanotechnology, telecommunications, software, system of systems and medical cyber physical systems. Confluence of transdisciplinary knowledge domains will be essential to synthesize the outcomes and coordinate the compass with the road map.

This is yet another dimension of the anticipated digital transformation in medicine. Medical IoT is a part of this forthcoming tsunami from ubiquitous connectivity. The confluence of molecular connectivity with 3D/4D printing and distributed additive manufacturing-on-demand facilities may deliver medical tools to benefit billions. The new business of billions may flourish if rooted in the concept of micro-payments for services.

Current cost of hip replacement in India is about US\$5,000 but at a per capita annual income of \$1500, nominal (\$5350 by purchasing power parity), it is still out of reach for many Indians (even though the cost is about one tenth of that in US). If this product was transformed into a service and distributed over the lifecycle of the implant (say 10 years) then the daily micro-payment amounts to \$1.40 (or more depending on cost of service). For 5.6 billion people in the world surviving on less than \$10 per day, the amount spent on healthcare will be minimal. Can the demographics, who need the hip replacement the most, afford to bear the cost of \$1.40 per day for 10 years if they earn about \$10 per day?

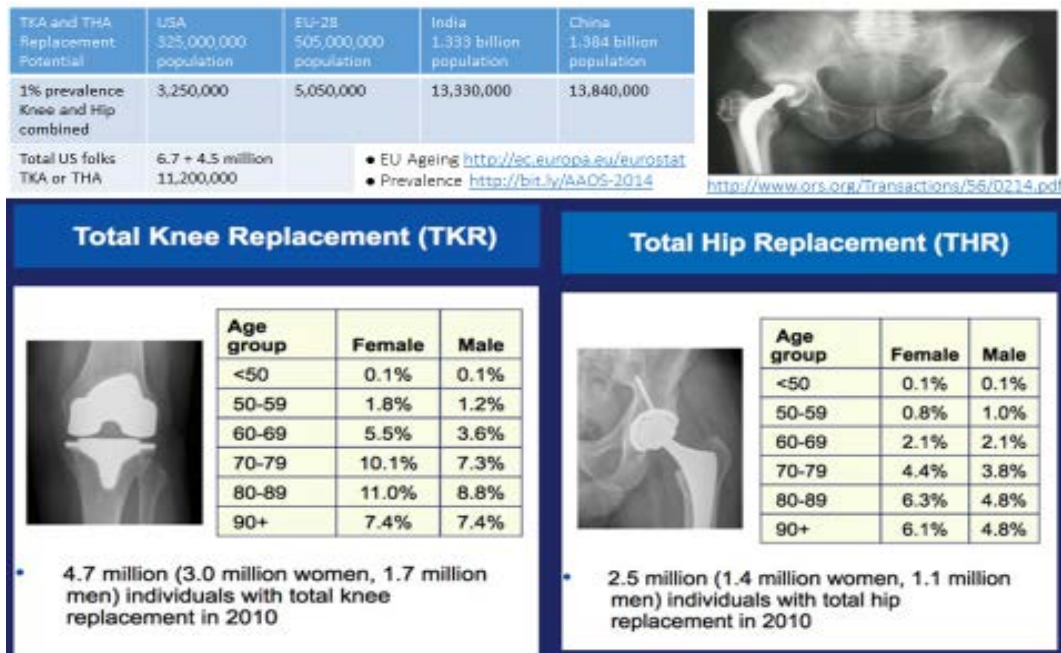


Table 2: If 1% of the population of India and China could afford hip or knee replacement then the demand for hip & knee implants (including US & EU) may exceed 35 million [106]

Advances in material science, chemistry of metal additive printing and lowering the capital expenses, related to the manufacturing infrastructure, may converge to lower the cost of the implant. Surgical costs and post-operative costs are, however, significant factors which may not be easily reduced. Spinal implants may need teams of orthopedic surgeons as well as neuro-surgeons. Patient-specific 3D printed implants will need access to imaging tools (MRI), design labs and technicians to produce the implant with a patient-specific fit.

Using an array of sensors to derive data from these implants (for example, for hip joints, femoroacetabular impingement) opens up yet another horizon. To go one step further, we can create a cavity within the implant and use the implant as a Trojan Horse to deliver a variety of molecular tools packed in that cavity. The challenge is to power the tools inside the implant for the lifecycle of the implant and communicate or extract digital signatures, data and signals from inside the implant. The external surface of the implant may serve as an internal “skin” embedded with nano-wire sensors. These nano-wires may serve as docking zones for bio-markers [107] or other analytes, which, when bound, elicit signals. Similar set of issues are applicable in identifying the signal over noise, replenishing the nano-sensor, capturing and transmitting the signal. In addition, the impact of angiogenesis and vascularization on the function of these nano-sensors remains to be determined.

Capturing signals released by our bodies may generate a wealth of data, for example, the temperature of our body (form of radiation/convection). Neural activity inside our bodies generate data we generally do not capture or analyze. This data may offer information about the state of neuromuscular or neurodegenerative diseases, such as ALS [108].

The field of terahertz radiation and imaging is yet another source of data which remains unexplored. Protein electrodynamics [109] suggests that proteins act as biological radios [110]. Proteins emit and absorb terahertz (THz) radiation [111]. Hence, protein signatures may be dynamic or may change, theoretically, depending on the stage of synthesis, modification or mutation. Hence, a potential for comparative analysis of protein signatures to identify modifications or mutations of protein structure. These changes may be implicated in the etiology of disease(s) or dysfunction. Detection of such signals may alter diagnosis and prognosis of disease states, many of which are not sufficiently expressed unless they reach a certain threshold or activation point. Problems pertaining to signal vs noise appears to corrupt data from terahertz imaging [112]. One wonders if innovative application of error correction techniques from information theory [113] or econometrics [114] or some combination of both (or modification of these principles) may help in curating data from terahertz imaging to identify authentic signals released by proteins.

Bringing together data from a variety of domains may revolutionize medicine and trigger thoughts that we don't know how to think, yet. These suggestions may not be correct.

It is to “dare to propose” ideas [115] and re-visit “dots” or renew thoughts which may be waiting to be connected or disconnected.

THE PRAGMATIC HORIZON – The Influence of Digital Transformation on Retail Healthcare

The tsunami of the principles and practice of connectivity is expected to usher in an unprecedented era of healthcare information technology that shall be woven into the daily fabric of our lives almost through our entire life-cycle, from conception to the grave.

Healthcare-associated infections may benefit from connectivity [Figure 8] and the connectivity as a medical IoT design principles, if used, may save lives. About 1 in 25 patients gets an infection each year while receiving medical care in the US [116]. Estimated 25,000 deaths per year from about 1 million infections each year from US healthcare at a projected cost of \$30 billion per annum. In addition to logging prescribed antibiotics and their use [117] it may be necessary to track and trace individual hand-washing habits and places, beds, patients, equipment they may touch. The tools for such visibility include RFID tracking of objects and their association with events. When added to the power of mobility and apps, this information can be available in real-time and potential nodes of infection predicted or identified before the spread commences (epidemic) or gains momentum.

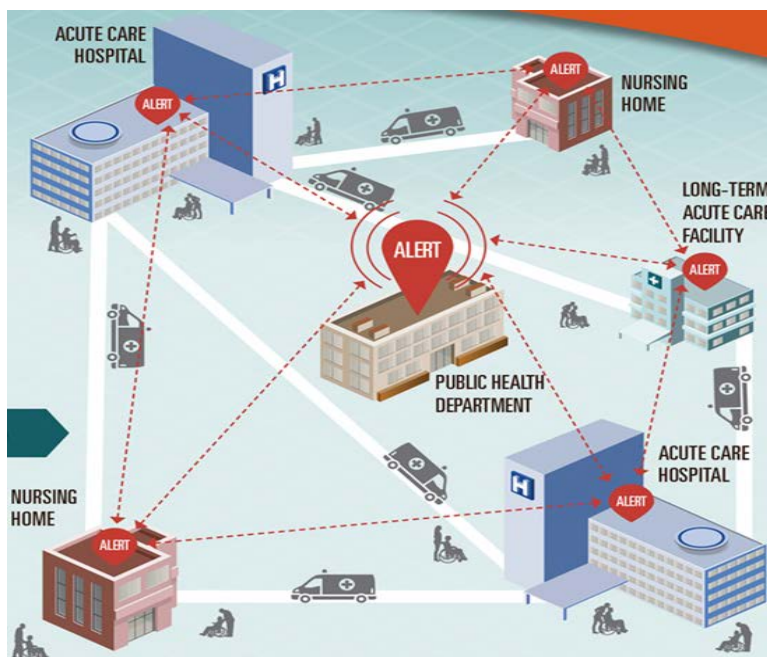


Fig 8: Principles and practice of connectivity coupled with RFID and medical IoT (MIoT) may help in tracking, predicting and containing Healthcare-associated Infections [118]

Digital by design is the fabric integrated above [Figure 8]. Businesses may use similar fabric in an era where IoT may be the dominant design metaphor. Digital entrepreneurship and intrapreneurship is exactly what the doctor ordered. Trans-disciplinary convergence of medicine and engineering may morph the brick and mortar health departments, clinics and pharmacies from its emergency or retail outlet concept. An integrated function for health and healthcare is necessary to decrease demand for high acuity events and the cost.

IoT is poised to recalibrate almost every facet of the business world by taking advantage of the progress of connectivity. Medical IoT will influence health and non-emergency health, as well as general wellness, by connecting precision metabolomics within primary care environments fostering the practice of preventive medicine and clinical attention/action.

Retail clinics and “pharmacies” will undergo transformation to create the 22nd Century service centers for medicine, perhaps something akin to “Jiffy Lube” (Boots, Walgreens, CVS) compared to a visit to Sears Auto Center (hospital). \$0.99 Dexa scan, \$1.99 PSA tests and \$2.99 mammograms may be done in-store when shopping for milk, bread and eggs.

The transformation will be catalyzed by pioneers who will usher in, albeit in phases, convergence of a wide variety of precision medicine tools applicable on a massive scale and harvest metabolomics data from device-agnostic, protocol-agnostic, platform aggregators (for example, ICE) which will connect to streaming data inside and outside the body (humans, animals). Predictive analytics from person-specific data will be the digital path for clinical “sense and response” system and offer prescriptive analytics. This may serve many facets of preventive medicine, non-emergency medicine but may exclude sudden trauma and ambulatory scenarios.

Retail healthcare may serve as the future point of contact for the confluence of preventive medicine, precision medicine, primary care, tele-health and remote diagnostics. Retail health industries must reform their mission from selling drugs to acquiring data, analyzing and advocating in addition to building alliances to serve individuals who are not patients. The potential of digital by design health IoT will generate business growth and generate massive revenues through pay-per-use micro-revenue schemes. It may help those in the US who are less fortunate [119] and reduce the barrier to entry in L-26 countries [120] where health spending is less than US\$50 per year per person for more than 2 billion people [121].

Imagination, invention and innovation must be coupled with wireless telecommunication based remote monitoring where changes in physiological status or alerts could trigger applications via intelligent agents using functional mesh (networks) for multi-directional multi-cast communication of data, information, analytics, intelligence and streams for real time decision support or at-home care or ambulatory access depending on the “sense and response” system of systems that provide one-on-one guidance at point of contact (POC).

The retail health industry must demonstrate this concept on a large scale, to build credibility. It must create the local and global ecosystem of competencies necessary to provide the end to end value chain. It must be driven by the principles of ethical profitability and in practice adopt a micro-payments model for pay-per-event services.

Cybersecurity [122], trust, authorization, validation, privacy, policy [123], regulatory compliance and authentication may require digital ledgers, for example, blockchain-like concepts, to track, trace and secure every instance and events related to every process and nested sub-process. Often data may have long shelf-lives (perishability of medical data).

The complexity calls for a global surge of and focus on, collective entrepreneurial as well as intra-preneurial recombinant innovation. It will create new lines of business and immense economic growth but not through traditional channels and existing business models or organizational *status quo*.

This calls for a new organizational platform approach where credible groups lead and coalesce tools from a diverse array of providers and champion a new form of delivery.

The leadership must embody the relentless pursuit of frontiers without the fear of failure to lift the future plight of humanity through distributed medical care beyond boundaries. One must continuously re-invent to re-align with new research, new inventions, new theories, new ideas, new science, new ways to help people and new customers, locally and globally. If one thinks that any one solution or company or provider or nation holds the key then one may be suffering from disequilibrium [124] due to an incurable ailment commonly referred to (in the medical jargon) as solipsistic bliss.

NEAR FUTURE – Prologue to Nonlinearity, Known Unknowns and Unknown Unknowns

A systems approach to preventing errors by enabling medical device interoperability depends on data synthesis from the “network” of devices. It may prevent deaths by treating the whole patient rather than responding to separate signals. Insufficient strides [125] and displaced focus [126] are certainly not in short supply [127].

One proposal in this article is to gather device data and acquire data from other sources (genomics, microbiomes, terahertz radiation) in order to combine, synthesize and analyze. The outcome may reveal one or more networks, connectivity, patterns and relationships, both obvious and non-obvious [Figure 11].

Patterns are ubiquitous - from Fibonacci in nature [128] to galaxies [129], even if it is amorphous to the naked eye in very large systems [130].

Network(s) thus revealed may be super-imposed (sub-imposed) on other networks in systems biology – network of gene circuits [131], network of cellular signals [132], neural network of networks [133]. Network layers are part of nature [left, Figure 8]. Cascade of layers and/or networks underlie many functions, such as the OSI model and TCP/IP which is at the core of the internet [center panel, Figure 8]. System of systems may connect and orchestrate public services for towns and communities [right panel, Figure 8] aspiring to join the global league of smart cities [134].

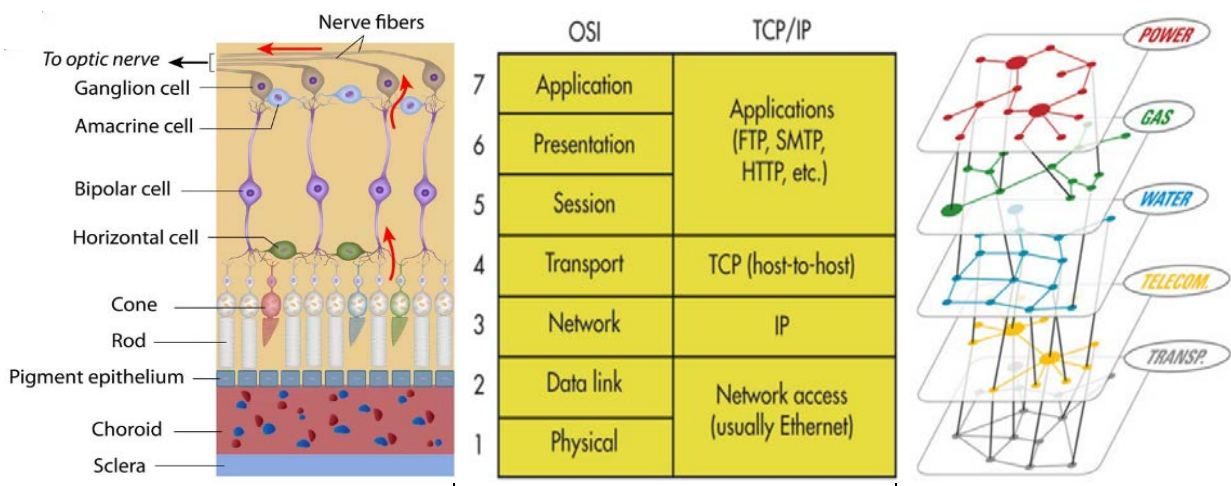


Fig 9: Layers, Networks and Cascades – the systems approach to form versus function

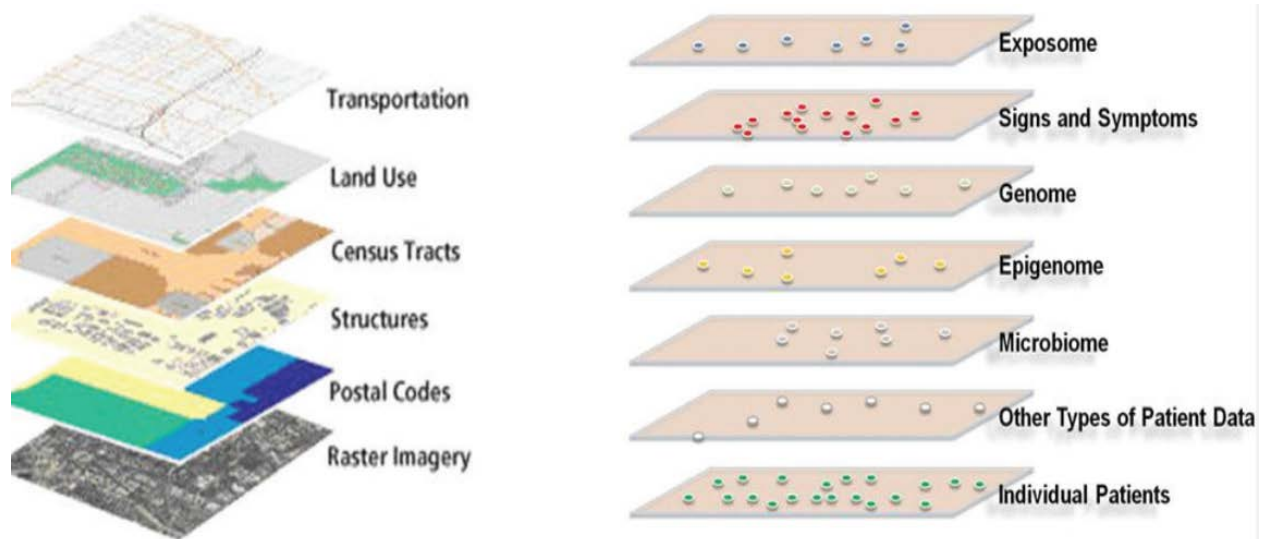


Fig 10: The principle of GIS (Google Map) helped to organize patient-centric data layers

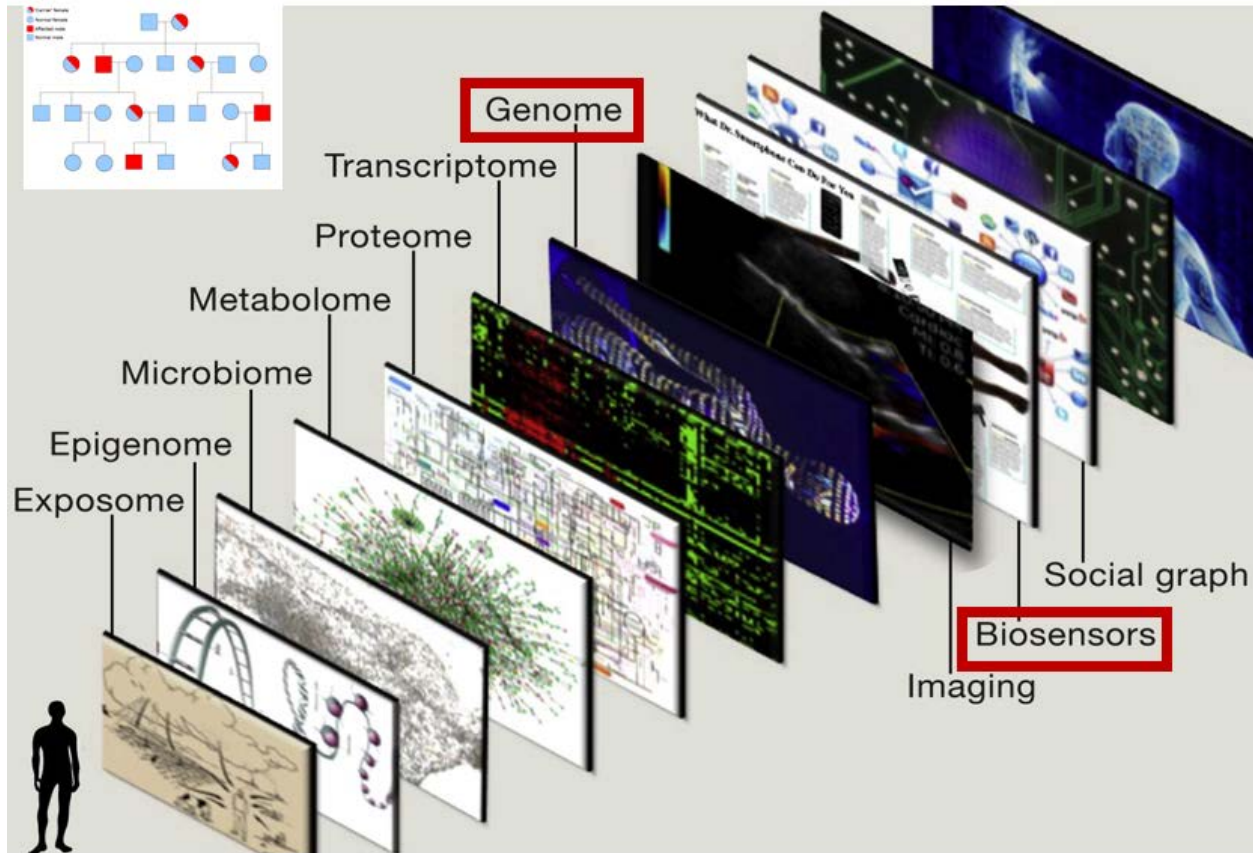


Fig 11: Cascade as a Platform – Combining information from omics with sensor data [135]

Network analytics of such diverse data may need new tools for data curation, as a first step. The relationships within and between these networks may need new description. Some are likely to be linear, perhaps a few of the IFTTT type [136] but non-linearity may be the norm.

Linear associations may have failed to extract the link between gum disease and arthritis [137]. Common gingivitis is implicated in the etiopathogenesis of autoimmune rheumatoid arthritis (RA) due to molecular mimicry. Autoantibody production is triggered by epitope spreading. *Porphyromonas gingivalis*, found in the oral cavity is responsible for certain forms of periodontal diseases. The α -enolase from *P. gingivalis* and humans share 82% homology at the 17-amino acid stretch of an immune-dominant region. Thus, antibodies against *P. gingivalis* α -enolase can recognize the homologous human α -enolase and promote the production of anti-human α -enolase autoantibodies. Anti-citrullinated human α -enolase antibodies were correlated with antibodies to *P. gingivalis* α -enolase in patients with rheumatoid arthritis [138].

Relationships likely to evolve out of this data and analytics effort may influence the future and economics of nations with respect to cost of healthcare.

Treatment of gingivitis using tooth floss, good brushing technique, suitable toothpaste and common sense applications of oral hygiene coupled with low cost adjunctive antibiotic treatment [139] may result in favorable response at the primary care stage. Reducing the risk of autoimmune rheumatoid arthritis reduces healthcare transaction cost, reduces cost of prescription medicine, reduces loss of wages due to disability, reduces morbidity, reduces arthritic pain and improves the quality of life as well as individual productivity which contributes to the national GDP. Ignorance is not a strength given the astronomical difference in cost of prevention due to treatment at the primary care level versus in-patient or ambulatory care.

CDC estimates [140] that about half of US adults (64.7 million American adults) have mild, moderate or severe periodontitis. In adults 65 and older, prevalence rates increase to 70% or higher [141]. Rheumatoid arthritis (RA) affects 1% (70 million) of the world population.

What if we could nearly eliminate gingivitis related autoimmune rheumatoid arthritis?

The 17 amino acid immune-dominant sequence may be subjected to genome surgery [142] using CRISPR/Cas9 tools [143] in eukaryotic systems [144] to edit the coding region (exon) of the human α -enolase gene in a manner which may alter the triplet code for amino acids in the immune-dominant stretch but the amino acid substitution will be highly conservative with respect to the human α -enolase secondary and tertiary structure. It appears that the function of the human α -enolase protein may be refractory to minor modifications [145].

The cost and impact on global mortality and morbidity from autoimmune diseases is staggering. In a few cases, the etiopathogenesis is known and the target is defined. Imagine if gene editing techniques (Cre-lox, ZFNs, TALENs, CRISPR/Cas9) could help to reduce the number of people affected by autoimmune and other diseases. The tools are at hand.

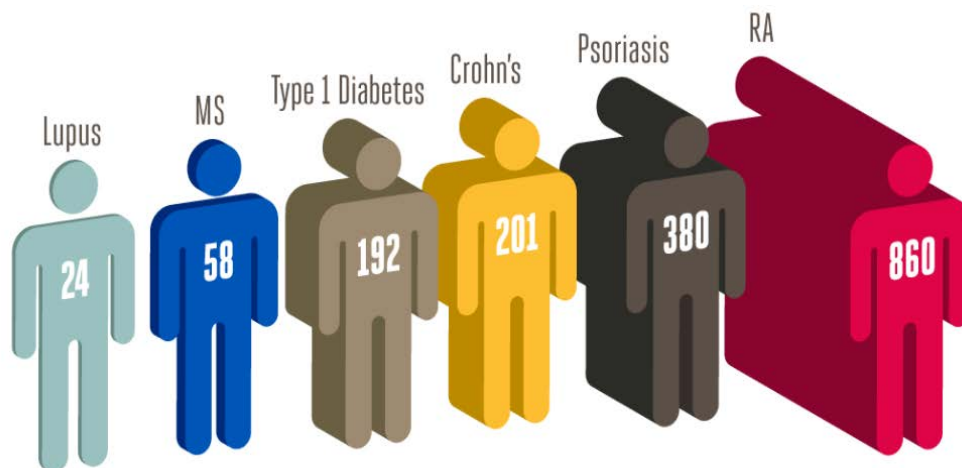


Fig 12: Selected autoimmune diseases and number of cases per 100,000 people [146]

Detection of polyps in the GI tract using disposable ingestible cameras coupled with non-surgical removal of polyps using biomarker-doped excretable micro- or nano-drones [147] may make a difference between an apparently normal life and a life with cancer surgery. The infrastructure for human-mediated surgery or laparoscopic robo-surgery may not be affordable, yet, in many parts of the world. Ingestible cameras and nano-drones may be available as FMCG retail goods, drone-delivered by Amazon or ordered via Alibaba or found in Wal-Mart or in the corner convenience store (where you also swap your solid metallic hydrogen [148] USB battery stick for your electric vehicle's source of energy [72]).

When combined with 3D/4D printing, we may print drones-on-demand (locally) for more specific needs, for example, precision delivery of biopharmaceuticals (3D printed insulin from peptides instead of Humulin or recombinant insulin). These drones may be powered by stomach acid [149], navigated by external wireless signals and carry sensors for analytes or metabolites or bio-markers to update decision systems with data from inside the body.

The breast cancer detecting bra [150], data from the toilet bowl [151] and non-invasive mapping of single nucleotide polymorphisms (coding or non-coding SNP) associated with disease markers [152] may offer clues to improving healthcare and reducing the cost.

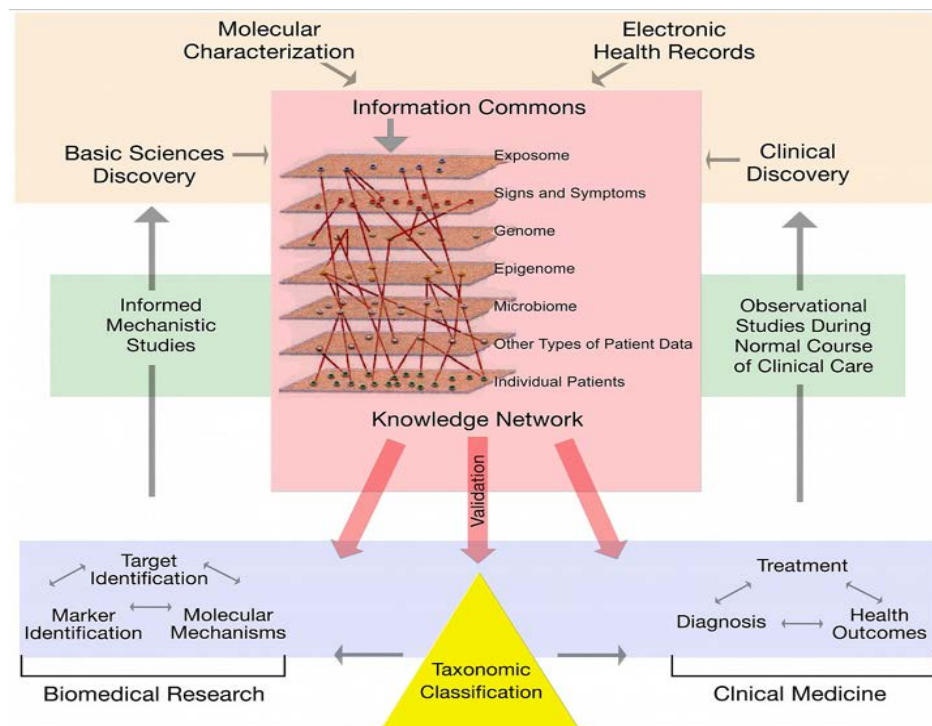


Fig 13: The Grand Convergence – Integration of Distributed Data and Information [153]

Making sense of this grand convergence needs new types of data gathering tools [154] and a combination of new data analysis tools with classical tools, such as, machine learning. Elements of rudimentary artificial intelligence [155] in higher order reasoning apps may be useful (claims of “intelligence” in AI [156] are generally due to commercial exaggeration). Vast numbers and types solvers or engines must be a part of this “analytics” portfolio. The choice of the solver may be triggered by the event or data stream or context awareness or semantic relationship. The architecture of such diversely distributed analytical complexity is uncommon in the current enterprise architecture world. These engines may operate at the edge [157], some in the mist, others in the fog and at the back-end (cloud). Efficacy will be determined by the limits of tolerable latency and time sensitive networking demands.

Crowd sourcing of solvers/engines may enable apps to embed the best in precision analytics. For example, a person in Timbuktu may develop an algorithm which can combine data from blood pressure with levels of uric acid, creatine and creatinine to predict with accuracy the onset of glomerular nephritis which can compromise renal function (kidney). The next gen architecture will have mechanisms to accept, verify and incorporate that app if approved by credible groups [158] or institutions where industry may invest [159] in order to partner with experts [160] who may create or evaluate the tools.

The type and nature of data for diagnostics and therapy may improve in granularity and enable precision measurements as we begin to incorporate nanomedicine [161] in our daily practice. The myth of the “silver bullet” may come to life if we could pin nano-particulates to target cells (eg cancer) and induce programmed cell death (apoptosis). Nano-markers may serve as biological cross-hairs, to create molecular identifying mechanisms or induce cellular suicide by design, using chemical or physical triggers, to specifically destroy rogue, dysfunctional, malignant or corrupted cells.

The many layers of complexity discussed above, if resolved, will save lives. In addition, we can save millions of lives (see table [162] on the right) if we improve sanitation or create simple sensors to monitor (via an app) pollution in an early warning decision system to prevent major outbreaks of epidemics and pandemics which affect billions, worldwide, each year.

	CHERG	GBD 2013
Neonates aged 0-27 days		
Congenital abnormalities	270 (207-366)	251 (221-291)
Diarrhoea	50 (17-151)	52 (44-61)
Pneumonia	325 (209-470)	213 (186-242)
Intrapartum-related complications*	717 (610-876)	657 (532-770)
Sepsis or meningitis	393 (252-552)	369 (237-504)
Tetanus	58 (20-276)	34 (16-48)
Other neonatal disorders	181 (115-284)	470 (411-557)
All causes	3072†	2807 (2719-2898)
Children aged 1-59 months		
Injury	354 (274-429)	350 (310-394)
Diarrhoea	751 (538-1031)	536 (461-607)
AIDS	159 (131-185)	102 (95-111)
Pneumonia	1071 (977-1176)	772 (693-850)
Malaria	564 (432-709)	699 (576-855)
Measles	114 (92-176)	95 (52-166)
Meningitis	180 (136-237)	129 (98-163)
Other disorders	1356 (1112-1581)	1355 (1211-1524)
All causes	4550†	4039 (3883-4207)

Data are thousands of deaths (95% uncertainty interval). GBD=Global Burden of Disease Study. CHERG=Child Health Epidemiology Reference Group. *Compares GBD cause "Neonatal encephalopathy (birth asphyxia/trauma)" with CHERG cause "intrapartum-related complications". †CHERG did not report uncertainty estimates for all-cause mortality in children.

GLOBAL PUBLIC HEALTH – 70% of the 11 million child deaths each year are preventable

Diarrhea is the third leading cause of death in children aged 1-59 months (above). The etiology (Table 3, below) leaves little to the imagination [162]. Unlike cancer or idiopathic neuropathy, the molecular targets for vast number of preventable yet neglected diseases are known to a large extent. The mortality and morbidity due to these diseases are immense. The control of these diseases through prevention, early diagnosis, low cost pharmaceutical therapy and real-time responses, are imminently possible and feasible.

	Children younger than age 5 years				All ages				Rate of change for deaths 1990-2013 (%)
	1990		2013		1990		2013		
	Deaths (thousands)	Population attributable fractions (%)	Deaths (thousands)	Population attributable fractions (%)	Deaths (thousands)	Population attributable fractions (%)	Deaths (thousands)	Population attributable fractions (%)	
Diarrhoea									
Adenovirus	63.0 (44.4 to 89.9)	3.9 (2.7 to 5.5)	18.3 (11.8 to 25.5)	3.5 (2.4 to 4.9)	81.3 (55.9 to 115.9)	3.2 (2.1 to 4.4)	31.8 (21.5 to 44.7)	2.5 (1.7 to 3.6)	-61.2% (-67.8 to -52.5)
Aeromonas	12.3 (6.4 to 21.4)	0.8 (0.4 to 1.3)	5.5 (2.6 to 10.1)	1.1 (0.5 to 1.9)	28.0 (16.7 to 44.9)	1.1 (0.7 to 1.7)	13.0 (7.3 to 22.0)	1.0 (0.6 to 1.7)	-53.6% (-66.1 to -37.8)
Amoebiasis	5.8 (2.6 to 10.0)	0.4 (0.2 to 0.6)	1.3 (0.6 to 2.3)	0.2 (0.1 to 0.5)	18.3 (8.9 to 30.6)	0.7 (0.3 to 1.2)	11.3 (5.0 to 19.7)	0.9 (0.4 to 1.6)	-39.1% (-57 to -17.5)
Campylobacter enteritis	20.8 (11.0 to 31.9)	1.3 (0.7 to 2.0)	9.5 (3.7 to 15.7)	1.8 (0.7 to 3.0)	28.4 (16.4 to 42.8)	1.1 (0.6 to 1.6)	14.1 (6.9 to 22.4)	1.1 (0.5 to 1.8)	-50.7% (-63.7 to -37.5)
Cholera	81.7 (39.1 to 117.0)	5.1 (2.5 to 7.2)	45.2 (23.4 to 67.6)	8.7 (4.5 to 12.7)	125.3 (61.1 to 173.4)	4.9 (2.4 to 6.7)	69.9 (37.7 to 97.0)	5.5 (3.0 to 7.7)	-44.3% (-56.8 to -26.6)
Clostridium difficile	2.1 (2.0 to 2.3)	0.1 (0.1 to 0.1)	2.5 (2.4 to 2.7)	0.5 (0.4 to 0.6)	20.8 (19.9 to 21.9)	0.8 (0.7 to 0.9)	41.5 (39.1 to 43.9)	3.3 (3.0 to 3.6)	99.4% (84.3 to 114.3)
Cryptosporidiosis	92.4 (68.7 to 125.1)	5.8 (4.3 to 7.8)	35.2 (25.9 to 48.2)	6.8 (5.1 to 9.3)	98.8 (72.8 to 132.7)	3.8 (2.8 to 5.2)	41.9 (30.0 to 58.4)	3.3 (2.4 to 4.7)	-57.8% (-64.8 to -49.6)
Enteropathogenic Escherichia coli infection	4.3 (1.3 to 7.8)	0.3 (0.1 to 0.5)	1.8 (0.7 to 3.4)	0.3 (0.1 to 0.7)	4.3 (1.3 to 7.8)	0.2 (0.1 to 0.3)	1.8 (0.7 to 3.4)	0.1 (0.1 to 0.3)	-57.5% (-76.5 to -32)
Enterotoxigenic Escherichia coli infection	86.0 (61.3 to 114.1)	5.4 (3.8 to 7.2)	23.1 (17.0 to 30.4)	4.4 (3.4 to 5.9)	134.7 (97.5 to 178.2)	5.2 (3.8 to 6.8)	59.2 (44.2 to 77.7)	4.7 (3.5 to 6.1)	-56.0% (-63.0 to -46.9)
Norovirus	7.3 (2.7 to 11.8)	0.5 (0.2 to 0.7)	1.8 (0.7 to 3.1)	0.3 (0.1 to 0.6)	7.3 (2.7 to 11.8)	0.3 (0.1 to 0.5)	1.8 (0.7 to 3.2)	0.1 (0.1 to 0.2)	-75.8% (-85.1 to -61.6)
Other Salmonella infections	19.2 (11.1 to 29.1)	1.2 (0.7 to 1.8)	3.8 (1.6 to 6.7)	0.7 (0.3 to 1.2)	58.9 (42.4 to 77.8)	2.3 (1.6 to 3.0)	24.3 (16.0 to 33.3)	1.9 (1.3 to 2.6)	-58.9% (-65.4 to -51.1)
Rotaviral enteritis	398.9 (334.5 to 464.2)	24.8 (21.4 to 28.2)	122.4 (96.6 to 152.1)	23.5 (20.1 to 27.2)	477.5 (397.9 to 555.1)	18.5 (15.8 to 21.2)	176.6 (140.4 to 218.4)	14.0 (11.4 to 16.6)	-63.2% (-68.5 to -57.1)
Shigellosis	161.0 (130.0 to 200.3)	10.0 (8.2 to 12.2)	33.4 (24.9 to 43.5)	6.4 (5.1 to 7.9)	254.2 (207.9 to 311.7)	9.9 (8.2 to 11.9)	73.9 (58.9 to 93.8)	5.8 (4.7 to 7.3)	-70.9% (-74.4 to -67.3)
No identified aetiology*	652.4 (542.4 to 783.1)	40.6 (35.3 to 46.8)	215.9 (169.6 to 265.2)	41.5 (35.7 to 48.1)	1240.9 (1096.8 to 1421.5)	48.1 (43.5 to 53.5)	702.9 (619.2 to 796)	55.6 (51.4 to 60.3)	-43.2% (-49.3 to -36.1)

Table 3 – Etiology of Diarrhea reveal tools to detect and prevent millions of deaths annually

The solution to the problem requires more than characterizing the molecular etiology. Solutions in the real world calls for convergence of biomedical research, medicine as an engagement platform, engineering tools, telecommunication technologies and software based decision systems integrated with clinical/healthcare platforms at the point of care or point of origin (may be a house or a hut). The challenge is to bridge this chasm in order to materialize the convergence through cross-pollination and collaboration, local and global.

About 29,000 children under the age of 5 die every day, mainly from preventable causes [163].

According to UNICEF [163] more than 70% of almost 11 million child deaths every year are attributable to only six causes: diarrhea, malaria, neonatal infection, pneumonia, preterm delivery, and lack of oxygen at birth. These deaths occur in the developing world. South-central Asia has the highest number of neonatal deaths while sub-Saharan Africa has the highest rates. Two-thirds of deaths occur in 10 countries. The majority are preventable.

Six million of the eleven million children who die each year may be saved by low-tech, evidence-based, cost-effective measures such as vaccines, antibiotics, micronutrient supplementation, insecticide-treated bed nets, improved family care and breastfeeding.

About 80% of health care in developing countries occurs in the home and the majority of children die at home, without being seen by a health worker. Hence, mobility (the mobile phone) is key to connect home health care to the professional health system to reduce child mortality. Better integration among systems that deliver basic supplies and health services include treatment for diarrhea, especially the use of oral re-hydration salts which can be administered by a parent or family member at home, as soon as symptoms appear.

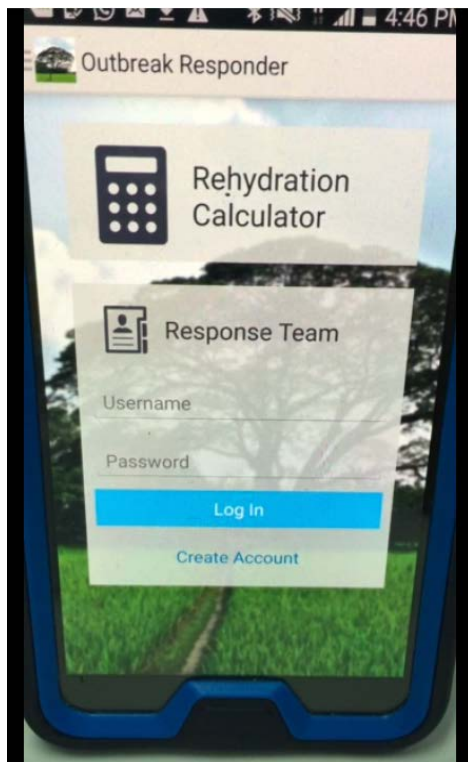



Fig 14: Oral rehydration calculator - smart phone app created by Dr Eric Jorge Nelson and Farhana Haque [164]. Oral rehydration therapy can prevent 1 million child deaths each year.

The importance of clean water [165] for consumption (below) and management of excreted water cannot be overemphasized. Water systems to sense (nano-sensors for detection), monitor, (early) warn and actuate/execute control is key to eliminating the risk due to water-borne diseases, like Guinea worm and cholera, that undermine child survival and development, reduce productivity, raise healthcare costs and depress economic growth.

Reality Check Arsenic in Water in Bangladesh causes acute morbidity



Internet of Things → Internet of Systems

Socio-Economic Impact and Healthcare Improvement due to Medical IoT



DIGITAL WATER

NOKIA

www.youtube.com/watch?v=LIRz9UI7SUw

U=Araihazar
M=Khaserkandi
V=Khaser Kandi
Start>=85'
Fail=22/100
Average arsenic 44 ppb
42 safe of 71 wells
45- 90' 40 of 69
115-130' 2 of 2

- WiFi
- Light Intensity
- Temperature
- 2x 1.5V AA Batteries

MoboSens

Fig 15: Early Detection of Arsenic in water may adopt IoT design principle to improve lives

The diffusion of medical IoT (MIoT) by design when integrated with developments in molecular sensing using nano technology and microbiomes [166] may provide us with tools. These tools (the sensor, the data, the app, the decision support, the execution response, the treatment, the patient) may form overlapping closed-loop segments [167] which are parts of networks and other system of systems. Connectivity by design between these systems is the core concept of internet of things and one paradigm of this design is medical IoT. This is not a tool or one technology. It is a convergence of medicine, engineering, communication as well as myriad of services plus patients, families, medical staff, communities and cities.

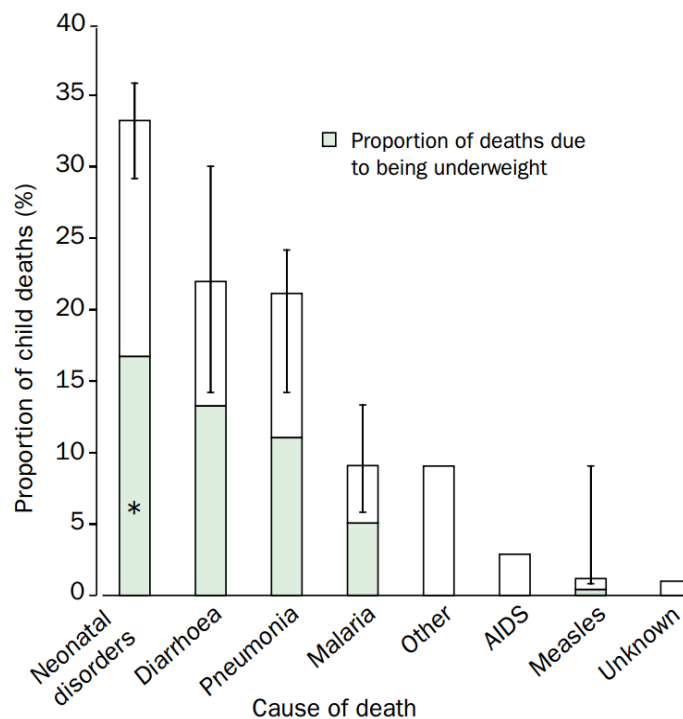


Fig 16: Bulk of the mortality due a few defined causes - diarrhea, pneumonia, malaria [168]

One should not infer that the recent euphoria about IoT serves as a panacea for healthcare. It is one approach which may increase the level of first response or primary care at the point where urgently needed. Other highly ignored [169] approaches include supplements of vitamin A. If taken every four to six months, vitamin A may eliminate xerophthalmia as well as reduce child mortality from all causes by as much as 23%, measles deaths by 50% and deaths from diarrhea by 33% [163]. The tremendous challenges for mapping the nodes in deeply entangled networks of interactions between diverse factors should not dissuade the application of modern tools and technologies in our pursuit to improve global public health outcomes.

NANO TOOLS - THE TALES THEY MAY TELL AND THE LONG TAILS

The powerful reach of medical IoT in medicine, in general, and in preventive medicine, in particular, is based on the premise that signals that precede physiological perturbations are often detectable years before a threshold is reached when symptoms may be obvious.

How do we know what to detect? How to detect? How do we know what we have detected?

Determining the target analyte (gas molecules, small molecules, macromolecules, peptides, nucleic acids, protein fragments, biomarkers) with sufficient specificity is key. That is the domain of omics, biochemistry and biophysics. Using the analyte to create a detection mechanism that can offer high signal to noise ratio is in the domain of material science, microfluidics and nanotechnology [170]. Capturing and transmitting the signal to a gateway is in the domain of radio waves (RF), telecom systems, IPv6 (sensor to internet direct) and other protocols. Replenishing the signaling mechanism of the nanowire sensor isn't trivial.

Do we know the content of the signal that we have captured? Do we know the meaning of that data? How is the data applicable to the specific problem and the general physiology? How should we act upon receiving this data? Can this data yield actionable information? Do we need to respond to that information? Is the response time sensitive? Should we expect events in real-time? Did we use time sensitive networking systems and protocols to ensure that the data did not perish? Should we store the data or the decision based on the data?

Most of the above questions may fall in the broad category of (biomedical) data analytics. There may not be a simple answer and each answer will depend on context and content. Hence, each question and answer, if any, may be patient specific. There may not be a "supply chain" *modus operandi* to pool the risk or aggregate the averages or choose a function where the error term may be "assumed" to be a homoskedastic distribution.

What we have not discussed here (but referred to in another section - ICE Data Logger) is the issue of data security during acquisition, distribution and sharing between devices and domains (eg hospital, home, patient, practitioner, parents, family member, care giver).

Notwithstanding the layers of complexity that accompanies the task of obtaining a bona fide signal from a sensor, one must ask, if we may have such a sensor for the purpose?

The advances that connect detection of a signal and subsequent visualization on mobile devices are a part of the design which we may continue to refer as medical internet of things (MIoT). Indeed a smartphone-based sensing strategy was developed which employs chemi-responsive nanomaterials integrated into the circuitry of commercial near-field communication (NFC) tags to achieve non-line-of-sight, portable, and inexpensive detection and discrimination of gas-phase chemicals (eg ammonia, hydrogen peroxide, cyclohexanone, and water) at part-per-thousand and part-per-million concentrations [171].

Fabrication of multiphase emulsions with controllably reconfigurable morphologies [172] may offer optical changes which can be detected by a smart phone qualitatively and can also be processed to quantify the amount of analyte, for example, proteins or bacteria [173].

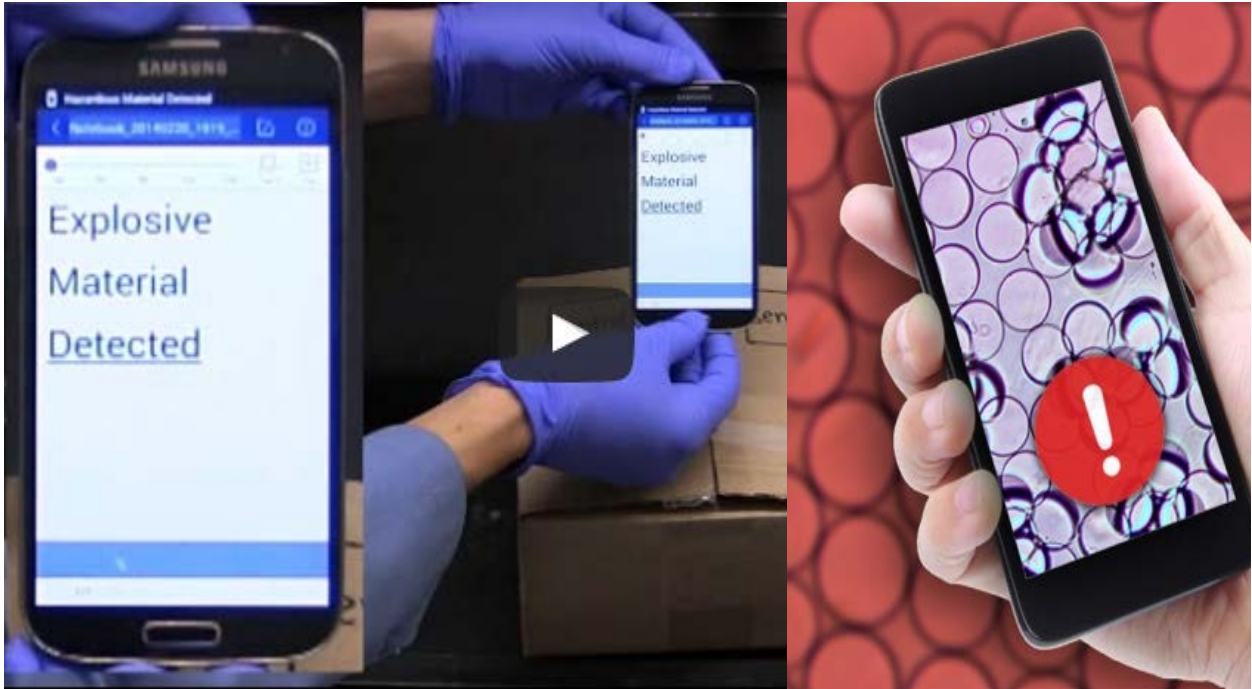


Fig 17: The Future of Mobile Digital Diagnostics and Health – Detection of gas molecules (L) and quantification of bacterial content from Janus emulsions (R) using any smart phone.

Millions of children die from dehydration due to watery diarrhea as a result of cholera caused by some strains of the gram negative bacteria *Vibrio cholerae*, a potent water-borne pathogen, which causes epidemics and pandemics, often annually, in the developing world.

Imagine the global diffusion of mobility in the remote parts of the world where neither electricity nor automobiles may have reached. Millions of smart phone users armed with phone-adaptable micro USB swappable “Swagger” sensors and the corresponding app can test water samples wherever they are located, as often as they may choose, from as many sources as possible. If the signal indicates presence of bacteria (eg *Vibrio cholerae*) or an analyte (eg Arsenic) then the crowd-sourced information is automatically transmitted via the telecommunication infrastructure (2G, 3G, LTE) to the cloud or fog or mist (repository data center) where data, information and decision systems converge to control the spread of pathogens or warn communities with respect to sewers, sanitation and supply of water.

The task ahead of us is to connect the dots and gather the experts to focus on the outcomes.

TEMPORARY CONCLUSION

Figure 18 epitomizes the Gandhi-esque aphorism that there may be enough for our need but perhaps never enough for our greed. CEOs at the 8 of the largest publicly traded US insurance companies made \$171.8 million in total compensation in 2016 ^[174] according to statements filed with the US Securities and Exchange Commission. The CEOs' combined 2016 realized compensation would be enough to cover the average annual premium for about 59,150 people enrolled in the most popular plan on the HealthCare.gov federal marketplace in 2016 (before financial assistance).

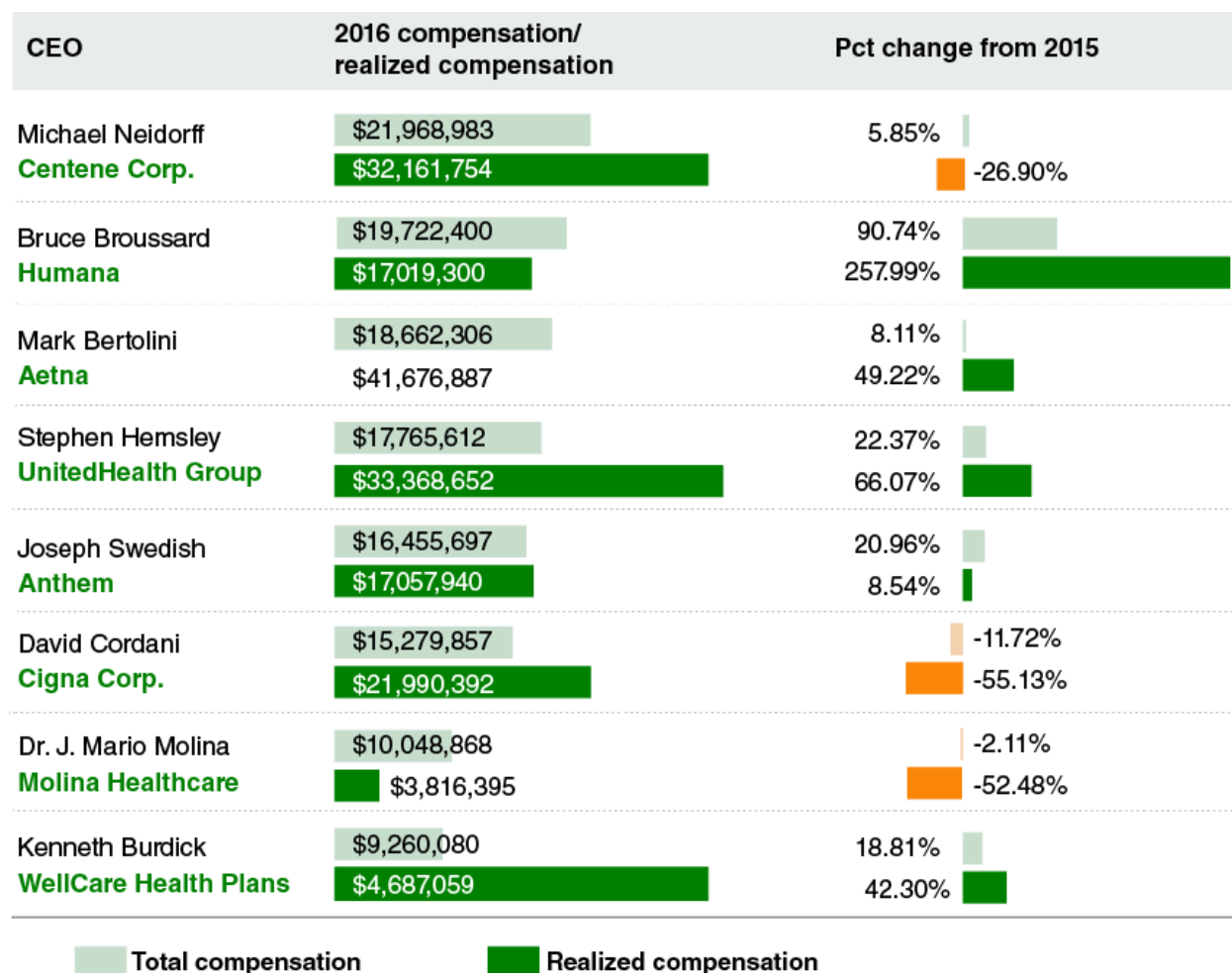


Fig 18: The combined realized compensation of 8 CEOs would be enough to cover the average annual premium for almost 60,000 people enrolled in the most popular plan on the HealthCare.gov federal marketplace in 2016.

Neither the US nor the nations aspiring to mimic US-style healthcare can afford to spend at current rates [Figure 19]. Where applicable, digital transformation, if enabled, may partially reduce transaction costs. Improving quality of care and increased access to healthcare for the masses may be facilitated by including digital health and medical internet of things in the portfolio of healthcare. But, these problems cannot be solved with yesterday's tools. Emerging tools, systems and standards must be part of the solution.

Convergence of new thinking, new technologies with new sources of data requiring new platforms, may be essential. To create this new momentum, we need ecosystems which can be formed under leadership which is both credible and can offer guidance for collaboration between different domains. The momentum must be channeled to solve complex problems which are also large, multi-national and the tsunami of data may influence evidence-based policies which may help to lift many boats, not just a few yachts. The sense of purpose of this endeavor must be integrated with global public health and a grand sense of the future.

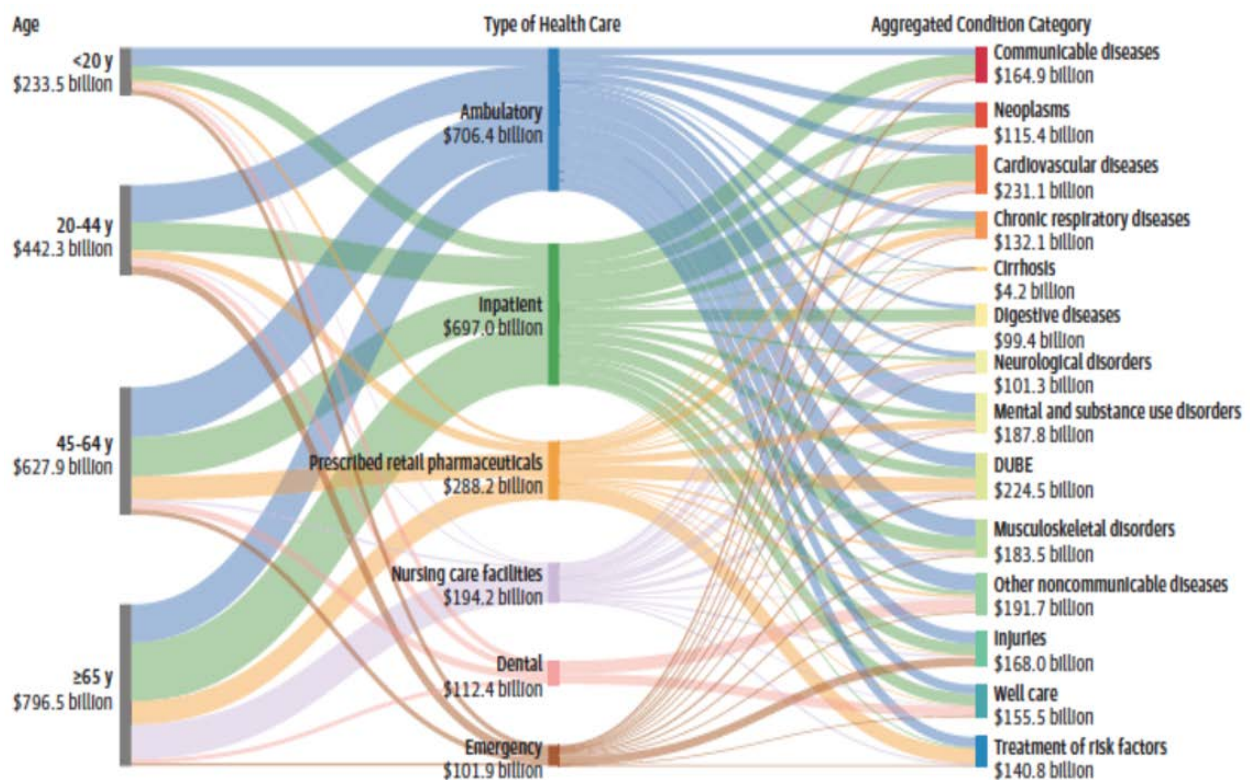


Fig 19: US Personal Healthcare Spending (2013) by Age and Condition Category [175]

REFERENCES

-
- ¹ Relman, Arnold S. (1980) *The New Medical-Industrial Complex*. N Engl J Med **303** 963-970 (October 23, 1980) <http://www.nejm.org/doi/pdf/10.1056/NEJM198010233031703>
- ² Obama, Barack (2012) *Securing the Future of American Health Care*. N Engl J Med **367** 1377-1381 (October 11, 2012) <http://www.nejm.org/doi/pdf/10.1056/NEJMp1211514>
- ³ Obama, Barack (2017) *Repealing the ACA without a Replacement — The Risks to American Health Care*. N Engl J Med **376** 297-299 (January 26, 2017) <http://www.nejm.org/doi/pdf/10.1056/NEJMp1616577>
- ⁴ Eisenhower, Dwight D. (1960) Public Papers of the Presidents, pages 1035-1040 http://avalon.law.yale.edu/20th_century/eisenhower001.asp
- ⁵ <https://wdyt.org/2009/07/20/hippocratic-oath-modern-and-original-versions/>
- ⁶ Porter, Michael E. (2010) *What Is Value in Health Care?* N Engl J Med **363** 2477-2481 (Dec 23, 2010) <http://www.nejm.org/doi/full/10.1056/NEJMp1011024?viewType=Print>
- ⁷ Smith, Adam (1776) *An Inquiry into the Nature and Causes of the Wealth of Nations*. <http://www.econlib.org/library/Smith/smWN.html>
- ⁸ <http://www.mckinsey.com/industries/healthcare-systems-and-services/our-insights/strengthening-health-cares-supply-chain-a-five-step-plan>
- ⁹ Arrow, Kenneth J and Debreu, Gerard (1954) *Existence of an Equilibrium for a Competitive Economy*. Econometrica **22** 265-290 <http://www.jstor.org/stable/1907353>
- ¹⁰ Arrow, Kenneth J. (1963) *Uncertainty and the Welfare Economics of Medical Care*. The American Economic Review **53** 941-973 <http://www.jstor.org/stable/1812044>
- ¹¹ www.nobelprize.org/nobel_prizes/economic-sciences/laureates/2001/stiglitz-lecture.pdf
- ¹² Forrester, Jay Wright (1961) *Industrial Dynamics*. MIT Press.
- ¹³ Lee, Hau, Padmanabhan, V and Whang, Seungjin (1997) *The Bullwhip Effect in Supply Chains*. MIT Sloan Management Review **38** (3) 93-102
- ¹⁴ Datta, S., Granger, C. W. J., Barari, M. and Gibbs, T. (2007) *Management of Supply Chain: an alternative modeling technique for forecasting*. Journal of the Operational Research Society **58** 1459-1469 <http://dspace.mit.edu/handle/1721.1/41906>

-
- ¹⁵ Sarma, Sanjay E, Brock, David and Ashton, Kevin (2000) *The Networked Physical World*. MIT Auto ID Center (MIT) http://cocoa.ethz.ch/downloads/2014/06/None_MIT-AUTOID-WH-001.pdf
- ¹⁶ Coustasse, Alberto, Tomblin, Shane and Slack, Chelsea (2013) *Impact of Radio-Frequency Identification (RFID) Technologies on the Hospital Supply Chain: A Literature Review*. *Perspectives in Health Information Management* **10** 1d
<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3797551/pdf/phim0010-0001d.pdf>
- ¹⁷ David, Paul A. and Thomas, Mark. (2006) *The Economic Future in Historical Perspective*. Oxford University Press.
- ¹⁸ Jones, Spencer S, Heaton, Paul S, Rudin, Robert S and Schneider, Eric C (2012) *Unraveling the IT Productivity Paradox - Lessons for Health Care*. *N Engl J Med* **366** 2243-2245
<http://www.nejm.org/doi/pdf/10.1056/NEJMp1204980>
- ¹⁹ Jasny, Barbara R and Stone, Richard (2017) *Prediction and its Limits*. *Science* **355** (6324) 468-469 <http://science.sciencemag.org/content/sci/355/6324/468.full.pdf>
- ²⁰ Angell, Marcia (2004) *The Truth About the Drug Companies: How They Deceive Us and What to Do About It*. Random House (ISBN 0-375-50846-5) *N Engl J Med* **351** 1580-1581 DOI: 10.1056/NEJM200410073511522
<http://www.nejm.org/doi/pdf/10.1056/NEJM200410073511522>
- ²¹ Goldfarb v Virginia State Bar <https://supreme.justia.com/cases/federal/us/421/773/>
- ²² Arnold S. Relman (1923–2014) *N Engl J Med* **371** 368-369 (July 24, 2014)
- ²³ Relman, Arnold S (1991) *The Health Care Industry: Where Is It Taking Us?* *N Engl J Med* **325** 854-859 DOI: 10.1056/NEJM199109193251205
<http://www.nejm.org/doi/pdf/10.1056/NEJM199109193251205>
- ²⁴ Starr, Paul (2011) *Remedy and Reaction: The Peculiar American Struggle Over Health Care Reform*. Yale University Press.
- ²⁵ H.R.3590 - *Patient Protection and Affordable Care Act* - 111th Congress (2009-2010)
<https://www.congress.gov/111/plaws/publ148/PLAW-111publ148.pdf>
- ²⁶ Iglehart, John K (1991) *Germany's Health Care System*. *N Engl J Med* **324** 503-508 (February 14, 1991) DOI: 10.1056/NEJM199102143240725
- ²⁷ Iglehart, John K (1991) *Germany's Health Care System*. *N Engl J Med* **324** 1750-1756 (June 13, 1991) DOI: 10.1056/NEJM199106133242428

-
- ²⁸ Stock, Stephanie (2015) *Integrated Ambulatory Specialist Care - Germany's New Health Care Sector*. N Engl J Med **372** 1781-1785 (May 7, 2015) DOI: 10.1056/NEJMp1413625 <http://www.nejm.org/doi/pdf/10.1056/NEJMp1413625>
- ²⁹ Iglehart, John K (1990) *Canada's Health Care System Faces Its Problems*. N Engl J Med **322** 562-568 DOI: 10.1056/NEJM199002223220827
- ³⁰ Bernard, E. (1991) *The Politics Of Canada's Health Care System*. Harvard University School of Law. <http://www.law.harvard.edu/programs/lwp/healthc.pdf>
- ³¹ <https://www.opensecrets.org/lobby/indus.php?id=H>
- ³² <https://www.opensecrets.org/industries/indus.php?ind=H>
- ³³ Khazan, Olga (2014) *What if America Had Canada's Healthcare System?*The Atlantic. (Oct 21, 2014) www.theatlantic.com/health/archive/2014/10/what-if-america-had-canadas-healthcare-system/381662/
- ³⁴ <http://catalyst.nejm.org/the-big-business-of-dialysis-care/>
- ³⁵ <http://genomed.com/pdf/diabetes.technology.therapeutics.pdf>
- ³⁶ http://genomed.com/images/guyot_dec09nl.pdf
- ³⁷ <http://biopharmguy.com/links/company-by-location-medical-devices.php>
- ³⁸ Makary M. A. and Michael, D. (2016) *Medical error - the third leading cause of death in the US*. British Medical Journal **353** i2139 DOI: <http://dx.doi.org/10.1136/bmj.i2139> PDF <http://www.west-info.eu/where-doctors-kills-more-people-than-road-accidents/medical-error-the-third-leading-cause-of-death-in-the-us-2/>
- ³⁹ Biller-Andorno, Nikola and Zeltner, Thomas (2015) *Individual Responsibility and Community Solidarity - The Swiss Health Care System*. N Engl J Med **373** 2193-2197 (December 3, 2015) <http://www.nejm.org/doi/pdf/10.1056/NEJMp1508256>
- ⁴⁰ Armesto, Sandra Garcia (2007) Health Care Quality Indicators Project: Patient Safety Data Systems in the OECD. <http://www.oecd.org/els/health-systems/38705981.pdf>
- ⁴¹ http://www.health.gov.il/PublicationsFiles/Leading_Causes_2012E.pdf
- ⁴² <http://www.oecd.org/els/health-systems/health-care-quality-indicators.htm>
- ⁴³ Goldman, Julian M. (2008) *Medical Devices and Medical Systems - Essential safety requirements for equipment comprising the patient-centric integrated clinical environment (ICE): General requirements and conceptual model*. ASTM F2761. http://www.mdnp.org/uploads/F2761_completed_committee_draft.pdf

⁴⁴ Foo Kune, D. a. (2012). *Toward a Safe Integrated Clinical Environment: A Communication Security Perspective*. Proceedings of the 2012 ACM Workshop on Medical Communication Systems (pp. 7--12). New York: ACM.

⁴⁵ Michael E. Chernew, Richard A. Hirth and David M. Cutler (2003) *Increased Spending On Health Care: How Much Can The United States Afford?* *Health Affairs* **22** (4) 15-25 (doi: 10.1377/hlthaff.22.4.15) <http://content.healthaffairs.org/content/22/4/15.full.pdf+html>

⁴⁶ Hill A, Ross-Adjie G, McPhail SM, *et al* (2016) *Incidence, risk factors and the healthcare cost of falls postdischarge after elective total hip and total knee replacement surgery: protocol for a prospective observational cohort study*. *British Medical Journal Open* doi: 10.1136/bmjopen-2016-011139 <http://bmjopen.bmj.com/content/6/7/e011139.full>

⁴⁷ <https://www.cdc.gov/homeandrecreationalafety/falls/fallcost.html>

⁴⁸ <https://www.cdc.gov/injury/wisqars/>

⁴⁹ <http://www.cimit.org/web/cimit/about>

⁵⁰ <http://www.massgeneral.org/cimit/about/>

⁵¹ <https://cimit.org/about>

⁵² <http://web.mit.edu/innovate/entrepreneurship2015.pdf>

⁵³ <http://www.community.harvard.edu/alumniimpact/>

⁵⁴ https://en.wikipedia.org/wiki/Kalighat_Home_for_the_Dying

⁵⁵ Fadel Adib, Zachary Kabelac, Dina Katabi and Robert C. Miller (2015) *3D Tracking via Body Radio Reflections* <http://witrack.csail.mit.edu/witrack-paper.pdf>

⁵⁶ <http://bit.ly/President-Obama-with-Dina-Katabi>

⁵⁷ <http://precise.seas.upenn.edu/research/medical-cyber-physical-systems/>

⁵⁸ Houssam Abbas, Zhihao Jiang, Kuk Jin Jang, Marco Beccani, Jackson Liang, Sanjay Dixit, and Rahul Mangharam (2016) *Computer Aided Clinical Trials for Implantable Cardiac Devices*. http://repository.upenn.edu/mlab_papers

⁵⁹ Framework for Cyber Physical Systems (2016) NIST https://s3.amazonaws.com/nist-sgcps/cpspwg/files/pwgglobal/CPS_PWG_Framework_for_Cyber_Physical_Systems_Release_1_0Final.pdf

⁶⁰ Dimitrov, Dimiter V. (2016) *Medical Internet of Things and Big Data in Healthcare*. Healthcare Informatics Research **22** (3) 156-163

<http://dx.doi.org/10.4258/hir.2016.22.3.156>

<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4981575/pdf/hir-22-156.pdf>

⁶¹ Datta, S. (2016) Medical IoT (MIoT / 03_Healthcare.pdf) *Digital by Design*

<https://dspace.mit.edu/handle/1721.1/104429>

⁶² Simon, Herbert A (1986) *The Steam Engine and The Computer: What Makes Technology Revolutionary* (EDUCOM Conference 12 November 1986)

<http://digitalcollections.library.cmu.edu/awweb/awarchive?type=file&item=34057>

⁶³ Weiser, Mark (1991). *The Computer for the 21st Century*. Scientific American **265** 94-104
doi:10.1038/scientificamerican0991-94

www.nature.com/scientificamerican/journal/v265/n3/full/scientificamerican0991-94.html

⁶⁴ www.cisco.com/c/dam/en_us/about/ac79/docs/innov/IoT_IBSG_0411FINAL.pdf

⁶⁵ <https://labs.wsu.edu/advancedmanufacturing/wpcontent/uploads/sites/238/2014/10/NSF-workshop-Adv-Mfg4Smart-Goods-090415.pdf>

⁶⁶ <https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/readiness-of-v2vtechnology-for-application-812014.pdf>

⁶⁷ <http://www.intel.com/content/www/us/en/energy/iot-smart-grid-paper.html>

⁶⁸ <http://www.forbes.com/sites/louiscolumbus/2016/11/27/roundup-of-internet-of-things-forecasts-and-market-estimates-2016/#1223e6a24ba5>

⁶⁹ <http://blogs-images.forbes.com/louiscolumbus/files/2016/11/IHS.jpg>

⁷⁰ Coase, Ronald H (1937) *The Nature of the Firm*

www.colorado.edu/ibs/es/alston/econ4504/readings/The%20Nature%20of%20the%20Firm%20by%20Coase.pdf

⁷¹ Williamson, Oliver E (1979) *Transaction-Cost Economics: The Governance of Contractual Relations*. Journal of Law and Economics **22** (2) 233-261

www.masonlec.org/site/rte_uploads/files/Williamson%20class%202%20background.pdf

⁷² Datta, S. (2016) MARKETS. Digital by Design.

<https://dspace.mit.edu/handle/1721.1/104429>

⁷³ <http://www.emeraldforhome.com/>

⁷⁴ Finding 3, page 16 from Non-integrated variations in clinical and business data and tools (2015) Prepared by CAMH under Contract No. HHS-M500-2012-00008I Task Order No. VA118A14F0373 (Modernize Healthcare FFRDC) US Department of Veterans Affairs https://www.va.gov/opa/choiceact/documents/assessments/integrated_report.Pdf

⁷⁵ Interoperability between IIC (Industrial Internet Consortium) Architecture and Industrie 4.0 Reference Architecture for Industrial Assets. <https://www.infosys.com/engineering-services/white-papers/Documents/industrial-internet-consortium-architecture.pdf>

⁷⁶ Parker, Geoffrey G, Van Alstyne, Marshall W and Choudary, Sangeet Paul (2016) *Platform Revolution: How Networked Markets Are Transforming the Economy--And How to Make Them Work for You*. W W Norton

⁷⁷ European Commission (2011) OPEN PLATFORMS FOR WEB-BASED APPLICATIONS AND SERVICES IN EUROPE, ENLARGING THE STAKEHOLDERS COMMUNITY. Publications Office of the European Union (Luxembourg)

⁷⁸ Simon, Phil (2011) *The Age of the Platform: How Amazon, Apple, Facebook, and Google Have Redefined Business*. Motion Publishing.

⁷⁹ Saikaly, Madeleine (2007) *Common Bus Architecture Throughput*. Texas Instruments. <http://www.ti.com/lit/an/spraan7/spraan7.pdf>

⁸⁰ Health Insurance Portability and Accountability Act of 1996. PUBLIC LAW 104-191 <https://www.gpo.gov/fdsys/pkg/PLAW-104publ191/pdf/PLAW-104publ191.pdf>

⁸¹ Datta, S. (2016) Emergence of Digital Twins. <http://arxiv.org/abs/1610.06467>

⁸² Premarket Submissions for Management of Cybersecurity in Medical Devices, Guidance for Industry & FDA Staff (October 2014)

⁸³ Postmarket Management of Cybersecurity in Medical Devices, Draft Guidance for Industry and FDA Staff (January 2016)

⁸⁴ Mullen, A. B. (2013) Premature enforcement of CDRH's draft cybersecurity guidance. http://www.fdalawblog.net/fda_law_blog_hyman_phelps/2013/09/prematureenforcement-of-cdrhs-draft-cybersecurity-guidance.html

⁸⁵ M. Rushanan, D. F. Kune, C. M. Swanson and A. D. Rubin. (2014) SoK: Security and Privacy in Implantable Medical Devices and Body Area Networks. IEEE Symposium on Security and Privacy, 2014.

⁸⁶ www.healthit.gov/sites/default/files/Draft_White_Paper_PGHD_Policy_Framework.pdf

⁸⁷ www.politico.com/agenda/story/2015/06/internet-of-things-privacy-risks-security-000096

⁸⁸ https://www.theregister.co.uk/2016/10/21/dyn_dns_ddos_explained/

⁸⁹ <http://m.healthcareitnews.com/news/massive-ddos-attack-harnesses-145000-hacked-iot-devices>

⁹⁰ Datta, S. (2016) Cybersecurity <https://dspace.mit.edu/handle/1721.1/104429>

⁹¹ Framework for Improving Critical Infrastructure Cybersecurity. National Institute of Standards and Technology. Draft version 1.1 (January 10, 2017)
<https://www.nist.gov/sites/default/files/documents/2017/01/30/draft-cybersecurity-framework-v1.1.pdf>

⁹² www.w3c.org

⁹³ Soroush, H., Arney, D. and Goldman, J.G. (2016) *Toward a Safe and Secure Medical IoT*. www.iiconsortium.org/news/joi-articles/2016-June-Toward-a-Safe-And-Secure-Medical-IoT.pdf

⁹⁴ Weininger, Sandy, Jaffe, Michael B., Robkin, Michael, Rausch, Tracy, Arney, David and Goldman, Julian M. (2016) *The Importance of State and Context in safe Interoperable Medical Systems*. IEEE Journal of Translational Engineering in Health and Medicine **4** DOI 10.1109/JTEHM.2016.2596283

⁹⁵ Angulo, Marco Tulio; Moreno, Jaime A.; Lippner, Gabor; Barabási, Albert-László; Liu, Yang-Yu (2017) *Fundamental limitations of network reconstruction from temporal data*. Journal of the Royal Society Interface **14** DOI: 10.1098/rsif.2016.0966

⁹⁶ Goldamn, Julian M (2012) www.mdnpn.org/mdfire.php
[www.mdnpn.org/uploads/MD FIRE August 2012 v2.0.pdf](http://www.mdnpn.org/uploads/MD_FIRE_August_2012_v2.0.pdf)

⁹⁷ <http://www.openehr.org/downloads/ehrcomponents>

⁹⁸ Bahcall, Orli, Eggleston, Angela K., Bot, Nathalie Le and Weiss, Ursula (2017) *Frontiers in biology*. Nature **541** 301 www.nature.com/nature/supplements/insights/frontiers-biology-2017/index.html

⁹⁹ Banerjee, Soumya (2017) *An artificial immune system approach to automated program verification: Towards a theory of undecidability in biological computing*. PeerJ Preprints 5:e2690v1 <https://doi.org/10.7287/peerj.preprints.2690v1>
<https://peerj.com/preprints/2690v1.pdf>

¹⁰⁰ Lamblin, N., Mouquet, F., Hennach, B., Dagorn, J., Sophie, S., Bauters, C. and de Groote, P. (2005) High-sensitivity C-reactive protein: potential adjunct for risk stratification in patients with stable congestive heart failure. *European Heart Journal* **26** 2245–2250
doi:10.1093/eurheartj/ehi501

¹⁰¹ <https://obamawhitehouse.archives.gov/precision-medicine>

¹⁰² Markita Patricia Landry, Hiroki Ando, Allen Y. Chen, Jicong Cao, Vishal Isaac Kottadiel, Linda Chio, Darwin Yang, Juyao Dong, Timothy K. Lu and Michael S. Strano (2017) *Single-molecule detection of protein efflux from microorganisms using fluorescent single-walled carbon nanotube sensor arrays*. *Nature Nanotechnology*. doi:10.1038/nnano.2016.284
<http://www.nature.com/nnano/journal/vaop/ncurrent/full/nnano.2016.284.html>

¹⁰³ <http://www.advancedsilicongroup.com/what-s-new.html> and
<http://nebula.wsimg.com/d4e65619cd3841474c5d7e3a8d8dad69?AccessKeyId=47B549337A11E84045AE&disposition=0&alloworigin=1>

¹⁰⁴ K. Jensen, J. Weldon, H. Garcia and A. Zettl (2007) *Nanotube Radio*. *Nano Letters* **7** (11) 3508–3511 DOI: 10.1021/nl0721113

¹⁰⁵ Datta, S. (2011) Future of Healthcare: Bio-Informatics, Nano-Sensors and Emerging Innovations (Chapter 8 in *Nanosensors: Theory and Applications in Industry, Healthcare & Defense* ed TC Lim) CRC Press <http://dspace.mit.edu/handle/1721.1/58972>
<http://www.crcpress.com/product/isbn/9781439807361> and
<http://esd.mit.edu/WPS/2008/esd-wp-2008-17.pdf>

¹⁰⁶ www.mayoclinic.org/medical-professionals/clinical-updates/orthopedic-surgery/study-hip-knee-arthroplasty-shows-7-2-million-americans-living-with-implants

¹⁰⁷ Tim Wang, Haiyan Yu, Nicholas W. Hughes, Bingxu Liu, Arek Kendirli, Klara Klein, Walter W. Chen, Eric S. Lander, David M. Sabatini (2017) *Gene Essentiality Profiling Reveals Gene Networks and Synthetic Lethal Interactions with Oncogenic Ras*. DOI: <http://dx.doi.org/10.1016/j.cell.2017.01.013>

¹⁰⁸ <http://bit.ly/EMG-BioFeedback> and <https://pisontechnology.com/>

¹⁰⁹ McCammon, J.A., Gelin B.R., Karplus, M. (1977) *Dynamics of folded proteins*. *Nature* **267** 585-90

-
- 110 Martin Karplus and J. Andrew McCammon (2002) *Molecular dynamics simulations of biomolecules*. Nature Structural & Molecular Biol **9** 646-652 doi: 10.1038/nsb0902-646
- 111 G. I. Groma, J. Hebling, I. Z. Kozma, G. Varo, J. Hauer, J. Kuhl and E. Riedle (2008) *Terahertz radiation from bacteriorhodopsin reveals correlated primary electron and proton transfer processes*. Proc Natl Acad Sci **105** (19) 6888-6893
www.pnas.org/content/105/19/6888.full.pdf
www.pnas.org/cgi/doi/10.1073/pnas.0706336105
- 112 Terahertz Imaging: Technology could aid disease diagnosis but faces challenges. (2015) Chemical and Engineering News, American Chemical Society. November 9, 2015
- 113 Shannon, Claude E. (1948) *A Mathematical Theory of Communication*. The Bell System Technical Journal **27** pages 379–423 (July 1948) and 623–656 (October 1948)
<http://math.harvard.edu/~ctm/home/text/others/shannon/entropy/entropy.pdf>
- 114 Robert F. Engle and C. W. J. Granger (1987) *Co-Integration and Error Correction: Representation, Estimation, and Testing*. Econometrica **55** (2) 251-276
DOI: 10.2307/1913236 <http://www.jstor.org/stable/1913236>
- 115 Pierre-Gilles de Gennes. *La Science des Rêves*, Science et Vie Junior 214 (18 May 07) p. 13
- 116 <https://www.cdc.gov/winnablebattles/healthcareassociatedinfections/>
- 117 <https://www.cdc.gov/winnablebattles/targets/pdf/hai-winnablebattles-progressreport.pdf>
- 118 www.cdc.gov/winnablebattles
- 119 Swartz, Katherine (2009) *Health care for the poor: For whom, what care, and whose responsibility?* Focus **26** 69-74 www.irc.wisc.edu/publications/focus/pdfs/foc2621.pdf
- 120 Varatharajan Durairaj and David B Evans (2010) *Fiscal space for health in resource-poor countries*. World Health Report (2010) Background Paper 41
<http://www.who.int/healthsystems/topics/financing/healthreport/41FiscalSpace.pdf>
- 121 www.pih.org
- 122 Datta, S. (2016) Cybersecurity by Engineering Design. <http://bit.ly/IOT-MIT> and <http://bit.ly/CS-eng-design>
- 123 Datta, S. (2016) Comments to US Government Accountability Office (GAO) and US National Academy of Sciences <http://bit.ly/IoT-Policy-Socio-Economic>

124 Datta, S. (2015) Dynamic Socio-Economic Disequilibrium. <http://bit.ly/IOT-MIT> and <http://bit.ly/DSED-IoT>

125 <https://www.statnews.com/2017/02/13/medical-error-patient-safety-joe-kiani/>

126 [http://medicalinteroperability.org/wp-content/uploads/2017/01/ICTToday Trusted%20Wireless%20Health Reprint NovDec16.pdf](http://medicalinteroperability.org/wp-content/uploads/2017/01/ICTToday_Trusted%20Wireless%20Health_Reprint_NovDec16.pdf)

127 <http://www.himss.org/library/quality-patient-safety/medical-devices>

128 http://jwilson.coe.uga.edu/emat6680/parveen/fib_nature.htm

129 http://thebeautifulstars.blogspot.com/2011_05_01_archive.html

130 <https://www.cfa.harvard.edu/~mjj/>

131 Jennifer A N Brophy and Christopher A Voigt (2014) *Principles of genetic circuit design*. Nature Methods **11** 508–520 doi:10.1038/nmeth.2926

132 Shu Fang Liu and Asrar B. Malik (2006) *NF- κ B activation as a pathological mechanism of septic shock and inflammation*. American Journal of Physiology - Lung Cellular and Molecular Physiology **290** (4) L622-L645 DOI:10.1152/ajplung.00477.2005 <http://ajplung.physiology.org/content/ajplung/290/4/L622.full.pdf>

133 Minsky, Marvin (1988) *Society of the Mind*. Simon & Schuster. <http://www.acad.bg/ebook/ml/Society%20of%20Mind.pdf>

134 <https://www.nist.gov/news-events/events/2016/10/global-city-team-challenge-gctc-2016-supercluster-kickoff>

135 Topol, E.J. (2014) Individualized medicine from prewomb to tomb. Cell **157** (1) 241-253 doi: 10.1016/j.cell.2014.02.012

136 <https://bits.blogs.nytimes.com/2011/09/23/a-web-tool-that-lets-you-automate-the-internet/>

137 Song Li, Yangsheng Yu, Yinshi Yue, Zhixin Zhang and Kaihong Su (2013) *Microbial Infection and Rheumatoid Arthritis*. J Clin Cell Immunology **4** (6) 174 doi:10.4172/2155-9899.1000174 www.ncbi.nlm.nih.gov/pmc/articles/PMC4131749/

¹³⁸ Lundberg K, Kinloch A, Fisher BA, Wegner N, Wait R, Charles P, Mikuls TR, Venables PJ (2008) *Antibodies to citrullinated alpha-enolase peptide 1 are specific for rheumatoid arthritis and cross-react with bacterial enolase*. *Arthritis Rheum* **58** (10) 3009-3019 doi:10.1002/art.23936 <https://www.ncbi.nlm.nih.gov/pubmed/18821669>

¹³⁹ Abinaya Prakasam, S. Sugumari Elavarasu and Ravi Kumar Natarajan (2012) *Antibiotics in the management of aggressive periodontitis*. *Journal of Pharmacy and Bioallied Sciences* **4** (Suppl 2) S252-S255 doi: 10.4103/0975-7406.100226 <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3467876/>

¹⁴⁰ <https://www.perio.org/consumer/cdc-study.htm>

¹⁴¹ P.I. Eke, B.A. Dye, L. Wei, G.O. Thornton-Evans and R.J. Genco (2012) Prevalence of Periodontitis in Adults in the United States: 2009 and 2010. *J Dent Res* **91** (10) 914-920 <http://journals.sagepub.com/doi/pdf/10.1177/0022034512457373>

¹⁴² van der Oost, J. (2013) New tool for genome surgery. *Science* **339** (6121) 768-770 doi: 10.1126/science.1234726

¹⁴³ Jinek M, Chylinski K, Fonfara I, Hauer M, Doudna JA and Charpentier E. (2012) A Programmable dual-RNA-guided DNA endonuclease in adaptive bacterial immunity. *Science* **337**(6096) 816-821 doi: 10.1126/science.1225829

¹⁴⁴ Cong L, Ran FA, Cox D, Lin S, Barretto R, Habib N, Hsu PD, Wu X, Jiang W, Marraffini LA, Zhang F. (2013) Multiplex genome engineering using CRISPR/Cas systems. *Science* **339** (6121) 819-823 doi: 10.1126/science.1231143

¹⁴⁵ Martin Read, Karen E. Hicks, Paul F. G. Sims and John E. Hyde (1994) Molecular characterisation of the enolase gene from the human malaria parasite *Plasmodium falciparum*. Evidence for ancestry within a photosynthetic lineage. *Eur. J. Biochem.* **220** 513-520 <http://onlinelibrary.wiley.com/doi/10.1111/j.1432-1033.1994.tb18650.x/pdf>

¹⁴⁶ <https://rheumatoidarthritis.net/what-is-ra/ra-statistics/>

¹⁴⁷ <http://robohub.org/bioinspired-robotics-1-swarm-collectives-with-radhika-nagpal/>

¹⁴⁸ <http://news.harvard.edu/gazette/story/2017/01/a-breakthrough-in-high-pressure-physics/>

¹⁴⁹ <http://news.mit.edu/2017/engineers-harness-stomach-acid-power-tiny-sensors-0206>

¹⁵⁰ <https://gigaom.com/2015/02/10/heres-a-cancer-detecting-bra-thats-better-than-a-mammogram/>

151 Datta, S. (2006) *Charlie's Skypeout Strategy*. ELO Report to Tekniikan edistämiskeskus (TEKES, Finnish Funding Agency for Technology and Innovation, Ministry of Employment and the Economy, Finland) <https://dspace.mit.edu/handle/1721.1/56251>

152 Eric, Lander – Whitehead Institute Human Genome Project (1986-2004)
<http://museum.mit.edu/150/128>

153 Toward Precision Medicine: Building a Knowledge Network for Biomedical Research and a New Taxonomy of Disease. Committee on a Framework for Development a New Taxonomy of Disease; National Research Council
http://www.ucsf.edu/sites/default/files/legacy_files/documents/new-taxonomy.pdf

154 James C. Corbett *et al* (2012) *Spanner: Google's Globally-Distributed Database*. Proceedings of Operating Systems Design and Implementation, 2012.
<https://static.googleusercontent.com/media/research.google.com/en//archive/spanner-osdi2012.pdf>

155 Launchbury, J. (2017) *DARPA Perspective on AI* www.darpa.mil/attachments/AIFull.pdf

156 Datta, S. (2016) *Intelligence in Artificial Intelligence*. Digital by Design. MIT Libraries
<https://dspace.mit.edu/handle/1721.1/104429> and <http://arxiv.org/abs/1610.07862>

157 Yu-Hsin Chen, Tushar Krishna, Joel Emer, & Vivienne Sze (2016) http://eyeriss.mit.edu/Designing_Energy-Efficient_Convolutional_Neural_Networks_using_Energy-Aware_Pruning
<https://arxiv.org/pdf/1611.05128.pdf> (An Energy-Efficient Reconfigurable Accelerator for Deep CNN <http://people.csail.mit.edu/emer/slides/2016.02.isscc.eyeriss.slides.pdf>)

158 <http://centerfordigitalhealthinnovation.org/>

159 <http://hitconsultant.net/2014/05/29/samsung-pumps-50m-into-digital-health-initiative/>

160 <https://www.ucsf.edu/news/2014/02/111976/samsung-ucsf-partner-accelerate-new-innovations-preventive-health-technology>

161

Beatriz Pelaz, Christoph Alexiou, Ramon A. Alvarez-Puebla, Frauke Alves, Anne M. Andrews, Sumaira Ashraf, Lajos P. Balogh, Laura Ballerini, Alessandra Bestetti, Cornelia Brendel, Susanna Bosi, Monica Carril, Warren C. W. Chan, Chunying Chen, Xiaodong Chen, Xiaoyuan Chen, Zhen Cheng, Daxiang Cui, Jianzhong Du, Christian Dullin, Alberto Escudero, Neus Feliu, Mingyuan Gao, Michael George, Yury Gogotsi, Arnold Grünweller, Zhongwei Gu, Naomi J. Halas, Norbert Hampp, Roland K. Hartmann, Mark C. Hersam, Patrick Hunziker, Ji Jian, Xingyu Jiang, Philipp Jungebluth, Pranav Kadhiresan, Kazunori Kataoka, Ali Khademhosseini, Jindřich Kopeček, Nicholas A. Kotov, Harald F. Krug, Dong Soo Lee, Claus-

Michael Lehr, Kam W. Leong, Xing-Jie Liang, Mei Ling Lim, Luis M. Liz-Marzán, Xiaowei Ma, Paolo Macchiaroni, Huan Meng, Helmuth Möhwald, Paul Mulvaney, Andre E. Nel, Shuming Nie, Peter Nordlander, Teruo Okano, Jose Oliveira, Tai Hyun Park, Reginald M. Penner, Maurizio Prato, Victor Puentes, Vincent M. Rotello, Amila Samarakoon, Raymond E. Schaak, Youqing Shen, Sebastian Sjöqvist, Andre G. Skirtach, Mahmoud G. Soliman, Molly M. Stevens, Hsing-Wen Sung, Ben Zhong Tang, Rainer Tietze, Buddhisha N. Udugama, J. Scott VanEpps, Tanja Weil, Paul S. Weiss, Itamar Willner, Yuzhou Wu, Lily Yang, Zhao Yue, Qian Zhang, Qiang Zhang, Xian-En Zhang, Yuliang Zhao, Xin Zhou, and Wolfgang J. Parak (2017) *Diverse Applications of Nanomedicine*. ACS Nano **11** 2313-2381
doi: 10.1021/acsnano.6b06040 <http://pubs.acs.org/doi/abs/10.1021/acsnano.6b06040>

¹⁶² Global, regional, and national age–sex specific all-cause and cause-specific mortality for 240 causes of death, 1990–2013: Systematic analysis for the Global Burden of Disease Study [http://www.thelancet.com/pdfs/journals/lancet/PIIS0140-6736\(14\)61682-2.pdf](http://www.thelancet.com/pdfs/journals/lancet/PIIS0140-6736(14)61682-2.pdf)

¹⁶³ <https://www.unicef.org/mdg/childmortality.html>

¹⁶⁴ <http://purl.stanford.edu/sv492bk0032>

¹⁶⁵ Sean C. O’Hern, Doojoon Jang, Suman Bose, Juan-Carlos Idrobo, Yi Song, Tahar Laoui, Jing Kong and Rohit Karnik (2015) *Nano-filtration across Defect-Sealed Nano-porous Monolayer Graphene*. Nano Letters **15** (5) 3254-3260 DOI: 10.1021/acs.nanolett.5b00456
<http://pubs.acs.org/doi/abs/10.1021/acs.nanolett.5b00456>

¹⁶⁶ Julie S. Biteen, Paul C. Blainey, Zoe G. Cardon, Miyoung Chun, George M. Church, Pieter C. Dorrestein, Scott E. Fraser, Jack A. Gilbert, Janet K. Jansson, Rob Knight, Jeff F. Miller, Aydogan Ozcan, Kimberly A. Prather, Stephen R. Quake, Edward G. Ruby, Pamela A. Silver, Sharif Taha, Ger van den Engh, Paul S. Weiss, Gerard C. L. Wong, Aaron T. Wright and Thomas D. Young (2016). *Tools for the Microbiome: Nano and Beyond*. ACS Nano **10** 6-37
DOI: 10.1021/acsnano.5b07826 <http://pubs.acs.org/doi/abs/10.1021/acsnano.5b07826>

¹⁶⁷ http://www.mdpnp.org/uploads/CLHC_June_12_Podium_email_size.pdf

¹⁶⁸ Robert E Black, Saul S Morris, Jennifer Bryce (2003) *Where and why are 10 million children dying every year?* Lancet **361** 2226–2234
http://www.who.int/maternal_child_adolescent/documents/pdfs/lancet_child_survival_10mill_dying.pdf

¹⁶⁹ Taverne, Dick (2005) *March of Unreason*. Oxford University Press
<http://www.oupcanada.com/catalog/9780199205622.html>

¹⁷⁰ <https://swagergroup.mit.edu/nanowire-chemicalbiological-sensors-status-and-roadmap-future>

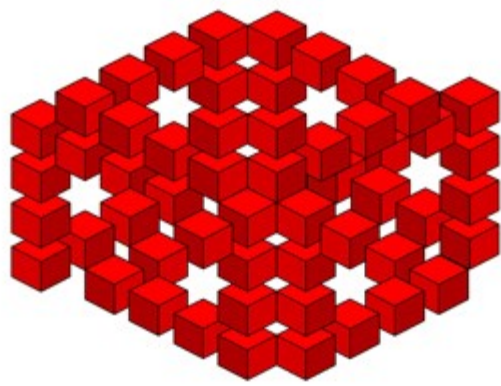
¹⁷¹ Joseph Azzarelli, Katherine Mirica, Jens Ravnsbæk and Timothy Swager (2014) *Wireless gas detection with a smartphone via rf communication*. PNAS **111** 18162-18166
doi:10.1073/pnas.1415403111 <http://www.pnas.org/content/111/51/18162.full.pdf>

¹⁷² Lauren D. Zarzar, Vishnu Sresht, Ellen M. Sletten, Julia A. Kalow, Daniel Blankshtein and Timothy M. Swager (2015) *Dynamically reconfigurable complex emulsions via tunable interfacial tensions*. Nature **518** 520-524 doi:10.1038/nature14168
<http://www.nature.com/nature/journal/v518/n7540/full/nature14168.html>

¹⁷³ Qifan Zhang, Suchol Savagatrup, Paulina Kaplonek, Peter H. Seeberger, and Timothy M. Swager (2017) *Janus Emulsions for the Detection of Bacteria*. ACS Central Science 10.1021/acscentsci.7b00021 <http://pubs.acs.org/doi/full/10.1021/acscentsci.7b00021>

¹⁷⁴ <http://www.modernhealthcare.com/article/20170427/NEWS/170429877>

¹⁷⁵ Dieleman, Joseph L., et al (2016) *US Spending on Personal Health Care and Public Health, 1996-2013*. JAMA **316** (24) 2627-2646. doi:10.1001/jama.2016.16885
<http://jamanetwork.com/journals/jama/fullarticle/2594716>



CHAPTER 8

Shoumen Datta

HAPHAZARD REALITY – IOT IS A METAPHOR

THIS PAGE IS LEFT BLANK

Chapter 8

Future Healthcare: Bioinformatics, Nano-Sensors, and Emerging Innovations

Shoumen Palit Austin Datta

Contents

8.1	Introduction.....	248
8.2	Problem Space.....	250
8.2.1	Background	250
8.2.2	Focus	252
8.3	Solution Space.....	253
8.3.1	Existing Electronic Medical Records Systems	253
8.3.2	Changing the Dynamics of Medical Data and Information Flow	257
8.3.3	Data Acquired through Remote Monitoring and Wireless Sensor Network	265
8.3.4	Innovation in Wireless Remote Monitoring and the Emergence of Nano-Butlers	273
8.4	Innovation Space: Molecular Semantics	290
8.4.1	Molecular Semantics Is about Structure Recognition	290

8.5	Auxiliary Space	296
8.5.1	Potential for Massive Growth of Service Industry in Healthcare	296
8.5.2	Back to Basics Approach Is Key to Stimulate Convergence	298
8.6	Temporary Conclusion: Abundance of Data Yet Starved for Knowledge?	301
	Acknowledgment	301
	References	302

8.1 Introduction

Proclaiming health as a human right [1] is a platitude when healthcare still remains inaccessible to millions, even in affluent nations, or billions elsewhere. Few dispute the fact that more than 30,000 children, less than 5 years old, die every day, many suffering from preventable diseases. According to the Institute of Medicine [2] at the National Academy of Sciences, healthcare is substantially underperforming on several dimensions: effectiveness, appropriateness, safety, cost, efficiency, prevention, and value. Increasing complexity in healthcare and regulatory steps is likely to accentuate current problems, unless reform efforts go beyond financing, to foster sustainable changes in the ethos, culture, practice, and delivery of healthcare. If the effectiveness of healthcare is to keep pace with the opportunity of prognostic, diagnostic, and treatment innovation, then the design must be based on systems thinking [3]. Information technology must be structured to assure access and application of evidence, at the right time, to facilitate continuous learning, and research insights, as a natural by-product of healthcare process. We need to reengineer the development of a research-driven learning healthcare organization [4] by integrating a systems engineering approach, to keep the individual in focus, while continuously improving concepts, quality, safety, knowledge, and value.

In particular, commitment to research may be emphasized by lessons from the past [5] to catalyze a future where creative cross-pollination of diverse concepts from unconventional [6] strategic thinkers is rewarded. It is equally essential to build multidisciplinary collaborative global research teams, imbued with the true spirit of discovery [7] in basic and applied domains. These teams must be enabled to drive an entrepreneurial [8] enterprise approach to create proof of concepts. Translation of unconventional concepts into reality may be guided by innovators with horizontal global vision rather than gatekeepers who prefer to stay “in the box” and avoid risks that leadership demands. The caveat in this process is the impatience of “practical” people for unconventional concepts, but the “nail on the coffin” is often driven by political polemicists who also get impatient with concepts, no matter how justified or pragmatic, because it gets in their way to sell their plans [9]. The latter may block funding or policy that may better enable the conversion of unconventional vision into reality, only limited by our imagination [10].

Yet, unconventional thinkers and business leaders [11] are largely credited for globalization [12]. Striking transformations have occurred through decision

systems and process engineering, not only in established markets but also in creating new markets [13] despite omnipresent global uncertainty [14]. These changes have reshaped political economy [15], governments [16], the service industry, and manufacturing sector, including business process [17], software, hardware, banking, retail, airline safety, automobile industry, national security, and the business of the military industrial complex [18].

Lessons from the failures and the fruits of success, enjoyed by the business world, may not be irrelevant for exploration and/or adaptation by healthcare organizations, despite the irreconcilable differences that exist in the dynamics of mechanical versus biological and social systems. The current challenges in healthcare compel a fresh view of the organization, structure, and function of the delivery and monitoring processes in healthcare, not only for the industrial world that may afford the increasing cost (macro-payments) but for global healthcare services, in a manner accessible to, as well as feasible for, the billions (micro-payments). Financial sustainability of healthcare is a key issue in the design of innovative health services. The latter evokes the paradigm of services that may be deliverable for “micro-payments” rather than the current spending that claims a double digit share of the gross domestic product of rich nations.

One of many lessons from the business world is that to survive in business, businesses must exploit the power of “now” [19], perhaps best illustrated by the surge in using real-time data, almost for everything, through the use of radio frequency identification (RFID) tools [20]. To remain profitable in an RFID-driven world, industry must “adapt or die” [21]. Real-time consumer-driven supply chain [22] dynamics also determine the speed at which the industry must change to remain competitive [23]. Hence, business models are continuously focused on data, new technologies [24], cost reduction, and the quest for new growth without sacrificing quality of product and/or service. Systems that help to maintain “everyday low cost” at Wal-Mart and efficiencies at Dell that still allow “making boxes” a profitable pursuit deserve strategic exploration and integration of germane ideas to improve sustainable healthcare delivery. Healthcare systems were not designed with scientific principles in mind [25], and the ethos of “innovate or die” [26] is not salient to healthcare providers.

While software systems, like enterprise resource planning (ERP), generate benefits for business and industry, through some degree of integration of data and automation of planning, there are few healthcare electronic medical records (EMR) systems (EMRS) that have autonomous decision-making capability. Healthcare, even preventative or wellness, if available, is still dependent on expensive human resources for data acquisition, monitoring, analysis, reporting, and follow-up. Reengineering this cost structure and hospital-centric service model is necessary. Configuring a reliable business service model for health services may meet with entrenched resistance to change but may catalyze extended healthcare for billions and may even improve healthcare quality of service.

8.2 Problem Space

8.2.1 Background

The multitude of problems and issues in management of healthcare are beyond the scope of any paper or book. Here, I briefly touch upon only one issue: acquisition of medical data to improve healthcare. However, the fundamental nature of this issue forces us to address a series of integrated problems, some of which may be text book cases in basic physiology [27] and biochemistry [28]. Therefore, it is well nigh impossible to do sufficient and equal justice to all the interdependent processes and areas.

The naive thrust of this issue is to reduce healthcare cost but with concomitant expansion of improved healthcare services for billions. Healthcare cost reduction is a hackneyed topic of discussion, but the thrust of this chapter is to suggest solutions where emerging ideas and innovation may help expand and improve healthcare service at a cost that may be soon sustainable even by the developing countries of the world. Hence, the solution space shall deal with the issue in focus: innovation in acquisition and analysis of medical data. It is obvious that one can remain oblivious of the fact that innovation in data collection calls for innovation in tools for data collection as well as analysis of data, to extract information and knowledge that can add value to healthcare services. Due to the latter, the problem (and solution) space of this chapter is bound to evolve in multiple directions, each indicating a further line of innovation.

One general problem in global healthcare is due to the mimicry of the Western model focused on acute-care hospital-centric view of what health “care” is supposed to deliver [29]. The aphorism that “better health is inherently less expensive than worse health” is equally applicable in the West and the East [30] yet seldom practiced. In fact, the profitability of the acute-care hospital-centric Western model appears to be the preferred line of health service delivery (Figure 8.1). It reasons that the word “care” must be omitted from healthcare [31] because the hospital-centric revenue model is at odds with the “care” that health services are expected to deliver for an individual in a patient-centric view of personalized healthcare.

I hasten to add that in general, the acute-care hospital-centric model still offers appreciable services when it concerns accidents and emergencies (A&E). It is vital to respond to the challenges of uncertainty in healthcare stemming from A&E. But, the criticism surfaces when the A&E modus operandi is extended to other areas of non-A&E healthcare. The systemic efficiencies necessary to respond to A&E situations must continue to be supported. Suggestions in this chapter or elsewhere about patient-centric personalized healthcare must not be viewed as a replacement but as a realignment of the existing system that is necessary for economic transformation to keep healthcare sustainable. A&E and non-A&E approaches are not mutually exclusive, and there is a need for elements of both systems to coexist for mutual enrichment.

Another problem that has evolved over the past few decades concerns an inability or incongruent response of the healthcare community to adopt advances in

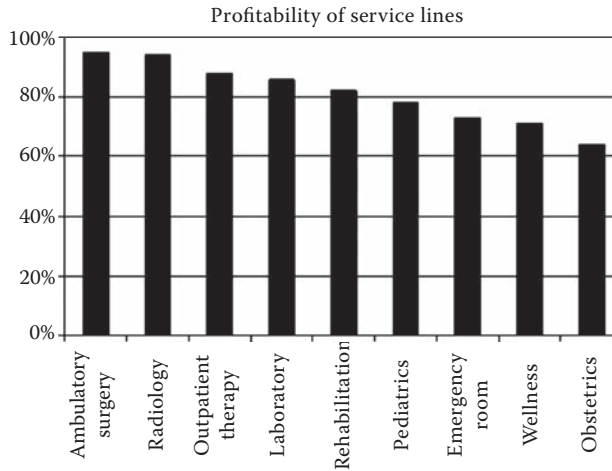


Figure 8.1 Reporting service lines as profitable (above 80% reporting) or unprofitable (below 80% reporting). (Adapted from Deloitte Consulting, *The Future of Healthcare: An Outlook from the Perspective of Hospital CEOs*, New York, 2005. With permission.)

information technology in order to develop an integrated systems approach to services. The human-driven decision model practiced by the medical community is adept in maintaining and/or sequestering data, information, and knowledge, about cases and patients in paper-driven silos. It prevents the improvement and development of a learning healthcare system based on insight and experience. Critics of information technology within the medical community will defend this status quo by pointing to issues of confidentiality of patient–doctor relationship, privacy of patient data, lack of standards for medical systems interoperability, and quagmire of ethical guidelines for medical knowledge diffusion. The critics are justified in their claims. But they also remain refractive to extract and use the principles that have increased profitability in the services industry and catapulted businesses such as GE, P&G, Nokia, and Wal-Mart to luminous heights of profitability. In addition, the chasm between medical education and engineering education creates a lack of awareness of the advanced tools and information technologies that exist and the potential for innovation in intelligent decision sciences, in order to provide data protection the critics demand and the patient and doctor deserve.

The business services approach to healthcare, admittedly, raises alarms if individuals or patients are to be viewed as cost-centers with the administration trying to function as a profit-center. This view assumes a literal translation of business services to health service, which is not what the proposal calls for. As an example of successful transformation of business service efficiencies, one may cite education, a domain with distinctly different dynamics from business. The Open University in

United Kingdom [33] and University of Phoenix in the United States [34] have pioneered profitable business service type approaches, integrated with extensive use of information communication technologies (ICT), to deliver education of a reasonable standard for vast number of individuals, who were unable to access traditional higher education, for a variety of reasons.

Remote access to education had humble origins in “correspondence” courses but was transformed by the growth of the ICT sector and accelerated by the diffusion of the Internet. This is a form of “personalized” education that enables individuals to move ahead in careers of their choice and contribute to economic growth. This educational–economic transformation may offer a paradigm for the healthcare industry. Of course, the academic level of OU and other similar outfits may not train an individual to be the next “big bang” theorist or lead researcher to garner a Nobel Prize. But for those elite purposes, the academic system is well prepared with its select institutions. The elite academic institutions may be analogous to the “elite” equivalent in healthcare, which may be the acute care and A&E. However, the elite model in healthcare system may exclude or restrict, on grounds of profitability or cost, the accessibility of non-A&E type preventative or early diagnostic modes of healthcare (analogous to OU and similar outfits) for the masses.

8.2.2 Focus

To reiterate, the focus of this chapter relates to innovation in acquisition and analysis of medical data to improve healthcare by expanding coverage for the masses yet deliver greater value of healthcare services. Service orientation, systems architecture, and the use of software as infrastructure depend on data sources and analytics needed from healthcare monitoring, sensing, and responding to situations. The business services concept of data, information transparency between systems, as well as data exchange and/or interoperability issues may be more complex in this context due to regulatory and security constraints. It may be quite useful if the business service type approach can also introduce some degree of automated decision making, even based on rules and workflow, for non-exceptional healthcare case management.

The next level of decision making based on acquired data with reference to standards (e.g., pulse rate, blood pressure, and normal range of blood glucose) may require some basic algorithms based on simple artificial intelligence (AI) principles that can induce a learning healthcare approach when evaluating data about a specific individual or patient. For example, if the individual is otherwise “normal” even under a higher systolic or diastolic blood pressure (BP) reading, then the analytical algorithm can learn that the deviation from the medical standard reference model (120/80 mm Hg) is not readily a cause for alarm in this specific case since the individual is physiologically “normal” even under an elevated or lower than standard BP reference data. Hence, billions of learning instances are necessary for a global model.

This very important decision, to conclude an individual or patient is normal despite a slightly aberrant standard data, must be made, under most current circumstances, by a trained medical professional. That translates to cost. Aggregated over numbers of inpatient- and outpatient-related data, these cumulative costs soon begin to destabilize the financial infrastructure. Equally and perhaps more important is the time spent by the trained medical professional to review the data and arrive at the decision. Time spent for non-exception management siphons away valuable time from exception management and patients who indeed need attention. Therefore, it is not difficult to comprehend that small changes in the healthcare process pose minimal risk, quantifiable using business tools (see Ref. [201]), yet may improve quality of service and reduce cost.

Documenting the acquired data, for example, the blood pressure reading mentioned above, is the next level that deserves exploration due to the cascade of events that this data may trigger. With a few exceptions, even in the most advanced industrialized nations, paper-based documentation is the norm [35]. Unless paper-based documentation is the exception, rather than the norm, healthcare systems may continue to be crippled from displaying their true functional potential. Given human errors of data input, the transformation of preexisting and accumulating data as well as notes and decisions poses a major challenge. Without the available information on existing patients and cases, the ability of decision systems to arrive at non-exception-management-related decisions, on these existing patients and cases, may be seriously flawed and hence may be rendered unacceptable, to help deal with existing patient management.

Thus far, we have referred to patients, but what about individuals who are not patients yet? Wellness or preventative medicine and early risk identification are critical to reduce the probability that an individual shall become a patient or need acute care or emergency attention. The acute-care hospital-centric model is largely viewed as a failure to address this broader spectrum of personalized healthcare even though it may be well equipped to deal with A&E in nations big (e.g., the United States) and small (e.g., Ireland).

8.3 Solution Space

8.3.1 Existing Electronic Medical Records Systems

Before embarking on the discussion of emerging trends and potential for innovation to address the problem focus outlined above (Section 8.2.2), it may be pointed out that medical data captured in electronic format (EMRS) exist in practice in some form or the other [36]. It may offer architectural clues or serve as a basic template (starting point) for nations beginning to grapple with the problem of creating EMRS. However, expecting the current EMRS to serve as a “best practice” or benchmark may not be prudent. There is ample room for improvement of EMR,

which is essentially a generic data aggregation platform. The evolution of future versions or variations of generic EMR platform may not bear any resemblance to current systems that are generally command-driven, archival data stores, with little, if any, analytical capabilities, such as clinical decision support (see Ref. [63]).

Since 1907, the Mayo Clinic (the United States) claims to have kept unified medical records that exist in electronic format since 1993 [37] in a single database with 5 million records including patient files, x-rays, laboratory results, and electrocardiogram (ECG) records. Since 2004, it includes data mining and pattern-recognition tools to discover relationships among specific proteins, genetic makeup, and treatment responses (see Sections 8.3.2 and 8.5.1). Information can be shared between the different geographic locations of the Mayo Clinic, and physicians can conduct a virtual consultation on any patient because the EMRs are accessible from all three sites. This may represent the primordial role of data in personalized healthcare.

The VistA system in use by the Veterans Administration (the United States) hospitals covers 150 medical centers and 1400 sites across the country [38]. Eighty-five percent of 57 million outpatient visits and almost all inpatient notes are available online through VistA. In addition, 94% of outpatient prescriptions (equivalent to 200 million 30 day prescriptions) and almost all of inpatient prescriptions are entered in VistA (EMR) directly by the prescribing clinician. A study in 2004 compared VA versus non-VA patients in 12 communities and found that VA patients scored higher on quality of care, chronic disease care, and preventative healthcare.

The scope of benefits that can be derived from EMRS, as one component in the solution space, is only limited by our imagination, but, at present, several thorny challenges remain. Unlike the Mayo Clinic records and their visibility across the three different geographic locations, the infrastructure of VA or Partners HealthCare [39] is more extensive. Patients can move between locations and their treatment can change over time. This introduces major systemic issues, as follows. Partial solutions are suggested, if applicable.

Of immediate concern is unique identification of data (see Ref. [39]). How do we uniquely identify the patient, and patient records, that may be assigned different ID numbers in different locations as well as different records of the same patient that may be numbered according to the system in operation at a given location? The critical value of unique identification that unambiguously links the individual to his/her records, irrespective of the physical location of the hospital, does not need emphasis. The sheer number of individual records (laboratory tests, x-ray, CT scan, ultrasound, physician's notes, medication, response) multiplies over time and may present a numbering scheme dilemma that requires a solution but without reinventing the wheel or introducing yet another "new" system.

Creating unique identification is not a competency of the healthcare industry. Hence, the health services may opt for an existing identification scheme that (1) can offer vast number of unique addresses [40] that can be organized in relationships or subclasses, (2) is truly portable, (3) Internet ready, (4) already in operation, and (5) globally pre-agreed in a manner that can aid adoption by the healthcare industry.

A proposal that can address this issue of unique identification of octillions of items using the globally agreed IPv6 format is presented in a separate paper (see Ref. [40]). Support for the potential use of IPv6-based identification may soon gain momentum [41], and the need for this approach in healthcare was highlighted in problems discussed elsewhere (see testimony that follows from Ref. [38]).

Personalized unique identification in healthcare may offer a robust id solution, but its value for the patient, who may move between various healthcare units (e.g., physiotherapy, stroke care, outpatient clinic) or hospitals, local and/or global, shall remain constrained without interoperability between systems of different healthcare providers, public and private, engaged with the patient. There is little value in deploying unique identification if an individual permanently resides in one location and receives healthcare from one medical professional, in one clinic or hospital, which is entirely self-contained in all its services and without any external interaction, guaranteeing total quality healthcare for the entire life cycle of the individual.

Interoperability segues to the issue of standards. The IPv6 standard governing the unique identification scheme mentioned above will make it possible to identify the unique number (“address”) in any healthcare system anywhere in the world, because the standard has made provisions for assigning that number or address to that record, or patient, in a manner that shall remain unique over the life of an individual. It is logical to anticipate that a “number re-claiming scheme” that may be deployed to claim back and reuse dormant numbers (e.g., a patient number may be claimed back and reused every 150 years if it is assumed that a human being is unlikely to live for more than 150 years).

Standards shall prominently feature in EMRS solutions space when and if the healthcare system begins to experiment with rule-based or intelligent decision sciences to help evolve clinical decision support (see Ref. [63]). Standards or “rules of operation” are immediately necessary for the granular and diverse quality of record-keeping that commences with patient history and physical examination. It is most often carried out by the local primary care physician or general practitioner (GP), in communities where primary care may be in operation and where EMRS may be available for record keeping. Of course, the same could commence for individuals who report to the A&E.

Standard “history” data in an EMRS that is also interoperable are a complex problem that must dig deep and wide for multidisciplinary convergence to generate a working solution. It is complicated by the multitude of descriptive syntax that may be used by the patient and the written form in which the medical professional scripts the information. The natural language (mother tongue), cognitive abilities, culture, education, values, and experience of both the patient and the physician or medical professional shall color the content and context of this history document. It is apparent that existing ICT and computer systems may find it difficult, if not impossible, to extract with reasonable precision the “meaning” of the history written in words and transform them to a standard format that is medically relevant for EMRS interoperability. Even more crucial is to “understand” the importance

of the phenotypic information relative to the context of the patient and his or her genotype, which, to be of value, must refer to a reference model of the community, geography, and environment where the patient lives or lived.

To the serendipitous reader, it may become obvious that the transformation from a paper-based localized healthcare system, with a limited number of professionals from a homogeneous background, to EMRS, may help to deliver global healthcare services, by any one, the myriad of diverse professionals. But it requires substantial research and innovation to develop standards [42]. The development of these standards requires integration with cognition and semantic theory. I will return to this issue when I discuss the proposal of molecular semantics (Section 8.4).

Before “boiling the biomedical ocean” in cognition and semantics, it may be useful if the healthcare system may globally agree to partially address the gulf between syntax and semantics in a “quick and dirty” approach, as adopted by business processes in global organizations [43] or the efforts spawned by the semantic web movement [44] to create biomedical ontologies [45]. These solutions, albeit temporary, if deployed and implemented in EMR type systems, are likely to offer some benefits, if the questions and content are less descriptive and are already expressed in a manner that is medically relevant, irrespective of the “background and culture” of the involved medical professional.

The development of “quick and dirty” rules and partial standards may help with (1) exchange of clinical data, (2) defining categories or circumstances when a physician in one healthcare organization can change or amend the problem list entry of a physician in another organization, (3) conditions under which clinical staff from one organization may discontinue medication prescribed by another clinician in the same organization or from another organization, and (4) types of data and information that must be secured by privacy policies and their enforcement, so that confidential data and patient information cannot be shared with, or released to, any external nonmedical organization without due authorization from the patient.

Finally, EMRS, even with its current healthcare service handicaps and restrictions, can still provide business value that may translate to cost savings. Because organization-specific EMRS like VistA operated by the VA cover a majority of its operations, the supply-demand profile of the operation can be deduced with a fair degree of precision. Using economies of scale, products, and services may be bought at a bargain. VistA offers an indication of volume of patients that are likely to be served and that volume information may be analyzed to forecast [46] inventory of supplies necessary to meet the projected demand. For perishable products (drugs, IV fluids, food), the design and management of supply chain [47] of vendors and partners can partner with the business operations unit to ensure adequate inventory of perishables to meet “peace” time and “war” time [48] type volatilities, analogous in the healthcare supply chain if one compares normal course of events versus epidemics, pandemics, natural disasters, or acts of terrorism. However, it is well nigh impossible to stress that the key performance indicators (KPI) for business

operations and inventory management or purchasing decisions must be based on different operating principles and are significantly distinct between business [49] and healthcare (see Section 8.5.1). Nevertheless, gaining business efficiencies in healthcare is not an automatic process simply because EMRS offers an aggregated view of potential consumption of products and services. It is for this reason that some countries with national health service, whether servicing a large [50] or small [51] population, may still suffer from an inability to take full advantage of the economies of scale to drive business efficiencies.

8.3.2 Changing the Dynamics of Medical Data and Information Flow

The thesis of this chapter outlined in Section 8.2.2 selects medical data as one conduit that may offer the potential to catalyze low-cost, high-quality healthcare services. An analysis of the nodes of origin of data in the context of their relationship to cost (to acquire data) and quality of service (decision based on data) may form the basis for suggesting how the current dynamics may benefit from a paradigm shift (Figure 8.2).

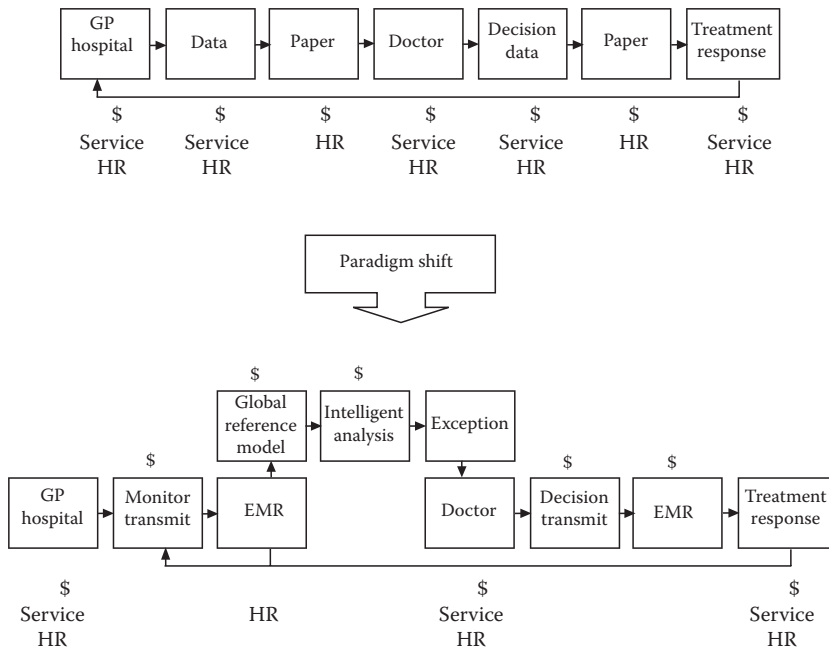


Figure 8.2 A generic model of data flow in healthcare and potential benefits of a paradigm shift.

In some industrialized nations and in the developing world, the current healthcare practice may be loosely represented by the schematic outline shown in the top portion of Figure 8.2. In the current scenario, almost all points of interaction (denoted by rectangles) incur cost (denoted by large \$ signs), and each action consumes time from professionals (denoted by “HR” and “Service HR”). The latter, as a result, is a drain on the available working hours of medical personnel and is an improper use of valuable time, which could have been, otherwise, put to better use by offering health “care” service focused on the elements connected to the treatment of the patient.

The paradigm shift outlined in the lower portion of Figure 8.2 is neither new nor an innovative breakthrough. It is a strategic process engineering that is driven by common sense. It suggests how basic integration of some tools and technologies may lead to savings in cost and improvement in quality of care by focusing the time of medical professionals on the patient, rather than on standard tasks and chores. In this scheme, the lack of the large \$ signs under the points of interaction (rectangles) indicates potential for cost savings. Above the points of interaction (rectangles), the small \$ signs imply that implementing and maintaining these changes are not free, but the cost is lower (than the large \$ signs) and return on investment (ROI) is higher if the cost of installing the systems is amortized over their productive life cycle. Less time spent by medical personnel at various stages (lack of HR and service HR) leaves more time to focus on patient care.

Three elements that drive the paradigm shift (Figure 8.2) are (1) data monitoring, addressed in Sections 8.3.3 and 8.3.4, (2) electronic data capture or EMR, discussed in Section 8.3.1, and (3) diversion in data flow. In the remainder of this current section, I will discuss the latter since it is perhaps the key in the proposed paradigm shift.

Diversion of data flow leads to an information loop that channels acquired data to flow through a global reference model and directs the outcome of analytics to medical personnel if it appears to be an exception. By concentrating on the patients that need attention (exceptions), the system is able to improve its quality of service.

Critics are eager to pose the thorny question: how reliable is the machine-based analytical process? Due to the experimental nature of the scientific process, I find it reasonable to conclude that there may not be, ever, a unanimously acceptable, complete, and absolute scientific certainty, with which anyone can predict that a machine-learning process can be guaranteed to be foolproof. Errors in medical diagnosis by medical experts are rare. Thus, neither humans nor machines are entirely infallible. It follows, therefore, that the “thorny” question is the wrong question. Attempts to find the precise answer to the wrong question have, thus far, fractured the determination of, and seriously distracted, the healthcare and decision sciences experts’ (see Ref. [63]) effort, to focus on finding an approximately reasonable answer to the right question: how much and for what type of cases can we generally depend on the analytical tools in clinical decision support?

In the United States, healthcare spending was in excess of \$2.1 trillion in 2007 and projected to double to \$4.2 trillion by 2016. Thus, reducing 10% of health

services workload through monitoring and analytics may save the United States nearly half a trillion dollars [52] in a few years. A small country like Ireland may save a couple billion euro [53] per year. It may also translate to a 10% improvement in the quality of service (QoS). Financial savings may be reinvested in community primary care centers, home help for independent living, and early risk identification, for example, for diabetes.

Therefore, the information loop proposed in the paradigm shift must be created and implemented, soon, even if the construction occurs in steps or modules. Inevitable “growing pains” are expected to accompany any change of direction. The “loop” is a generic expression that involves critical sub-elements of great depth that require precision knowledge. This chapter does not provide a prescription for building the sub-elements but strives to present examples that may convey the nature of these components. It goes without saying that the loop is not an “IT” job but demands collaboration between IT and medical experts.

Figure 8.2 alludes to a Global Reference Model (GRM) where the acquired data is fed via a database, such as an EMRS. The schema indicates that the data flow through the GRM into the intelligent analytics domain. What is unclear from the illustration and requires explanation is that the suggestion positions the GRM to represent an umbrella, or collection, of multiple modular databases, each embedded with some form of rule-based analytical engine that can evaluate the incoming data (streaming data) and use conventional workflow to query its database (specific to that module) to find relationships, homologies, or discrepancies based on its own stored data, specifically with reference to and in the context of that module of the GRM.

For example, a patient with elevated temperature suffering from severe bouts of coughing undergoes exploration in an outpatient clinic. A nurse records the blood pressure and temperature, draws blood for total blood count, and, based on the ethnicity of the patient, decides to take a sputum (saliva) sample in addition to administering a Manteaux test. It is an immunological test designed to detect tuberculosis (TB), an infectious disease [54], caused mainly by the microorganism *Mycobacterium tuberculosis*.

What types of modules in the GRM can process and analyze the data from this patient? Medical experts can define the nature of the GRM sub-modules, but, for the nonmedical reader, it may be of interest to note the following. Reference for normal blood pressure, correlated to age, is common, as is temperature. Total blood count is a common standard and is easily included in a GRM module. However, the GRM module that can deal with the results of the Manteaux test requires medical details as well as environmental details that relate to the epidemiology of TB, length of habitat of the patient in geographies where TB is prevalent, immunological profile of individuals with confirmed infection by *Mycobacterium tuberculosis*. The Manteaux test is an intracutaneous tuberculin skin test usually applied on the forearm and contains tuberculin purified protein derivative (PPD) to elicit the immune response that is visible on the epidermis within 2–3 days. For a patient who was born or lived in Southeast Asia or a resident of warm humid coastal areas

in the United States, a positive Mantoux test, but measuring less than 10 mm in transverse diameter of induration, as detected by gentle palpation at 48–72 h, is not indicative of TB but rather indicates tuberculin hypersensitivity, resulting from contact with nonpathogenic environmental mycobacteria or childhood vaccination by *Bacillus Calmette-Guerin* (BCG), which is an attenuated strain of *Mycobacterium bovis* [55].

The above example illustrates the web of relationships that the GRM and analytics must be able to extract and transmit, to the point-of-care medical professional, using a visualization interface such as personal digital assistant or Blackberry type mobile phone. However, irrespective of the apparent complexity of the above example to the nonmedical reader, most of the data and information mentioned above are already available in several databases and are classified under variety of topics, including the obvious heading of infectious diseases. There is no need to create, de novo, any basic medical data or information database. For example, from the scenario above, the sputum sample from the patient may hold several clues for early detection and diagnosis, based on advances in saliva-based biomarkers [56]. The data from sputum analysis may be transmitted to the GRM, and it can query the SKB or Salivaomics Knowledge Base [57] to extract the information for further analysis. Several such databases exist with specialized knowledge and information, which are accessible via the World Wide Web. Unfortunately, the traditional web works as a directed graph of pages with undifferentiated links between pages. This is not conducive to the type of relationships necessary for healthcare analytics. Emerging principles from social networking may be quite helpful for healthcare service analytics (see Section 8.5.1). Blogosphere (see Ref. [10]) has a much richer network structure in that there are more types of nodes that have more kinds of relations between the nodes. Deploying the principles of blogosphere in healthcare analysis may be quite promising.

Thus, the challenge is to find new ways or tools to identify and relate the selected sources that may serve as components of GRM through a virtual amalgam. GRM requires a mechanism to search and detect the information database and then query the database depending on the case or patient under investigation. For every patient, these strands of data-dependent, symptom-dependent, or test-dependent tasks must be created, in real time, on demand, perhaps, as a higher layer integrated abstraction in the form of an application module (poor choice of word but hopefully, it conveys the concept). For example, continuing the TB scenario, the data from the Mantoux test plus the symptom of cough and the eosinophil count from blood test may serve as three variables that may trigger an ad hoc application that asks, either as single queries or collectively, “What is the potential diagnosis if the Mantoux test reveals a 10 mm transverse diameter, chesty coughs are persistent, and eosinophil count is 8%?” To execute this process, the system may create an ad hoc application-specific interface (ASI), application-specific query (ASQ), and an application-specific relationship (ASR) that can act, either alone or as a bundled application, to probe relevant knowledge repositories or databases, to extract the information. This information

may be further refined by the intelligent analytics component in the information loop or transmitted to the point-of-care (POC) medical professional.

The scenario above may be loosely suggestive of a medical example of mash-up software [58] that is gaining popularity in business services utilizing SOA or service-oriented architecture [59]. SOA is touted to help business services remain agile and adaptable to meet the competitive challenges due to volatility of consumer preferences and uncertainty stemming from globalization of the supply chain. To capture sales, these business services, on demand, in real time, create a personalized web service and display a collage of objects, optimized for consumer choice. The collage is culled from different domains or databases that may or may not belong to the business but secure content on demand through licensing. The mash-up appears seamless through the wizardry of visualization tools. The consumer views it as a web page on a computer screen or mobile phone. The view may include, for instance, a company logo (a software object), price of a product (database table format, stored as an object) aimed at a market segment (extracts clients preferences and matches with stored classes of objects, e.g., sports), and ordering information (another standard shipping and handling object) with links to track and trace details provided by a third-party logistics provider (e.g., link to FedEx site).

The analogy in the above two paragraphs may fall short of the specifics or lack the precision that experts in respective domains (medicine and information technology) may demand, but it may convey the essence of case-specific exploration, on demand, integrated to knowledge discovery from databases, or other domains, necessary for delivering healthcare analytics. Each country may create their own GRM infrastructure to optimize how the GRM may be relevant to the nation and deliver value in medical analytics, at least in cases that are simple enough to be acted upon by machine intelligence, where reasonable confidence can be placed in the decision. Determining what is “simple” may vary, widely.

Triggered by patient data input, the search function of GRM may evoke the notion of Medical Google. One difference is that the search is not the end point of GRM but is for the Google search engine [60]. The granularity of the search process implicit in GRM also differs from that of Google in its quest for knowledge databases, followed by the extraction of relevant data and/or information and/or knowledge that must be first “discovered” and then resynthesized and presented to the intelligent analytical engine.

The “intelligent analysis” referred to in Figure 8.2 is a “place holder” for multiple analytical tools that are available and may be developed in future where the “learning” ability of the tools may be a key emphasis in addition to rule-based applications. The tools, for example, artificial neural networks (ANN), originate from the domain of artificial intelligence (AI), and new algorithms may continue to evolve. Since medicine is an intensely integrated science, the network of interrelationships between medical parameters and physiological function is key to understanding health. The plethora of reasons that may offer generic symptoms, for example, fever, makes it imperative that the point-of-care (POC) physician is sufficiently aware

of the spectrum of reasons why an individual may present the symptoms of fever. Presentation of a list of reasons may stem from the use of rule-based engines that may search and compile a list. However, the value of the “list” is limited unless the context of the patient and history is taken into consideration.

Rules, to combine and select the best possible match between the list and context, may be created, but the rigidity of rule-based selection may make it less reliable if compared to a set of algorithms based on AI principles that can “learn” and forget the subtle, or not so subtle, changes in the context of the patient that may include parameters, such as age, activity, profession, environment, habitat, and nutrition. For this reason, GRM and the intelligent analysis cluster of the information loop may use data cubes [61] and components that may be country specific, nation specific, or community specific but may also draw on synergies between demographically related co-localized nations (e.g., Scandinavia or Eurasian Steppes).

Let us consider an example where Jane, 11, contracts a fever on Monday morning after a hot weekend that she spent on the beach and swimming in the ocean. On Monday, Patrick, 71, complains of fever, too. He also has chronic obstructive lung disease (COLD). The attending physician may focus on determining whether Jane may have an ear infection while gearing to treat Patrick for chest infection. But can we approach this level of interaction and perhaps a treatment suggestion without incurring the cost and time of the physician? The use of acquired data (see Section 8.3.3) and decision sciences may offer a route to savings. To execute this interaction and offer a reliable, low-risk decision or treatment suggestion, intelligent analytics views the GRM-evaluated raw data plus list of possibilities for the fever and integrates the context with patient history. It also checks the GRM pharmacology module. The system transmits the exploratory analytical sequence log and diagnosis and recommends age-appropriate antibiotics, in each case.

Although the use of artificial neural networks (ANN) and artificial intelligence-based algorithms (e.g., ant-based algorithms) was mentioned only for business services applications (e.g., mash-up), the use of AI-based agent systems [62] can provide a robust and granular system. The experimental use of AI in clinical decision making [63] and productive implementation of AI in industry [64], business [65], business-to-business exchanges [66], and other applications [67] provides confidence that agent-based systems may become the norm in healthcare, too. Due to the interrelated nature of medicine, numerous parameters must be concomitantly evaluated for any decision, and each patient must be treated as an independent instance that is specific for that patient only. Data related to the patient always remain patient specific without sharing, aggregating, or clustering data, in any form, whatsoever. For each patient, the classes of data and volume of data points are likely to be quite high. All data points must be stored and relationships evaluated for diagnosis and prognosis. Therefore, the use of data cubes and the ability of agent systems to connect between all data points through the cube-on-cube organization of data cubes may make this approach particularly essential and beneficial for the billions of instances necessary for healthcare services.

Revisiting the earlier example where a Manteaux test was administered, from an agent perspective, the applications, in that discussion, may be dissociated into single agents, each with its specific task in relation data and exploration of the web of relationships with respect to the data or task assigned to the agent. In other words, the agent that holds the results of the Manteaux test (data = 10 mm) for the observed induration is charged with the task to find out, through the medium of the GRM, the implications of the observed data (10 mm). The development of intelligent agents systems [68] is within the grasp of current technology (see Ref. [182]) and can be implemented in healthcare systems. The “bundled” higher layer abstraction of individual applications (ASI+ASQ+ASR) mentioned earlier in this section is analogous to multi-agent systems [69] that work with agents in a hierarchical fashion with higher level agents tasked to integrate the information or data from lower-level agents. It is likely that multi-agent systems (MAS) may become the workhorse of the AI-based intelligent analytics in healthcare.

AI-based agents generally use programming languages from the open source domain. Hence, agents are highly mobile and suited to query a variety of databases for knowledge discovery using open source tools, for example, RDF or resource description framework [70] and OWL or ontology working language [71]. Agents are likely to form an integral part of the emerging semantic web [72]. But, agents need special interfaces if interacting with proprietary databases. Proprietary software vendors [73] deny RDF from accessing their data dictionaries through the use of proprietary programming language, for example, the use of proprietary ABAP programming by the software behemoth SAP AG. These problems may spur novel approaches. One data transformation tool called Morpheus [74] may facilitate extraction of data from various locations by transforming them into a common format, which is then sent to “holding tank” or a repository of transformations. Morpheus, used as a browser tool, may help to find a repository transformation that GRM (Figure 8.2) may be seeking. The transformation tool may drag and drop data or information in a format used by GRM.

In another vein, the open source movement is catalyzing the diffusion of software tools that may make it easier for agents to access proprietary formats through standard application programming interfaces (API) that still preserve the proprietary nature of the system but through a “translational interface” or flat file type format exchanges data or information. If the data or information sought by the agent is secured and in need of authorization for release, agent systems are capable of exchanging proofs to provide such authorization and release the data. The mobility of agents raises important questions about data security and its implications for healthcare. It is well documented that agent-based models are more robust to ensure data security by virtue of the AI algorithms used in its construction. At present, generally, most software architecture, for example, of the type used in EMRS, depends on equation-based models that are inherently far less secure.

Taken together, agent-based architecture may soon become pervasive in emerging healthcare systems. Agent-based software may form part of the infrastructure

of the healthcare system of systems (HSOS). HSOS not only consists of the components illustrated in Figure 8.2 but extends to include mobile agents that (1) monitor the functional status of medical devices, (2) schedule human resources, (3) aid in the planning of meal services to match nutritional needs or restrictions of patients, (4) guide business functions to benefit from economies of scale, and (5) oversee financial records to monitor the fiscal health of the healthcare service. Other forms of conventional non-AI software (Morpheus, mash-up, SOA, ERP, web services) may coexist within the agent-based software infrastructure for routine transactions.

Agent-based “learning” systems may augment the depth and precision of data mining and pattern recognition (see Sections 8.3.1 and 8.5.1). Rule-based data mining and pattern recognition may be out-of-date soon after “new” rules are updated. The latter may be particularly relevant to healthcare tools, data structures, and analysis of parameters in diagnosis or early risk identification. Systems must continuously learn, adapt, or improve to extract and use the subtle changes that may be indicative of future disease potential or can differentiate between closely related types of anomalies. Some of these parameters may differ or be altered sometimes, albeit slightly, between populations [75]. In the context of the patient, that can impact the outcome, considerably, to prevent false positives or wrong treatment. Agent systems can continuously “learn” about changes and hence offer greater confidence in the outcome of agent-based GRM-integrated intelligent analytics (AGRMIA) compared to rule-based tools. Algorithms for relation analysis are emerging from research on social networking [76] and reality mining [77] that may be adapted for use in AGRMIA (see Section 8.5.1).

Application of pattern recognition, in one study, achieved perfect discrimination (100% sensitivity, 100% specificity) of patients with ovarian cancer, including early-stage disease [78]. The study identified subset of proteomic biomarkers using mass spectroscopy of proteomic analysis of serum from ovarian cancer patients and cancer-free individuals. Statistical algorithms analyzed the mass spectral data and selected, using random field theory, all biomarkers that were significantly different in expression levels between affected and unaffected subjects. The best discriminating pattern was chosen among all significant biomarkers by using the best-subset discriminant analysis method (Linear Discriminant Analysis). Another study along the same lines developed an algorithm employing principal component analysis followed by linear discriminant analysis on data from mass spectrometry and achieved sensitivity, specificity, and positive predictive values above 97% on three ovarian cancer and one prostate cancer dataset [79]. Detection of ovarian cancer using sensitive molecular biomarkers is especially urgent in women who have a high risk of ovarian cancer due to family or personal history of cancer and for women with a genetic predisposition to breast cancer due to abnormalities in genes such as BRCA1 and BRCA2 [80].

Application of remote monitoring (see next section) of body fluids using protein microarray chips [81] that can transmit data, advanced mathematical tools for biomarker data analysis, AI-based intelligent pattern recognition, and agent-based

GRM information flow (AGRMIA), if taken together, may hold promise for global healthcare. Tools, such as mass spectroscopy (MS), provide clues about molecular identities of differentially expressed proteins and peptides in body fluids or in breath [82] that may be critical for early diagnosis. Agent-based systems, operating through the GRM (Figure 8.2), can extract these types of data as well as information catalogues of biomarkers from other fields [83] and apply the knowledge to patient data, to identify risk and improve diagnosis. Hence, MS analysis of protein or peptide biomarkers [84] in body fluids using micro-fabricated miniaturized MS device [85] operating as a low-cost wireless sensor may offer a general population-based assessment of proteomic pattern technology, as a screening tool for early risk identification for several diseases, to complement lab-on-a-chip type sensors for early detection of cardiovascular diseases (CVD) [86] and carcinomas [87]. A proposed systems approach, by which mass spectroscopic data (protein and peptide biomarkers) may be compared between systems, will be explored in Section 8.4 on molecular semantics.

8.3.3 Data Acquired through Remote Monitoring and Wireless Sensor Network

The paradigm shift in Figure 8.2 illustrates that data acquisition and transmission, even if partially assisted by the use of medical devices for remote monitoring tools and information communication technologies, may reduce cost and free up time for medical professionals. In principle, few can argue about the value of this approach. In Section 8.3.2, references were made to potential for remote monitoring and sensors to improve healthcare services. In this section, I focus on one remote monitoring device. The basic strategy, from a medical device perspective, may be similar for the majority of vital measurements (data) carried out by the primary care GP or at the hospital. Security of transmitted data and unauthorized access is preventable using agents. To guarantee even more stringent data security, recent research on PUF or Physical Unclonable Functions [88] may generate unique “fingerprints” that can distinguish identical chips or IC from the same manufacturing batch, that are used in bio-sensors and other medical devices.

Remote sensing technologies are well developed [89], yet their application to noninvasive, wearable bio-instrumentation capable of wireless transmission of reliable data has only emerged in the past few years. One innovative device, the Ring Sensor (Figure 8.3), has emerged from the convergence of robust self-organizing wireless radio frequency (RF) transmission and an improved photoplethmographic (PPG) wearable sensor to monitor vital signs [90]. The Ring Sensor minimizes motion artifacts when measuring arterial blood volume waveforms and blood oxygen saturation, noninvasively and unobtrusively, from the wearer’s finger base. Figure 8.4 shows the results from Ring Sensor monitoring of heart rate (data transmitted through a wireless sensor network) and compares the results to conventional electrocardiogram and wired finger photoplethmograph. The latter is susceptible to motion artifacts.

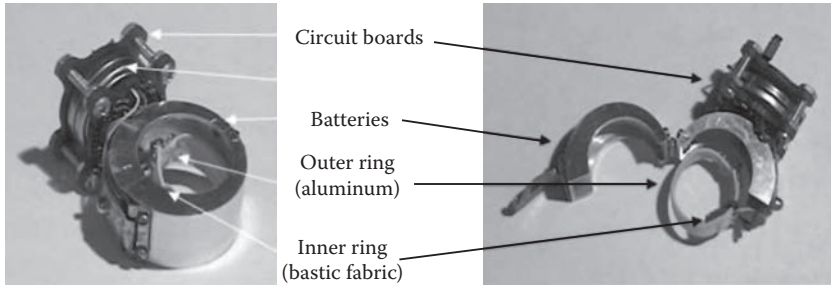


Figure 8.3 Noninvasive ring sensor for wireless monitoring of heart rate. (From Rhee, S. and Liu, S., *An ultra-low power, self-organizing wireless network and its applications to non-invasive biomedical instrumentation*, in *IEEE/Sarnoff Symposium on Advances in Wired and Wireless Communications*, West Trenton, NJ, March 13, 2002. © 2002 IEEE.)

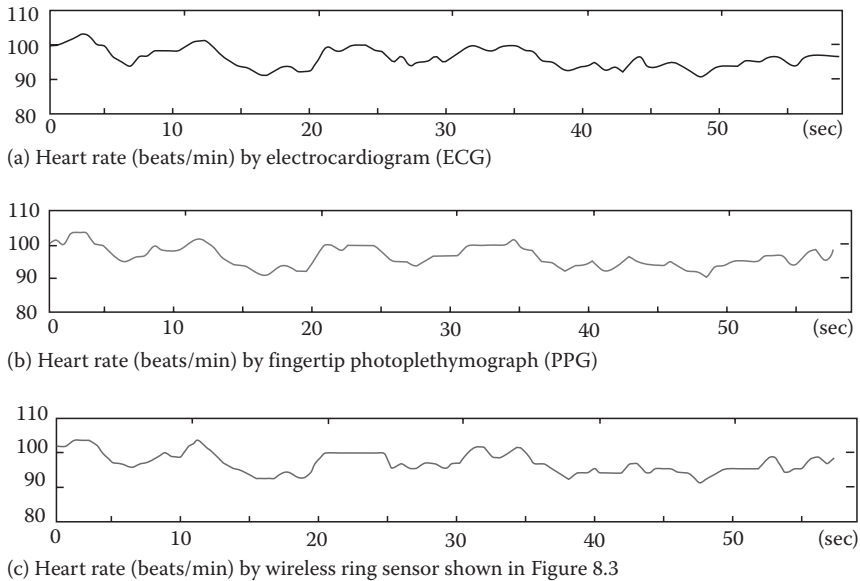


Figure 8.4 Heart rate monitoring by conventional, wired and wireless devices. (From Rhee, S. and Liu, S., *An ultra-low power, self-organizing wireless network and its applications to non-invasive biomedical instrumentation*, in *IEEE/Sarnoff Symposium on Advances in Wired and Wireless Communications*, West Trenton, NJ, March 13, 2002. © 2002 IEEE.)

It does not require any stretch of imagination to slip on the Ring Sensor (or a refined version of a similar device shown in Figure 8.3) on a patient's finger to monitor key vital signs, such as heart rate, continuously. Real-time streaming data under the "watchful eye" of a dedicated AI-based agent, embedded in the monitoring system or even in the Ring Sensor operating system (OS), monitor waveforms in real-time. It may be similar in principle to motes with TinyDB (database) and TinyOS [91]. If the Ring Sensor "senses" reasonable deviation of the PQRST wave in the context of the patient (rather than the PQRST standard in GRM or global reference model), then it immediately "responds" by sending an alert (code blue, code red) to the PDA or mobile phone of the medical professional on duty. Reference to context is important for patients with chronic CVD in order to prevent false alarms. Patients diagnosed with myocardial infarction or angina pectoris may display a PQRST waveform that may be different from the standard GRM version, but this altered PQRST waveform may be the "patient-specific normal" waveform. The data monitoring and analysis components of the system must be able to contextualize this difference.

This distinction in the analysis of monitored data highlights the need for caution to treat this suggestion as a medical device business bonanza. The challenge is to combine the sophistication of the waveform monitoring medical device (e.g., the Ring Sensor) with patient-specific context and history under the "supervision" of an agent (intelligent analytical tools). Agents may optimize the "sense, then respond" outcome, to be transmitted in a visual format comprehensible by a consultant cardiologist as well as a student nurse, to initiate the medical professional-driven response, decision, and treatment plan, if needed.

In practice, patients with cardiovascular problems are often required to wait. Intermittent monitoring of their vital signs is possible when the student nurse or trainee gets around to the patient. Physiological events that may happen in between the human resource-dependent monitoring may well determine the long-term morbidity (stroke victims) or mortality of the patient.

In the at-home scenario, Ring Sensor type applications offer greater value. Continuous monitoring is the key to preventative care, in this case, for people with chronic CVD or individuals at a high risk of CVD that may stem from other conditions, for example, increasing blood cholesterol or obstructive pulmonary diseases. Transmitted data from continuous real-time monitoring in the home, if subjected to real-time analysis (systems located in the community or primary care center or local hospital), are likely to (1) improve the quality of life for the patient; (2) reduce health service expenses by keeping the patient out of the hospital for longer periods; (3) optimize resource planning by creating a management plan and predicting when the patient may need to visit GP or outpatient clinic for non-acute follow-up or treatment; (4) reduce health service expenses and demand on service from A&E medical professionals by decreasing the probability for acute-care emergency services that may be required by the patient, more often, without remote monitoring provisions; (5) improve the overall quality of healthcare by extending

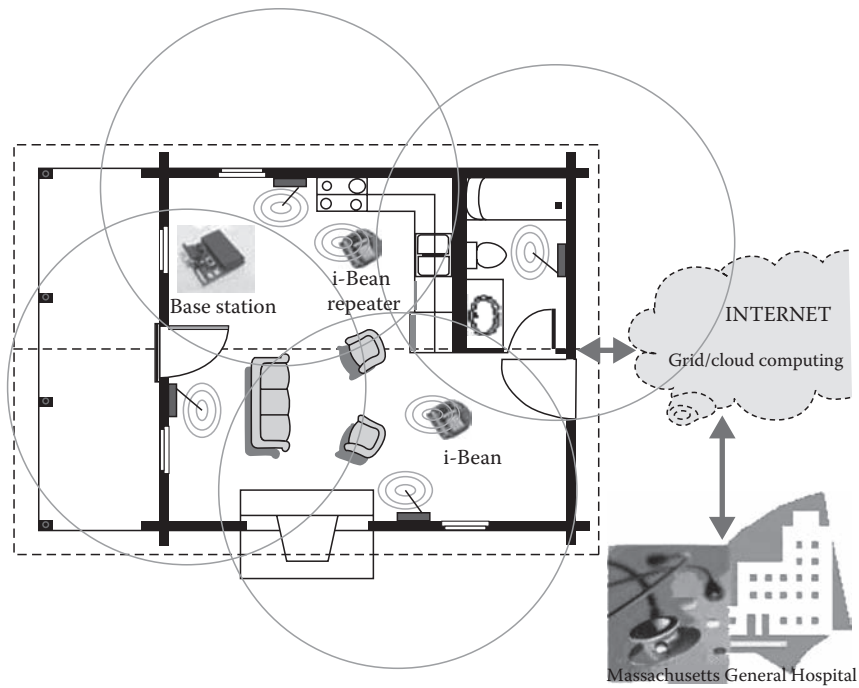


Figure 8.5 Wireless cardiac monitor uses plug-n-play i-Bean sensor network. (From Rhee, S. and Liu, S., *An ultra-low power, self-organizing wireless network and its applications to non-invasive biomedical instrumentation*, in *IEEE/Sarnoff Symposium on Advances in Wired and Wireless Communications*, West Trenton, NJ, March 13, 2002. © 2002 IEEE.)

remote monitoring not only for patients but the at-risk group, as well, by using the Ring Sensor with an ultralow power wireless device, the “i-Bean,” which is an ad hoc, self-organizing network protocol that is as simple as plugging in a wireless WiFi router in home or office (Figure 8.5) or any location that can connect to the medical analytical system through the Internet; and (6) expand the reach of healthcare services (without mortgaging the treasury) by extending low-cost remote monitoring to an otherwise healthy demographic who may volunteer to keep an eye on their cardiovascular wellness profile.

The benefits from remote monitoring are undoubtedly robust, but it is also necessary to remain cautious because, whether remote or on-site, wireless or wired, local or global, healthcare produces data that may be difficult to interpret, and lack of proper interpretation may be fatal. The role of the medical professional and human-driven decisions, even for apparently routine instances, such as blood pressure check, may, sometimes, cast a doubt if data or symptoms are too generic. Table 8.1 (in Section 8.3.4) illustrates this point by highlighting that monitoring blood pressure and recording an elevated, lower, or normal reading, in some

Table 8.1 Single Gene Diseases That Elevate or Lower Blood Pressure

<i>Disease</i>	<i>Mutation</i>	<i>Molecular Mechanism</i>	<i>Effect on Blood Pressure</i>
Glucocorticoid-remediable aldosteronism	Duplication of genes encoding aldosterone synthase and 11 β -hydroxylase, caused by an unequal crossover	Ectopic expression of a protein with aldosterone synthase activity regulated by corticotropin; increased plasma volume	Increased
Aldosterone synthase deficiency	Mutations in the gene encoding aldosterone synthase	Defective aldosterone synthase activity; decreased plasma volume	Decreased
21-Hydroxylase deficiency	Mutations in the gene encoding 21-hydroxylase	Absence of circulating aldosterone; decreased plasma volume	Decreased
Apparent mineralocorticoid excess	Mutation in the gene encoding 11 β -hydroxylase	Absence of circulating aldosterone; decreased plasma volume	Increased
Hypertension exacerbated by pregnancy	Mutation in the ligand-binding domain of the mineralocorticoid receptor	Activation of the mineralocorticoid receptor by steroids lacking 21-hydroxyl groups (probably due in part to the rise in progesterone levels during pregnancy)	Increased
Pseudo-hypoaldosteronism type I (autosomal dominant)	Loss-of-function mutations in mineralocorticoid receptor	Partial loss of function of the mineralocorticoid receptor, impairing salt reabsorption; improvement with age and a high-salt diet	Decreased

(continued)

Table 8.1 (continued) Single Gene Diseases That Elevate or Lower Blood Pressure

<i>Disease</i>	<i>Mutation</i>	<i>Molecular Mechanism</i>	<i>Effect on Blood Pressure</i>
Liddle's syndrome	Mutations in the ENaC β or γ subunit	Deletion of the C-terminal domain of ENaC, resulting in increased ENaC activity	Increased
Pseudo-hypoaldosteronism type I (autosomal recessive)	Loss-of-function mutations in ENaC subunits	Impairment of ENaC subunits, which is not ameliorated by activation of the mineralocorticoid receptor by aldosterone; no improvement with age; massive salt supplementation required	Decreased
Gitelman's syndrome	Loss-of-function mutations in the sodium–chloride cotransporter of the distal convoluted tubule	Salt wasting from the distal convoluted tubule, leading to activation of the renin–angiotensin system; subsequent activation of the mineralocorticoid receptor increases ENaC activity, preserving salt homeostasis	Normal or decreased
Barter's syndrome	Loss-of-function mutations in genes required for salt reabsorption in the thick ascending loop of Henle	Salt wasting in the thick ascending loop of Henle leads to activation of the renin–angiotensin system and the mineralocorticoid receptor, increased ENaC activity, and relative salt homeostasis	Normal or decreased

Source: Reprinted from Nabel, E.G., *New England Journal of Medicine*, 349, 60, 2003. With permission. © 2003 Massachusetts Medical Society. All Rights Reserved.

Note: ENaC denotes epithelial sodium channel.

cases, may not identify the reason or provide diagnosis based on that data, alone. Convergence of diagnostic tools is necessary to further any decision on such diagnosis. Current tools and tests may gradually undergo changes with the emergence of personalized healthcare, made possible by sequencing of the human genome [92] and development of genomics-based tools [93] (see Section 8.3.4).

The illustration in Figure 8.5 has yet another dimension that is particularly important in global healthcare, especially for emerging and developing economies where the number of and access to medical experts are limited. The goal is to support local data analysis either with information or connectivity that may enable access to experts, opinions, and resources. Various efforts to deliver information [94] through ICT [95] have been pioneered [96]. However, there is room for further advances with diffusion of broadband and other high-speed networks to the far corners of the world. It may transform the vision where a patient in a remote village clinic in Malawi may have access to an electrocardiograph (ECG) or low-cost Ring Sensor and can transmit that data through a standard network or innovative 3G system [97] that offers mobile phone service even from airplanes, during flight [98]. In the village in Malawi, a nurse practitioner may be the only medical professional in the clinic and may be unable to decipher the ECG and hence incapable of suggesting medication. It is here that the value of the transmitted ECG data becomes obvious. Through a consultancy network, on the other end of the world, a cardiologist [99] may review the data and diagnose cardiac arrhythmia due to repolarization abnormality (clinical effect) causing Long-QT syndrome [100].

This simple example and other types of analysis, which, in addition to connectivity, may also require computational power, for example, analysis of brain activity data from magnetoencephalography (MEG), may immensely benefit from grid computing [101]. Advances in microfabrication of atomic magnetometers could enable the development of precision magnetic resonance imaging (MRI) systems for self-monitoring, in any location [102].

The striking benefits that may emerge from the trinity of grid infrastructure, remote MRI monitoring, and intelligent or expert data analysis (AGRMIA) may be appreciated in view of the fact that mental health anomalies often display signs that may resist diagnosis due to lack of adequate expression of symptoms. Individuals may even fail to recognize that something is amiss because the rate of increment in the expression of some mental health conditions may be infinitesimal and over several years or decades. It may not be uncommon that individuals may even adapt to these changes as “age relevant” rather than differentiating them as potential symptoms of a disease and demanding medical exploration or treatment. Personal MRI devices coupled with microfabricated MS may create the remote ms-MRI personal monitoring device that could work as a noninvasive wearable wireless sensor that can be placed on the head to fit as a swimming cap. This development shall unleash a new horizon in “being digital” [103] in personalized medicine. In particular, remote monitoring using ms-MRI sensors may be instrumental for early detection of biochemical changes in the brain, either sporadic or due to aging.

The immeasurable value of ms-MRI remote sensors may be best illustrated by Alzheimer's disease. It is a condition where the activity of the choline acetyl transferase (CAT) enzyme, responsible for the synthesis of acetylcholine, shows a 60%–90% decrease [104]. Acetylcholine is a key neurotransmitter and a marker for cholinergic neurons. The ability of ms-MRI to detect and profile (using MS) biological and biochemical molecules is the driving technology to determine the shape and concentration of acetylcholine molecules and hence by extrapolation determine the activity of CAT. The biochemical identification of molecules (and in future identify differences in the structure or shape of the molecules) is critical in Alzheimer's disease and ms-MRI is one promising tool that is amenable to work as a wireless sensor for remote monitoring. The choice for ms-MRI over conventional MRI is based on the fact that conventional MRI only identifies physical structures. Recent developments in functional imaging using MRI have created the functional-MRI (fMRI) that can identify the rate of blood flow within a physical structure or area in the brain. Hence, fMRI may be useful to monitor learning disabilities where external stimuli may fail to activate certain regions of the brain, suggesting abnormalities. However, in Alzheimer's disease, the biochemical loss of enzyme activity of choline acetyl transferase occurs in the cerebral cortex, hippocampus, and related areas, but cell counts of the neocortex and hippocampus of patients with Alzheimer's disease did not reveal major reductions in numbers of cholinergic neurons when compared with age-matched controls. Thus, for the purpose of early detection, individuals developing Alzheimer's disease may appear "normal" by conventional MRI analysis since the physical structure of the potentially affected areas of the brain remains unchanged as far as the numbers of neurons are concerned. The formation of plaques in the brain of patients affected by Alzheimer's disease may be detected by MRI. Remote monitoring using ms-MRI wireless sensors may be also applicable to other conditions related to changes in neurotransmitter-related proteins and molecules in the brain, for example, Parkinson's disease, Huntington's disease, and some forms of dementia.

The adoption of these developments in personal remote monitoring of mental health coupled with the ability of individuals to obtain an expert opinion by transmitting the data as well as learn about the implication, of the changes recorded over time, may help determine a medical management plan that may improve the individual's quality of life. The analysis of data may require computational resources that may be unavailable in many locations, even in affluent nations. The ability of the transmitted data via the local network to access "medical grid"-based expert services offers immense benefits. The access to these resources through the network and medical grid services, even from the developing nations [105], can reshape the fabric of global mental health.

In addition to MRI, grid computing has the potential to add remarkable value to other forms of remote biomedical imaging systems as well as bio-telematics [106] since current operations [107] are limited to groups [108] that engage in stand-alone point-to-point systems [109] without the benefit of a platform to aggregate medical

grid type services. Bringing together this platform may be similar in effort to creating the GRM and is expected to be a part of the GRM (Figure 8.2) that may run on a grid infrastructure. Several biomedical imaging databases are in existence, and taken together, they may form a biomedical imaging platform (BIP) tethered to a proposed “bMDs” services infrastructure [110] through an accessible open format where images (data) may be uploaded from anywhere in the world and viewed (analyzed) by expert(s) who will share observations and/or deliver their interpretation or diagnosis directly to the patient or the healthcare service provider. Tools for simulation and visualization are important and significant advances [111] can be resourced. Agents embedded in the architecture may monitor, device to device (D2D), machine to machine (M2M), and device to system (D2S) or vice versa (S2D), medical data to ensure data security and privacy issues.

Progress in the AI vision of autonomic computing may gradually transform BIP, either independently or in combination with an AGRMIA type infrastructure. Inclusion of embedded intelligence may provide opinions or recommendations or diagnosis or referrals (exception management) without active human intervention. The latter should be welcome news to the aging population in Europe and Japan who wish to remain independent and live in their own homes rather than in long-term healthcare communities that can drain national healthcare resources. Nations may be prudent to explore ms-MRI type high technology medical practices and find new ways to think about diseases [112] with long-term impact and challenge the medical governance [113] to reduce cost by investing in and accelerating the convergence of medical knowledge and engineering technologies. The convergence proposed in bMDs shall include advances such as ms-MRI remote monitoring platforms and may be a part of future healthcare tapestry.

Thus, grid computing is an enabling technology for healthcare service connectivity in much the same way that grid can facilitate business services [114]. In healthcare, as in business, grid computing may provide access to on-demand computational resources (that are in a different location) for real-time data processing and analysis, through grid-based tools, such as Globus [115].

8.3.4 Innovation in Wireless Remote Monitoring and the Emergence of Nano-Butlers

Nano-butlers is a facetious term but is expected to convey an “image” to suggest that nano (small)-tools and technologies act as “small butlers” serving the demands of healthcare. (Their “fees” are also small; hence, they work for “micro” payments.) The “tongue-in-cheek” image is expected to create an awareness that the detection of biological molecules including proteins or peptides at nano levels may be critical for the identification of biomarkers that may be associated with the risk of a disease. When the investment to develop nano-detection is recovered (return on investment) from the savings from reduced acute-care responses, if may be, the actual cost of nano (small)-detection will be small enough to enable global diffusion of the

tools, which can be sustained by micro (small) payments, mimicking the concept of micro-finance that has gained global acclaim [116] for alleviating poverty in some parts of the developing world. This approach, due to the inclusion of the term “nano,” may also draw some unfounded attention [117].

Early risk identification, prior to detectable symptoms, offers the potential to develop a management plan to contain the disease or even stop it from presenting any symptoms. This approach reduces the acute-care response that may be necessary if the condition was not detected and left unattended. A&E responses and acute-care are far more expensive and often increase morbidity and mortality if the response fails to be administered in near real-time. For example, from the time of onset of a cardiac attack, there is only a 30 min window for successful administration of tissue plasminogen activator (TPA) to dissolve clot(s) if a patient with CVD or stroke is the victim of thrombosis (blood clot). It is likely that more than 30 min may elapse between recognizing that a person is having a “heart attack” and the arrival of A&E services at the location, assuming not only that the paramedics will correctly diagnose the reason (clot) but also that they will have an inventory of TPA-type drugs in their mobile unit (ambulance). It is also assumed that the person is coordinated and coherent enough to call to A&E services if the individual is alone in the location.

Prevention through preventative healthcare may require, in the above scenario, the convergence of wireless sensors with remote monitoring technologies and data-driven analytics based on biomedical research knowledge bases. Advances in understanding the basic physiological, biochemical, and molecular relationships (Figure 8.6) that contribute to heart disease [118] offer hope for rigorous early detection mechanisms. There is ample evidence both from basic biological sciences [119] and clinical research [120] that early warning signs of CVD are amenable to identification from research on biomarkers. Several biomarkers for CVD are already in the market [121], but the commercial “kit” approach is far from the innovative potential of next generation diagnostics [122].

Innovation in detection is based on the generally applicable principle that physiological systems respond to thresholds. In other words, few, if any, reactions occur in the human body or fetus without a critical mass or concentration of molecules. If allowed to reach the “threshold” only, then the “rogue” molecules may trigger a cascade of events, which may, eventually, over time, present itself as a detectable symptom. Hence, molecular identification of the biomarkers and rogue molecules is vital for noninvasive detection. Tools for detection require convergence of the knowledge from identification of molecules from biomedical research with engineering-based detection technologies to determine the number and concentration of the molecules, beginning at the single molecule [123] level or at the pico (10⁻¹²) level, but most reliably at the nano level. A medical management plan or treatment must exist to prevent the concentration of the molecules from reaching the threshold, where it may commence the cascade of events leading to a disease or symptom or precipitating a heart attack. In case of fetal diagnosis, the management issues may be complex, but the early detection of sporadic or genetic diseases of the

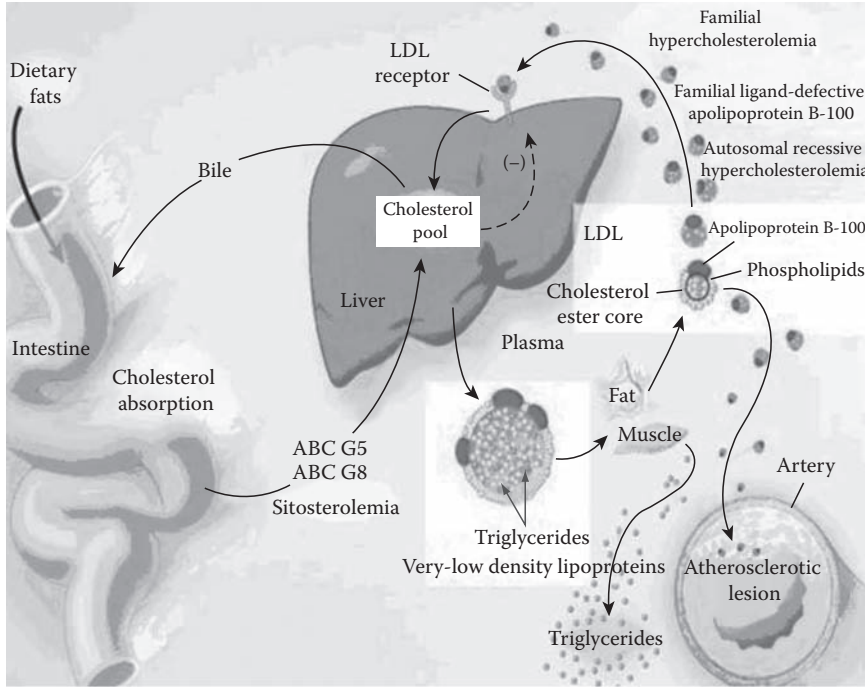


Figure 8.6 Components of cholesterol synthesis and excretion. (Reprinted from Nabel, E.G., *N. Engl. J. Med.*, 349, 60, 2003. With permission. © 2003 Massachusetts Medical Society. All Rights Reserved.)

unborn child may offer scope for medical intervention. Foolproof identification of specific biomarkers for multi-factorial diseases such as CVD is complex. Without reliable specificity, the next generation nano-diagnostic tools may offer less value. Therefore, the healthcare industry must remain vigilant to combine advances in one field with another through parallel investments both in medicine and engineering.

To illustrate, let me revisit the case of blood pressure (BP) measurement and what diagnostic information the BP data may provide if the BP is elevated, lower, or normal, compared to the standard reference. In short, the BP data, alone, provide little diagnostic value unless they are analyzed in conjunction with existing case history or other data. One reason for this is summarized in Table 8.1. If a definitive diagnosis of the BP data is sought, in some patients, it will be necessary to identify which particular gene is affected.

Sequencing of the human genome and advances in search tools and genomic technologies [124] makes it possible to extract the DNA sequence from the Human Genome Database [125] of the genes implicated in a disease (e.g., genes that may elevate or lower blood pressure). Based on the DNA sequence, anti-sense RNA may be used to determine gene expression profile. By extrapolation from the DNA

sequence, protein-based peptide fragments can be synthesized for use in noninvasive proteomics-based microarrays, using the lab-on-a-chip wireless sensor, to detect expression levels of one or more proteins and/or their mutant variations, in body fluids, that may be involved in the etiology of the condition under investigation. Based on the gene and protein expression profile, in some cases and some diseases, the promise of gene therapy may be realized by “silencing” harmful candidate genes using RNAi [126] and snRNA techniques that are already under intense commercial exploration and have reported some degree of success [127] for future therapeutic applications.

This scenario, starting with a possible gene, followed by expression profiling data remotely monitored by a wireless sensor and potential for selective silencing therapy of the disease, is a part of the evolution likely to chart the future of individualized medicine and personalized healthcare. The value and impact of this approach may not qualify as a “disruptive innovation” [128] but may reflect the systemic lessons from the age of introduction of the electric dynamo, at the turn of the twentieth century [129], the wisdom of which may have been ignored by other emerging technologies [130].

The pragmatic credibility of this vision garners support both from current practices, albeit in part, and information based on recent research that clearly points to the need for this vision. Current practices already use one or more of the steps outlined in this strategy, for example, the use of genomic [131] and proteomic biomarkers in the diagnosis of CVD [132] and some forms of cancer [133]. But even more important support for this vision draws on seminal medical research [134] that has identified one single human gene, for low-density lipoprotein (LDL) receptor-related protein 6 (LRP6), that is involved in the etiology of a specific type of CVD, referred to as coronary artery disease (CAD). It is a leading cause of death worldwide, and early detection is essential to save lives.

CAD is commonly caused by a constellation of risk factors called the Metabolic Syndrome, the symptoms of which include hyperlipidemia, hypertension, diabetes, and in addition, osteoporosis. Analysis of LRP6, the gene identified as responsible for CAD, has uncovered a single nucleotide substitution that changes the wild-type (normal) cytidine base to thymidine. This single nucleotide missense mutation, located in the protein-coding region (exon 9) of the human gene for LDL LRP6, causes a single amino acid substitution, which inserts the amino acid cysteine to replace the normal counterpart, arginine, at codon 611 (R611C). The importance of this finding and the fundamental significance of the LRP6 gene in human evolution are further highlighted by the extremely high degree of conservation of the protein sequence from humans to amphibians, such as frogs (*Xenopus laevis*). Among the species surveyed, the amino acid arginine (R) is conserved from frogs to humans (Table 8.2). Substitution of arginine with cysteine (R611C) creates havoc and results in CAD and accompanying diabetes, hyperlipidemia, hypertension, and osteoporosis.

Table 8.2 Conserved Amino Acid Arginine (R) Is Substituted in LRP6 Gene and Causes Heart Disease

Human	C	L	Y	R	P	Q	G	L	R	C	A	C	P	I	G	F	E	L
Chimp	C	L	Y	R	P	Q	G	L	R	C	A	C	P	I	G	F	E	L
Monkey	C	L	Y	R	P	Q	G	L	R	C	A	C	P	I	G	F	E	L
Mouse	C	L	Y	R	P	Q	G	L	R	C	A	C	P	I	G	F	E	L
Rat	C	L	Y	R	P	Q	G	L	R	C	A	C	P	I	G	F	E	L
Dog	C	L	Y	R	P	Q	G	L	R	C	A	C	P	I	G	F	E	L
Cow	C	L	Y	R	P	Q	G	L	R	C	A	C	P	I	G	F	E	L
Opposum	C	L	Y	F	P	Q	G	L	R	C	A	C	P	I	G	F	E	L
Chicken	C	L	Y	R	P	Q	G	L	R	C	A	C	P	I	G	L	E	L
Frog	C	L	Y	F	P	Q	G	P	R	C	A	C	P	I	G	L	E	L

Genomic technologies can help identify R611C mutation in at-risk populations even in the fetal state since this LRP6 is transmitted as an autosomal dominant trait. Lifelong management plan for inherited genetic diseases, for example, phenylketonuria, is common. Individuals homozygous for R611C, if diagnosed early, may follow a recommended lifestyle that may enable them to enjoy normal life expectancy. The evolutionary conservation of LRP6 gene and its protein product indicates a fundamental role of this protein in physiology. Indeed, LRP6 is involved in cellular signaling pathways, disruption of which leads to a plethora of problems. Proteins and other molecules, referred to as transcription factors [135], are often conserved and fundamental to gene expression [136] from bacteria to humans. Transcription factors can alter gene expression positively and negatively [137] or may serve as secondary or tertiary targets [138]. Early detection of nonfatal mutations in transcription factors is warranted because they may also cause profound physiological disturbances and present multiple symptoms, related in scope to mutation in LRP6.

While the case for early detection of genetic diseases needs little emphasis, the need for early detection of the bulk of sporadic cases such as type II diabetes mellitus and several other disease states deserves emphasis. Globalization has also created a need for remote monitoring. To make globalization work better for the world economy [139] it is imperative to contain infectious diseases by determining the risk and at-risk factors at the origin rather than at an immigration check-point of a country. The lightning spread of SARS, from its origin in Hong Kong to Toronto, in a few days, highlights the need for remote monitoring tools and the vulnerability of current healthcare system (in most nations) that is ill-equipped for global challenges and may actually aid an epidemic or pandemic.

Epidemics, however, are no longer limited to only infectious diseases. Type II diabetes may reach nearly epidemic proportions in many nations. It is alarming in some countries, where, despite a small population [140] a high number of sporadic cases of diabetes are documented. In addition, an equally high number of projected at-risk population are acknowledged, but the latter estimates exclude the segment of population projected to be defined as clinically obese. That can potentially increase the at-risk numbers for sporadic type II diabetes but remains unaccounted by the system. Individuals with other anomalies may also have diabetes, as pointed out in course of the discussion on LRP6 where heart disease and diabetes can occur simultaneously. Recent evidence suggests that in individuals without any genetic predisposition, there may be a direct effect of elevated cholesterol level on reducing insulin production by the β (beta) cells in the pancreas [141]. This increases the risk of diabetes for obese as well as for non-obese individuals who have elevated levels of cholesterol, without genetic predisposition.

Diagnosed diabetics often monitor their blood glucose levels using over the counter kits but its use in preventative healthcare remains dubious. For diabetics, the frequency of testing using kits is weekly or daily but expert interpretation and

advice may be far in between. Let us assume that a weekly outpatient visit to the clinic for blood glucose test and insulin therapy costs the healthcare service an average of \$25 in direct cost and costs the economy another \$25 in indirect costs, such as the cost of time spent by patient, cost of travel and decrease in productivity due to time taken off work by patient. If only 1% of the population require weekly attention (serious diabetics), then for a hypothetical nation with a population of 5 million, there will be 50,000 diabetics requiring this attention. For 50 visits a year at \$50 a visit, the attention to 50,000 diabetics for simple monitoring of blood glucose and administration of insulin, will cost the nation \$125 million per year. The focus on those who need it the most aggravates the unattended conditions in other diabetics and at-risk population, driving them to seek acute-care services or catapulting them to the \$50 category. However, a far greater concern is the need for inpatient services if some of the diabetic patients need hospitalization. Can the national healthcare system respond adequately [142] if only 1% of the 50,000 diabetics (that is, 1% of the 1% documented diabetics in the population) need hospital beds? For example, in Ireland, overall, there are 2.9 beds available per 1000 people [143].

Preventative remote monitoring can alter this vicious cycle of crisis, reduce cost, and improve actual care.

Apart from individuals who are obese or juvenile diabetics or those with history of genetic predisposition to early onset diabetes, the definition of “early stage” in monitoring is rather vague for sporadic diabetes. There is little scientific rationale either to include or to exclude young adults and individuals with dynamic vivacity in the prime of their life and in their 40s or even younger. Hence, effective monitoring of blood glucose that is not shunned by the otherwise healthy population may require a lifestyle approach that offers a product and service that are easy to use, of low risk, of low maintenance, socially acceptable, of robust value, safe, and medically effective. Since the adoption of this device may be voluntary, it may be less attractive if the monitor is a visible wearable [144] or a “thing” that an individual must “remember” to do. Thus, nanotechnology-based [145] monitoring tools may function as “always-on” wireless nano-sensors which remain under the epidermis. It may make blood glucose monitoring of general population an attractive *modus operandi* for early risk identification and prevention of diabetes as well as associated morbidity, such as diabetic glaucoma, which can lead to partial or complete blindness in severe diabetics or juvenile diabetics, if left untreated.

Early detection of diabetes as a function of monitoring blood glucose concentration benefits from a plethora of glucose sensors developed over the past 25 years, but challenges still exist. A key advantage in the development of a miniaturized or nanoscale device that can quickly and reliably monitor glucose *in vivo*, is based on the fact that the level of blood glucose detection does not require nano-level detection. The benefit of a nano-device or nano-sensor is to make the

monitoring tool virtually unobtrusive to the user. The normal clinical range for blood glucose is in the millimolar (mM) range between 3.5 and 6.1 mM, but abnormal glucose levels may reach 20 mM. This concentration range can be easily monitored using electrochemical reactions. What is critical for diabetes is a tool that does not deter early-stage frequent vigilance about the changes in blood glucose levels, also measured in milligrams per deciliter of blood. Alterations may signal the ability or inability to maintain the standard equilibrium concentration of glucose (120 mg/dL or 3.5–6.1 mM). For example, if the blood glucose concentration in an individual takes longer to return to normal after meals, then it may signal germinating problems with glucose clearance and/or tolerance in the individual.

The innovation required to develop a wireless blood glucose nano-sensor that is capable of subcutaneous monitoring of blood glucose and transmission of the data to a wireless node may be simple and at hand. The core components are a nano-sensor [146] capable of detecting blood glucose concentration in vivo and a nano-radio [147] that can transmit the data. The combination is illustrated in Figure 8.7.

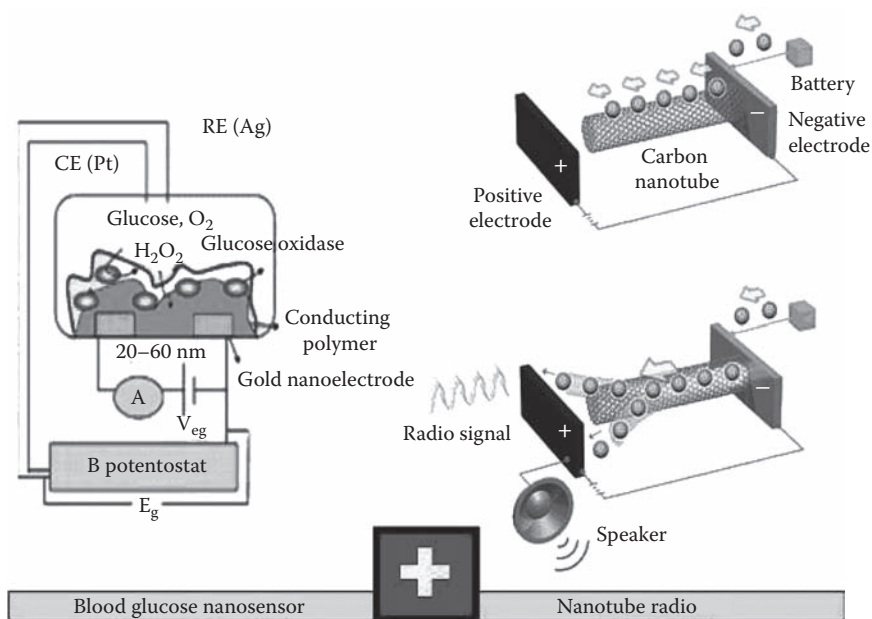


Figure 8.7 Blood glucose monitoring and wireless data transmission 24.7.365. (Adapted from Forzani, E.S. et al., *Nano Lett.*, 4, 1785, 2007; Jensen, K. et al., *Nano Lett.*, 7, 3508, 2007. With permission. © 2007 American Chemical Society.)

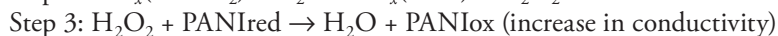
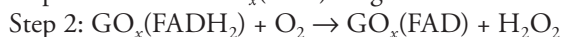
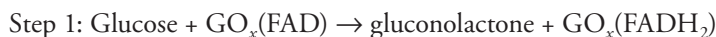
The open questions presented by this innovative potential may be divided into two broad categories: data acquisition and data transmission. The issues are as follows:

1. Glucose sensor data transmission by the nanotube radio illustrated in Figure 8.7 and other similar [148] devices is not proven because they are constructed as receivers, not data transmitters. But, in general, single-wall nanotubes (SWNT) are like single-mode fiber for electrons (Figure 8.7) and hence have data properties that were made to act as a receiver (Figure 8.7) for the nano-radio but may be altered to transmit the acquired data from the glucose sensor.
2. Functional co-fabrication or simply co-locating or “housing” glucose nano-sensor and data transmitter on a nonallergenic matrix or platform suitable for use as a subcutaneous implant.
3. Optimizing signal-to-noise ratio.
4. Interference minimized nano-communication link to wireless sensor node.
5. Physical locations for safe subcutaneous insertion per customer preference.
6. Procedure for safe extraction of sensor device with minimal discomfort.
7. Foolproof immobilization of implant.
8. Containment of degradation or breakage of components within the housing of the nano-device.
9. Customer’s ability to “forget” about sensor implant.
10. Customer control (agent-based web tool) over function of the device.
11. Customer control over data transmission or modulating the frequency of monitoring.
12. Low maintenance of sensor and transmitter.
13. Battery life of transmitter.
14. Explore use of electrolyte gradient of the body or energy from movement to power data transmission.

The responses to the open questions are beyond the scope of this chapter, but the different mechanisms of detection by sensors are important to review, briefly, because wireless nano-communication must be an integral part of the sensor or sensor combination in order to reliably transmit the data outside the body.

The glucose sensor in Figure 8.7 detects glucose based on principles of electro-chemistry. The assumption is that the sensor will perform *in vivo* as well as it has performed in body fluids tested *in vitro*. Specific detection of glucose is mediated by glucose oxidase, GO_x , an enzyme (hollow circles with pink borders, Figure 8.7) that is immobilized onto PANI-PAA, a conducting polymer (green area, Figure 8.7) made up of polyaniline (PANI) polymerized with PAA (poly{acrylic acid}). Upon exposure to glucose, GO_x , with the help of a natural coenzyme, flavin adenine dinucleotide (FAD), catalyzes the oxidation of glucose to gluconolactone and becomes reduced, $\{GO_x(FADH_2)\}$, Step 1. The reduced GO_x form, $\{GO_x(FADH_2)\}$,

is regenerated via reoxidation by oxygen (O_2) in solution to $GO_x(FAD)$ and produces hydrogen peroxide (H_2O_2), Step 2. Polyaniline, which exists in its reduced (red) state (PANIred), is oxidized (ox) by H_2O_2 to PANIox and triggers an increase in polyaniline conductivity (Step 3) due to the sensitive dependence of polyaniline conductivity on its redox state. This change of conductivity is data, indicating glucose detection.



Other types of construction use carbon nanotubes (CNT) but may still use the electrochemical principles for detection of glucose on a CNT scaffold (instead of PANI-PAA, as shown in Figure 8.7). Nano-wires [149] represent one such type of construction. Nano-wire-based glucose biosensors [150] use CNT nano-electrode ensembles (NEE) for selective detection of glucose based on the high electro-catalytic effect and fast electron-transfer rate of CNT but employ the same electrochemical mechanism described above. GO_x , glucose oxidase, is immobilized on CNT-NEE, instead of PANI-PAA, via carbodiimide chemistry by forming amide linkages between the amine (NH_2) residues and carboxylic acid ($COOH$) groups of the enzyme, GO_x , covalently linked to the exposed tips of single CNT, illustrated as perpendicular black bars in Figure 8.8 (center). Numbers of CNT on a CNT-NEE are in the millions, with each nano-electrode being less than 100 nm in diameter, thereby, increasing sensitivity of the sensor (by analogy, the speed of a processor, e.g., Intel Pentium, is a function of the number of microprocessor circuits etched on the chip). The catalytic reduction of hydrogen peroxide liberated from the enzymatic reaction of glucose oxidase covalently immobilized on the CNT-NEE, in the presence of glucose and oxygen, leads to the selective detection of glucose. CNT are excellent electrochemical transducers, and each CNT serves as a nano-electrode that detects the change in current (conductivity) when glucose reacts with GO_x -linked CNT (the coupling drives the specificity of glucose detection) in a CNT-NEE sensor. The sensor effectively performs a selective electrochemical analysis of glucose in the presence of interference from common molecules, for example, acetaminophen {AA}, uric acid {UA}, and ascorbic acid {AC}, shown in Figure 8.8 (top panel). But most important, the sensor is sensitive to increments of glucose. Detecting fluctuations in concentration of blood glucose is the key to early detection in diabetes (Figure 8.8, lower panel and inset).

It is relevant to note that nano-wire sensors that detect changes in chemical potential, accompanying a target or analyte binding event, such as DNA or RNA hybridization, peptide interactions, or oxidation reduction in electrochemical reactions, can act as a field effect gate upon the nano-wire, thereby changing its conductance. This is similar, in principle, to how a field-effect transistor (FET) works [151].

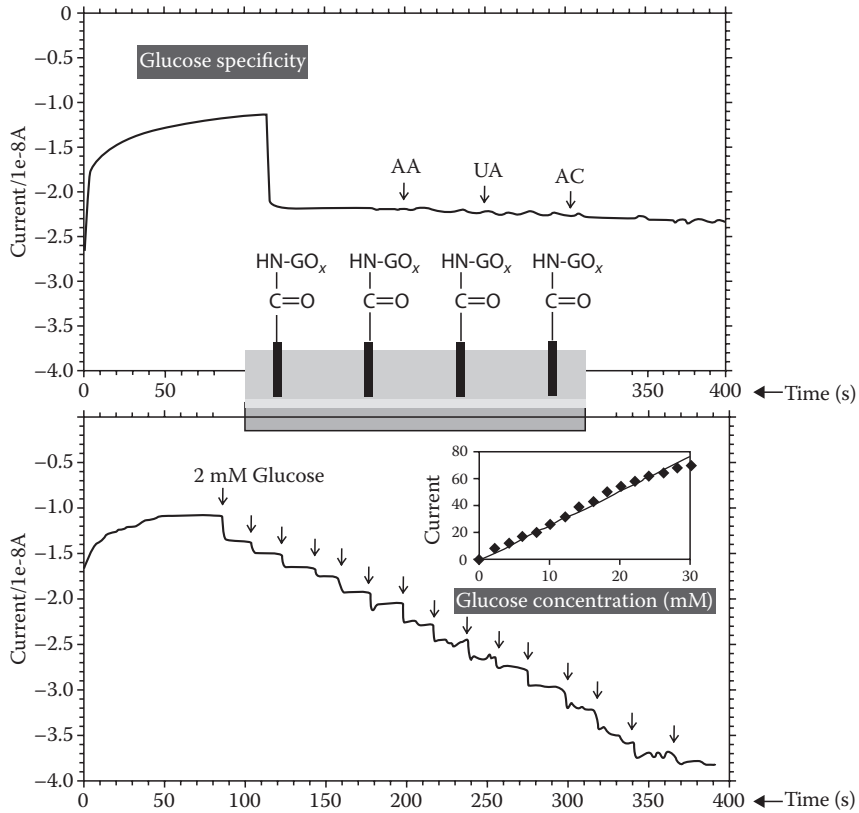


Figure 8.8 Nano-wire glucose sensor shows glucose specificity and sensitivity to concentration. (Adapted from Lin, Y. et al., *Nano Lett.*, 4, 191, 2004. With permission. © 2004 American Chemical Society.)

Today, FETs are low cost and in extensive use in environmental and agricultural monitoring. Advances in technology have made the expensive electronic marvel of a “transistor radio” of the 1950s only suitable for infant’s toys mass manufactured in China and sold in discount chains. The transistor radio has evolved to dirt cheap FETs now used in animal farms to alert owners that the stench from the ammonia-rich waste from animal excreta in the holding tanks needs attention. The expensive transistor of yesterday is a low-cost (or no cost) component today that delivers significant value for environmental monitoring. It benefits the meat industry at such a negligible cost that it has only increased productivity of the meat industry and concomitant increase in global consumption. The evidence for the latter is gleaned from the beef and chicken consumption data from the United States and EU that exceeded 120 kg per person per year (330 g/day) compared to 16 kg per person per year (44 g/day) in China and India, combined [152].

Knowledge from research and applications of FET are available from archives that may date back to the initial discovery of transistors [153], nearly 70 years ago. The development of nano-wire, nano-sensors, and nano-communication may benefit from the experience and wisdom of the FET pioneers.

The principle of FET indeed may be crucial for nano-communication for wireless transmission of data from the *in vivo* sensor to a sensor communication link or node outside the body that can connect to the Internet. The characteristic of a CNT to act as fiber that can transport electrons is under scrutiny in order to use the material for high-speed data transmission in a variety of ways that includes the emerging field of plasmonics [154] that studies interactions between light and nanoscale particles and structures. Remote monitoring *in vivo* that may take advantage of light-emitting luciferase [155] enzyme-linked sensors, by immobilizing luciferase (on PANI-PAA matrix or) preferably on CNT-NEE type scaffolds, may find it useful to exploit the potential of nanoscale antennae that converts light into broadband electrical signals capable of carrying approximately one million times more data than existing systems [156].

The illustration in Figure 8.7 is simple to understand and conveys the image of the components necessary to drive the convergence of *in vivo* detection and transmission of data. But, caution is necessary to extrapolate the application of the components illustrated in Figure 8.7. Although it may be ideal for visualizing the concept, the components illustrated are not proven or guaranteed to be the combination of choice that could drive the development of an *in vivo* nano-device that is equally reliable as a detection tool and a nano-communication tool, for reasons that I shall explain in the next few paragraphs. But of course that argument holds for any innovation. We shall not know the outcome unless we attempt to create the device if there is even “just enough” reason that the innovation may bear fruit. Reasonably, one issue in the glucose nano-junction sensor is that it does not use nano-materials, that is, in this case, CNT, in its construction. Nano-wire glucose biosensors use CNT as the nano-electrode, as shown in the CNT-NEE sensor illustrated in Figure 8.8 (center). This may be an issue in terms of the ability to transmit the data out of the body.


If the nanotube radio receiver illustrated in Figure 8.7 can be modified or designed as an *in vivo* transmitter and if it can successfully detect the data emerging as the change in conductivity between the two states of PANI (PANI reduced versus PANI oxidized, as shown in Step 3) from the non-CNT glucose nano-junction sensor illustrated in Figure 8.7, then the nano-device may be produced, by the combination illustrated in Figure 8.7, for wireless *in vivo* glucose monitoring.

The preference for CNT-based sensors like CNT-NEE (Figure 8.8, center) is linked to the central need to transmit the data from the *in vivo* sensor and the potential for using individual nanotubes within CNT networks to carry information. Innovation in nano-communication using CNT communication network [157] is likely to become a core competency necessary for the future of nano-device

use in healthcare, in general. It is in this context that the principle of field effect transistors (FET) springs back into action. Current technology utilizes an entire CNT network as semiconducting material to construct a single FET. Several FETs are required to build traditional or legacy network equipment. The result is that there are many nanoscale networks embedded within each device (FET) that might be otherwise more effectively utilized for communication. In other words, the CNT network itself is the communication media, and individual CNT are the links. But, individual CNT and tube junctions (forming nodes) do not have the equivalent processing capability of a traditional network link and network node. To compensate for this, the system needs to leverage large numbers of CNT. The illustration in Figure 8.8 (center) shows individual CNT linked to GO_x (black bars), but millions of CNT (black bars) make up an ensemble (CNT-NEE). The latter is precisely what is necessary for the single-wall CNT communication network (NanoCom) of the future. However, NanoCom may not function according to the traditional architecture of data communication layers [158]. Comparison of legacy communication and NanoCom highlights the changes necessary, as shown in Table 8.3.

At the bottom level (least sophisticated level), communication links may be between hosts and routers in a communication network, or they may be CNT overlapping at points that will be identified as nodes. A network functions by changing state. Data must either flow or be switched or routed through nodes. State may be implemented as a routing table on a router or an electromagnetic field controlling the resistance within a specific area of a CNT network. Finally, a mechanism needs to be in place to control state (ascending level of sophistication, Table 8.3), be it a routing algorithm or FET gate voltages applied to a CNT network. The traditional networking protocol stack is inverted in this approach because, rather than the network layer being logically positioned above the physical and link layers, as in the

Table 8.3 NanoCom Requires Modification of Current Networking Concepts

<i>Basic Network Components</i>	<i>Traditional Networking</i>	<i>Nanoscale Networking</i>	 Increase in conceptual sophistication
Protocol	Processors	Gate control	
State	Node memory	Semiconducting tube resistance	
Network	Links	Nanotubes	

Source: Bush, S.Y. and Li, Y., *Nano-Communications: A New Field? An Exploration into a Carbon Nanotube Communication Network*, Technical Information Series, GRC066, GE Global Research Center, Niskayuna, NY, 2006. © 2006 Inderscience.

standard OSI model [159], the CNT network and routing of information are an integral part of the physical layer.

Data transmission in a CNT network occurs via modulated current flow (changes in conductance) through the CNT network guided towards specific nano-destination addresses. The addresses identify spatially distinct areas of the CNT network that may be made up of nanosensor arrays. Since gate control is used to induce routes through the CNT network, nano-addresses are directly mapped to combinations of gates to be turned on that induce a path from a source to a destination. Is the “combination of gates” in any way analogous to the network, subnet, host type of partitions that specify a 32-bit IPv4 address of the type 151.193.204.72 or the 128-bit IPv6 format 21DA: 00D3: 0000: 2F3B: 02AA: 00FF: FE28: 9C5A (or equivalent 21DA: D3: 0: 2F3B: 2AA: FF: FE28: 9C5A with leading zero suppression)?

Does nano-addressing require an entirely new scheme for unique identification? Is unique identification necessary at the level of individual nano-addresses? If necessary, is a relativistic identification of information [160] necessary? Are “source” and “destination” comparable to client–server architecture?

These and several other open questions are likely to emerge. Figure 8.9 illustrates a conceptual network view of the CNT infrastructure. Superimposed on NanoCom are some of the medical benefits that make CNT-based sensors and data communication a powerful ally for healthcare improvements.

Diabetes is not the only disease that merits prevention and monitoring. For early detection and monitoring, several other diseases qualify prominently. Sensor

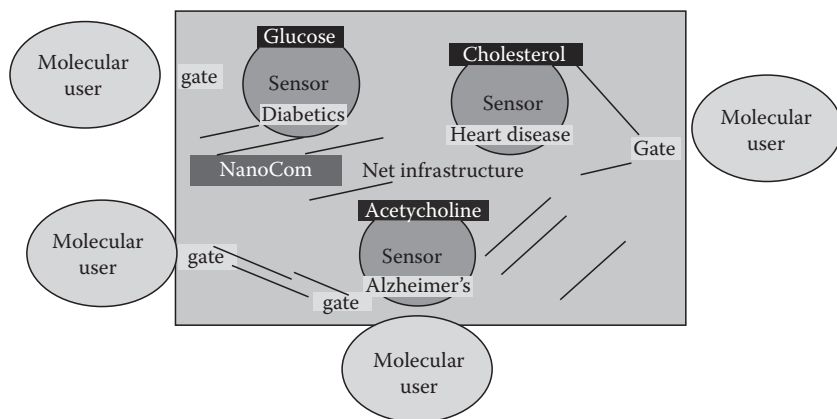


Figure 8.9 NanoCom transmits data for multiple biomarkers from in vivo sensor nano-array. (From Bush, S.Y. and Li, Y., *Nano-Communications: A New Field? An Exploration into a Carbon Nanotube Communication Network*, Technical Information Series, GRC066, GE Global Research Center, Niskayuna, NY, 2006. With permission. © 2006 Interscience.)

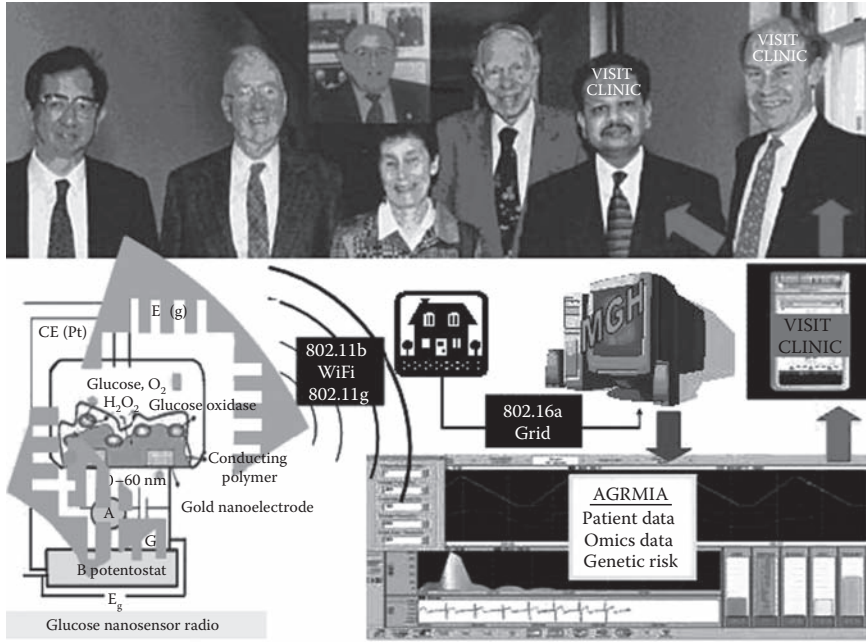


Figure 8.10 Improving healthcare from the home to the hospital: “sense, then respond.”

nano-arrays may be one answer for a multifunctional detector, as conceptualized in Figure 8.10. Sensors constructed from nanotubes change their resistance based on the amount and specificity of the material or biomarker detected (sensed). Thus, the act of sensing may change the routing through the NanoCom network. In other words, in a staggered approach, the duty cycle and/or the sleep time [161] of the different CNT nano-sensors can be regulated to allow any one sensor to function in a specified interval and detect or sense its specific analyte (glucose, cholesterol, or acetylcholine, Figure 8.9). The change in the properties of the CNT, when the act of sensing is in progress, opens the appropriate “gate,” and when a gate is turned on, the nanotubes within the gate area become conducting. Then, the data acquired for that specific sensor are transmitted to an external node. For complex diseases, where multiple pieces of data and vital signs may be necessary to make an informed decision, either by humans or initially by an AI-based intelligent analytical system (AGRMIA, Figure 8.2), properly choosing the sequence of sensor, hence gates, to turn on, changes the current flow to the edges of NanoCom, the CNT network. The latter effectively creates a controlled NanoCom, which may act as or provide weights in a neural network for AGRMIA type system requiring a collection of different biomarker data, to determine the relative impact or relationships or values of variables that may be co-integrated [162], which, if taken

together, may better reflect the state of the patient and the status of the disease. The Metabolic Syndrome caused by the mutation in the LRP6 gene may be an example of a multi-factorial disease where multiple conditions are affected and may require simultaneous monitoring.

Although this chapter, thus far, may have synthesized a number of promising practical ideas, far better and innovative ideas and concepts about products and services, than the ones mentioned here, have perished. Rarely acknowledged is the observation that no matter how good an idea may be, it may only shine in obscurity unless there is a strategic plan that charts an appropriate use and adoption path in context of other complementary technologies and social awareness of its value. A common example is the introduction of the first hand-held “Newton,” the personal digital assistant (PDA), from Apple that few may recall. Apple only sold 140,000 Newton PDAs at its peak in 1993–1994 and soon discontinued production. A few years later, 3Com introduced the Palm Pilot PDA with features that were even primitive to Apple’s Newton but with the option of Internet access. Today, it may be hard find anyone in the industrial world and professionals in the developing world who do not have a PDA, of some form or the other. The “social awareness” of the value of PDA accelerated with the penetration of the Internet. Newton, RIP, was slightly ahead of its time.

Calls to contain the unbridled cost of healthcare are demanding exploration of tools and technologies. The need for wireless remote monitoring and the use of nano-biosensors in healthcare are as vital as desalination projects, carbon sequestering, metabolic engineering, clean water, and clean air. Hence, innovative tools and technologies must also outline a strategic path for their integration and potential for adoption by healthcare systems without expecting a complete overhaul of the existing system, anytime soon.

The overall strategy for the use of wireless remote monitoring tools and the manner in which it may function in the landscape of healthcare cost reduction (Figure 8.2) is illustrated in Figure 8.10. The time saved by attending to the two individuals identified in Figure 8.10 instead of outpatient visits by seven individuals (Figure 8.10) saves cost of service and supplies and enables healthcare professionals to devote necessary time to those who need the attention, hence improving the quality (QoS) of healthcare.

The normal clinical concentration of glucose in blood is in the millimolar range, and that precludes the need for nano-level detection. However, early detection of other diseases may indeed be far more effective if detection is possible at the nano-level of proteins, peptides, molecules, or degraded macromolecules that may hold clues to problems in their embryonic stages. The task of medical research is to identify these markers, and the task of the technical experts is to find ways to identify these markers through remote sensing tools. Differential profiling of gene and protein expression between normal and disease states may be helpful to identify biomarkers that are only expressed in disease states. The amounts of such

disease-dependent biomarkers may benefit from pico or nano-level detection and offer “true” early detection.

Data and detection as components of the systems approach to future healthcare require medical science and engineering technology to create tools linked to systems that may be purchased, as ubiquitous generic plug-n-play commodities, from the local pharmacy or convenience store in a gas station or corner grocery store. Consider the revolutionary discovery of transistors that produced FETs. The field has been shaped by evolutionary market forces over the years, and FETs are now used as low-cost commodities in the design of environmental and agricultural monitoring. It is this trend that Figure 8.7 illustrates, in concept. The value they deliver through specificity and sensitivity is illustrated in Figure 8.8. The strategy for integration and adoption pathway is illustrated in Figure 8.10, which includes one of the key “behind the scene” drivers that may materialize as modular analytical engines of the AGRMIA type collection of resources, illustrated in Figure 8.2, connected on global grids. Taken together, remote monitoring by internal wireless nano-sensors or external sensors (as fashion rings, bracelets, wrist watches) will coevolve and diffuse as a lifestyle approach in healthcare, not because individuals are sick but because they prefer to stay healthy. The healthcare industry may benefit from business advice in order to take advantage of time compression. In other words, the time to market from idea (Figure 8.7) to adoption (Figure 8.10) may be shorter than the decades between the discovery of transistors and the use of FET as a dirt cheap commodity for agricultural and environmental monitoring.

This is the “writing on the wall” for what is in store for remote monitoring by wireless nano-sensors, the nano-butlers, that can deliver value at a reduced cost, for micro-payments, in local and global healthcare. Ignoring the suggestions in this and other reviews or the failure to accelerate the necessary convergence to create the suggested healthcare services as well as support research [163] may lead to chaos.

Healthcare imbalances will continue to proliferate in the United States, and severe consequences are also predicted for EU nations, particularly Ireland. Projected rise in age-related government spending as a share of GDP of Ireland, over the ext 40 years, is among the highest in the euro zone [164]. In the absence of reforms and adequate investments in Ireland, the advances in innovative convergence suggested here may be sluggish, at best. But, the cost of healthcare in Ireland, which is approaching €3000 per capita, may continue to increase (see Ref. [53]). Rising public debt in Ireland may force spending cuts with a concomitant decrease in the quality of life for those who need healthcare services. Cost containment in healthcare services may grossly reduce preventative measures, selective or elective procedures, palliative care, and all nonemergency services. Individualized medicine and personalized healthcare will be a matter of fiction, and A&E type acute-care services may be the healthcare skeleton. Enterprise, academia, and government can prevent this state of affairs.

8.4 Innovation Space: Molecular Semantics

The proposal of molecular semantics, whether right or wrong, does not impact the implementation of nano-butlers. Introducing the concept of molecular semantics as an independent paper may have been prudent, but the preliminary idea merits inclusion in this chapter to indicate the importance of structure in medical science. Current systems, such as EMRS and AGRMIA, may be, in general, incapable of dealing with structures unless dedicated programs are used.

8.4.1 *Molecular Semantics Is about Structure Recognition*

Classical semantics includes descriptive ontologies and extracting word relationships that form bulk of the thinking [165] prevalent presently to move from the syntactic to the semantic web. Molecular semantics may not be necessary for general usage but may aid special analytical applications in the future to uniquely identify molecular or chemical structures or units of structures or epitopes, in a manner that may have some similarity with the concept of digital semantics (see Ref. [40]). Unique identification of structures may enable diverse systems to compare structures in a catalogue or database with those that may be identified in some disease states, or query, if an identified structure has any known homologies or close similarities to one or more parts of chemical or biological molecules. The significance of partial structures and segments of structures or epitopes in healthcare diagnostics may be better appreciated from the discussion, later in this section, on autoimmune diseases and molecular mimicry [166].

To deliver value in healthcare, part of the solution calls for analytical tools to extract information from data. Healthcare presents three types of data that may need to work together, in some cases:

1. Numerical data in EMRS and AGRMIA platforms may be fed directly to the analytical engines.
2. Syntax from patient history and physician “notes” still on paper is likely to create syntax versus semantics nightmare if transcription is necessary to create EMRs. The syntactic web of today also plagues the business world. The semantic web movement and organic growth of ontological frameworks contributed by experts from various disciplines are continuing their valiant efforts to enable computer systems to “understand” and extract meaning from syntax. In this context, I have proposed a parallel approach to explore semantic and ontological frameworks using an IPv6 type unique identification scheme to enumerate data, information, and decision in a relativistic approach (see Ref. [40]).
3. Molecular patterns may be partially novel and especially relevant for healthcare diagnostics.

This section on molecular semantics is similar yet distinct from “digital semantics” proposed earlier (see Ref. [40]), but both share the concept of unique identification to enable global systems interoperability without ambiguity of identification or errors due to ambiguity in ontological frameworks that may be incomplete. Both proposals, however, are also likely to be incomplete.

The current proposal on molecular semantics addresses the third type of health-care-relevant data structure, that is, molecular patterns or molecular structures. Organic chemistry and biomedical sciences place a great deal of emphasis on patterns and structures. Hence, it may be worthwhile to dare to forward this new idea of how to enable computer systems to recognize patterns and structures through the use of agreed units of molecular structure that form parts of macromolecules. This proposal freely borrows ideas from seminal works of great scholars but with rudimentary understanding of their depth and without any guilt. In addition to a few building blocks of linguistic theory [167], I have also stretched the outlines of semantic theory and cognition [168], perhaps to an unnatural and unreasonable extent.

Cognition as related to structure in natural language is mapped to the units of molecular structure in biological macromolecules. I have extrapolated the ideas and elements of the linguistic system to fit molecular semantics in a way that proposes the use of molecular units of structures (of macromolecules, such as proteins) as “agreed lexicon” to catalyze recognition and understanding of these structures between diverse systems to aid systems interoperability. However, in my biased view, elements of the linguistic system (Figure 8.11) seem to resonate with the proposal of molecular semantics. But, I shall be the first to recognize that this convergence, however attractive, may not be right, in the form proposed, and admit that it may be in error, if it is.

There may be other ways, but the concept of molecular semantics may be yet another tool to explore this scenario: MS analysis of serum from a patient with unidentified type of fever has identified a high concentration of a short peptide with some ambiguity about its sequence, but it appears that the peptide may be part of a common protein, myelin. First, a GP may rarely send a serum sample for MS analysis. Second, if the MS data are uploaded and an AGRMIA type system is available, is there a tool to compare the MS signature from this patient (MSpat) with other MS data in a database? The data (MSpat) entry point in the linguistic system is the conceptual structure, the EMRS part of the EMRS-AGRMIA system, in this context. The computational resources that may be needed to perform the comparative search, one MS data at a time in the database, may make this approach untenable. If there is a catalogue of unusual MS signatures (MScat) in the form of a (data) dictionary, then, perhaps, it may be feasible to perform this search and determine if a match or close relationship exists between MSpat and a pattern in MScat.

In the linguistic system, the dictionary equivalent may be the Lexicon (Figure 8.11). Is it really necessary to bring the Lexicon into this discussion? The MS data

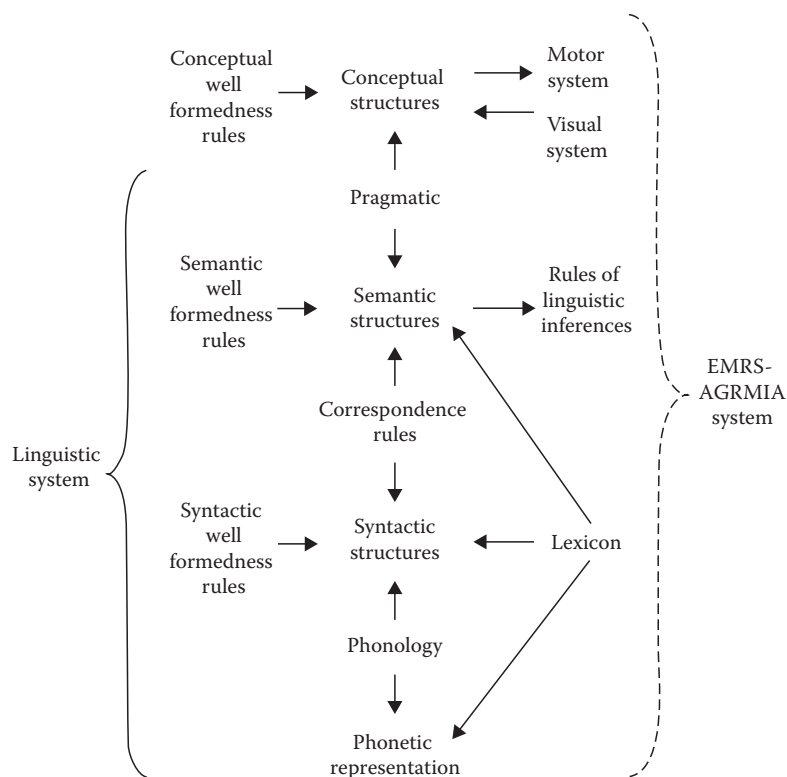


Figure 8.11 Proposed molecular semantics extrapolates concepts from the linguistic system.

and accompanying explanatory notes could also exist in a relational database, and it may suffice for this exploration. The introduction of the Lexicon in this scheme may seem, initially, on shaky grounds, but following the model of the linguistic system, it reasons that if the MS data catalogue (MScat) does exist in a Lexicon equivalent, it may also have links to syntactic structure and semantic structure (Figure 8.11). The wide variation in syntax needs no extra justification. Hence, the difficulty to match syntactic structures with respect to the Lexicon even if it contained a match to MSpat may not be unexpected. But the data (MSpat) could point to descriptions that may be more specific in the semantic structures. It may identify MSpat as belonging to neural proteins (myelin is a neural protein). Once the MSpat data matched to data from the Lexicon (MScat) points to neural proteins in the semantic structure, the correspondence rules could point back to the syntactic structures and identify one or more descriptions of neural proteins that may offer matching segments to MSpat. The real finding is however the match between MSpat and the potential link to myelin that may happen if an extensive MScat is matched by protein sequence and classified in the semantic structure. It is quite possible that

an equivalent set of rules may work in place of the Rules of linguistic inference to relate the MS data with MSpat and point out the class of neural proteins and the ontological relationship: myelin is a neural protein. The Lexicon (data) and Rules of linguistic inference (rules) may be working in concert to indicate the semantic structure, and another set of rules, Correspondence Rules, could point to syntax or descriptions in the syntactic structure that builds on the identified semantic structure. The extent of the classification, precision, granularity, and other factors of the semantic and syntactic structures could be determined by rules; the equivalent in the linguistic system are the Semantic and Syntactic Well Formedness Rules (SemWFR and SynWFR, Figure 8.11), respectively. The presentation of the data may find some far-fetched relatedness to the phonetic representation and phonology domains in EMRS-AGRMIA, when visualization of the data is important.

Thus far, I have not addressed molecular semantics but attempted to explore how the linguistic system seems may offer a parallel in data analysis. The latter is expected because linguistics and artificial intelligence share common elements such as cognition, semantics, and ontology. The idea of molecular semantics was camouflaged in the discussion because the data (MSpat) attempted to find a match to an existing equivalence relationship to a description of relevance of the structure. Molecular semantics indeed performed its task in trying to find a match between MSpat and MScat. The location of the MScat in the lexicon may not be an optimal explanation, and the lexicon may have a database equivalent where the incoming data through EMRS, equivalent to the visual system that feeds the conceptual structures in Figure 8.11, are formatted by certain rules (equivalent to the Pragmatics in Figure 8.11) and channeled to MScat that operates under the AGRMIA umbrella, which could be a database with MS data, linked to the Lexicon (dictionary).

Molecular semantics, the definition and identification of structures, may contribute to the ability of the system to compare MSpat to MScat profiles. Although MS analysis does not deliver an actual structure, the spectral data offer a pattern, and for this discussion, this pattern or profile is referred to as structure. This comparison can be performed today only by special applications.

Current semantic web efforts are striving to stimulate global groups to contribute descriptive ontologies for chemical and biological systems that may be accessible by the software tools and standards promoted by the semantic web experts. That effort may not include the potential for considering ontological frameworks for chemical and biological structures or data patterns. Tools such as MS, echocardiogram, and magnetoencephalography do not generate syntax and thus may be excluded from ontological frameworks. This deficiency in the current practice is addressed by this proposal on molecular semantics.

Conservation of the amino acid arginine in LRP6 protein product from frogs to humans may help make it less surprising to understand, following the logic of evolution, why viruses and bacteria may also share homologies with sections of human DNA or why viral proteins [169] and bacterial proteins [170] may have some homology to amino acid sequences found in normal and common human

proteins, such as myosin. This apparently benign observation often produces some disastrous medical consequences. Because small segments of proteins are involved, these segments or epitopes may have structures that may be distinct. Understanding the form (structure) is crucial to understanding the function in biological systems, hence the need for molecular structure in healthcare analysis, albeit only in special cases, and the potential importance of a mechanism that enables analysis of structure, that is, molecular semantics.

Disastrous medical consequences are observed due to the phenomenon commonly referred to as molecular mimicry. The situation is often caused by a foreign protein from a virus or bacteria that share a short stretch of amino acid sequence homology to a normal human protein. The immune system happens to target the foreign protein but for some reason specifically recognizes this homologous region that serves as the antigen. The body elicits an immune response and attacks the protein. Because this antigenic region (epitope) is also a part of a normal human protein, the antibodies produced by the body's immune system also recognize the epitope that is present on normal "self" proteins. Unfortunately, the immune system begins to destroy the self protein (autoimmune) with severe consequences for the patient. Because the short amino acid sequence of the foreign protein, as short as only six amino acids [171], may mimic the corresponding sequence of the normal self protein, the phenomenon is referred to as molecular mimicry.

This autoimmune response is partly to blame in some cases where an individual in almost perfect health suddenly drops dead from cardiac arrest or succumbs to a heart attack. The etiology may be linked to common Streptococcal infection (strep throat) that most children and adults experience at some stage or the other. Segments of some proteins from *Streptococcus* share homology to proteins specifically found in heart tissue [172]. Various other cases of molecular mimicry are well known including T-cell-mediated autoimmunity [173] and ankylosing spondylitis caused by only six amino acids (QTDRED) found in *Klebsiella pneumoniae* nitrogenase enzyme (protein) that exactly matches the human leukocyte antigen (HLA) receptor protein (HLA-B27) antigenic epitope [174].

Do these very short stretches of amino acids create antigenic epitopes with certain structures that may form a class of "super antigens" responsible for eliciting the human immune response that leads to autoimmune diseases? Using basic rules of protein structure and conformation, these epitopes may reveal structural patterns that may influence "function" in biological systems, such as eliciting an immune response. The structure of a short sequence of amino acids may be almost identical to another structure of a short sequence of amino acid, but the structural homology may not indicate that the two short stretches of amino acids share sequence homology. Computer systems of the syntactic web and of the semantic web may help in the data analysis that involves sequence (words, such as QTDRED) homologies or differences but may be incapable of dealing with structures that may be homologous whereas sequences are not. The likely analytical result of a system presented with QTDRED versus QTDREG may suggest, erroneously, that the structures are

different. However, if the system, in future, could use the tools of molecular semantics and refer to the Lexicon (Figure 8.11) of structures, it might reveal that the two stretches of six amino acids analyzed are different in sequence but produce identical structures. Because antigen–antibody binding is structure dependent as long as the side chains and groups are similar, it is possible that two slightly different amino acid sequences may result in nearly identical structures that can still elicit the same autoimmune response. A relevant scenario often occurs in organic chemistry where the empirical formula of a chemical or compound is same but the properties of the resonant structures may be different. The current semantic web may be impotent to address these structural issues. In combination with the power of the semantic web, there may be a need to address structural issues in healthcare diagnostics, hence the value of the proposal of molecular semantics.

Why did I choose molecular mimicry and autoimmune diseases to make the case for the value of the structural approach in the proposal of molecular semantics? The partial answer is based on the fact that almost an infinite number of allergens and antigenic epitopes can share short homologies to self proteins. By exploiting molecular mimicry, it can lead to autoimmune diseases. Healthcare, in general, and clinical immunologists, in particular, may wish to understand at a greater depth the form and function relationship in biological systems and autoimmunity. It cannot be done without structure and structural comparison, for reasons already elaborated above. Globalization now provides wide access to food from all around the world. This window on world cuisine has the potential to spawn new and undocumented forms of allergies to various ingredients and antigens foreign to the body. The potential to cause some forms of autoimmune reaction may manifest as inflammatory bowel disease [175] or the generic irritable bowel syndrome [176].

Globalization and mobility will usher new domains of healthcare and seek knowledge about many more issues to diagnose complex diseases, for example, autoimmunity caused by antigens in food products. Early detection of antigens, which can pose the threat of molecular mimicry, may be of great significance. Research is needed to determine how to identify candidates for molecular mimicry and what type of assays, *in vivo* or *in vitro*, can detect these short segments. Only time can tell whether the growing demand for detection and need for analysis in healthcare may trigger an exploration to “productize” molecular semantics. In some cases, structural analysis may be necessary or even pivotal to complement numerical data and syntactic/semantic information for use in EMRS-AGRMIA (Figure 8.2) type systems that must be globally interoperable and locally responsible.

Molecular semantics or ideas that may originate from linguistics [177] may evolve when more people, on both sides of the aisle, medicine and engineering, can better appreciate the value, however subtle, of form versus function in biology. This proposal in its current format may become irrelevant, but it may provide some clues or may even serve as The Golden Key [178] to unlock creativity and innovative patterns in the mind [179] of young people to drive convergence of syntax, traditional semantics, numerical data, and structure, to improve analysis and benefit healthcare.

8.5 Auxiliary Space

8.5.1 *Potential for Massive Growth of Service Industry in Healthcare*

Adoption of this data-driven model may increase the diffusion of a new class of service industry. The growth of health services may create new markets and trigger new business and revenue models (pay-per-use) even in sectors not directly involved in healthcare, but it offers products that may be used by health services, for example, (1) software vendors deploying cloud and grid computing platforms, (2) telecommunications companies billing for data transmitted in real-time, (3) data routing or IP connectivity architects to ensure privacy, data confidentiality, and address verification using Internet Protocol version 6 (IPv6) and other security tools, and (4) data mining outfits that may create intelligent differential decision engines (IDDE) running on grids, cloud computing environments, in-network processing, embedded browser applications, or a host of other platforms yet to be determined or discovered.

The pivotal role of data mining in healthcare data analytics is expected to evolve in ways that are yet to be defined. Data mining as applied to so-called “business intelligence” applications may play a role but may be inadequate to address the service part of healthcare because the “service” of healthcare is about an individual or patient-centric data. On the other hand, the healthcare industry may have distinctive needs, but, in general, it is about business and operational efficiencies. Data, information, and knowledge hold the potential to improve both healthcare service and the healthcare industry, but the tools and applications are expected to differ in their pursuit of different goals and functions. This is where the prevalent view of data mining is expected to diverge.

The tools of data mining were enriched with a sea of changes when principles associated with complexity theory and swarm intelligence [180] emerged to offer practical business solutions [181] for a wide variety of routing and scheduling needs. A similar wave (see Ref. [10]) is imminent under the generic banner of data mining tools that may stem from reality mining (see Ref. [77]) and its link with social networking relationships (see Ref. [76]). Principles extracted from reality mining and social networking paradigms may yield tools applicable to a variety of fields including business services and healthcare analytics.

Data mining in healthcare, service, and industry perspectives taken together also offers a fertile ground for exploring whether the convergence of economic principles, tools, and techniques in healthcare data analytics may lead to further innovation. The healthcare ecosystem offers the opportunity to test at least four different economic principles as analytical tools. For healthcare service, the focus is on patient data, and these data are generated by the physiological system. Since human physiology is highly integrated, it may follow, naturally, that the physiological variables (e.g., blood pressure, heart rate, pulse rate) are likely to be co-integrated

(see Ref. [163]). In other words, because physiological systems strive to maintain homeostasis, it follows that the goal of physiology is to attain equilibrium. When one variable is affected, for example, pulse rate, its effect is “integrated” or reflected or related to another linked variable, for example, blood pressure. Physiological balancing mechanisms within the human body will attempt to rectify this situation and may try to restore the blood pressure of the individual to 120/80 mm Hg, the normal reading. Due to the innate physiological drive to restore equilibrium, data analysis in healthcare service may benefit from a potential exploration and application of the principles of Nash Equilibrium [182] to predict from a set of patient data what other parameters (co-integrated) are likely to change or may be influenced by the change documented (data at hand). It may provide clues to improve diagnosis.

Data mining tools for the healthcare industry may benefit from some traditional approaches coupled with a few emerging concepts. Like most businesses, healthcare industry suffers from systemic gaps of data and information in its complex supply chain. Consequently, the healthcare industry is prone to information asymmetry [183] and expected to benefit if information asymmetry could be reduced through appropriate acquisition of data including real-time data, for example, from RFID. Availability of high volume data from deployment of automatic identification technologies (see Ref. [131]) may help improve forecasting to better manage human resources and inventory planning in the healthcare industry. High volume data may be instrumental in improving the accuracy of forecasting using time-series data in combination with a host of forecasting tools including the econometric technique of generalized autoregressive conditional heteroskedasticity (see Ref. [46]).

Contrary to public opinion in business consulting, except in specifically designed business collaborations, the application of Nash equilibrium in business (see Ref. [65]) may be conceptually flawed. It is less useful for business decisions but better suited to healthcare analytics for healthcare service. In contrast, the concept of information asymmetry is foreign to human physiology but is almost a second nature to the competitive dynamics of business, which makes it useful as an analytical tool in the healthcare industry.

The global growth of the health services industry through the model illustrated in Figure 8.5 will dwarf the current revenues of \$748 billion [184] from business services. The three major global giants that currently offer business services (IBM, HP, Microsoft), taken together, command less than 10% of the \$748 billion in revenues. Therefore, by extrapolation, it seems reasonable to suggest that small companies, start-ups, and small and medium enterprises (SME) shall find the barrier to entry in the healthcare service industry to be low or nil. The healthcare service industry will be driven by innovation, which is best executed by small “skunk” works of talented individuals. Due to multiple convergences necessary to produce a complete product and/or health service, core competencies will be a driving factor. The latter may stimulate the need for collaboration and partnerships between a number of small or medium enterprises with local and global research institutions and medical facilities. Each group or alliance or SME may contribute its own

specific module or component but may find it essential to cooperate with multi-talented team made up of scientists, other companies, medical personnel, patient advocates, and strategists to act as an interface to catalyze implementation.

Stringent requirement for a higher level world-class advising and supervision to guarantee credibility of the process, products, and health services is necessary and essential. The noncommercial ad hoc supervisory team may begin their involvement from the conceptualization stage and continue through the cycle of planning, research, product development, service creation, testing, and implementation. Critical evaluation by a team of academic and commercial experts [185] may help define performance indicators (KPI) and determine the strength of this emerging vision of healthcare by exploring (1) quality of care improvements, (2) impact on human resources in terms of time savings for medical professional, (3) reduction in cost and potential for savings, (4) length of time required for return on investment, (5) profitability of businesses (SME) and growth of high potential start-ups, (6) economic benefits for the nation's healthcare system, (7) reproducibility, portability, and sustainability of the services model as a global template, (8) business opportunities to implement similar services in other communities or nations, (9) creating market alliances in emerging economies to implement healthcare services, and (10) liaison with global organizations (World Health Organization, United Nations Development Fund, World Bank, Asian Development Bank, Bill & Melinda Gates Foundation) to help in the global diffusion and adoption of health services industry model.

8.5.2 *Back to Basics Approach Is Key to Stimulate Convergence*

The discussion in this chapter, in general, has continuously oscillated between medicine, engineering, and information technology in an attempt to emphasize convergence and suggest fruitful analogies between the fields. This chapter is about data, analytics, and tools from research that may improve healthcare. Hence, the preceding sections seek to harvest advances in systems engineering and information communication technologies (ICT) as well as translational medicine to improve healthcare through multidisciplinary confluence. Therefore, I shall be ethically remiss if I do not digress and fail to highlight in this section why the need for convergence is accepted but in reality organizations are sluggish to address the challenges in the clinical enterprise [186]. The problem has deeper implications, and unless reformed, the ramifications are bound to be increasingly disappointing.

In its simplest form, implementing convergence is often inhibited by the general biomedical illiteracy of technical experts and technical illiteracy of biomedical experts. Insightful degree programs in biological engineering [187] and health science technology [188] are key mechanisms to create the supply chain of talented individuals who have understanding of one field and depth in another, to

act as a knowledge bridge, which is key for the progress of convergence. The U.S. physician-scientist programs [189] that produce graduates with a PhD and MD are equally valuable and other countries are beginning to implement related strategies [190]. However, these programs only attract the *crème de la crème* of the nation, and in some countries the total number of these highly qualified individuals fails to reach a critical mass. Consequently, the few who succeed often move to other parts of the world where a critical mass of talent exists and where their multiple skills are valued, duly rewarded, and challenged to guide the nation or global groups.

What is sorely needed and missing in most countries is the focus on training programs for “middle level” workforce executing the bulk of the work yet remain firmly sequestered in one job or domain without the scope or the desire to become multifunctional. Programs with financial incentives, paid leave of absence, structured academic training, and practical internships are necessary to provide technical education for medical experts [191] and other healthcare professionals (consultants, GPs, nurses, physiotherapists, home-helpers, mental health workers) to understand (not necessarily gain expertise) the fundamentals of medical device engineering, sensors, remote monitoring, communication technologies, transmission protocols such as TCP/IP, software architecture, statistics, principles of artificial intelligence, basic principles of logic, and programming. Similarly, experts in engineering and technology should be offered the attractive opportunity to gain understanding of human physiology, pathology, pharmacology, anatomy, cellular and molecular biology, neurology and mental health, genetics, principles of internal medicine, nuclear medicine, medical imaging, biomedical data, inpatient and outpatient management in hospitals, hierarchy of decision-making, nutrition, social, and environmental factors in health, laboratory data reporting, and epidemiology. Cross-pollination of ideas is a key to innovation.

Implementing these parallel training programs may not pose an insurmountable barrier in most countries even if their vision of the future and commitment to financially invest in its people is modest, at best. What is likely to surface is the difficulty of attracting sustainable number of cohorts to the programs. The problem to attract mature mid-level working class for retraining or lifelong learning, at the tertiary level, is partially rooted in the primary and secondary education of the nation. The emphasis or lack thereof on mathematics and science education either due to (1) archaic policies, (2) compromised rigor to feign inclusion, (3) misguided teacher education programs that chooses process and dilutes content to serve the lowest common denominator, (4) emphasis on test preparatory teaching without room for problem-based learning, (5) inability to stimulate increasing number of female students to take up advanced mathematics and science or catalyze young women to pursue career paths in the hard sciences, or (6) shoddy and second grade teacher qualifications (especially in mathematics and science) masquerading as good enough [192].

In the United States, a seminal report [193] revealed that 51% of mathematics teachers in the U.S. public K-12 (primary and secondary) schools never took

mathematics as a part of their college curriculum. A third of the “education-school-certified” science teachers never took science as a major in college. A national survey [194] of high school physics found that 25% of students took “some” physics in high school and 1.2% of senior students (33,000 out of 2.8 million) enrolled in advanced physics. About 18% of certified teachers teaching high (secondary) school physics had degrees in physics while 11% certified teachers had “degree in physics education but not physics,” and 27% certified teachers teaching physics had neither a degree nor any relevant experience in the subject.

In the Third International Mathematics and Science Study (TIMSS), the United States ranked 28th in mathematics and 17th in science, lower than countries like Slovakia, Slovenia, Bulgaria, not to mention nations in Asia [195]. In 1998, U.S. high school students outperformed only two (Cyprus, S. Africa) of the participating countries. In addition, the TIMSS classroom study revealed 90% of U.S. middle school mathematics lessons are of low quality compared to Japan (10% low) and Germany (30% low). The quality of mathematics teaching was reflected in the poor performance of U.S. eighth graders (middle school) reported in the 1999 TIMSS analysis.

The declining effectiveness of mathematics and science education is reflected in the fact that U.S. colleges and universities awarded 24,405 bachelor degrees in computer science in 1996, 50% less than 1986 (30,963 in 1989), and engineering graduates dropped from 66,947 in 1989 to 63,066 in 1996 [196].

Despite these disappointing trends, the United States is still regarded as the “cradle of innovation” by global experts and organizations [197]. The enigma clears if one considers the actual number of qualified graduates: in thousands. It generates a critical mass of talent to innovate and contribute to economic growth. Each qualified individual contributes several magnitudes more than the average per capita contribution to the U.S. gross domestic product (GDP). As an example, by 1997, graduates of one U.S. institution, alone, had founded 4000 companies employing over 1.1 million people with annual sales close to \$250 billion [198]. A recent analysis of the same institution indicates that innovation and inventions of this one institution, annually, create new companies that add 150,000 jobs and \$20 billion in revenue to the U.S. economy, each year [199]. By extrapolation, this institution alone, therefore, thus far, has created companies that may directly employ over 2.5 million people and generate about half a trillion dollars in annual revenue. The dedication to research-based entrepreneurial spirit coupled with the freedom of some U.S. institutions to think out of the box as well as the strength of the U.S. investors to assume substantial risks are factors that continue to ignite innovation and profit even though investments, both academic and financial, are not immune from failure.

Attempts by other industrialized nations, with far smaller population, to partially mimic the U.S. strategy have produced mixed results. The striking visibility of the global success of the graduates and faculty from U.S. research institutions in creating innovative companies, products, and services is buoyed by investors willing to assume great risks. In addition to the favorable financial environment, the

numbers or critical mass necessary for innovation is a major determinant to spawn success, and it may not be available for countries with limited population. Equally, a public basic education system that lacks emphasis on rigorous mathematics and science education at the primary and secondary level reduces the supply chain of talent for the future MD or PhD pool. It may be one reason why mature mid-level professionals in one field prefer to cast a “blind eye” to convergence and stay in their comfort zone rather than acknowledge and take measures to improve their basic skills in mathematics and/or science. The latter prevents them from exploring training options to acquire new dimensions or pursue lifelong learning, as is necessary to create the type of multidisciplinary convergences important for healthcare and help build a knowledge economy.

8.6 Temporary Conclusion: Abundance of Data Yet Starved for Knowledge?

Patients want answers, not numbers. Evidence-based medicine must have numbers to generate answers. Therefore, analysis of numbers to provide answers is the Holy Grail of healthcare professionals and its future systems. Lack of action due to paralysis from analysis of risk associated with the complexities [200] in healthcare is no longer acceptable in view of spiraling costs. Generating data without improving the quality of healthcare service and extracting its value for business benefits [201] will not provide the return on investment (ROI). Distributed data and their relationships are dispersed in multiple network of systems or system of systems (SOS). The role of data analysis is central. The comatose stage of the Information Age due to data overload and information overdose is predicting its demise unless new ideas [202] emerge as its savior. The imminent death of the information age makes it imperative to better understand the systems age. The single most important system that deserves our attention in the twenty-first century is the healthcare ecosystem. The convergence of characteristics such as enterprise, innovation, research, and entrepreneurship (EIRE), often common in organizations with foresight in parallel with the vision to drive convergence of biomedical sciences, engineering, and information communication technologies, may act as the purveyor to advance healthcare for the progress of civilization [203].

Acknowledgment

Nothing in this chapter was invented by me. It is only original as a document because I have re-created ideas by borrowing from others. I am the combined effort of people who have inspired me. Hence, this chapter owes part of its origin to Bernard Lown, friend, cardiologist, and peace activist. The wisdom of Clive Granger, mathematician and economist, and the spirit of Glenn Seaborg, scientist and statesman, were

omnipresent, too. That I exist today is due to my wife, Rebecca Jane Austin Datta, chemist and educator, who forcibly took me to the hospital in May 2008, when we were in Europe. She “sensed” something was wrong. The majority of the content of this chapter was drafted while convalescing in the Anagh Ward of Kerry General Hospital in Tralee, Ireland, following an emergency cancer surgery on May 8, 2008, a few hours after arriving at the hospital, in a remote Irish hamlet. This chapter is dedicated to the exceptionally skilled surgeons Kevin Murray and Haris Shaikh as well as the nurses, aides, and staff of the surgical and the palliative care unit of the hospital in Ireland. The professional treatment and compassion of the Kerry General Hospital team during my recovery and subsequent chemotherapy is a shining example of the “art of healing” and the true ethos of global health care.

References

1. Robinson, M. (2008). Health as a human right. *European Journal of Dental Education* 12 (suppl 1): 9–10.
2. Olsen, L.A., Aisner, D., and McGinnis, J.M. (2008). *Engineering a Learning Healthcare System: A Look at the Future*. Institute of Medicine, National Academy of Sciences and National Academy of Engineering, Washington, DC.
3. Emery, F.E., ed. (1976). *Systems Thinking*. Penguin, London, UK.
4. Senge, P.M. (1990). *The Fifth Discipline: Art and Science of the Learning Organization*. Doubleday, New York.
5. Townes, C.H. (1999). *How the Laser Happened: Adventures of a Scientist*. Oxford University Press, New York.
6. Kanigel, R. (1991). *The Man Who Knew Infinity*. Charles Scribner's Sons, New York.
7. Lewis, S. (1925). *Martin Arrowsmith*. Jonathan Cape Ltd, London, UK.
8. Sarma, S. and Brock, D. (2000). *The Networked Physical World*. White Paper. Auto-ID Center, MIT, Cambridge, MA.
9. Krugman, P. (1994). *Peddling Prosperity*. W. W. Norton & Company, New York.
10. Finin, T., Joshi, A., Kolari, P., Java, A., Kale, A., and Karandikar, A. (2008). The information ecology of social media and online communities. *Artificial Intelligence Magazine* 28: 1–12, http://ebiquity.umbc.edu/_file_directory_/papers/376.pdf
11. Gates, B., Myhrvold, N., and Rinearson, P. (1995). *The Road Ahead*. Penguin, New York.
12. Friedman, T.L. (2000). *The Lexus and the Olive Tree*. Anchor Books, New York.
13. Kambil, A. and van Heck, E. (2002). *Making Markets*. Harvard Business School Press, Boston, MA.
14. Rubin, R.E. and Weisberg, J. (2003). *In An Uncertain World: Tough Choices from Wall Street to Washington*. Random House, New York.
15. Fallows, J. (1994). *Looking at the Sun: The Rise of the New East Asian Economic and Political System*. Pantheon Books, New York.
16. Harris, J. (2005). Home improvement: Changing government business processes for good with the help of technology. *Government Finance Review*, April 2005.
17. Joshi, Y.V. (2000). Information visibility and its effect on supply chain dynamics. MS thesis, MIT, Cambridge, MA, <http://www.autoidlabs.org/single-view/dir/article/6/101/page.html>

18. Boot, M. (2005). The struggle to transform the military. *Foreign Affairs* 84: 106.
19. Ranadive, V. (1999). *The Power of Now: How Winning Companies Sense and Respond to Change Using Real-Time Technology*. McGraw-Hill, New York.
20. Finkenzeller, K. (1999). *RFID Handbook: Radio Frequency Identification Fundamentals and Applications*. John Wiley & Sons, Hoboken, NJ.
21. Heinrich, C. and Betts, B. (2003). *Adapt or Die: Transforming Your Supply Chain into an Adaptive Business Network*. John Wiley & Sons, Hoboken, NJ.
22. Cole, P.H. and Engels, D.W. (2005). *21st Century Supply Chain Technology*. White Paper. Auto ID Labs, MIT, Cambridge, MA, <http://www.autoidlabs.org/uploads/media/AUTOIDLABS-WP-SWNET-015.pdf>
23. Fine, C.H. (1998). *Clockspeed: Winning Industry Control in the Age of Temporary Advantage*. Basic Books, Cambridge, MA.
24. Caprio, D. (2003). *RFID Myths and Urban Legends*. White Paper. Information Technology Association of America, Arlington, VA, http://www.itaa.org/upload/RFID/RFID_Myths_Legends.pdf
25. Berwick, D. (2006). How to fix the system. *TIME Magazine*, April 24, www.time.com/time/magazine/article/0,9171,1186717,00.html
26. Reich, R.B. (2001) *The Future of Success*. Alfred A. Knopf, NY.
27. Guyton, A.C. (1991). *Textbook of Medical Physiology*. W. B. Saunders & Company, Philadelphia, PA.
28. Lehninger, A.E. (1993). *Principles of Biochemistry*. W.H. Freeman & Company, New York.
29. Means, C. (2007). Rise in patient-centric care to affect healthcare. *Healthcare IT News*, February 23, <http://healthcareitnews.eu/content/view/148/40/>
30. Porter, M.E. (2006). Value-based competition in health care: Issues for Singapore. November 28, http://www.isc.hbs.edu/pdf/20061128_Singapore_Health_Care.pdf
31. Schletzbaum, A. (2007). King County healthcare system emergency response planning, http://nvac.pnl.gov/meeting_spring07/presentations/Schletzbaum_Healthcare_Coalition.ppt
32. Deloitte Consulting. (2005). *The Future of Healthcare: An Outlook from the Perspective of Hospital CEOs*. Deloitte Consulting Research Division, Boston, MA.
33. The Open University, www.open.ac.uk
34. The University of Phoenix, <http://online.phoenix.edu/>
35. Health Information and Quality Authority, www.hiqa.ie
36. Grimson, J., Eoghan, F., Stephens, G., Grimson, W., and Berry, D. (1997). Interoperability issues in sharing electronic healthcare records—The synapses approach. In *Proceedings of the 3rd IEEE International Conference on Engineering of Complex Computer Systems*, pp. 180–185, www.cs.tcd.ie/synapses/public/deliverables/pubs.pdf
37. Puppe, J. (2005). Transforming healthcare. Executive Healthcare Management, <http://www.executivehm.com/pastissue/article.asp?art=270556&issue=210>
38. Lucas, S.M. (2007). Current state of affairs of information technology within VHA medical centers. *Testimony to the U.S. Senate Committee on Veterans' Affairs, U.S. Congress*, September 19, 2007, www.senate.gov/~veterans/public/index.cfm?pageid=16&release_id=11324&sub_release_id=11362&view=all
39. Glaser, J.P. (2003). Clinical information systems: The strategy at partners healthcare, <http://www.hisi.ie/html/ppt03/John%20Glaser.pdf>

40. Datta, S. (2007). Unified theory of relativistic identification of information in a systems age: Convergence of unique identification with syntax and semantics through internet protocol version 6 (IPv6). MIT Engineering Systems Division Working Paper Series, Massachusetts Institute of Technology, <http://esd.mit.edu/WPS/2007/esd-wp-2007-17.pdf>
41. Cheekiralla, S. and Engels, D.W. (2006). An IPv6-based identification scheme. *IEEE International Conference on Communications* 1: 281–286. doi: 10.1109/ICC.2006.254741.
42. Datta, S., Lyu, J. and Chen, P.-S. (2007). Decision support and systems interoperability in global business management. *International Journal of Electronic Business Management* 5: 255–265. MIT Engineering Systems Division Working Paper Series, Massachusetts Institute of Technology, <http://esd.mit.edu/WPS/2007/esd-wp-2007-24.pdf>, http://140.114.54.215/IJEBM/IJEBM_static/Paper-V5_N4/A01.pdf
43. UN/CEFACT, OASIS. (1999). ebXML terms of reference, www.ebXML.org
44. The World Wide Web Consortium, www.W3C.org
45. The Biositemaps Consortium. (2008). National Centers for Biomedical Computing, www.ncbcs.org, www.ncbcs.org/biositemaps/Biositemaps_white_paper_v4.0.doc
46. Datta, S., Granger, C.W.J., Barari, M., and Gibbs, T. (2007). Management of supply chain: an alternative modeling technique for forecasting. *Journal of the Operational Research Society* 58: 1459–1469. MIT Engineering Systems Division Working Paper Series, <http://esd.mit.edu/WPS/esd-wp-2006-11.pdf>
47. Simchi-Levi, D., Simchi-Levi, E., and Kaminsky, P. (2000). *Designing and Managing the Supply Chain: Concepts, Strategies and Cases*. McGraw-Hill, New York.
48. Parlier, G.H. (2008). *Transforming U.S. Army Supply Chains: Strategies for Management Innovation* (in press), <http://www.amazon.com/Transforming-Army-supply-chains-architecture/dp/B002I2V0Y8>
49. Hilmola, O.-P., Ma, H., and Datta, S. (2008). A portfolio approach for purchasing systems: Impact of switching point. MIT Engineering Systems Division Working Paper, Massachusetts Institute of Technology, <http://esd.mit.edu/WPS/2008/esd-wp-2008-07.pdf>
50. Noll, C. (2003) Information Systems and the NHS Strategy, http://www.ppa.org.uk/pdfs/bolton/information_systems_strategy.pdf
51. Drumm, B. (2006). HSE transformation programme 2007–2010. Report of the Health Services Executive, http://www.hse.ie/eng/Staff/FactFile/FactFile_PDFs/Other_FactFile_PDFs/Transformation/Transformation%20Programme%202007-2010.pdf
52. National Health Expenditure Projections 2007–2017. (2008). Centers for Medicare and Medicaid Services, Office of the Actuary, National Health Statistics. U.S. Department of Health and Human Services (HHS), <http://www.cms.hhs.gov/NationalHealthExpendData/Downloads/proj2007.pdf>
53. Measuring Ireland's Progress. (2006). Central Statistics Office, Ireland, http://www.cso.ie/releasespublications/documents/other_releases/2006/progress2006/measuringirelandsprogress.pdf
54. Datta, S. (2006). Global Public Goods, #42 <http://dspace.mit.edu/handle/1721.1/42903>
55. Fauci, A.S., Braunwald, E., Kasper, D.L., Hauser, S.L., Longo, D.L., Jameson, J.L., and Loscalzo, J., eds. (2008). *Harrison's Principles of Internal Medicine*, 17th edn. McGraw-Hill, New York.
56. Wong, D. (2006). Salivary diagnostics powered by nanotechnologies, proteomics and genomics. *Journal of the American Dental Association* 137: 313–321.
57. UCLA Human Salivary Proteome Project, www.hspp.ucla.edu

58. Mulholland, A., Thomas, C.S., Kurchina, P., and Woods, D. (2006). *MashUp Corporations: The End of Business as Usual. Chronicle of Service-Oriented Business Transformation*. Evolved Technologist Press, New York.
59. Amendolia, S.R., Estrella, F., Hassan, W., Hauer, T., Manset, D., McClatchey, R., Dmitry, R., and Solomonides, T. (2004). MammoGrid: A Service Oriented Architecture based Medical Grid Application, <http://arxiv.org/ftp/cs/papers/0405/0405074.pdf>
60. Google, www.google.com
61. Minsky, M. (1988). *The Society of Mind*. Simon & Schuster, New York.
62. Datta, S. (2002). Agents, #21 <http://dspace.mit.edu/handle/1721.1/41914>
63. Clinical Decision Making, <http://www.medg.csail.mit.edu/>
64. Famili, A., Nau, D.S., and Kim, S.H., eds. (1992). *Artificial Intelligence Applications in Manufacturing*. AAAI Press, Menlo Park, CA.
65. Datta, S., Betts, B., Dinning, M., Erhun, F., Gibbs, T., Keskinocak, P., Li, H. et al. (2003). Adaptive value network. In: Chang, Y.S., Makatsoris, H.C., and Richards, H.D. *Evolution of Supply Chain Management: Symbiosis of Adaptive Value Networks and ICT*, Chapter 1. Kluwer Academic Publishers, Boston, MA, www.wkap.nl/prod/b/1-4020-7812-9?a=1 and #3 <http://dspace.mit.edu/handle/1721.1/41908>
66. The MIT Report. (2001). Automated B2B contracting aided by new generation of software agents, <http://www.mit.edu/~bgrosof/paps/mit-report-05-01-distrib.pdf>
67. Bradshaw, J.M., ed. (1997). *Software Agents*. AAAI Press, Menlo Park, CA.
68. Padgham, L. and Winikoff, M. (2004). *Developing Intelligent Agent Systems: A Practical Guide*. John Wiley & Sons, Hoboken, NJ.
69. Weiss, G., ed. (2000). *Multiagent Systems: A Modern Approach to Distributed Artificial Intelligence*. MIT Press, Cambridge, MA.
70. Haase, P., Broekstra, J., Eberhart, A., and Volz, R. (2004). A comparison of RDF query languages, <http://www.aifb.uni-karlsruhe.de/WBS/pha/rdf-query/rdfquery.pdf>
71. Cesar, P., da Costa, G., Laskey, K.B., and Laskey K.J. (2005). PR-OWL: A Bayesian ontology language for the semantic web, http://mars.gmu.edu:8080/dspace/bitstream/1920/454/1/URSW05_PR-OWL.pdf
72. Fensel, D., Hendler, J., Lieberman, H., and Wahlster, W. (2003). *Spinning the Semantic Web: Bringing the World Wide Web to its Full Potential*. MIT Press, Cambridge, MA.
73. Muir, N. and Kimbell, I. (2007). *Discover SAP*. SAP Press, Rockville, MD.
74. Stonebraker, M. (2007). Next-generation data transformation tool, http://web.mit.edu/deshpandecenter/proj_stonebraker2.htm
75. Lanfear, D.E., Marsh, S., Cresci, S., Shannon, W.D., Spertus, J.A., and McLeod, H.L. (2004). Genotypes associated with myocardial infarction risk are more common in African Americans than in European Americans. *Journal of the American College of Cardiology* 44: 165–167.
76. Joshi, A., Finin, T., Java, A., Kale, A., and Kolari, P. (2007). Web 2.0 mining: Analyzing social media. In *Proceedings of the NSF Symposium on Next Generation of Data Mining and Cyber-Enabled Discovery for Innovation*, http://ebiquity.umbc.edu/_file_directory_/papers/379.pdf
77. Eagle, N. and Pentland, A. (2006) Reality mining: Sensing complex social systems. *Journal of Personal and Ubiquitous Computing* 10: 255–268, <http://reality.media.mit.edu/pdfs/realitymining.pdf>
78. Zhu, W., Wang, X., Ma, Y., Rao, M., Glimm, J., and Kovach, J.S. (2003). Detection of cancer-specific markers amid massive mass spectral data. *Proceedings of the National Academy of Sciences (United States)* 100: 14666–14761.

79. Lilien, R.H., Farid, H., and Donald, B.R. (2003). Probabilistic disease classification of expression-dependent proteomic data from mass spectrometry of human serum. *Journal of Computational Biology* 10: 925–946.
80. Petricoin, E.F., Ardekani, A.M., Hitt, B.A., Levine, P.J., Fusaro, V.A., Steinberg, S.M., Mills, G.B., Simone, C., Fishman, D.A., Kohn, E.C., and Liotta, L.A. (2002). Use of proteomic patterns in serum to identify ovarian cancer. *Lancet* 359: 572–577.
81. Grifantini, K. (2008). A faster way to detect heart attacks. *Technology Review*, May 9.
82. Bourzac, K. (2008). New breath-based diagnostic. *Technology Review*, March 14.
83. Denny, P., Hagen, F.K., Hardt, M., Liao, L., Yan, W., Arellanno, M., Bassilian, S. et al. (2008). The proteomes of human parotid and submandibular/sublingual gland saliva collected as the ductal secretions. *Journal of Proteome Research* 7: 1994–2006.
84. Biomarkers, <http://www.biophysicalcorp.com/forms/Biophysical250Biomarkers.pdf>
85. Velasquez-García, L.F. and Akinwande, A.I. (2008). A PECVD CNT-based open architecture field ionizer for portable mass spectrometry. In *21st IEEE International Conference on Micro Electro Mechanical Systems*, Tucson, AZ, January 2008, <http://eecsfacweb.mit.edu/facpages/akinwande.html>
86. Cardiac Diagnostics, http://www.tastechip.com/cardiac/cardiac_diagnostics_research.html
87. Ohshiro, K., Rosenthal, D.I., Koomen, J.M., Streckfus, C.F., Chambers, M., Kobayashi, R., and El-Naggar, A.K. (2007). Pre-analytic saliva processing affect proteomic results and biomarker screening of head and neck squamous carcinoma. *International Journal of Oncology* 30: 743–749.
88. Devadas, S. (2008). Authenticating and protecting digital information in portable devices, http://web.mit.edu/deshpandecenter/proj_devadas.html
89. Wilson, J.S. (2005). *Sensor Technology Book*. Elsevier, Amsterdam, the Netherlands.
90. Rhee, S. and Liu, S. (2002). An ultra-low power, self-organizing wireless network and its applications to non-invasive biomedical instrumentation. In *IEEE/Sarnoff Symposium on Advances in Wired and Wireless Communications*, West Trenton, NJ, March 13.
91. Levis, P., Madden, S., Gay, D., Polastre, J., Szewczyk, R., Woo, A., Brewer, E., and Culler, D. (2004). The emergence of networking abstractions and techniques in TinyOS, <http://berkeley.intel-research.net/dgay/pubs/04-nsdi-tinyos.pdf>
92. Lander, E.S., Linton, L.M., Birren, B., Nusbaum, C., Zody, M.C., Baldwin, J., Devon, K. et al. (2001). Initial sequencing and analysis of the human genome. *Nature* 409: 860–921.
93. Guttmacher, A.E. and Collins, F.S. (2003). Welcome to the genomic era. *New England Journal of Medicine* 349: 996–998.
94. Moahi, K.H. (1999). Health information networks for telehealth in Africa—Challenges and prospects. *Libri* 49: 43–50, <http://www.librijournal.org/pdf/1999-1pp43-50.pdf>
95. Grimson, J. (2008). ICT4D. The Irish-African partnership for research capacity building. Dublin, Ireland, <http://www.universitiesireland.ie/pubs/IAP-programme.pdf>
96. Lown, B. (2002). Health technology, the developing world and satellite, <http://www.SatellLife.org/programs/procor/9702comm.html>
97. Intel Communications Alliance. (2005). With Altobridge gateway, remote wireless communications gets easier, more cost efficient, <http://developer.intel.com/netcomms/casestudies/Altobridge.pdf>
98. World's first commercial inflight mobile phone service enabled by Altobridge's technology, www.altobridge.com/2010/06/11/global-times-altobridge-connecting-the-unconnected/

99. Bernard Lown's defibrillator has jolted patients back to life for more than 40 years. *Technology Review* November 2004, <http://www.technologyreview.com/biomedicine/13894/>
100. Murphy, J.G. and Lloyd, M.A., eds. (2006). *Mayo Clinic Cardiology: Concise Textbook*, 3rd edn. Mayo Clinic Scientific Press, New York.
101. Buyya, R., Date, S., Mizuno-Matsumoto, Y., Venugopal, S., and Abramson, D. (2003). Economic and on demand brain activity analysis on global grids, <http://arxiv.org/ftp/cs/papers/0302/0302019.pdf>
102. Schwindt, P.D.D., Knappe, S., Shah, V., Hollberg, L., Kitching, J., Liew, L.-A., and Moreland, J. (2004). Chip-scale atomic magnetometer. *Applied Physics Letters* 85: 6409–6411, <http://tf.nist.gov/general/pdf/2001.pdf>
103. Negroponte, N. (1996). *Being Digital*. Vintage Books, New York.
104. Kandel, E.R. and Schwartz, J.H. (1985). *Principles of Neural Science*. Elsevier, New York.
105. United Nations Foundation. (2008). Case study 2: Connecting health clinics and remote health workers (Uganda). *Wireless technology for social change: Trends in mobile use by NGOs*, pp. 16–18, http://www.unfoundation.org/files/pdf/2008/vodafone/tech_social_change/health_case2.pdf
106. Truppe, M. (2005). Telenavigation with the Vodafone mobile connect card from A1. In *International Congress for Oral and Maxillofacial Surgery*, Vienna, Austria.
107. Hoyt, C.C., Richards-Kortum, R.R., Costello, B., Sacks, B.A., Kittrell, C., Ratliff, N.B., Kramer, J.R., and Feld, M.S. (1988). Remote biomedical spectroscopic imaging of human artery wall. *Lasers in Surgery and Medicine* 8: 1–9.
108. Lin, N. (2005). Direct control of robots using brain neural signals. MS thesis, MIT, Cambridge, MA, <http://touchlab.mit.edu/>
109. Antani, S., Demner-Fushman, D., Li, J., Srinivasan, B.V., and Thoma, G.R. (2008). Exploring use of images in clinical articles for decision support in evidence-based medicine. In *Proceedings of the SPIE-IS&T Electronic Imaging*, San Jose, CA, <http://archive.nlm.nih.gov/pubs/ceb2008/2008004.pdf>
110. Datta, S. (2004). Biomedical decision systems [bMDs] initiative, #52 <http://dspace.mit.edu/handle/1721.1/41911>
111. The Visible Human Project, <http://www.nlm.nih.gov/research/visible/animations.html>
112. Weatherall, D. (1995). *Science and the Quiet Art*. W. W. Norton & Company, New York.
113. Stiglitz, J.E. (2002). *Globalization and Its Discontents*. W. W. Norton & Company, New York.
114. Datta, S. (2006). Advances in SCM decision support systems: Semantic interoperability between systems. MIT Engineering Systems Division Working Paper Series, Massachusetts Institute of Technology, <http://esd.mit.edu/WPS/esd-wp-2006-10.pdf>
115. Tuecke, S., Czajkowski, K., Foster, I., Frey, J., Graham, S., Kesselman, C., Maquire, T., Sandholm, T., Snelling, D., and Vanderbilt, P. (2003). Open grid services infrastructure (OGSI). Global grid forum globus toolkit 3, <http://www.ggf.org/documents/GFD.15.pdf>
116. Muhammad Yunus, http://nobelprize.org/nobel_prizes/peace/laureates/2006/press.html
117. Taverne, D. (2005). *The March of Unreason: Science, Democracy and the New Fundamentalism*. Oxford University Press, Oxford, UK.
118. Goldstein, J.L. and Brown, M.S. (2001). The cholesterol quartet. *Science* 292: 1310–1312.

119. Knowlton, A.A. and Srivatsava, U. (2008). Heat-shock protein 60 and cardiovascular disease: A paradoxical role. *Future Cardiology* 4: 151–161. doi:10.2217/14796678.4.2.151.
120. Stone, P.H. (2007). C-reactive protein to identify early risk for development of calcific aortic stenosis: Right marker? Wrong time? *Journal of the American College of Cardiology* 50: 1999–2001.
121. Cardiovascular disease diagnostics kit, www.roche.com/prod_diag_cardio.htm
122. Bourzac, K. (2008). Next-generation diagnostics. *Technology Review*, May 13, <http://www.technologyreview.com/Biztech/20760/>
123. Rissin, D.M., Gorris, H.H., and Walt, D.R. (2008). Distinct and long-lived activity states of single enzyme molecules. *Journal of the American Chemical Society* 130: 5349–5353, www.quantarix.com
124. Venter, J.C., Adams, M.D., Myers, E.W., Li, P.W., Mural, R.J., Sutton, G.G., Smith, H.O et al. (2001). The sequence of the human genome. *Science* 291: 1304–1351.
125. Human Genome Research, <http://www.broad.mit.edu>
126. Fire, A., Xu, S., Montgomery, M.K., Kostas, S.A., Driver, S.E., and Mello, C.C. (1998). Potent and specific genetic interference by double-stranded RNA in *Caenorhabditis elegans*. *Nature* 391: 806–811.
127. ALNYLAM, <http://www.alnylam.com/science-technology/index.asp>
128. Christensen, C.M. (1997). *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*. Harvard Business School Press, Boston, MA.
129. David, P.A. and Wright, G. (2003). *The Economic Future in Historical Perspective*. Oxford University Press, New York.
130. Datta, S. (2008). Auto ID paradigm shifts from internet of things to unique identification of individual decisions in system of systems. MIT Engineering Systems Division Working Paper, Massachusetts Institute of Technology. Supply Chain Europe, May–June, 2008, Vol. 12(3), pp. 38–43, http://www.scemagazine.com/sce/magazines/archives/SCE_MayJune08.pdf
131. Samuel, J.-L., Schaub, M.C., Zaugg, M., Mamas, M., Dunn, W.B., and Swynghedauw, B. (2008). Genomics in cardiac metabolism. *Cardiovascular Research* 79(2): 218–227.
132. Zimmerli, L.U., Schiffer, E., Züribig, P., Good, D.M., Kellmann, M., Moulis, L., Pitt, A.R. et al. (2008). Urinary proteomic biomarkers in coronary artery disease. *Molecular and Cellular Proteomics* 7: 290–298.
133. Villanueva, J., Martorella, A.J., Lawlor, K., Philip, J., Fleisher, M., Robbins, R.J., and Temps, P. (2006). Serum peptidome patterns that distinguish metastatic thyroid carcinoma from cancer-free controls are unbiased by gender and age. *Molecular and Cellular Proteomics* 5: 1840–1852.
134. Mani, A., Radhakrishnan, J., Wang, H., Mani, A., Mani, M.-A., Nelson-Williams, C., Carew, K.S., Mane, S., Najmabadi, H., Wu, D., and Lifton, R.F. (2007). LRP6 mutation in a family with early coronary disease and metabolic risk factors. *Science* 315: 1278–1282.
135. Datta, S., Soong, C.J., Wang, D.M., and Harter, M.L. (1991). Purified adenovirus 289R E1A protein stimulates polymerase III transcription in vitro by altering transcription factor TFIIC. *Journal of Virology* 65: 5297–5304, <http://dspace.mit.edu/handle/1721.1/42835>
136. Datta, S., Magge, S., Madison, L., and Jameson, J.L. (1992). Thyroid hormone receptor mediates transcriptional activation and repression of different promoters. *Molecular Endocrinology* 6: 815–825, http://www.jamesonlab.northwestern.edu/Bibliography/Jameson_1992_MolEndo_6_815.pdf

137. Rentoumis, A., Chatterjee, V.K.K., Madison, L., Datta, S., Gallagher, G., DeGroot, L.J., and Jameson, J.L. (1990). Negative and positive transcriptional regulation by thyroid hormone receptor isoforms. *Molecular Endocrinology* 4: 1522–1531, <http://dspace.mit.edu/handle/1721.1/42902>
138. Chatterjee, V.K.K., Nagaya, T., Datta, S., Madison, L., Rentoumis, A., and Jameson, J.L. (1991). Thyroid hormone resistance syndrome: Inhibition of normal receptor function by mutant thyroid hormone receptors. *Journal of Clinical Investigation* 87: 1977–1984, <http://dspace.mit.edu/handle/1721.1/42900>
139. Bhagwati, J. (2004). *In Defense of Globalization*. Oxford University Press, New York.
140. Datta, S. (2008). Can convergence of innovation catalyse economic growth? In *DRIVE Conference*, #75, Kerry, Ireland, <http://dspace.mit.edu/handle/1721.1/41909>
141. Hao, M., Head, W.S., Gunawardana, S.C., Hasty, A.H., and Piston, D.W. (2007). Direct effect of cholesterol on insulin secretion: A novel mechanism for pancreatic β -cell dysfunction. *Diabetes* 56: 2328–2338.
142. Datta, S. (2008). Information identification in decision systems. In *CIDS Conference*, Institute of Technology, Tralee, #77 <http://dspace.mit.edu/handle/1721.1/41910>
143. Irish Medical Organization: Submission to Budget (2006), http://www.imo.ie/news/uploads/20061108IMO_Submission_Budget_2007final.pdf
144. Akcivi, H.A. (2003). Implementation and validation of a real-time wireless non-invasive physiological monitoring system in a high-G environment. MS thesis, U.S. Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio School Of Engineering and Management (MIT Institute for Soldier Nanotechnologies, <http://web.mit.edu/isn/>).
145. Vo-Dinh, T., ed. (2007). *Nanotechnology in Biology and Medicine: Methods, Devices, and Applications*. CRC Press, Boca Raton, FL.
146. Forzani, E.S., Zhang, H., Nagahara, L.A., Amlani, I., Tsui, R., and Tao, N. (2004). A conducting polymer nanojunction sensor for glucose detection. *Nano Letters* 4: 1785–1788.
147. Jensen, K., Weldon, J., Garcia, H., and Zettl, A. (2007). Nanotube radio. *Nano Letters* 7: 3508–3511.
148. Rutherglen, C. and Burke, P. (2007). Carbon nanotube radio. *Nano Letters* 7: 3296–3299.
149. Cheng, M.M.-C., Cuda, G., Bunimovich, Y.L., Gaspari, M., Heath, J.R., Hill, H.D., Mirkin, C.A., Nijdam, A.J., Terracciano, R., Thundat, T., and Ferrari, M. (2006). Nanotechnologies for biomolecular detection and medical diagnostics. *Current Opinion in Chemical Biology* 10: 11–19.
150. Lin, Y., Lu, F., Tu, Y., and Ren, Z. (2004). Glucose biosensors based on carbon nanotube nanoelectrode ensembles. *Nano Letters* 4: 191–195.
151. Javey, A., Guo, J., Wang, Q., Lundstrom, M., and Dai, H.J. (2003). Ballistic carbon nanotube field-effect transistors. *Nature* 424: 654–657.
152. U.S. Department of Agriculture Report: 2006–2007. Crop Season, <http://usda.mannlib.cornell.edu/usda/nass/CropProg//2000s/2007/CropProg-11-26-2007.pdf>
153. Discovery of transistor, http://nobelprize.org/nobel_prizes/physics/laureates/1956/
154. Park, T.H., Mirin, N., Lassiter, J., Hafner, J., Halas, N.J., and Nordlander, P. (2008). Plasmonic properties of nanoholes. *ACS Nano* 2: 25–32, <http://lanp.rice.edu/research.php>
155. Edwards, S.K., Bernal-Mizrachi, L., and Ratner, L. (2006). Accumulation of Nf κ B1 and Nf κ B2 is essential for apoptosis induced by proteasome inhibition in a lymphoma model. *The Ohio Journal of Science* 106: A14. Abstract. Science and engineering on a nanoscale. In *115th Annual Meeting*, The Ohio Academy Of Science, Dayton, OH, [http://www.ohiosci.org/OJS106\(1\).pdf](http://www.ohiosci.org/OJS106(1).pdf)

156. Talley, C.E., Jackson, J.B., Oubre, C., Grady, N.K., Hollars, C.W., Lane, S.M., Huser, T.R., Nordlander, P., and Halas, N.J. (2005). Surface-enhanced Raman scattering from individual Au nanoparticles and nanoparticle dimer substrates. *Nano Letters* 5: 1569–1574.
157. Bush, S.F. and Li, Y. (2006). Nano-communications: A new field? An exploration into a carbon nanotube communication network. Technical Information Series, GRC066. GE Global Research Center.
158. Cerf, V.G. and Kahn, R.E. (1974). A protocol for packet network interconnection. *IEEE Transactions in Communication Technology* COM-22 5: 627–641.
159. Walrand, J. and Varaiya, P. (2000). *High-Performance Communication Networks*, 2nd edn. The Morgan Kaufmann Series in Networking, San Francisco, CA.
160. Datta, S. (2007) Unified theory of relativistic identification of information in a systems age. #99 <http://dspace.mit.edu/handle/1721.1/41902>
161. Karl, H. and Willig, A. (2006). *Protocols and Architectures for Wireless Sensor Networks*. Wiley, London, UK.
162. Granger, C.W.J. and Swanson, N.R. (1996). Further developments in the study of cointegrated variables. *Oxford B Economics and Statistics* 58: 374–386.
163. O’Dowd, T. (2007). The private sector in healthcare: Contributing to service but not to research. *Irish Journal of Medical Science* 176: 261–265.
164. Botman, D. and Iakova, D. (2007). Policy challenges of population aging in Ireland. International Monetary Fund (IMF) Working Paper WP/07/247, www.imf.org/external/pubs/ft/wp/2007/wp07247.pdf
165. Berners-Lee, T. and Fischetti, M. (2000). *Weaving the Web: The Original Design and Ultimate Destiny of the World Wide Web by its Inventor*. Harper-Collins, New York.
166. Oldstone, M. (1987). Molecular mimicry and autoimmune disease. *Cell* 50: 819–820.
167. Chomsky, N. (2002). *Syntactic Structures*. Mouton, The Hague, the Netherlands.
168. Jackendoff, R. (1990). *Semantics and Cognition*. MIT Press, Cambridge, MA.
169. Lane, D. and Hoefler, W. (1980). SV40 large T shares an antigen determinant with cellular protein of molecular weight 68,000. *Nature* 288: 167–170.
170. Krisher, K. and Cunningham, M. (1985). Myosin: A link between streptococci and heart. *Science* 227: 413–415.
171. Fujinami, R. and Oldstone, M. (1985). Amino acid homology and immune responses between the encephalitogenic site of myelin basic protein and virus: A mechanism for autoimmunity. *Science* 230: 1043–1045.
172. Baird, R., Bronze, M., Kraus, W., Hill, H., Vasey, L., and Dale, J. (1991). Epitope of group A streptococcal M protein shared with antigens of articular cartilage and synovium. *Journal of Immunology* 146: 3132–3137.
173. Wucherpfenning, K.W. and Strominger, J.L. (1995). Molecular mimicry in T cell-mediated autoimmunity: Viral peptides activate human T cell clones specific for myelin basic protein. *Cell* 80: 695–705.
174. Husby, G., Tsuchiya, N., Schwimmbeck, P., Keat, A., Pahle, J., Oldstone, M., and Williams, R. (1998). HLA-B27-related antigens in tissues of patients with ankylosing spondylitis. *Scandinavian Journal of Rheumatology* 76 (suppl): 23–25.
175. Barnes, R., Allan, S., Taylor-Robinson, C., Finn, R., and Johnson, P. (1990). Serum antibodies reactive with *Saccharomyces cerevisiae* in inflammatory bowel disease: Is IgA antibody a marker for Crohn’s disease? *International Archives of Allergy and Applied Immunology* 92: 9–15.

176. Zwetchkenbaum, J. and Burakoff, R. (1988). The irritable bowel syndrome and food hypersensitivity. *Annals of Allergy* 61: 47–49.
177. Java, A., Nirneburg, S., McShane, M., Finin, T., English, J., and Joshi, A. (2007). Using a natural language understanding system to generate semantic web content. *International Journal on Semantic Web and Information Systems* 3: 1–28, http://ebiquity.umbc.edu/_file_directory_/papers/373.pdf
178. Derbyshire, J. (2004). *Prime Obsession: Bernhard Reimann and the Greatest Unsolved Problem in Mathematics*. Penguin Books, New York.
179. Jackendoff, R. (1994). *Patterns in the Mind*. Basic Books, New York.
180. Bonabeau, E., Dorigo, M., and Theraulaz, G. (1999). *Swarm Intelligence: From Natural to Artificial Systems*. Oxford University Press, New York.
181. Icosystem, http://www.icosystem.com/about_management.htm
182. Nash, J.F. (1950). Equilibrium points in N-Person games. *Proceedings of the National Academy of Sciences (USA)* 36: 48–49, <http://www.pnas.org/misc/Nash.pdf>
183. Akerlof, G. (1970). The market for lemons: Quality uncertainty and the market mechanism. *Quarterly Journal of Economics* 84: 488–500, http://nobelprize.org/nobel_prizes/economics/laureates/2001/
184. International Herald Tribune, May 14, 2008, www.iht.com
185. <http://www.intota.com/expert-consultant.asp?bioID=765593&perID=722084>
186. Sung, N.S. et al. (2003) Central challenges facing the national clinical research enterprise. *Journal of the American Medical Association* 289: 1278–1287, <http://jama.ama-assn.org/cgi/content/abstract/289/10/1278>
187. MIT Department of Biological Engineering, <http://web.mit.edu/be/index.htm>
188. Harvard-MIT Health Sciences and Technology, <http://hst.mit.edu>
189. NIH Physician Scientist, <http://www.training.nih.gov/careers/careercenter/mdphd.html>
190. Molecular Medicine Ireland Clinician Scientist Fellowship Programme, http://www.dmmc.ie/MML_Clinician_Scientist_Fellowship.htm
191. Technical education for medical experts, <http://www.wpi.edu/Pubs/Catalogs/Grad/Current/bmecourses.html>
192. Gardner, D.P., Larsen, Y.W., Baker, W.O., Campbell, A., Crosby, E.A., Foster, C.A., Francis, N.C. et al. Technical education for medical experts, http://datacenter.spps.org/sites/2259653e-fb3-45ba-8fd6-04a024ecf7a4/uploads/SOTW_A_Nation_at_Risk_1983.pdf
193. Carnegie Foundation Report, 1996.
194. American Institute of Physics, Statistical Research Center. 1986–1987 and 2000–2001 High School Physics Surveys, www.aip.org/statistics/trends/hs_teacher.html and www.aip.org/statistics/
195. Trends in International Mathematics and Science Study, <http://nces.ed.gov/timss>
196. Information Technology Association of America (ITAA) and U.S. Department of Commerce Encourage Companies to Support Tech Education for Women and Minority Small Businesses, May 14, 2008, <http://www.ita.org/newsroom/headline.cfm?ID=2648>
197. World Economic Forum Technology Pioneers, www.weforum.org/en/Communities/Technology%20Pioneers/index.htm
198. Industrial Liaison Program, Massachusetts Institute of Technology, <http://ilp-www.mit.edu>
199. MIT Innovation, <http://web.mit.edu/deshpandecenter>

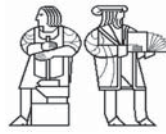
200. Bonabeau, E. (2007). Understanding and managing complexity risk. *MIT Sloan Management Review* 48: 62–68, <http://www.bauer.uh.edu/2007augmgmsl7-23.pdf>
201. Simchi-Levi, D., Wu, S.D., and Shen, Z.-J., eds. (2004). *Handbook of Quantitative Supply Chain Analysis: Modeling in the E-Business Era*. Kluwer Academic Publishers, Boston, MA.
202. Wolpert, D.H. (2005). *Information Theory: The Bridge Connecting Bounded Rational Game Theory and Statistical Physics*. NASA Ames Research Center, Moffet Field, CA.
203. Schweitzer, A. (1961). *The Decay and the Restoration of Civilization*. Unwin Books, London, UK.
204. Nabel, E.G. (2003). Cardiovascular disease. *New England Journal of Medicine* 349: 60–72.

APPENDIX I

Shoumen Datta

HAPHAZARD REALITY – IOT IS A METAPHOR

THIS PAGE IS LEFT BLANK



Massachusetts Institute of Technology
Engineering Systems Division

Working Paper Series

ESD-WP-2007-17

.....

UNIFIED THEORY OF RELATIVISTIC IDENTIFICATION OF
INFORMATION IN A SYSTEMS AGE:

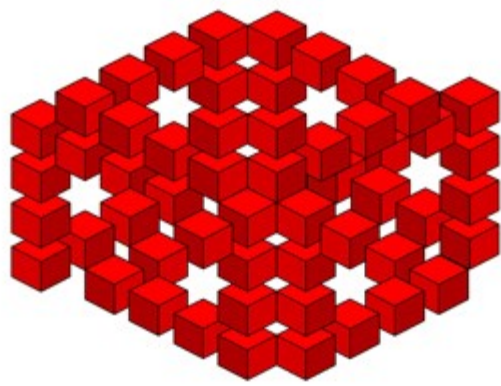
Proposed Convergence of Unique Identification with Syntax
and Semantics through Internet Protocol version 6

.....

Shoumen Palit Austin Datta

Research Scientist, Engineering Systems Division
Department of Civil and Environmental Engineering
Research Director & Co-Founder
MIT Forum for Supply Chain Innovation
School of Engineering
Massachusetts Institute of Technology
shoumen@mit.edu

March 2007



Unified Theory of Relativistic Identification of Information in a Systems Age: Proposed Convergence of Unique Identification with Syntax and Semantics through Internet Protocol version 6

Shoumen Palit Austin Datta

Research Scientist, Engineering Systems Division, Department of Civil and Environmental Engineering and Co-Founder and Research Director, MIT Forum for Supply Chain Innovation, School of Engineering, Massachusetts Institute of Technology, Building 1, Room 1-179, Cambridge, Massachusetts 02139, USA

shoumen@mit.edu

Abstract. This paper proposes to utilize internet protocol version six (IPv6) to uniquely identify not only things (objects) but also processes, relationships (syntax, semantics) and interfaces (sensors). Convergence of *identification with information* using the 128-bit IPv6 structure offers 3.4×10^{38} unique instances. It is not necessary that all instances must be connected to the internet or routed or transmitted simply because an IP addressing scheme is suggested. This is a *structure* for identification which (1) may improve revenue potential from data routing (P2P packet tracking) for telecommunication industries, (2) potential use in healthcare and in biomedical sciences, (3) scope of use in the semantic web structure by transitioning URIs used in RDF, (4) applications involving thousands of mobile *ad hoc* sensors (MANET) that demand dynamic adaptive auto-reconfiguration. This paper offers clues for innovation based on a confluence of ideas that may augment systems interoperability necessary for operational transparency in a global economy.

Keywords: Interoperability, Data, Information, IPv6, Semantics, Syntax, Security, MANET, Sensors, Healthcare, Biomedical Ontology, Decision Systems, RFID, EPC, Logistics, Adaptive Value Networks, Supply Chain, P2P, ZigBee, WiFi, WiMax, WiTriCity

1 Introduction

Data (bits) from unique identification of objects or things (atoms) are often helpful to the decision making process. Decisions, however, are often based on information that takes into account multiple factors. Physical objects and their unique identification may be one of many factors, as is the internet of things, from the perspective of a systems approach. Real-world decisions are often based on collective information gathered from multiple sources (or systems) that includes data (bits) about “things” (atoms) and processes associated with “things” which may be used in combination with a higher level domain that may eventually trigger a decision or execute an action, aided or unaided by a human. Currently, we do not have a globally unique mechanism to identify *information* derived from data originating from things (objects) *and* processes. Unique identification of information, hence, is an open question.

Information, to be of value, must be *relative* to the context of the process. In general, contextual information is of greater relevance in the decision making process or in decision systems. In this paper, I shall refer to such information as *decisionable information*.

Since information is key, one who holds information can use data, for profit, as a pay-per-use or pay-per-access service. Hence, unique identification of data has gained considerable momentum. Transmission of data is essentially the domain of routers. Routing data is an ubiquitous and essential function (real-time data, supply chain, emergency, medical results, networked entertainment, video-on-demand, energy-use optimization, any data) performed by products in boxes (for example, routers). Some corporations are likely to explore new revenue streams simply from use of raw data, for example, data-as-a-service or how to profit from data routing by providing access to data (pay-per-use hosted services). The next higher level for potentially higher revenue originates from processed data or information-as-a-service, in addition to physical data routing.

The transformation of data to information is made even more difficult by the inability of systems and software to comprehend or understand. Advances in systems interoperability [1], adoption of sophisticated analytical techniques [2] for forecasting

and risk analysis [4] and growth of the semantic web [4] infrastructure may stimulate in-network processing of data to boost the information-as-a-service business model by making sense of data and information relative to each other. These are new sources of revenue emerging from a function that is massive in scale but poorly regulated due to inadequate ability to document and charge for individual events and instances. The identification and identity structure necessary for a scale so massive calls for a system that is able to uniquely identify and assign identity to objects, process and decision layers. This paper explores the use of the structure and alphanumeric format [5] in Internet Protocol version 6 (IPv6), for this task.

2 Format of Internet Protocol version 6 (IPv6)

This paper advocates the most obvious distinguishing feature of IPv6 due to its use of much larger number of unique addresses. The size of an address in IPv6 is 128 bits, which is four times the larger than an IPv4 address. A 32-bit address space allows for 2^{32} or 4,294,967,296 unique addresses. IPv6 uses the 128-bit address space allowing for 2^{128} or 340,282,366,920,938,463,374,607,431,768,211,456 (3.4×10^{38}) unique addresses. The relatively large size of the IPv6 address was designed to be subdivided into hierarchical routing domains that reflect the topology of the modern internet. The use of 128 bits allows for multiple levels of hierarchy and flexibility in designing hierarchical addressing and routing that is currently lacking in the IPv4-based internet (as well as 64-bit and 96-bit versions of the electronic product code or EPC).

IPv4 addresses are represented in the dotted-decimal format. This 32-bit address is divided along 8-bit boundaries. Each set of 8 bits is converted to its decimal equivalent and separated by periods. For IPv6, the 128-bit address is divided along 16-bit boundaries. Each 16-bit block is converted to a 4-digit hexadecimal, separated by colons (colon-hexadecimal).

The following is an IPv6 address in binary form:

```
00100001110110100000000011010011000000000000000010111100111011
0000001010101010000000001111111111111110001010001001110001011010
```

The 128-bit address is divided along 16-bit boundaries:

```
0010000111011010    0000000011010011
0000000000000000    0010111100111011
0000001010101010    0000000011111111
1111111000101000    1001110001011010
```

Each 16-bit block in an IPv6 address, converted to hexadecimal and delimited with colons (colon hexadecimal format) 21DA:00D3:0000:2F3B:02AA:00FF:FE28:9C5A. IPv6 representation can be simplified by removing the leading zeros within each 16-bit block but each block must have at least one digit. The representative address is: 21DA:D3:0:2F3B:2AA:FF:FE28:9C5A (with leading zero suppression).

3 Opportunity Spaces

3.1 Network Services

In-network processing of data to generate information may emerge as a value-added differentiator in the data-as-a-service model. The latter may be possible with grid computing by standardizing the use of operating system and system architecture, for example, Globus Tool Kit and Open Grid Services Architecture [6] which represents evolving architecture facilitating web services (Web 2.0, Web 3.0, Web X.0) with tools, such as, SOA (service oriented architecture) over transmission medium “mesh” (including FTTH, FTTB, ATM, SONET, WiFi, WiMax, ZigBee, PLC, UWB, GPRS,

GPS, WiTriCity¹). Grid based ‘in-network’ processing functions may be pervasive with increasing diffusion of software as infrastructure, which may, in turn, offer systems the functionality to harvest and route distributed data from various sources to analytical engines running various hosted applications, analytics, predictive tools, forecasting algorithms, event management alerts, scheduling and planning updates. Output from online analytical processing (OLAP) engines may be made available to businesses on a pay-per-use and/or pay-per-access basis, with costs reflecting real-time versus near-real-time service delivery.

Hence, service may “mature” to provide “answers” and not only numbers (raw data). In this scenario the network is the business. With vast quantities of data (instances of data) that need accounting (if you are the service provider), it becomes critical to find a robust, globally feasible and easily adoptable *modus operandi* to contextualize and “number numbers” that does more than deliver data. Distributed data from multiple sources is dynamic, often sporadic and volatile yet must have unique identification, usually, to be valuable. The key to profitable service is to deliver information of value that can be uniquely identified, for example, in buckets or data cubes [7]. The ability to count and account for the identity of every instance of buckets on *your network*² catalyses the profits if one can bill (charge) for every instance a new bucket is created.

¹ Electrical power without wires <http://web.mit.edu/newsoffice/2007/wireless-0607.html>

² Expanded routing and addressing capabilities that offer greater ability to control the path of traffic in order to direct the transmission of packets on the service provider’s network (hence billing for service or use) is a business driver for networks seeking new revenue streams. IPv6 offers this functionality by improving the scalability of multicast routing and by introducing a new type of address called “anycast” address. When used as a part of a route sequence, anycast permits a node to select which of the several internet service providers (ISP) it wants to carry its traffic (source selected policy). This is implemented by configuring anycast addresses to identify the set of routers assigned to the ISP (one anycast address per ISP). These anycast addresses can be used as intermediate addresses in an IPv6 routing header to direct a packet to be delivered via a particular provider or sequence of providers (alliances between ISPs). These new routing extensions in IPv6 are powerful tools for provider selection and mobility. If users are enabled to change routing, then it will increase competition between service providers because choices may be guided by cost factors and quality of service. (<http://playground.sun.com/pub/ipng/html/INET-IPng-Paper.html>).

It could be argued that distributed data identification, of the type referred above, may be achieved using distributed hash tables [8] commonly used in peer-to-peer (P2P) systems (eg. Napster, Gnutella, Freenet, BitTorrent). However, the implications of using variants of consistent hashing to map key nodes may introduce the same type of nomenclature issues (disagreement) as with the date/format/EPC type keys. Node keys (identifier or ID) are linked to the keyspace between two keys, in other words, a node with ID i owns all the keys in the keyspace. The benefit of consistent hashing in distributed hash tables are due to the fact that alterations in the keyspace, i.e., addition or removal of nodes, changes one associated/adjacent key, leaving all other nodes unperturbed (in traditional hash tables changes require the entire keyspace to be re-mapped).

In the context of this idea, the change of nodes in the keyspace (addition or removal) may be viewed as independent events, for example “buckets” containing inventory data from a third-party supplier that is updated at regular intervals. In the pay-per-access business model, every instance or event of uploading or updating the data cube “bucket” with inventory data (for example hourly data after completion of batches of work-in-progress or WIP data) should incur a fee, payable by the user to the host network provider, as a fee for pay-per-access. It is unclear if event detection and link to pay-per-access for this type of itemization is possible through use of DHT.

In the same vein, the manufacturer (OEM) may periodically “ping” the bucket to determine inventory (supply) data. Each time the manufacturer “looks” in the bucket, there should be a mechanism to capture this event and the manufacturer (user) pays a fee to the service provider (network carrying the data and/or data cubes) for the service type: pay-per-use/access. The observation (inventory of specific item) could impact higher level WIP (work-in-progress) functions. For example, if 3 components are required for sub-assembly of a part then updating one SKU in the BOM (bill of materials) may not reflect a change of status of the *sub-assembly inventory* (this is no longer merely raw data, but *information*) because all 3 parts are required in a certain volume (ratio) to ensure that the sub-assembly can proceed and will produce the next higher level component, in question.

This is *contextualized* numbering of information where inventory of sub-assembly of component – *is the information* – dependent on inventory – *which is itemized raw data* – of individual components. While DHT is an advanced mapping tool that reduces bandwidth requirement to rapidly connect nodes in a vast network topology, it is unclear if DHT may be as useful as IPv6 to assign unique identification to every change in, or access to, data and information, that may profit from being *accounted*.

Hence, identification requires a unique way to *innumerate* packets or the data and the data holders (data cubes). Application of granular “innumeration” of data packets is in demand and likely to offer significant value for internet service providers (ISP) who are usually loathe to carry P2P (peer-to-peer) traffic on their networks because the P2P *modus operandi* (leaf to leaf) bypasses the current accounting practices of tracking packet flow (hence, revenue generation) which generally operates on the “trunk” of the system (charges for operations or content delivery that use bandwidth on the trunk of the ISP). Due to proliferation of P2P users who are taking advantage of the networks, ISPs are seeking tools to track and trace P2P traffic through the leaf nodes in order to charge P2P users for transactions (video, music, data) based on volume rather than the current flat-fee revenue model used by the telecommunication industries and ISPs because they do not yet have a granular mechanism to track how much data (packets) an user is downloading or uploading. A satisfactory revenue model based on tracking P2P usage in units of packets may further bolster revenue from legitimate P2P users and help reduce ISP bandwidth congestion by distributing payload to leaf nodes or mesh networks (away from trunk lines). To help with these accounting problems in P2P mesh networks, in one approach³ files are reassembled in ‘slices’ where a slice consists of the *n*th bit of every block. It is open to exploration whether in this context the numbering of files (the *n*th bit of every block) with an unique IPv6 id may offer business value through granularity of accountability.

³ Hui Zhang of Carnegie-Mellon University has founded Rinera Networks and Paul Francis of Cornell University has developed a system called Chunkyspread to partially address these problems (MIT Technology Review, March-April 2007).

3.2 Event Management

In event management and related supply chain operations, database tables with unique identification for each data cube may lend itself to re-use as data holders. Each event (that is, every time data or a data cube or a data holder is used) is uniquely numbered (companies subscribe to number domains) and itemized for pay-per-access service charges based on instances. Event data update and/or management may utilize online analytical and/or transaction processing (OLAP/OLTP) type systems for customer relationship and billing purposes, respectively. This proposal to use IPv6 may address the central dilemma: how do you number numbers? How does one number events? Merely “counting” the number of numbers is not enough. This will run into octillions of instances of data and even more instances of contextualized data that is of value (relativistic or decisionable information).

Consider problems faced by retailers if they double-count or re-count. Then imagine if a system-wide data duplication goes unnoticed and if services (finance, insurance) are duplicated or irregular. Individual pieces of data are often sterile as decisionable information but the collective analysis of data in the context of the process or transaction (where it is used) is far more critical and valuable as decisionable information. Object data identity using other formats, such as the electronic product code (EPC) or GUID (global unique id), are static identification formats that remain oblivious of context (process). Although EPC and other formats such as the UCR (unique consignment reference) offers unique id for things or objects, they lack structure to offer *contextual information* that may have unique identification.

The problem with “unique id” is addressed, grossly inadequately, by EPC Global and other related bodies (GS1) through the EPC-IS interface standard. Entities stored in EPC-IS are events, contextualized through “what/where/when/why/how” combination of parameters. Unique numbering for events rely on generating a combined key by using, for example, EPC+location+time. Pre-agreement of time, location coordinates and formats are core assumptions when creating such a key. It promotes the fallacy that such agreements are universal and universally accepted (explore how many

permutations and combinations are possible with different formats of times and dates used on different continents).

Therefore, this problem may benefit from innovation and further exploration of “numbering of numbers” to include EPC type information (if necessary) in a sub-layer of a multi-layer data and information aggregation model to provide unique *identity* for information. One practical example of data “layers” may be viewed as a substitute or replacement for EPC IS where a unique serial number (bottle of Aspirin with EPC) is combined with attributes (not designed for EPC association) such as [a] who checked the packaging, [b] where was it packed, [c] where was it manufactured, [d] what is the expiration date, [e] when was it shipped, [f] when was it received, [g] where was it shipped from, [h] where was it received. “Who” denotes a role and individuals with unique IPv6 id may be linked to role based authorization for accessibility purposes. Location, transportation vehicles, physical spaces (distribution center, retail store) may have unique IPv6 type id, too. The *combined* higher level information linked with the serial number of the bottle of aspirin (with its unique IPv6 id) with the “who-what-where-when” parameters is as simple as a “name” (John Smith) in a relational database linked to mailing address, phone number, date of birth, biometric data, social security number. If the “name” forms the skin of an IPv6 type crawl [9], it may extract the *related* data to generate information about John Smith. Alternatively, if the zip code or post code serves as the skin in a Web X.0 “search and discover” function, it may help track and trace all who are John Smith in Cambridge (02139 or CB2 1HQ). Thus, *layers* of unique IPv6 id representing object data and semantic data (who-what-when-where) collectively generates *information* when combined. The “simple sensed” semantic data (local distribution centre *is a* regional distribution centre) may not be mixed up with EPC type id. It may be worth the upheaval to forge a new direction by associating semantic data (such as, a retail store, that does not serve as an actuator) with IPv6 type identification to facilitate future search engines and “intelligent” agent-based systems to help track and trace not only the movement of objects but the linked data and processes in relation to information.

In this respect, it may be rather unfortunate that EPC has deviated from its insightful 128-bit structure that was proposed by Sanjay Sarma and Dan Engels (MIT, 1998). It may have successfully aligned EPC with IPv6 evolution. EPC 128-bit was a format for data (id) transmission but without routing yet it had the potential for convergence or structural amalgam with routing if translated to IPv6 format with substantial unique identification provision and transmission-routing capabilities for any RF mode (RFID, UWB, sensors) that can be plugged directly into the internet. Currently, sensor data cannot be uploaded directly to the internet because individual sensors cannot be assigned IP addresses due to limitations of the IPv4 unique addressing system. This proposal works with sensors (interfaces) because individual sensors can now have unique IPv6 address. However, the fundamental question is how to extract value from data and how can providing data as a network service evolve a robust revenue model?

Thus, data as a service model begs to find a mechanism that can number numbers in a rational manner to generate the higher order contextual and relativistic information. This mechanism must exist within the current framework of TCP/IP because it is aligned with the internet architecture. Hence, the suggestion to use the 128-bit IPv6, a scheme that is already at hand and being deployed, gradually but globally. This may be the “one-size-fits-all” hyper-id. IPv6 hyper-id may be a lucrative accounting tool in event recognition network delivered services to enable billing, for example, for high volume entertainment events, such as, iTunes from Apple. Management of iTunes billing, tracking and tracing, may be overwhelmed by sheer volume. It may also experience constraints not only for billing services but also up-selling/cross-selling types of customer relationship management (CRM) and marketing due to its inability to track and trace combinations of parameters that identify customer (nodes) choices.

3.3 Relativistic Information

In a similar vein, it may be necessary to identify people and process, in combination. How do we uniquely identify people and their linked or related context (process), for example in healthcare or in eGovernment functions (such as pension, voting).

EPC is object based identification. Think of IPv6 as a solution that is pre-agreed for global adoption. Consider contextual relevance of data and how to “number the numbers” but especially how to route numbers (data) which may be identical but with different identities. For example, a blood glucose result of 120 mg/dl may be identical for multiple individuals (same number, 120, with same units, mg/dl) but with different identities at the informational level because it belongs to different individuals. This may seem an esoteric brain teaser to some but *au contraire*. This is a fundamental information infrastructure issue that requires serious attention. It may have critical impact, for example, in a healthcare scenario where in-network data processing may be valuable with concomitant development of semantic tools for discovery and hosted analytics over semantic grid (Web X.0) services. However, in-network processing is granular but only for the application in question (*per se* it does not lead to higher order aggregation or network topology). Connecting data from, for example, from an emergency scenario (heart rate) with patient history may be viewed as a higher layer “abstraction” where not only the data (heart rate in bpm; corrected for age) but the information (heart rate and patient history) is identifiable and accessible through a “hyper-id” accessible via web services with linked information that is unique and uniquely identifiable. Thus, healthcare is a fertile ground for such applications. This suggestion may work with Agent-integrated security systems (to guarantee data security, confidentiality and privacy⁴) and monitoring systems to scan for errors (double counting, double dosage) as well as duplicate address detection (DAD)

⁴ Service providers can now offer secure services by using two integrated options in IPv6. One mechanism, termed “IPv6 Authentication Header” is an extension header which provides authentication and integrity *without* confidentiality. This may prevent a number of network attacks. The other mechanism, “IPv6 Encapsulating Security Header” provides data integrity *and* confidentiality. Authentication, data integrity and confidentiality are core elements of IPv6 and offers an improved option mechanism over IPv4 (not limited to 40 bytes). It permits IPv6 options to be used as functions which were not practical for IPv4 (authentication and security encapsulation for security and confidentiality, respectively). In addition, the use of anycast address enables service provider selection. This feature may be used for secure services (dedicated service provider) where the anycast address may not be altered and hence the data must be routed according to a source selected policy, eg: healthcare, customs, military and finance. (<http://playground.sun.com/pub/ipng/html/INET-IPng-Paper.html>)

systems to prevent data binding irregularities that may have fatal consequences in healthcare. These applications may also develop to include “Medical Google” type web services for point-of-care reference where human experience or human-aided searches may be necessary to supplement diagnosis or diagnostics or automated information processing, distribution and execution systems.

The industry may not yet consider this a mature or profitable endeavour because it is erroneously concluded by some that the impact of this mechanism may not manifest soon enough. Japan and the Nordic countries have sufficient internet penetration and an increasing percentage of the population are e-savvy yet grey (over 65 year old with increasing demand on healthcare services, as one example). They may soon seek and need e-healthcare “sense *then* respond” systems (Figure 1) to stem down healthcare costs. The system must respect privacy, data identity and security. This problem is real and will require a solution if industrialized nations expect that their healthcare expenditure remain a reasonably small percentage of their gross domestic product.

Clearly a broad spectrum of applications will find it essential to “number numbers” in a manner where identity and relativistic identification lends itself to information and context including provision for quality of real-time⁵ service at the right-time, all the time, plus authentication, data integrity, confidentiality and privacy.

⁵ The buzz around “real-time” data is as intense as the inability of most businesses to extract value from real-time data (see <http://esd.mit.edu/WPS/esd-wp-2006-11.pdf>). However, the cost of network delays in data transmission can have hazardous or even fatal effects in emergencies or accidents. Thus, IPv6 offers a new capability by introducing [a] the 24-bit Flow Label and [b] the 4-bit Priority field in the IPv6 header to enable labeling of packets belonging to particular traffic “flows” for which the sender can request special handling for real-time applications. Currently some hosts and routers do not support this function.

[a] The 24-bit Flow Label in the IPv6 header is designed to be used by a host to identify packets for non-default quality of service (QoS) or “real-time” service. A flow is a sequence of packets sent from a particular source to a particular (unicast or multicast) destination for which the source requests special handling by intervening routers. The nature of the special handling may be conveyed to the routers by a control protocol (eg: resource reservation protocol) or through embedded information in the flow packet (eg: hop-by-hop option). There may be multiple active flows from a source to a destination, uniquely identified by combination of a source address and a non-zero flow label. Packets that do not belong to or not associated with any flow traffic, carry a flow label of zero. (<http://playground.sun.com/pub/ipng/html/INET-IPng-Paper.html>)

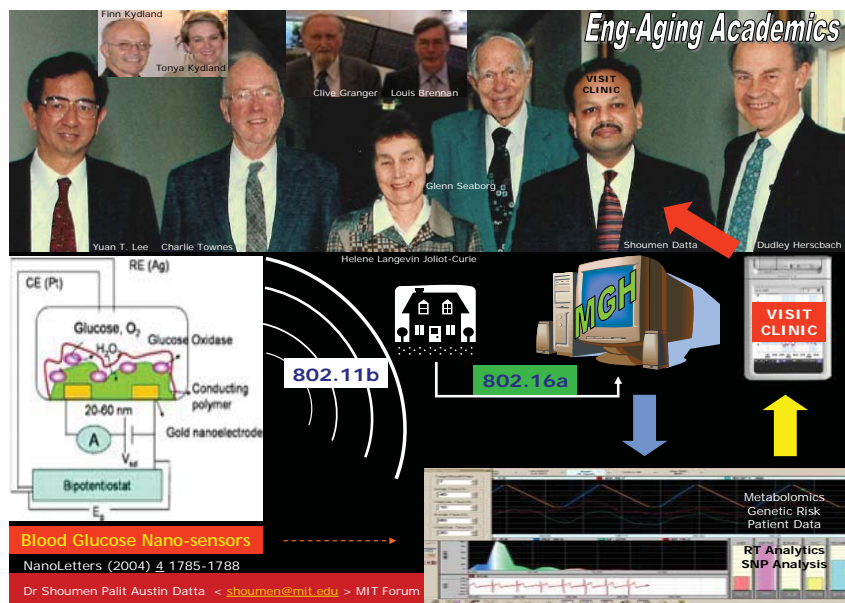


Fig. 1. Emerging eHealthcare “sense *then* respond” decision system may reduce cost of old age

3.4 Convergence with Semantic Web

The sub-title of this section is still really a question or a hypothesis, not a statement. The convergence is imminent because it is well nigh impossible to mention the word “information” without thinking about syntax, semantics, relations and other elements of interoperability, which are crucial for increasing the value of information to generate decisionable information.

[b] The 4-bit Priority field in the IPv6 header enables a source to identify the desired delivery priority of its packets relative to other packets from the same source. The Priority values are divided into 2 ranges: values 0 through 7 specify the priority of traffic for which the source is providing congestion control (traffic “backs off” in response to congestion). Values 8 through 15 are used to specify the priority of packets that does not back off in response to congestion (transmitted in real-time at a constant rate).

The ontological framework necessary for the semantic web uses a powerful tool, RDF or resource description framework, which works, in part, through use of URI (universal resource identifier). The latter is a higher layer abstraction that uniquely identifies a resource (even if the resource lacks a web address). These relationships must be *pre-designed* before RDF and RDF/XML can be applied.

These relationships, for example in the biomedical field, are referred to as “controlled ontological vocabulary” which must be created to plumb (search) the depths of the repertoire. This process generates even more syntax or labels to script the triples (subject-predicate-object) and introduces variability due to type of group, individual, nationality, mother tongue and a host of factors that may be difficult to standardize in an open environment (hence, routed through slew of committees for acceptance). The vast number of groups involved in creating ontologies uses a myriad of formats to specify application-specific domains. When these relation “trees” are consecutively added to higher level hierarchies (ontological soup ensues) the problem of keeping track of tags and meta data may create quagmire for which yet another standard may be sought! This problem is illustrated by the omics initiative [10] involving a handful of post genomic technologies (transcriptomics, proteomics, metabolomics). Several standardization groups are working on metadata and ontology in this sub-field.

If ‘omics’ may be defined as processes operating within a cell and the ‘cell’ subclass contains two related fields (intra-cellular and extra-cellular) and if cells are considered parts of ‘tissues’ and tissues are classified under ‘organs’ then, imagine the plethora of committees necessary to standardize and define biological molecules. Is there a feasible alternative to track and trace these ontology relationships that is amenable to machine intelligence and include use of metadata tags?

Hence, there are several deep issues involved in this simple example. Therefore, for the context of this argument, the focus is only on one sub-issue: the nature of the unique resource identifier (URI). Is there a benefit to transition the URI to a pre-agreed system that all groups may agree to use without further standardization? My naïveté (fools rush in where angels fear to tread) proposes the use of IPv6 to uniquely identify (map) URI layer from domains of pre-subscribed numbers which are assigned to classes and subclasses (illustrated in Figure 2 and Figure 3).

Table 1. An ever increasing number of standardization activities

<i>Community effort and website</i>	<i>Standardization activities</i>	<i>Citation in this issue</i>
Genomic research		
The Genomic Standards Consortium (GSC): (www.genomics.ceh.ac.uk/genomecatalogue/)	Content (Minimal Information about a Genome Sequence: MIGS), syntax, and semantics	(Field et al., 2006; Morrison et al., 2006a)
International Nucleotide Sequence Database Collaboration (INSDC): (www.insdc.org)	Content (INSDC Third-Party Annotation Submission Guidelines)	(Cochrane et al., 2006)
Genome Reviews: (www.ebi.ac.uk/GenomeReviews/)	Content (review of standardization within the Genome Reviews database) and syntax	(Sterk et al., 2006)
GSC: Chair of Organelles Working Group: (www.genomics.ceh.ac.uk/genomecatalogue/)	Content (call for standardization of descriptions of organelles)	(Boore, 2006)
Post-genomic standardization		
MGED Society: (www.mged.org)	Content (Minimal Information about a Microarray Experiment: MIAME), syntax, and semantics	(Ball and Brazma, 2006)
HUPO-Proteomics Standards Initiative (PSI) (http://psidev.sourceforge.net)	Content (Minimal Information about a Proteomics Experiment guidelines: MIAPE), syntax, and semantics	(Taylor et al., 2006)
Experimental Standards for Proteomics	Content (call for development of standard experimental mixtures of proteins)	(Hogan et al., 2006)
Metabolomics Society-MSI (Metabolomics Standards Initiative): (www.metabolomicsociety.org)	Content, syntax, and semantics	(Fiehn et al., 2006)
Integration activities		
Reporting Structures for Biological Investigations Working Group (RSBI): (www.mged.org/Workgroups/rsbi/rsbi.html)	Contributions to content and semantics	(Sansone et al., 2006)
"Env" Community led by the Environmental Genomics Working Group (EGWG): (http://envgen.nox.ac.uk/miame/miame_env.html)	Content (MIAME/Env checklist), syntax, and semantics	(Morrison et al., 2006b)
The Functional Genomics Experiment Object Model (FuGE): (http://fuge.sourceforge.net/)	Syntax	(Jones et al., 2006)
National Center for BioMedical Ontology (cBIO): (www.bioontology.org/)	Semantics	(Rubin et al., 2006)
Functional Genomics Investigation Ontology (FuGO): (http://fugo.sourceforge.net/)	Semantics	(Whetzel et al., 2006)
Other initiatives		
MISFISHIE Working Group: (http://mged.sourceforge.net/misfishie/)	Content (MI Specification for <i>In Situ</i> Hybridization and Immunohistochemistry Experiments: MISFISHIE), syntax, and semantics	(Deutsch et al., 2006)

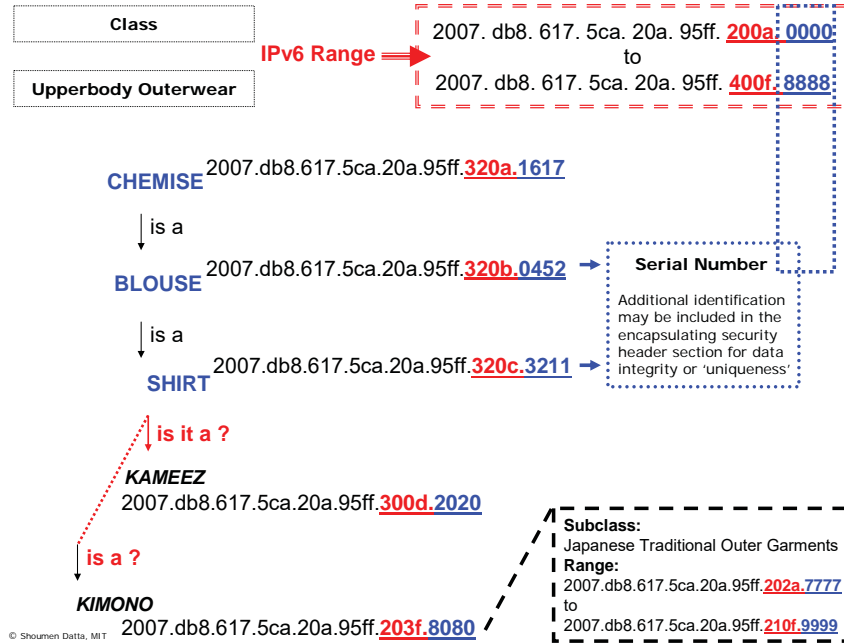


Fig. 2. Co-embedding unique id with syntax and semantics?

Uniquely Numbering URIs in the Ontological Framework
 Extend (?) IP Addressing Strategies of Subnet & Subnet Masks to Label Class & Subclass Abstractions

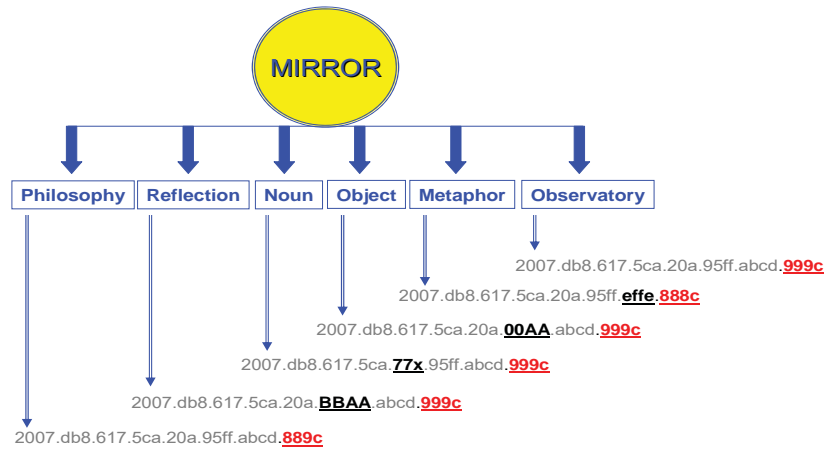


Fig. 3. Moving from descriptive or “analog” to unique or “digital” relationships?

Because IPv6 has a reasonable chance to be adopted globally, a mechanism to map URI abstractions to IPv6 structure offers synergistic convergence. It may reduce the gulf between business thinking and systems (ICT) specifications.

However, the creators of IPv6 pointed out that no matter how good a new protocol (or idea) may be, it may not matter if there isn't a practical way to transition from one to another. There may be several known reasons why the suggestion in Figure 4 (below) of transitioning URI to an IPv6 format may not be feasible. On the other hand, unknown unknowns (reasons) may exist that may make this suggestion feasible or practical when and if the unknowns emerge as knowledge.

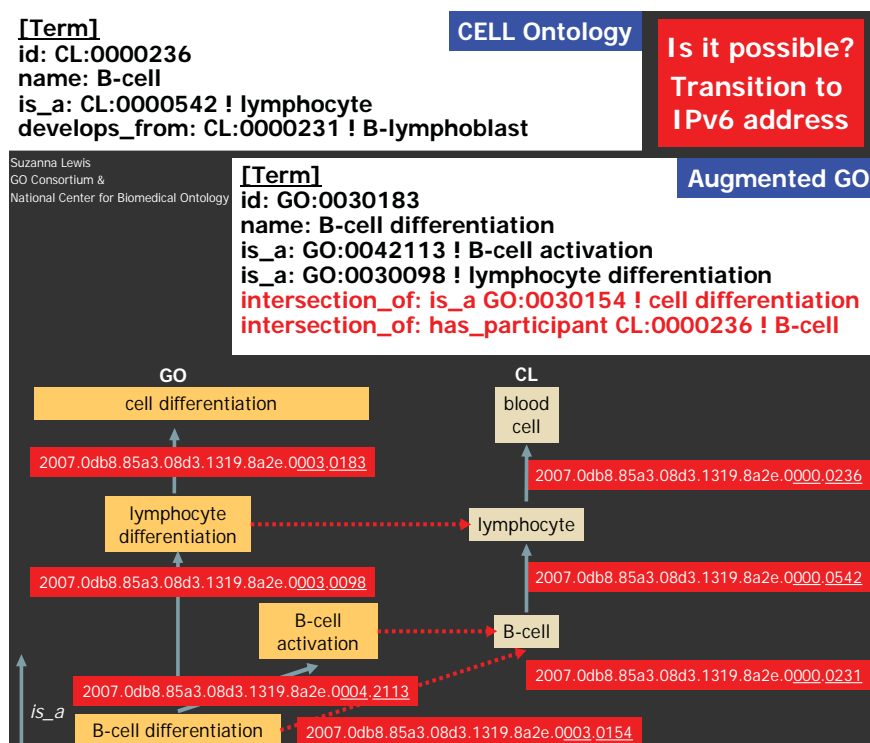


Fig. 4. Potential transition strategy?

3.5 Security

Another application area that may benefit from a vast library of detailed resources with unique identification that can be selected in a dynamic manner, is that of policy. Often, a “handbook” of policy may contain several thousand clauses and sub-clauses (assume that all these details exist as thousands of separate URIs). When a scenario surfaces (for example, US Department of Homeland Security certified Tier 2 business group authorized to import finished goods in containers, files a manifest that indicates additional inventory of sub-components) that calls for use of selected policies (to authorize a search of the container, in this case) then resources (that is, policies) that are applicable for that scenario can be selected (from a remote management location) by using the routing capability of IPv6 to choose sets of interfaces (with IPv6 addresses) from thousands of policies (from the policy domain) that may be involved in the analysis, assessment and management of security threats and risk (Figure 5).

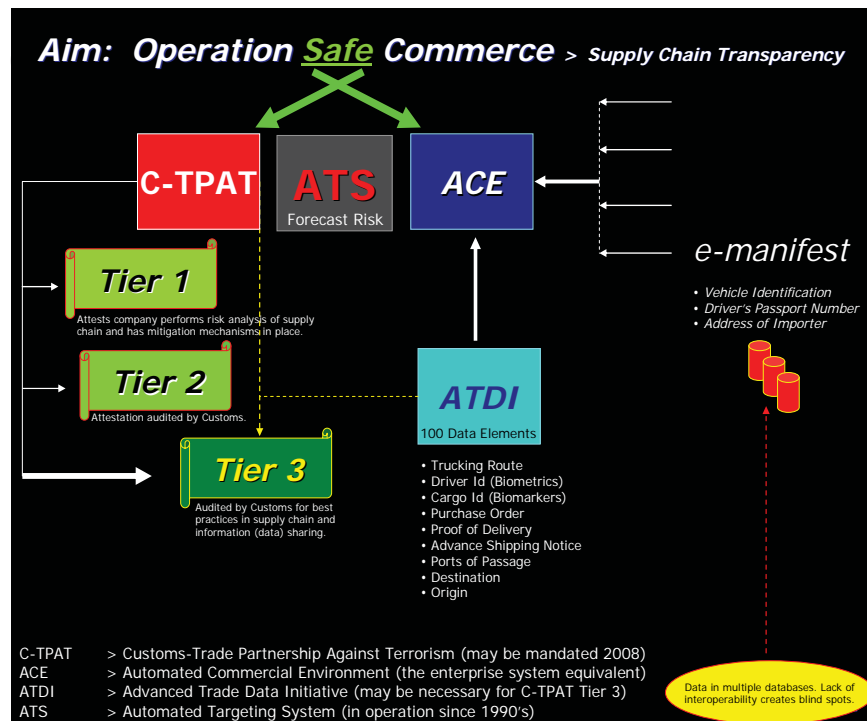


Fig. 5. Risk Management through systems approach (convergence of data, policy, information)

In a related security scenario, it may be significant to analyse the following: data acquired from sensors (data element 1) linked to a specific container (data element 2) transported on a vehicle (data element 3) driven by a credentialed driver (data element 4) who belongs to a logistics provider (data element 5) registered as a NVOCC (non-vessel operating common carrier) with a NVOCC code (data element 6). If customs and border protection (CBP) wants to analyse this sensor data at a local port of entry for targeting purposes, it is likely to assign a key, quite similar in concept and practise to EPC-IS (see section 3.2). In this scenario the key is a field or combination of fields used to “anchor” other fields. These methods may still be in use for “look data up” using key fields which are “arbitrarily created, for example, by creating some unique record ID or other unique count to distinguish otherwise unidentifiable data” [11].

It is, therefore, amply clear to understand why such arbitrary identification does not lend itself to portability and interoperability between systems. A clue uncovered and assigned a “key” at a port of entry by the US Coast Guard (USCG) remains “unique” in that system but may not be visible or meaningful in its association within the Automated Commercial Environment (ACE) or other targeting systems where non-obvious relationship analysis (NORA) is performed (for threat assessment and risk).

If NORA points to possible need for inspection, in a related scenario, confluence of policy becomes equally important to ensure execution of action is within legal limits. The laissez-faire concept of creating keys for supposedly unique identification needs a careful review, especially in threat assessment and risk analysis. Few “red handed” instances will be revealed through obvious relationships. Non-obvious relationship analysis is increasingly crucial to connect arcane associations that must be sorted from vast amount of essential and non-essential data, uniquely identified in a manner that can be accessed by any authorized system in any geographic location and analysed repeatedly in different contexts in diverse domains to determine risk profile.

Data analysis for domestic (US) threat assessment in the transportation sector alone, could originate anywhere, in any form, in several instances, several times a minute or

hour, in the network connecting towns, cities, manufacturers and retailers, moving large volumes of goods and individuals through a system of approximately 4 million miles of roads and highways, 120,000 miles of rail road, 600,000 bridges, more than 300 tunnels and numerous sea ports, 2.2 million miles of pipeline, 500,000 train stations, 500 public airports operating more than 200,000 commercial aircrafts [12].

Table 2: Why IPv6 unique identification of information may be crucial for security and NORA

- 3.9 million miles of public roads
- 1.2 million trucking companies
- 15.5 million trucks
- 42,000 hazardous material (HAZMAT) trucks
- 10 million commercial vehicle drivers including 2.7 million HAZMAT drivers
- 2.2 million miles of hazardous liquid and natural gas pipeline
- 120,000 miles of major railroads
- 15 million daily riders on mass transit and passenger rail, nationwide
- 25,000 miles of commercial waterways
- 361 ports
- 250,000 containers per day
- 9.0 million containers through 51,000 port calls
- 11.2 million containers via Canada and Mexico
- 19,576 general aviation airports, heliports and landing strips
- 459 Federalized commercial airports
- 211,450 general aviation aircraft
- 77% of all flights are general aviation

3.6 Mobile *ad hoc* Sensor Networks (MANET)

By some estimates, the scope of unique identification using IPv6 is a staggering 6×10^{19} addresses per mm^2 of the surface of the Earth, based on the fact that IPv6 supports 3.4×10^{38} addresses and an approximation that $5 \times 10^{14} \text{ m}^2$ is the surface area of our planet. It may be argued that the number (6×10^{19} addresses per mm^2) represents a monolayer of interfaces (a node may have multiple interfaces, each with a globally unique IPv6 id) which is an unlikely scenario in internet devices, for example, an automobile or equipment such as HVAC (high voltage air conditioning) system. In a

vehicle or HVAC there may be a vast array of interfaces (nodes, sensors) packed in close proximity (multi-layer topology). Other internet devices or internet appliances (example: refrigerator, light switches) may have multi-layer topologies. Internet infrastructures, for example, buildings, may be densely packed with interfaces (for example, if every TV or light switch is an IP node, then think about the number of televisions and switches in Taipei 101, the tallest building in Taiwan).

Hypothetically, assume that the entire surface of the Earth may be organized as layers of interfaces 1 mm apart and that this hypothetical layer is 100 km in depth (consider sensors and actuators in deep sea drilling equipment and observatories on top of the Mount Everest). Even if we have such an improbable density of interfaces demanding globally unique id, the number of possible unique id is approximately 6×10^{10} IPv6 addresses for mm^2 of Earth's surface that is 100 km or 1×10^9 mm deep! In other words, 60 billion unique addresses per square mm of the Earth at a depth of 1 billion mm (Figure 6). This logic fuels the speculation that internet communication with Martians and objects in Mars may be within the scope of the design of IPv6.

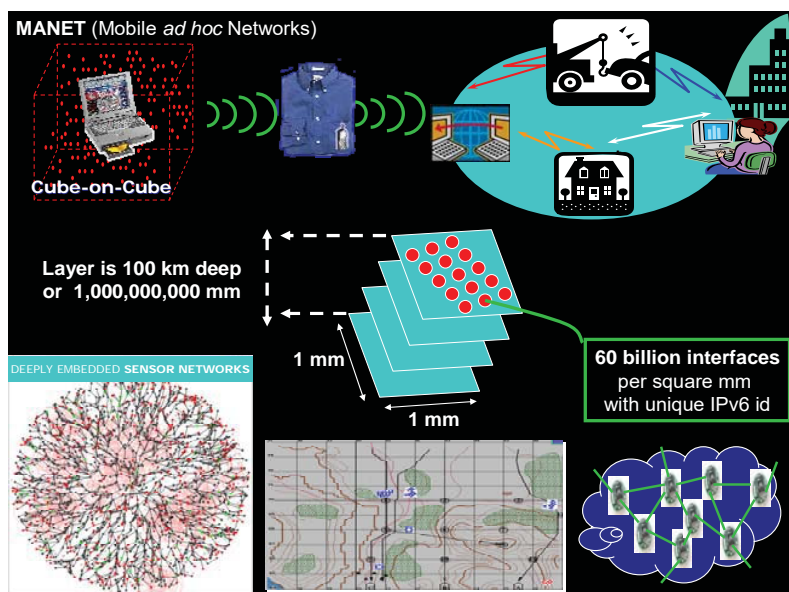


Fig. 6. Uniquely identifiable sensors

This logic supports the extrapolation that IPv6 addresses may be used for unique id in mobile *ad hoc* sensor networks (MANET) in military applications where trillions of sensor nodes may be connected to logistics decision or monitoring systems of the war-fighter (Figure 7). These systems demand dynamic adaptive routing and auto-reconfiguration yet must retain critical data links, identity, coordination and interoperability with multiple commands or legacy (ERP) systems operating in vastly separated geographic locations.

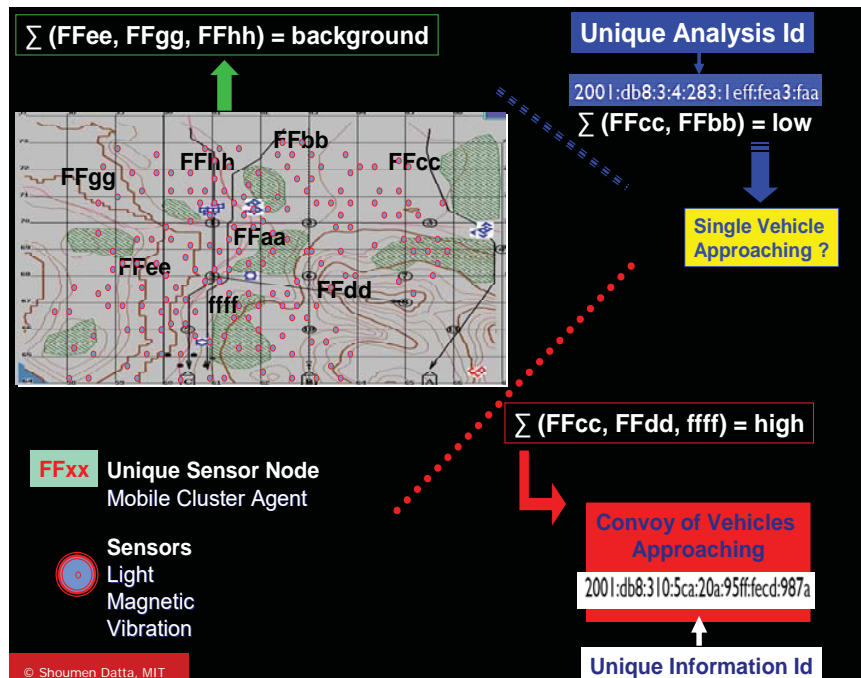


Fig. 7. Military Monitoring in Practice

Individual sensors may now be directly “plugged” in the internet using IPv6. Routing extensions in IPv6 support powerful functionalities like host mobility (route to current location) and auto-readdressing (route to new address) that may be useful for mobile *ad hoc* networks (MANET). The routing option is used by IPv6 source to list one or more intermediate nodes (in the network topology) to be “visited” on the path to the

destination of the packet. For dynamic and adaptive MANET, the management of host mobility and automatic readdressing functionalities may require convergence of IPv6 features in combination with mobile agents [13] or mobile cluster agents that can manage the “measure of distance” of routing protocols to a higher level of abstraction where granular data (packets) are aggregated (Cluster Agents) and decision or higher level information with unique IPv6 id is transmitted to one or more (unicast, anycast or multicast) superior node in the network (MANET) topology or linked to other decision systems (legacy, applications). Assignment of IPv6-based id (pre-subscribed domain) may be managed by higher order Cluster Agents. Because some of the activities may be closed loop or terminal, it is possible to reclaim underutilized assigned network id. The reclaiming process may follow a pattern of inactivity (loss of signal over extended period) and the recovery of id may be governed by elementary autonomic paradigms drawn from the AI (artificial intelligence) domain.

For consumer purposes, an example of MANET is a vehicle. Hence, transportation, logistics, supply chain and business, military, healthcare operations that need real-time data plus analysis of information may access granular data (unique data cubes) yet extract decisionable information in a manner that may be uniquely identified (traced) to its source. Track and trace identification is key to guarantee food-water safety and in customs operation where *ad hoc* assessment of threat or risk is crucial. Thus, IPv6 supported large hierarchical addresses will enable the functional growth of the internet and provide new routing capabilities that were not robust enough in IPv4.

4 Concluding Comments

The inclination to reap, with haste, the ‘low hanging fruits’ often derail convergences necessary for adaptive strategies [14] in business and in a broad spectrum of decision systems including logistics management [15]. Contextual numbering of numbers and contextual identification of decisionable information, using IPv6 represents, albeit only one element, but a potentially valuable confluence of identification, transmission and routing of data relative to information in systems to provide answers [16]. IPv6

Shoumen Datta, MIT

may offer a plausible and simple mechanism not only to track global movement of bits (data) and atoms (physical goods) and to connect bits and atoms but also to connect *bits to bits*. This suggestion has received some preliminary [17] support.

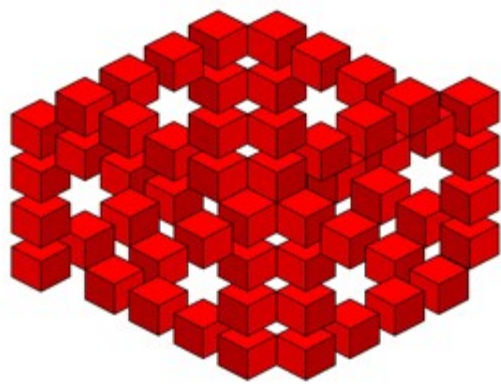
Acknowledgements. This idea germinated while attempting to explain to a class of international Master's students the future potential for innovative tools in systems interoperability and visibility (www.student.chalmers.se/ka/hp/hp?hp_id=3013). The author is indebted to the vibrant students in the ITR536 course for their reluctance to accept shoddy explanations of what constitutes and attributes necessary for, increasing visibility and in future, transparency, in geographically agnostic intelligent decision systems. This was during November 2006 while teaching the Master's course in Supply and Demand Chain Design and Management (ITR536) at the Chalmers University of Technology in Gothenberg (Sweden), where the author was a visiting faculty in the Division of Logistics and Transportation in the School of Technology Management and Economics. The author is grateful to Professor Kenth Lumsden of Chalmers University of Technology and Professor Gunnar Stefansson of Chalmers University of Technology and University of Iceland, for this rewarding invitation to teach and advise students at Chalmers University of Technology. Generous financial support for this period was provided by the Division of Logistics and Transportation, Chalmers University of Technology. The author's teaching duties for ITR536 were particularly invigorating due to the kind support offered by Mr Ola Hultkrantz and Mr Per Medbo of the Division of Logistics and Transportation at Chalmers University of Technology (Goteborg, Sweden). In addition, the author has gained insights from discussions about this idea with Professor Gunnar Stefansson (University of Iceland and Chalmers University of Technology), Mr Andy Mulholland (Global Chief Technology Officer, CapGemini), Dr Joseph Salvo (Director, GE Global Research), Dr Robert Ciskowski (IBM Innovation Center), Professor Rodney Brooks (Director, Computer Science and Artificial Intelligence Laboratory, MIT), Professor John Williams (Director, Auto-ID Lab, MIT), Mr Micah Samuels (Senior Manager, Amazon), Dr Richard Swan (Chief Technology Officer, T3Ci), Dr Maria Azua (Vice President, IBM), Dr Ralph Droms (Chief Engineer, Office of the Chief Technology Officer, Cisco Systems) and Professor Joseph Sussman (J R East Professor, Professor of Engineering Systems and Civil and Environmental Engineering, MIT). This idea has received some support from Charles Simonyi of IntentSoft (formerly with Microsoft Corporation), Mark Greaves of

Vulcan (formerly with DARPA, US Department of Defense) and Professor Sanjay Sarma, MIT (Member of the Board of EPC Global and Co-Founder and former Research Director of MIT Auto-ID Center). Encouragement from my colleagues at the MIT Forum for Supply Chain Innovation (Professor David Simchi-Levi, Dr William Killingsworth, Ms Janet Kerrigan and Miss Megan Gately) is gratefully acknowledged. I am thankful to Ms Janice Hall for her help with uploading and updates on the MIT ESD website while this was a working paper.

References

- (1) Datta, S.: Semantic Interoperability between Systems. Working Paper. Engineering Systems Division, MIT <http://esd.mit.edu/WPS/esd-wp-2006-10.pdf> (2006)
- (2) Datta, S., Granger, C: Potential to Improve Forecasting Accuracy. Working Paper. Engineering Systems, MIT <http://esd.mit.edu/WPS/esd-wp-2006-11.pdf> (2006)
- (3) Datta, S., Granger, C.W.J., Barari, M., Gibbs, T.: Management of Supply Chain: an alternative modeling technique for forecasting. *Journal of Operations Research Society (in press)*
- (4) World Wide Web Consortium www.w3c.org
- (5) Hinden, R.M.: <http://playground.sun.com/pub/ipng/html/INET-IPng-Paper.html> (1995)
- (6) Foster, I., Kesselman, C., Nick, J., Tuecke, S.: The Physiology of the Grid: an Open Grid Services Architecture for Distributed Systems Integration. Technical report, Global Grid Forum (2002)
- (7) Minsky, M.: The Society of Mind. Simon and Schuster, New York (1988)
- (8) Balakrishnan, H., Kaashoek, M.F., Karger, D., Morris, R., Stoica, I.: Looking up data in P2P systems. *Communications of ACM* (February 2003)

- (9) Sarma, S.: *personal communication*
- (10) Rubin, D.L.: Advancing Biomedicine through Structured Organization of Structured Knowledge” OMICS Journal of Integrative Biology 10, 185-198 (2006)
- (11) Joslyn, C., Mniszewski, S.: Relational Analytical Tools: VisTool and Formal Concept Analysis. Report prepared for Advanced Knowledge Integration for Terrorist Threats (2002)
- (12) Transportation Security Administration, Department of Homeland Security
www.tsa.gov
- (13) Maes, P., Minar, N.: Mobile Software Agents for Dynamic Routing
<http://nelson.www.media.mit.edu/people/nelson/research/routes-sigmobile/> (1999)
- (14) Datta, S., *et al* Adaptive Value Networks in Chang, Y. (Ed.) Evolution of Supply Chain Management: Symbiosis of Adaptive Value Networks & ICT. Kluwer Academic Publishers, Amsterdam, 3-75 www.wkap.nl/prod/b/1-4020-7812-9?a=1 (2004)
- (15) Datta, S.: Adapter, optimiser, prévoir - La convergence des concepts, des outils, des technologies et des normes peut-elle accélérer l'innovation? *Logistique & Management* 12, 3-20 (2004)
- (16) Datta, S.: Answers, not Numbers: Catalysing a Solutions Approach for Distributed Decision Systems (*in preparation*)
- (17) Simonyi, C.: *personal communication*



APPENDIX II

Shoumen Datta

HAPHAZARD REALITY – IOT IS A METAPHOR

THIS PAGE IS LEFT BLANK



Management of supply chain: an alternative modelling technique for forecasting

S Datta^{1*}, CWJ Granger^{2**}, M Barari³ and T Gibbs⁴

¹Massachusetts Institute of Technology, Cambridge, MA, USA; ²University of California at San Diego, La Jolla, CA, USA; ³Missouri State University, Springfield, MO, USA; and ⁴Intel Corporation, DuPont, WA, USA

Forecasting is a necessity almost in any operation. However, the tools of forecasting are still primitive in view of the great strides made by research and the increasing abundance of data made possible by automatic identification technologies, such as radio frequency identification (RFID). The relationship of various parameters that may change and impact decisions are so abundant that any credible attempt to drive meaningful associations are in demand to deliver the value from acquired data. This paper proposes some modifications to adapt an advanced forecasting technique (GARCH) with the aim to develop it as a decision support tool applicable to a wide variety of operations including supply chain management (SCM). We have made an attempt to coalesce a few different ideas toward a 'solutions' approach aimed to model volatility and in the process, perhaps, better manage risk. It is possible that industry, governments, corporations, businesses, security organizations, consulting firms and academics with deep knowledge in one or more fields, may spend the next few decades striving to synthesize one or more models of effective *modus operandi* to combine these ideas with other emerging concepts, tools, technologies and standards to collectively better understand, analyse and respond to uncertainty. However, the inclination to reject deep-rooted ideas based on inconclusive results from pilot projects is a detrimental trend and begs to ask the question whether one can aspire to build an elephant using mouse as a model.

Journal of the Operational Research Society advance online publication, 23 May 2007

doi:10.1057/palgrave.jors.2602419

Keywords: forecasting; supply chain management; multivariate GARCH; risk analysis; intelligent decision systems; RFID; sensor data

1. Background

Forecasting is an ancient activity and has become more sophisticated in recent years. For a long time, steady steps in a time series data set, such as simple trends or cycles (such as seasonals), were observed and extended into the future. However, now a mixture of time series, econometrics and economic theory models can be employed to produce several forecasts which can then be interpreted jointly or combined in sensible fashions to generate a superior value.

The variable being forecast is a random variable. Originally attention was largely directed towards the mean of this variable; later to the variance, and now to the whole marginal distribution. Pre-testing of the data to find its essential features has become important and that has produced modern techniques such as cointegration.

The horizon over which the forecast is attempted is also important, and longer-run forecasts are now being considered as well as forecasts of 'breaks' in the series.

The question of evaluation of forecasts has also been greatly developed. Most forecasts are quite easy to evaluate but others, coming from the Global Models (which attempt to model the global economy), are more difficult. Business, commerce, global organizations and governments may find that these models, if explored, may offer valuable guidance for their forecasting activities or their attempts to improve accuracy of forecasts.

Thus, forecasting is a necessity almost in any operation. However, the tools of forecasting (software) in general business use are still primitive in view of the strides made by research. Hence, promoting advances in forecasting to aid predictive analytics is deemed a worthwhile endeavour and is the purpose of this paper. Such tools may further reduce uncertainty and volatility characteristic of global trade. The relationship of various business parameters that may change and impact decisions are so abundant that any credible attempt to drive meaningful associations are in demand by global businesses. This paper proposes some modifications to adapt an already advanced forecasting technique with the aim to develop it as a decision support tool applicable to a wide variety of operations including supply chain management (SCM).

*Correspondence: S Datta, Engineering Systems Division, Department of Civil and Environmental Engineering, School of Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139, USA.

E-mail: shoumen@mit.edu

**Co-author shared the 2003 Nobel Prize in Economics.

2. Introduction

Total quality management (TQM) gained prominence in the 1970s by claiming to boost quality at a lower cost through proper management and operational design. Lean (manufacturing) was the euphoria in the 1980s following Toyota's exemplary adoption of Just In Time (JIT) processes to enable flexible manufacturing and minimize costs by reducing inventory level. However, it soon became clear that manufacturing costs could not be reduced further by pursuing variations of TQM and JIT simply through classical operations research. Globalization of markets in the 1990s combined with improvements in ICT (information communication technologies) and short product life cycles shifted the focus on SCM that could adapt to demand or reduce costs through improvement in efficiency.

SCM is a set of approaches to efficiently integrate suppliers, manufacturers, distributors, warehouses and retail stores so that merchandise is produced and distributed in the right quantities, to the right locations, at the right time in order to minimize system wide costs while satisfying (customer) service-level requirements (Simchi-Levi *et al.*, 2003). Viewed from this perspective, similarities exist between SCM practices and a competitive market economy. A market economy ensures that right mix of goods and services get produced (those that are most wanted by consumers) in the right way (ie least cost) and eventually distributed to the right people (those who are willing to pay the most). Therein lies the attractiveness of a market-based economy, that it gives rise to most efficient allocation of resources. Likewise, SCM, if appropriately designed and executed, may offer efficient business solutions, thereby minimizing costs and improving readiness or competitiveness.

Despite rapid advances in SCM and logistics, inefficiencies still persist and are reflected in related costs. During 2000, supply chain-related costs in the United States alone exceeded \$1 trillion (10% of GDP), which is close to the 2005 GDP of Russia and Canada or the combined GDP of the 22 nations who are members of the oil-rich League of Arab Nations. A mere 10% savings of supply chain costs in the United States is close to the 2005 GDP of Ireland (Datta *et al.*, 2004). More than US\$3 trillion have been spent on global logistics in 2004 and this represents almost 5% of the global GDP or more than the GDP of Germany and just less than the GDP of India in 2005. Inefficiencies in the global logistics network estimated at an approximate of US\$600 billion (close to the 2005 GDP of Australia) offers untapped opportunities for organizations to optimize or adapt to improve sustainable profitability. Hence, serious questions have been raised as to how to make decision systems more efficient in order to reduce cost of transaction (Coase, 1960, 1992). This, in turn, requires a thorough understanding of the factors that make design and operation of effective SCM strategy a challenging task due to the volatility of supply and demand.

It is challenging enough to design and operate a supply chain for one facility, in order that costs are minimized and service levels are maintained. The difficulty increases exponentially when the system as a whole is considered and system-wide costs must be minimized, that is, optimizing the interactions between various intermediaries, such as retailer, wholesaler, distributor, manufacturer and supplier of materials. This is mathematically equivalent to finding a global optimal solution as opposed to local optimization, the predominant business practise. Global optimization, involving several stages in the decision-making process, is far more complicated. It is also much broader in scope and encompasses local optimization, but only as a special case.

Some may argue, justifiably, that optimization itself is to be blamed for the inefficiencies in global SCM practices. Perhaps optimization suggests an innate assumption that operations are capable of reaching a steady state or equilibrium, once 'optimal' conditions are determined and executed. Global volatility, even in peaceful or stable political economies, may disprove this assumption. Hence, dynamic or recurrent real-time optimization is required and reflects the fundamental necessity of global supply chains to continuously adapt.

The task of global optimization is rendered difficult by the uncertainty of the business environment. First, businesses need to continually adapt to demand uncertainty and its impact on inventory management. In a market-based economy, production decision is primarily demand driven and must be made *ex ante* (before customer demand is realized). Furthermore, due to lack of information sharing *ex post* (after actual customer demand is realized) between partners, the variability in orders is amplified upstream, along the supply chain. This phenomenon is commonly referred to as the 'Bullwhip Effect' and it is a key driver of inefficiencies associated with SCM. It distorts the demand signals, resulting in costs in the form of excess capacity and inventory, need for increased storage, and transportation cost increases (due to less-than-truckload or LTL scenarios), to name a few (Lee *et al.*, 1997).

The Bullwhip Effect and the resulting inefficiencies associated with traditional supply chains may be reduced, in theory, by centralizing information relating to supply and demand (Datta *et al.*, 2004). In other words, a 'centralized' supply chain model is one where such information is made available to all participating businesses at various stages of the supply chain or network of partners. Advances in information and communication technologies in the past decade has made it easier to acquire, share, access and analyse data in a manner that is increasingly feasible for 'sense and response' systems. In the context of SCM, the idea is to enable intermediaries in the supply chain process to act as 'infomediaries' or serve as agents for sharing and accessing the real-time data flow through common interfaces, such as web-based services (Datta, 2006, 2007).

Acquisition of or access to data is not equivalent to use of decisionable information that can be extracted from data. Differences in forecasting methodologies applied (to the same

data) at different stages of SCM by the participants (process owners) may yield varying types of information that may further obscure the value of data or give rise to increased fluctuations, thus distorting the signals, such as demand (Lee *et al.*, 1997). To rein in the Bullwhip Effect, one contribution may stem from a standardized forecasting model, that may be used by the supply chain partners, as an analytical tool to extract value from the data that is accessible to all the partners. Sharing of such an analytical engine by a group of businesses is possible through the use of grid computing (Datta, 2004). Although we have the tools and technologies at our disposal, the sluggish growth of collaborative systems such as CPFR (collaborative planning, forecasting and replenishment) may be indicative of only a mild interest in the benefits of collaborative information processing. It is quite possible that lack of trust between businesses and heightened data security risks may be slowing real-world implementations of valuable strategies such as CPFR.

While a standardized forecasting model applied to near real-time data in a shared or centralized database may try to tame the Bullwhip Effect, it may never be eliminated due to outlier events and inherent or unexplained variability. In SCM, innumerable sources of variability exist, including factors such as demand forecasting, variability in lead time, batch processing or bulk ordering to take advantage of transportation discounts, price variability due to product promotion or discount, to name a few.

Hence, the objective of this paper is to propose the potential use of an advanced statistical modelling technique for the purpose of forecasting (originally proposed by Datta, 2003, 2004). Based on the pioneering work on time series econometrics by Clive W. J. Granger and Robert F. Engle (Engle and Granger, 1987, 1991), this paper proposes a few modifications to the statistical model proposed by Robert F. Engle based on advances in time series econometrics. The modifications were introduced to make the model more amenable for use in decision support systems, such as, SCM. If the proposed modifications are indeed viable, it is expected to explicitly model the interactions between various intermediaries of SCM as well as the time varying (non-constant) variability that manifests, at least in part, as the Bullwhip Effect. For example, our proposed model captures the cross-variable dynamics as reflected in interaction between supply chain nodes or stages (retailers, wholesalers, distributors) using vector auto regression (VAR) methodology which is essentially a model for the means of a vector process. The framework also explicitly models the time varying volatility (perhaps observed, in part, as the Bullwhip effect) by using a Generalized Autoregressive Conditional Heteroskedasticity (GARCH) technique (Engle and Kroner, 1995). GARCH is a model for volatility of a single series, whereas multi-variate GARCH (MGARCH) is a model for volatility (variances and covariances) for a vector. Therefore, the proposed model may also be denoted as a VAR-MGARCH model.

While these techniques have been widely used in finance (and economics) in the past few decades (and also earned Engle and Granger the 2003 Nobel Prize in Economics), to our knowledge, they have not been applied or explored as decision support tools by supply chain planners or analysts in the area of SCM.

By using a dynamic model of volatility (defined as standard deviation of variance), a GARCH type model has the added advantage of providing a forecast of volatility in near term. Such a forecast may be useful in calculating value at risk (VaR). However, VaR is estimated with a simplifying assumption, such as (joint) normality. Consequently, ARCH technique has become an indispensable tool in risk assessment and management in the financial sector (Engle and Manganelli, 1999). Globalization of the supply chain has concomitantly increased the risk in the supply chain due to potential for loss of profits from over-capacity (cost of excess inventory) or opportunity lost due to out-of-stock situations. Hence, it is our contention that use of similar methodology in supply chain processes may enable businesses to better manage or even quantify the risk in the process.

VAR-GARCH type models require estimating a large number of parameters and hence cannot be used in practice unless a large sample of data is available. The lack of availability of high volume granular data may explain the scarce interest in applying this modelling technique as a forecasting tool in decision support systems. High volume accurate data is the single most important driver for forecasting accuracy. The recent rejuvenation of the use and adoption of automatic identification technologies (AIT) may partly ameliorate the lack of high volume data. The surge in the use of radio frequency identification (RFID) or ultrawideband (UWB) tags that may be embedded or attached with physical objects, will make it possible to track and locate objects along the entire supply chain, if the systems used by manufacturers, distributors, logistics providers and retailers are able to take advantage of middleware and hardware interoperability (software defined radio or SDR) to monitor, access and share near real-time data from RFID tags or sensors.

Thus, pervasive use of automatic identification may provide high volume object data in near real time with the maturing trend toward ubiquitous computing. Businesses may not have a clear understanding of how to use this data efficiently to extract decisionable and actionable information that offers business value not merely through savings but may actually increase profitability. We propose that businesses explore advanced techniques such as multivariate GARCH that requires high volume of data for estimation but offers the potential to deliver increasingly accurate forecasts along with a measure of VaR. Success in applying similar models to analyse financial market returns is well documented. Global SCM and any operation in need of planning for the future (healthcare, military, emergency) offers interesting applications for VAR-MGARCH techniques.

In the next section, we develop this statistical model for forecasting on a sequential, step-by-step basis, with the idea that independent variables represent operational ‘nodes’ (for example, the ‘stages’ or entities in supply chain). Section 4, discusses data requirements for model validation including the significance of automatic identification data. Risk in the global supply chain is qualitatively discussed in Section 5. Concluding thoughts are offered in Section 6 including comments about preliminary results obtained in (only) one study that explored the use of the modification proposed in this paper to simulate improvements in forecasting based on (only) one data source from an ongoing real-world operation.

3. Statistical model: VAR-MGARCH

Forecasting demand is a key tool in managing uncertainty. Forecast accuracy may depend on the understanding and coverage of parameters taken into account and the accuracy of historic data available for each variable that may have an impact on the prediction. In this section, we propose a statistical model that combines classical regression analysis with advanced time series techniques, hopefully to improve accuracy of forecasts.

3.1. CLRM

Classic linear regression models (CLRM) have been around for a century (Studenmund, 2000) and used for a variety of purposes including traditional supply chain planning software. CLRM may be expressed as follows:

$$y_t = \beta_0 + \beta_1 x_t + \varepsilon_t \quad (1)$$

where y is the dependent variable of interest to be modelled for forecast (eg sales of a product, say aspirin); t the time period (frequency of observation, for example, $t - 1$ may indicate prior week 1, $t - 2 \rightarrow$ week 2); β the coefficients to be estimated (based on values of y and x); x the explanatory variable that is used to ‘explain’ variations in the dependent variable y (for example, low sales of aspirin may be explained by low in-store inventory $\{x\}$ of aspirin) and ε the random (stochastic) error term.

This simple technique can model multiple independent or explanatory variables, that is, multiple x ’s, since the variation in y , say, sales of aspirin, is dependent on multiple parameters, such as inventory (x_1), price (x_2), expiration date (x_3). The choice of x ’s (number of explanatory variables) will drive the validity and accuracy of the model. X ’s may be based on underlying economic principles (theoretical) or business logic (practical underpinnings). However, no matter how many x ’s are included, there may be an inherent randomness in y that cannot be explained. Thus, the random error term (ε) is included in the equation (admission of the fact that the dependent variable (y) cannot be modelled perfectly). The corresponding mathematical equation is given by Equation (2):

$$y_t = \beta_0 + \beta_1 x_{1t} + \beta_2 x_{2t} + \cdots + \beta_K x_{Kt} + \varepsilon_t \quad (2)$$

Objective of CLRM is to estimate the parameters ($\beta_0, \beta_1, \dots, \beta_K$) of the model based on a *sample* of observations on y and x , assuming that ε is characterized by a normal distribution with mean = 0 and variance = σ^2 for all time periods (t). Normality assumption is needed for hypothesis testing with respect to β ’s based on sample of data, unless the sample size is large.

$$\varepsilon_t \sim N(0, \sigma^2)$$

Given the multiple sets of ($\beta_0, \beta_1, \dots, \beta_K$) may be estimated, the objective of CLRM is to choose that set of ($\beta_0, \beta_1, \dots, \beta_K$) which minimizes the sum of squared residuals ($e_1^2, e_2^2, \dots, e_N^2$):

$$\sum_{t=1}^N e_t^2$$

where e_t = empirical counterpart of ε (and is estimated based on sample data). Intuitively, this amounts to finding a line that best fits the data points by minimizing the sum of squared vertical distances of the actual data points from the fitted line. Thus, residuals are essentially in-sample forecast errors as they measure the difference between actual y and fitted y . This technique is commonly referred to as the principle of ordinary least squares (OLS) and widely used due to its simplicity. The attractiveness of CLRM-based OLS forecasting stems from the fact that we can model cross variable linkages. This feature is especially useful to carry out ‘what-if’ analysis. For example, what may happen to sales (y , the dependent variable) of aspirin-based painkillers in retail sales if the in-store inventory of non-aspirin painkillers were increased by 10%? Clearly, ‘what if’ analysis is conditional upon assumptions we make about x ’s in the model. Therefore, in building this model, the choice of x is a *process* decision based on the model builder’s knowledge about an operation or business or industry.

One may wonder if we are playing a ‘what if’ game or is 10% increase, cited above, a real-world scenario. The retail outlet surely knows what has happened in the past. This segues to the next phase in the development of our statistical model where it is no longer necessary to assume values of the explanatory variable to forecast y (the dependent variable). Instead of inserting arbitrary values for future x ’s (such as a 10% increase), we start by forecasting the values of x based on its own past data to obtain an unconditional forecast for y . In this stage of model development, the regression technique gets intertwined with time series techniques. By fitting a univariate autoregressive model to x where we use past (lagged) values of x to forecast x , we obtain the following equations (for x_{1t}, \dots, x_{Kt}):

$$\begin{aligned} x_{1t} &= \alpha_{10} + \alpha_{11}x_{1t-1} + \alpha_{12}x_{1t-2} + \cdots + \alpha_{1N_{x_1}}x_{1t-N_{x_1}} + u_{x_{1t}} \\ x_{Kt} &= \alpha_{k0} + \alpha_{k1}x_{kt-1} + \alpha_{k2}x_{kt-2} + \cdots + \alpha_{kN_{x_k}}x_{kt-N_{x_k}} + u_{x_{kt}} \end{aligned} \quad (3)$$

Rewriting using general notation:

$$y_t = \beta_0 + \sum_{i=1}^{N_{x_{1t}}} \alpha_{1i} x_{1t-i} + \cdots + \sum_{i=1}^{N_{x_{kt}}} \alpha_{ki} x_{kt-i} + \varepsilon_t \quad (4)$$

or

$$y_t = \beta_0 + \sum_{k=1}^K \sum_{i=1}^{N_{x_{kt}}} \alpha_{ki} x_{kt-i} + \varepsilon_t \quad (4a)$$

where x_{1t} is the variable x_1 at time t (for example, we used x_1 for inventory, thus x_{1t} is inventory at time t), x_{kt} the variable x_k at time t (up to k number of x 's), x_{1t-1} the value of x_1 at time $t-1$ (referred to as the lagged value by one period), N the period up to which the lagged values of x_{1t} will be used in the equation, u the random error term.

Note that β_0 in Equation (4) is a combination of constants from Equations (2) and (3), respectively.

In Equation (3), α_{11} , α_{12} are coefficients of x_{1t-1} , x_{1t-2} and are referred to as lagged weights. An important distinction is that instead of arbitrarily assigning weights, these coefficients are estimated using OLS. The error term in Equation (3) represented by u is analogous to ε in Equation (1). Depending on the number of x 's (x_1, \dots, x_K) that adequately represents the process being modelled in Equation (1), there will be K number of equations as given by (3) that must be estimated to forecast the x 's (x_1, \dots, x_K) which will then be used to obtain an unconditional forecast of y . Thus, to simplify the task, we can estimate all the parameters (α, β) simultaneously by re-writing Equation (1), the basic CLRM equation, as Equation (4) or its shortened version, as in Equation (4a).

Equation 4 is a step toward forecasting the dependent variable (y) with greater accuracy using forecasts of x 's based on historical data of x 's (lagged values). But, it is also clear that Equation (4) ignores the impact on y of the past values of y itself (lagged values). Consequently, a preferable model will include not only lagged values of x but also lagged values of y , as shown in Equation (5).

$$y_t = \beta_0 + \sum_{j=1}^{N_y} \varphi_j y_{t-j} + \sum_{k=1}^K \sum_{i=1}^{N_{x_{kt}}} \alpha_{ki} x_{kt-i} + \varepsilon_t \quad (5)$$

In moving from conditional to unconditional forecasts of y using a time series model, we are increasing the number of parameters to be estimated. In Equation 2, we estimate K parameters (β_1, \dots, β_K) excluding (β_0). In Equation 3, we estimate n parameters ($\alpha_1, \dots, \alpha_N$) excluding the intercept (α_0) for each of the K number of x 's (X_1, \dots, X_K). In Equation 5 we estimate j parameters for lagged values of y_{t-j} ($\varphi_1, \dots, \varphi_j$) in addition to all the parameters for Equation 4. If we set $K=5$ (five explanatory variables, the x 's), $N_x=10$ (number of lagged values to forecast the x 's) and $N_y=10$ (number of lagged values of y_t), then, we have increased the number of parameters to be estimated from 5 in Equation (2) to 50 in Equation (4) to 60 in Equation (5) (excluding intercept). To

drive precision to the next (logical) step, equation 5 may be expanded further to include the important real-world observations regarding trend, seasonality and other cyclical dynamics. Businesses struggle to uncover 'trends' and once found, they are avidly pursued, often for short term gains but increasingly with less than stellar results due to fickle customer preferences.

3.2. GARCH

Thus far, our discussions have centred on CLRM in conjunction with time series techniques. CLRM is based on a set of assumptions mainly about ε , that, when satisfied, gives rise to desirable properties of the OLS estimates. Needless to emphasize, in the real world, these assumptions are almost always violated. Developments in time series, over the past couple of decades, have addressed the challenges that stem from the violation of some of these classical assumptions leading to inaccurate forecasts.

One of the assumptions often violated in practice relates to homoskedasticity (homo≈equal, skedasticity≈variance or mean squared deviation (σ^2), a measure of volatility) or constant variance for different observations of the error term. Forecast errors are frequently found to be heteroskedastic (unequal or non-constant variance). For example, in multi-stage supply chains, the error associated with manufacturer's forecast of sales of finished goods may have a much larger variance than the error associated with retailer's projections (the assumption being that the proximity of the retailer to the end consumer makes the retailer offer a better or more informed forecast of future sales through improved understanding of end-consumer preferences). The upstream variability reflected in the Bullwhip Effect violates the basic premise of CLRM, the assumption of homoskedasticity. CLRM ignores the real-world heteroskedastic behaviour of the error term ε_t and generates forecasts which may provide a false sense of precision by underestimating the volatility of forecast error.

Homoskedastic and heteroskedastic error term distributions are illustrated in Figure 1. In a homoskedastic distribution, all the observations of the error term can be thought of as being drawn from the same distribution with mean = 0 and variance = σ^2 for all time periods (t). A distribution is described as heteroskedastic when the observations of the error term may be thought of as coming from different distributions with differing widths (measure of variance). In supply chains, the variance of orders is usually larger than that of sales. This distortion tends to increase as one move upstream from retailer to manufacturer to supplier. Therefore, the assumption of heteroskedasticity seems more appropriate as a characteristic that may be associated with the Bullwhip Effect.

While variance of error term may change across cross-sectional units at any point in time, it may also change over time. This notion of time varying volatility is frequently observed in financial markets and has been the driving force behind recent advancements in time series techniques. Robert

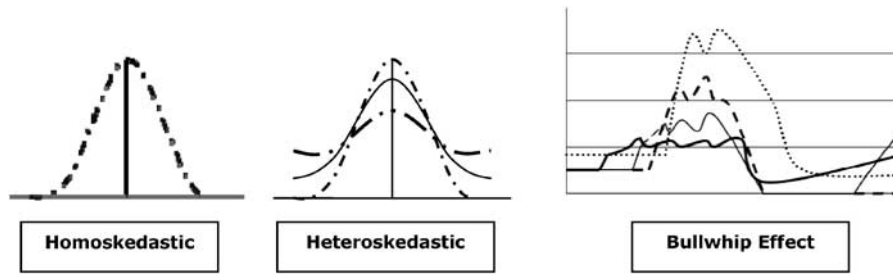


Figure 1 Homoskedasticity, heteroskedasticity and the Bullwhip Effect.

Engle is credited with the observation that not only is volatility non-constant (of financial asset returns), it also tends to appear in bursts or clusters. Instead of considering heteroskedasticity as a problem to be corrected (approach taken by CLRM practitioners in assuming homoskedasticity of error term), Robert Engle seized this opportunity to model this non-constant time-dependent variance (heteroskedasticity) using an autoregressive moving average (ARMA) technique.

ARMA has been in use for several decades and is a combination of AR (autoregression) and MA (moving average) techniques. We have already invoked autoregressive (AR) representation in Equations (4) and (5). AR links the present observation of a variable to its past history, for example:

$$y_t \text{ to } y_{t-1}, y_{t-2}, \dots, y_{t-p}$$

where p is the order of the autoregressive process $AR(p)$ or the period up to which the historical data will be used (a determination made by using other statistical tools).

Thus, AR is a technique by which a variable can be regressed on its own lagged values. For example, today's sales (y_t) may depend on sales from yesterday (y_{t-1}) and the day before (y_{t-2}). $AR(p)$ is appealing since it links the present to the past. MA expresses observations of a variable in terms of current and lagged values of squared random error terms ε_t , ε_{t-1} , ε_{t-2} , \dots , ε_{t-q} where q is the order of the moving average process $MA(q)$. Combining $AR(p)$ and $MA(q)$, we get $ARMA(p, q)$ where p and q represent the lagging order of AR and MA, respectively.

Robert Engle used the MA technique to model the time varying volatility in a series and proposed the so-called AutoRegressive Conditional Heteroskedasticity model or ARCH. The 'conditional' nature of non-constant variance (heteroskedasticity) refers to forecasting of variance *conditional* upon the information set available up to a time period (t). Using ARCH, the variance of the random error term (ε_t) in Equation (5) can be expanded in terms of current and lagged values of squared $\varepsilon_{t-1}^2, \varepsilon_{t-2}^2, \dots, \varepsilon_{t-q}^2$ as follows:

$$\sigma_t^2 = \theta_0 + \theta_1 \varepsilon_{t-1}^2 + \theta_2 \varepsilon_{t-2}^2 + \dots + \theta_q \varepsilon_{t-q}^2 \quad (6)$$

where $\sigma_t^2 = \text{variance of } \varepsilon_t [\text{var}(\varepsilon_t)]$.

This $MA(q)$ representation of σ_t^2 was later generalized to an ARMA representation of σ_t^2 and is referred to as the

Generalized AutoRegressive Conditional Heteroskedasticity model or GARCH. The GARCH technique represents a parsimonious model than ARCH, while allowing for an infinite number of past error terms to influence current conditional variance. Hence, GARCH is widely used than ARCH.

GARCH evolved when Tim Bollerslev extended the $MA(q)$ representation of σ_t^2 (the ARCH model) to include an $AR(p)$ process, that is, regressing a variable (σ_t^2) on its own (past) lagged values ($\sigma_{t-1}^2, \sigma_{t-2}^2, \dots, \sigma_{t-p}^2$) as well. Thus, variance of the random error term in a certain period (ε_t) can be modelled to depend not only on squared past errors ($\varepsilon_{t-1}^2, \dots, \varepsilon_{t-q}^2$) but also on the lagged value of the variance ($\sigma_{t-1}^2, \sigma_{t-2}^2, \dots, \sigma_{t-p}^2$) as shown in Equation (7) below.

$$y_t = \beta_0 + \sum_{j=1}^{N_{yt}} \varphi_j y_{t-j} + \sum_{k=1}^K \sum_{i=1}^{N_{Xkt}} \alpha_{ki} X_{kt-i} + \varepsilon_t$$

$$\sigma_t^2 = \theta_0 + \sum_{i=1}^q \theta_i \varepsilon_{t-i}^2 + \sum_{j=1}^p \tau_j \sigma_{t-j}^2 \quad (7)$$

Thus, GARCH may enable supply chain practitioners to model the volatility in the supply chain, a phenomenon documented by the Bullwhip Effect. How GARCH may help calculate the VaR for various supply chain stages deserves deeper investigation. Future research may reveal a mechanism to quantitatively determine the risk associated with various supply chains. The latter tool, when developed, may be of considerable value in general risk management in the globalized world of international commerce.

3.3. VAR-GARCH

In developing the GARCH model, Equation (7) takes into account the lagged values of the dependent variable (sales), the impact of multiple explanatory variables (K number of x 's that influence sales such as inventory, price) and their respective lagged values, as well as time-dependent heteroskedasticity of the error term. But, thus far, we have not considered the fact that to predict sales h periods ahead, it is also crucial to model the interaction between the entity level nodes (manufacturer, supplier, distributor in supply chain) which can impact sales.

In any operation, including supply chains, interaction between partners can influence any outcome (profit, service,

readiness, response). The strikingly different business ‘clock-speed’ and dynamics of the supply chains partners is what partly fuels the Bullwhip Effect. Thus, to incorporate the dynamics of interaction between players, it is essential to explicitly model the dynamics between the entities to be a useful real-world model. A combination of vector autoregression technique with GARCH captures this dynamics. Vector autoregression (VAR) is a model for the means of a vector process and was developed over a quarter century ago by Sims (1980). Previously, we discussed AR(p) with respect to Equation (5), which is a univariate model. In contrast, VAR(p) is a n -variate (multivariate) model where we estimate n different equations (for $Y_1, Y_2, Y_3 \dots Y_n$). In each equation, we regress a variable on p lags of itself as well as p lags of every other variable in the system. Thus, the right-hand side variables are the same for every equation in the system.

The key advantage of VAR lies in its ability to capture cross-variable dynamics (vector process). For example, future sales (prediction) of Michelin brand tyres may not be precisely forecasted by Sears unless the store takes into consideration the events or sales (vector) at the distributor. Thus, there are at least two parties (vectors) in this example (interaction between retail store and distributor). To model this cross variable dynamics of $n=2$ using VAR(p), let us assume that $p=1$ (lagged by 1 period). Equation (7) may be extended to the VAR-GARCH type model for two entities with ($n=2, p=1, q=1$) as shown in Equation (8).

$$\begin{aligned} y_{1t} &= \beta_0 + \sum_{k=1}^K \sum_{i=1}^{N_{skt}} \alpha_{ki} X_{kt-i} + \phi_{11} y_{1t-1} + \phi_{12} y_{2t-1} + \epsilon_{1t} \\ y_{2t} &= \beta_0 + \sum_{k=1}^K \sum_{i=1}^{N_{skt}} \alpha_{ki} X_{kt-i} + \phi_{21} y_{1t-1} + \phi_{22} y_{2t-1} + \epsilon_{2t} \\ \sigma_{1t}^2 &= c_{11} + \theta_{11} \epsilon_{1t-1}^2 + \tau_{11} \sigma_{1t-1}^2 \\ \sigma_{2t}^2 &= c_{22} + \theta_{22} \epsilon_{2t-1}^2 + \tau_{22} \sigma_{2t-1}^2 \end{aligned} \quad (8)$$

In the VAR-GARCH model represented by Equation (8), this dynamics is captured by estimating the coefficient ϕ_{ij} which refers to changes in y_i with respect to y_j . For example, if y_1 represents Michelin tyre sales at Sears retail store and y_2 represents Michelin tyre sales at the distributor, then the parameter ϕ_{12} refers to changes in sales at retail store (y_1) with respect to sales at the distributor (y_2). If any one of the two random error terms (ϵ_{1t} and ϵ_{2t}) changes, it will impact both the dependent variables (y_1 and y_2). In terms of Equation (8) above, if ϵ_{1t} changes, it will change y_{1t} and since y_{1t} also appears as one of the explanatory variables for y_{2t} in the equation, the change in any error term impacts both dependent variables in this VAR representation. This cross variable dynamic interaction has thus far been ignored by current modelling practices for forecasting. The VAR component of the proposal in this paper is closer to the real-world scenario and VAR-GARCH may make it possible to quantify such cross-variable dynamics.

3.4. Multivariate GARCH (MGARCH)

To move beyond the realm of univariate autoregression to a vector autoregression system, for further precision of forecast, it is necessary to model time varying conditional covariance (measuring the degree of association between any two variables) between ϵ_1 and ϵ_2 in addition to time varying conditional variance of the error term. In other words, the error terms associated with the retailer’s sales forecast and the distributor’s inventory level may be correlated (Granger and Swanson, 1996). This type of multivariate interaction is not explicitly captured by the VAR-GARCH model (Section 3.3), yet in the business world the association between, say, sales forecast and inventory level, is crucial for the overall efficiency and profitability of the supply chain. Thus, the next task is to combine the VAR representation with a multivariate GARCH component. Assuming $p=q=1$, MGARCH specification can be expressed as follows:

$$\begin{aligned} y_{mt} &= \beta_0 + \sum_{k=1}^K \sum_{i=1}^{N_{skt}} \alpha_{ki} X_{kt-1} + \sum_{l=1}^2 \phi_{ml} y_{lt-1} + \epsilon_{mt} \quad \forall m=1, 2 \\ \sigma_{1,t}^2 &= C_{11} + \theta_{11} \epsilon_{1t-1}^2 + \tau_{11} \sigma_{1,t-1}^2 \\ \sigma_{12,t} &= C_{12} + \theta_{12} \epsilon_{1t-1} \epsilon_{2t-1} + \tau_{12} \sigma_{12,t-1} \\ \sigma_{2,t}^2 &= C_{22} + \theta_{22} \epsilon_{2t-1}^2 + \tau_{22} \sigma_{2,t-1}^2 \end{aligned} \quad (9)$$

where $\sigma_{12,t}$ indicates conditional covariance between ϵ_1 and ϵ_2 in time period t , based on information set available up to period $(t-1)$.

Thus, the conditional variances and conditional covariances will depend on their respective lagged values, as well as the lagged squared errors and the error cross products. Clearly, estimating such a model may be a formidable task, even in a bi-nodal scenario, for example, a retailer and distributor. If the GARCH system is functional, it may be used to better analyse Impulse Response Function (IRF). At present, IRF values are of limited use because it is difficult to provide confidence intervals for the values. Confidence intervals are necessary for forecasts. GARCH values may provide these confidence intervals. IRF traces the impact of changes (‘shock’) in error terms on the dependent variable for several periods in the future. Applied to operational planning, IRF may offer insight about ‘sense and respond’ scenarios. IRF simulation may enable exploration of multi-component ‘what if’ scenarios by creating challenges and learning (from simulation) how to prepare (readiness) for such challenges (hurricane, fire, flood, earthquake, epidemics, pandemics, military escalations).

3.5. Is there a link between Bullwhip effect and GARCH processes?

We have often used ‘volatility’ to indicate the observation of fluctuation represented by the Bullwhip effect but it is unclear if there is an actual link between Bullwhip Effect and GARCH processes. Simply going ‘along’ the supply chain, there may

not be an use for GARCH but going over ‘time’ there might be, as explained below.

Consider a supply chain with a sequence of stages or locations: L_0 (origin), L_1 (stage one or first location), L_2 (second), \dots , L_f (final stage or end). Goods moving along the chain are associated with a number of delivery times between these locations. Let us denote $T_{j \rightarrow k}(t)$ as the time taken to deliver a good from location j to location k , the goods having started at time t at L_0 (origin). The 1st leg of the chain takes time $T_{0,1}(t)$, the 2nd leg $T_{1,2}(t)$ and so forth. These L values are positive random variables, possibly auto correlated, but initially considered as an independent sequence. Note that,

$$T_{0,k}(t) = \sum_{j=0}^{k-1} T_{j,j+1}(t)$$

is, essentially, a random walk, with an increasing mean and variance. If all the $T_{j,j+1}(t)$ are uncorrelated with mean $m > 0$ and variance v , then $T_{0,k}(t)$ will have mean km and variance kv . As k increases, volatility will increase, which is the Bullwhip Effect (there is no need to use GARCH models to fit this process).

The total time taken for the supply chain $T_{0,f}(t)$ will, as t varies, generate a time series which can be analysed. In the unlikely event that the chain does not change, this will be a stationary series, but it is likely that volatility (Bullwhip Effect) will be experienced by the chain. Thus, an AR-GARCH model may be appropriate.

4. Data

The modelling technique proposed above, may represent an opportunity to apply advanced statistical and econometric tools to improve the quality of predictive analytics in general and supply chain forecasting, in particular. However, validating such a model requires high volume data and involves estimating a large number of parameters. It is possible that advanced organizations, such as the military establishments, may have considered using these techniques but could not substantiate the models due to fewer than necessary reliable data points (degrees of freedom).

However, data ‘points’ may no longer be the limiting factor if the increasing interest in adoption of AIT is transformed to reality. Widespread adoption of AIT (such as RFID or UWB tags and sensor data) may pave the way for use of real time data to validate a model such as the one proposed in this paper. The innovative convergence of fields as diverse as AIT and time series econometrics may improve decision support systems in domains beyond finance and economics (Datta, 2004).

AIT and progress toward embedding intelligence into physical objects may allow them to communicate with each other (thing-to-thing) as well as with business systems or users (consumers) in near real-time. Hence, businesses may soon be faced with ultra high volume multi-gigabit data streams

that may be expressed succinctly only in terms of exabytes per second (1 exabyte = 10^{18} bytes or 10^9 gigabytes). Infrastructure necessary to acquire such data may not offer a satisfactory return on investment (ROI) unless decisionable information derived from this data offers value or profitability. The question of value from high volume data may be considerably enhanced by using data in advanced statistical models (as proposed above) to yield useful analytics.

Availability of near real-time data at the right time may be especially useful for industries where historical data is an agonizing cliché due to short product life cycles, such as mobile phones, digital cameras and laptop computers, which are characteristic of high ‘clockspeed’ industries (Fine, 1998). For a product with a sales life cycle of 200 days (about 6 months), if we use data from the past 100 days (more than 3 months) in the time series model, it may be difficult to ‘change course’ and respond or adapt (based on forecasts or predictions from such models). This is where the granularity of high volume AIT data from RFID tags offers the potential to deliver real business value and ROI.

Re-consider the above example but assume the availability of high volume accurate AIT data (from RFID tags on high value products with rapid obsolescence). The data from RFID tags may be modelled with $N = 100$ where data is lagged every hour ($N = 100$ hours instead of $N = 100$ days). However, whether the quality of the information that may be extracted from such data, may change if $N = 100$ is in hours or days, is a business question, not a technology or analytics issue. Consequently, whether high volume data of a certain granularity is sufficient for reliable forecasts will depend on process. If the hourly data is used ($N = 100$), then predictive analysis can be made available within 5 days from launch of a product with 195 days (97.5%) of its sales life cycle still viable, in case it is necessary to re-engineer the product in order to respond to or meet customer preferences. If compared to daily batch data with $N = 100$, analytics may be available after 100 days or with only 50% of the product sales life cycle still viable.

Thus, use of high volume real-time data in these models may make it possible and feasible for sales, marketing, production or distribution to adapt in real-time or at the right-time. Changes can be initiated, based on forecasts, earlier in the (sales) cycle of the product or even at the production stage, by using delayed product differentiation strategies, if products were designed with modular architecture or if the product lifecycle was carefully optimized by balancing the demands of development *versus* fulfillment supply chain parameters.

Regarding estimation technique, the OLS technique, although simple, may not be preferred for use with GARCH. OLS technique proceeds by minimizing sum of squared residuals but residuals, by definition, do not depend on the parameters of the conditional variance equation. Thus, in the presence of GARCH specification, minimizing residual sum of squares is no longer an appropriate objective. Instead, to estimate models from the GARCH family, the maximum likelihood estimation (MLE) is the technique of choice. However,

under an assumption of normality, MLE is simply generalized OLS.

MLE works by finding the most likely values of the parameters given the actual data. Multivariate GARCH models are similar to their univariate counterparts and thus MLE technique can be used. However, due to explicit modelling of conditional covariances over time in MGARCH, the number of parameters to be estimated increases exponentially. A few different MGARCH specifications have been proposed, such as the VEC model proposed by Bollerslev *et al.* (1988) and the BEKK model proposed by Engle and Kroner (1995). This is an area that warrants deeper exploration keeping in mind increased data availability through use of AIT data acquisition tools.

5. Implications for risk management

Risk in SCM originates from two key areas: supply and demand. At the next level of equal importance are environmental, political, process and security risks. Political and environmental risks may always remain amorphous and refractory to adequate quantification. Security risks are even more volatile but on a higher priority level that demands advanced risk management tools and analysis for targeting operations in global trade.

Too often, risk is viewed as simplistic as merely the product of frequency and consequence. A high-frequency but low-consequence event (currency exchange rates) is viewed as similar to a low-frequency but high-consequence event (sinking of a cargo ship laden with spare parts). In reality, such apparently 'similar risks' may have vastly different effects. Sensational risks grab attention and beg for resource-consuming mitigation while risk managers tend to ignore the smaller risks that create the real friction in the supply chain. With the increasingly complex business environment that is the hallmark of globalization, today's supply chain presents a myriad of specific risks ranging from external sources (such as, terrorist strikes or vulnerability to political instability in developing countries due to global outsourcing) to internal sources (pressure to enhance productivity and reduce costs by eliminating waste, removing duplication through use of single source supplier). If accounted as parameters in traditional optimization equations, the sheer number of factors will exponentially increase the state space and as a result may grind the computation of the optimization algorithms to a pace that may become unacceptable for decision support systems to aid in the management of supply chain adaptability.

The VAR-MGARCH model proposed here may be well suited to take into account the details of the operational nodes (assuming we have data available from each of these nodes/processes). Recurring analysis performed in near real-time (assuming real-time data is available to the analytical engine) may offer results that predicts or detects risks in the operational model (supply chain) far in advance of what is possible at present. The validity of the proposed model as a

tool for risk analysis may be tested by simulating a model of a real-world business operation and running the simulation with real-time data (observed or simulated).

Availability of abundant data from various supply chain nodes (supplier, distributor, logistics provider) will reduce risk, if the data is analysed and its impact sufficiently understood to deploy risk mitigation steps, at the right time. Operational transparency at or within supply chain nodes is likely to improve with the increase in object associated data acquisition that may be possible through pervasive adoption of automatic identification (RFID, UWB, GPS, sensors, GE VeriWise System). The use and analysis of this data in a model that captures the end-to-end business network (as well as links to other factors that may impact the function of a specific node) may help to reduce risk. It is in this context that a combination of MGARCH and VAR techniques may offer value hitherto unimaginable.

This model is also relevant to businesses increasingly using 'lean' principles and depends on global outsourcing practices which may compromise the visibility of the supply chain. Transparency of operations within the corporation (internal risk drivers) is as critical as data from business partners in 'lean' and 'global' operations to evaluate external risk drivers. In some cases, outlier events may be even more influential given that uncertainty is far greater than risk and it is very difficult to assign proper weights to distant elephants.

Use of GARCH in supply chain to estimate risk through VaR (value at risk) analysis may also help create a merger of financial and physical supply chains. The financial supply chain, which drives financial settlement, takes over where the physical supply chain ends. Exporters want rapid payment while importers demand accurate data on goods received to better manage inventory and cash-flow to optimize working capital management. Thus, capital efficiency (the traditional domain of the chief financial officer or CFO) depends on data and sharing of information (traditional domain of the chief information or chief technology officer, CIO or CTO) about cross-border movement of goods (customs and excise), transfer of title, risk mitigation and payment. Facilitation of the flow of (decisionable, actionable) information across physical and financial supply chains has a direct impact on working capital.

From a risk management perspective, the supply chain, therefore, appears to evolve as a component of the CFO's responsibility. Adapting the GARCH model to serve as a tool in supply chain risk analysis may offer financial managers a familiar tool that may yield clues to effective supply chain risk mitigation strategies. In general, comprehensive solutions are necessary over the life of a transaction cycle that may integrate cash management, trade settlement, finance, logistics, supply nodes, procurement, demand projections, inventory, human resources, regulatory compliance and management of information across physical and financial supply chain boundaries. Creating one or more models that may work in synergy and integrating such real-world scenarios is a challenge.

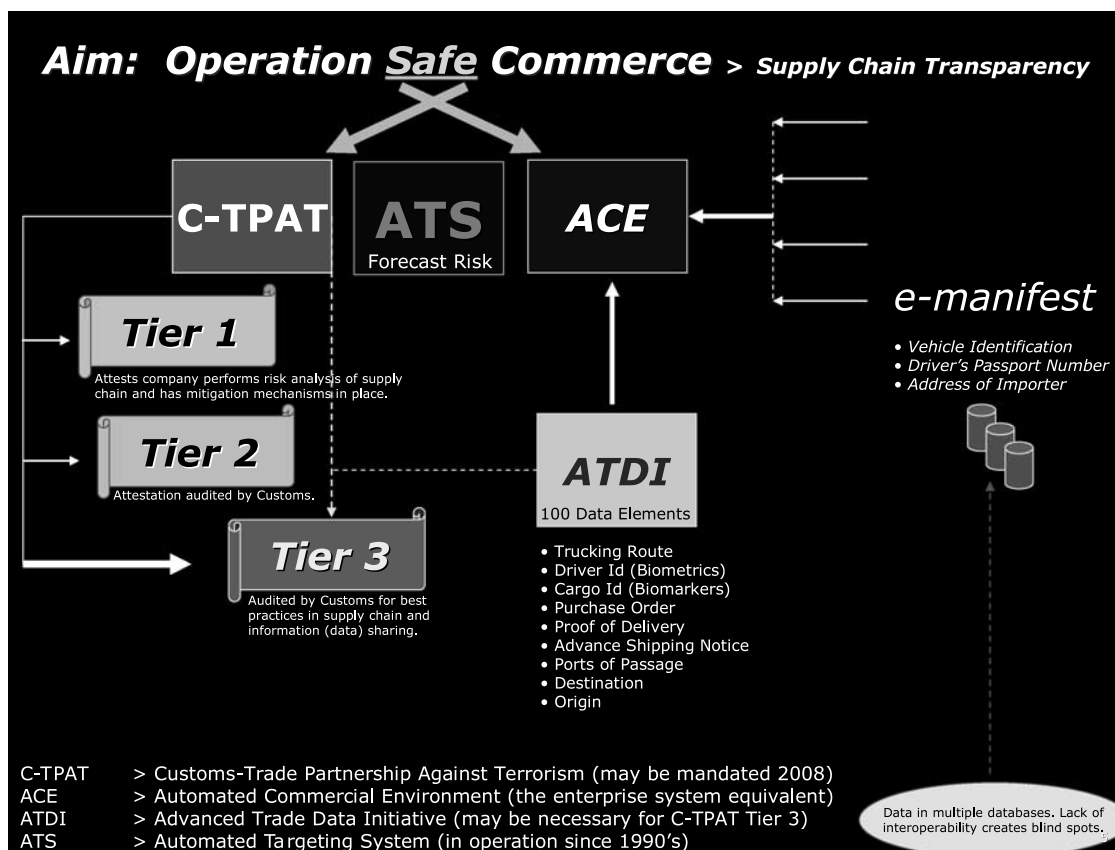


Figure 2 GARCH and Global Risk Management? This illustration outlines some of the pilot projects in progress in the US. There exists a possibility of a mandate by the US in the form of Customs-Trade Partnership Against Terrorism (C-TPAT). To qualify for C-TPAT Tier 3 certification, business must share data through the Advanced Trade Data Initiative (ATDI). Sharing sensitive data will add layers of data security. With data from ATDI, the customs 'enterprise' system or Automated Commercial Environment (ACE) is expected to run analysis to spot anomalies, integrate biometric information (individuals, meat and agricultural products), perform non-obvious relationship analysis (NORA) and forecast risk profile associated with containers or shipments. Armed with this information, customs aims to selectively 'target' cargo for inspections.

However challenging, risk management may soon become a 'household' issue for business and industry. Cost of doing business with and in the US may soon have to figure in the cost necessary to implement transparency in order to mitigate risk. Businesses must share data with US Department of Homeland Security if their goods originate overseas. This model of data sharing may soon be adopted by other countries, determined to counter terrorism. The move toward global supply chain transparency is not a matter of if but a question of when, due to the great uncertainty posed by terrorists that heighten security risks. The lack of analytical tools to make sense of this data may create many more problems before it starts providing solutions. If even a tiny fraction of the 25 000 containers that arrive in US ports each day require inspection, then businesses will face costly delays in receiving customs clearance. In October 2002, a war game that mimicked this delay found that closing US ports for only 12 days created a 60-day container backlog and cost the economy roughly \$58 billion (Worthen, 2006).

The proven success of GARCH in finance and the potential to adapt GARCH for business operations may be viewed as one of the promising solutions to offer a synergistic multi-faceted tool for risk-adjusted SCM by acting as a bridge for some of the interdependent issues in global business: finance, supply chain and security risk analysis (Figure 2).

6. Concluding remarks

In this paper, we propose a model for forecasting with potential broad spectrum applications that include SCM. The model is based on advances in time series econometrics. GARCH technique is used to explicitly model the volatility generally associated with supply chains. A VAR framework captures the dynamics of interactions that characterize multi-stage SCM. From a theoretical point of view, such a model is expected to yield an accurate forecast, thereby reducing some of the operational inefficiencies. In addition, businesses and security organizations may benefit from GARCH because it may

enable the quantification of VaR associated with a wide variety of processes that require better tools for management of risk.

The proposed model, by its very construction, requires high volume data to estimate a large number of coefficients. Availability of high volume data may not be the limiting factor in view of the renewed interest in AIT that may facilitate acquisition of real-time data from products or objects affixed with RFID tags. Although speculative, it stands to reason that use of a GARCH type model may enhance the ROI from AIT infrastructure by delivering value from acquired data. However, understanding the ‘meaning’ of the information from data is an area still steeped in quagmire but may soon begin to experience some clarity if the operational processes take advantage of the increasing diffusion of the semantic web and organic growth of ontological frameworks to support intelligent decision systems coupled to agent networks (Datta, 2006).

Rigorous validation of the proposed model with real-world data is the next step. In one isolated experiment, the model proposed in this paper was tested to compare forecasting accuracy. When simulated using real-world data and compared to traditional CLRM type techniques, the GARCH type model provided a forecast that was appreciably closer to the observed or realized value (Don Graham, personal communication). This observation is immature. Several more experiments with rigorous controls must be performed before this result may be even considered to offer ‘preliminary’ evidence that the GARCH type model proposed in this paper may represent an advanced tool.

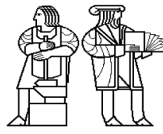
In this paper, we have attempted to coalesce a few ideas toward a ‘solutions’ approach aimed to model volatility in supply chain and in the process, perhaps, better manage risk. It is possible that business, industry, governments, consultants and academics with deep knowledge in one or more fields, may spend the next few decades striving to synthesize one or more models of effective *modus operandi* to combine these ideas with other emerging concepts, tools, technologies and standards to collectively better understand, analyse and respond to uncertainty. However, the inclination to reject deep-rooted ideas based on inconclusive results from pilot projects is a detrimental trend and begs to ask the question whether one can aspire to build an elephant using a mouse as a model.

Acknowledgements—Part of this work was made possible by the financial support from the sponsors of the MIT Forum for Supply Chain Innovation. The corresponding author (S Datta) is the Co-Founder and Research Director of the MIT Forum for Supply Chain Innovation. The corresponding author benefited from numerous discussions with industry and government thought leaders, worldwide. Special thanks are due to Robert Engle, New York University.

References

- Bollerslev T, Engle R and Woolridge J (1988). A capital asset pricing model with time varying covariances. *J Polit Econ* **96**: 116–131.
- Coase RH (1960). The problem of social cost. *J Law Econ* **3**: 1–44.
- Coase RH (1992). The institutional structure of production. *Am Econ Rev* **82**: 713–719.
- Datta S (2003). Future tools for real time data: Can econometric tools model real-time RFID data? http://supplychain.mit.edu/innovation/docs/MIT_STARCH_Shoumen_Datta_09_DEC_2003.doc.
- Datta S (2004). *Adapting decisions, optimizing facts, predicting figures*. Working Paper, Engineering Systems Division, Massachusetts Institute of Technology, <http://supplychain.mit.edu/shoumen>
- Datta S (2006). *Potential for improving decision support catalysed by semantic interoperability between systems*. Working Paper. Engineering Systems Division, MIT (<http://esd.mit.edu/WPS/esd-wp-2006-10.pdf>).
- Datta S (2007). *Unified Theory of Relativistic Identification of Information: Convergence of Unique Identification with Syntax and Semantics through Internet Protocol version 6*. Working Paper. Engineering Systems Division, MIT (<http://esd.mit.edu/WPS/2007/esd-wp-2007-17.pdf>).
- Datta S, Betts B, Dinning M, Erhun F, Gibbs T, Keskinocak P, Li H, Li M and Samuels M (2004). *Adaptive Value Networks in Evolution of Supply Chain Management*. Kluwer Academic Publishers: Amsterdam.
- Engle RF and Granger CWJ (1987). Co-integration and error-correction: Representation, estimation and testing. *Econometrica* **55**: 251–276.
- Engle RF and Granger CWJ (1991). *Long-Run Economic Relationships: Readings in Cointegration*. Oxford University Press: Oxford.
- Engle RF and Kroner KF (1995). Multivariate simultaneous generalized ARCH. *Econom Theory* **11**: 122–150.
- Engle RF and Manganelli S (1999). *CAViaR: Conditional autoregressive value at risk by regression quantiles*. Working paper 99-20, Department of Economics, University of California, San Diego.
- Fine C (1998). *Clockspeed*. Perseus Books: New York.
- Granger CWJ and Swanson NR (1996). Further developments in the study of cointegrated variables. *Oxford Bull Econ Stat* **58**: 374–386.
- Lee HL, Padmanabhan P and Whang S (1997). The Bullwhip effect in supply chains. *Sloan Mngt Rev* **38**: 93–102.
- Simchi-Levi D, Kaminsky P and Simchi-Levi E (2003). *Designing and Managing The Supply Chain*. McGraw Hill: New York.
- Sims CA (1980). Macroeconomics and reality. *Econometrica* **48**: 1–48.
- Studenmund AH (2000). *Using Econometrics: A Practical Guide*. Addison Wesley Longman Publishers: Reading, MA.
- Worthen B (2006). Customs rattles the supply chain. *CIO*, 1 March. www.cio.com/archive/030106/supply_security.html

*Received August 2005;
accepted September 2006 after two revisions*



Massachusetts Institute of Technology
Engineering Systems Division

Working Paper Series

ESD-WP-2006-11

.....

ADVANCES IN SUPPLY CHAIN MANAGEMENT:
POTENTIAL TO IMPROVE FORECASTING ACCURACY

.....

Shoumen Palit Austin Datta¹ and Clive W. J. Granger²

¹Research Scientist, Engineering Systems Division
Department of Civil and Environmental Engineering
Research Director & Co-Founder, MIT Forum for Supply Chain Innovation
School of Engineering
Massachusetts Institute of Technology
shoumen@mit.edu

²Research Professor
Department of Economics
University of California
cgranger@ucsd.edu

July 2006

**Advances in Supply Chain Management and Decision Support Systems:
Potential to Improve Forecasting Accuracy**

by

Shoumen Palit Austin Datta †
Research Scientist, Engineering Systems Division
Department of Civil and Environmental Engineering
Research Director & Co-Founder, MIT Forum for Supply Chain Innovation
School of Engineering
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139
shoumen@mit.edu

and

Clive W. J. Granger *
Research Professor
Department of Economics
University of California
9500 Gilman Drive
La Jolla, California 92093
cgranger@ucsd.edu

† Corresponding author

* Co-author shared the 2003 Nobel Prize in Economics

Publication version may include additional authors.

Abstract

Forecasting is a necessity almost in any operation. However, the tools of forecasting are still primitive in view of the great strides made by research and the increasing abundance of data made possible by automatic identification technologies, such as, radio frequency identification (RFID). The relationship of various parameters that may change and impact decisions are so abundant that any credible attempt to drive meaningful associations are in demand to deliver the value from acquired data. This paper proposes some modifications to adapt an advanced forecasting technique (GARCH) with the aim to develop it as a decision support tool applicable to a wide variety of operations including supply chain management. We have made an attempt to coalesce a few different ideas toward a "solutions" approach aimed to model volatility and in the process, perhaps, better manage risk. It is possible that industry, governments, corporations, businesses, security organizations, consulting firms and academics with deep knowledge in one or more fields, may spend the next few decades striving to synthesize one or more models of effective *modus operandi* to combine these ideas with other emerging concepts, tools, technologies and standards to collectively better understand, analyze and respond to uncertainty. However, the inclination to reject deep rooted ideas based on inconclusive results from pilot projects is a detrimental trend and begs to ask the question whether one can aspire to build an elephant using mouse as a model.

Key Words

Forecasting, Analytics, Automatic Identification, Radio Frequency Identification, RFID, Ultrawideband, UWB, sensors, Value of Data, Decision Systems, Decision Support Systems, DSS, Supply Chain, Supply Chain Management, SCM, Operations, Operations Management, Inventory Management, Out-of-Stock, OOS, Process Knowledge, Knowledge Management, Collaboration, Semantics, Interoperability, Collaborative Planning Forecasting and Replenishment, CPFR, Vendor Managed Inventory, VMI, Operational Efficiency, Econometrics, Time Series, CLRM, Regression Analysis, Classical Linear Regression Model, AR, Autoregression, MA, Moving Average, VAR, Vector Autoregression, GARCH, Generalized Autoregressive Conditional Heteroskedasticity, MGARCH, Multivariate GARCH, Bullwhip Effect, Homoskedasticity, Uncertainty, Optimization, Risk Analysis, Value at Risk, VaR, Enterprise Resource Planning, ERP, Software Defined Radio, SDR, Globalisation, Volatility, ICT, Information and Communication Technologies, Supply Chain Adaptability, Adaptive SCM, Sense & Respond, Clockspeed, Value Networks, Product Lifecycle Management, PLM, Information Lifecycle Management, ILM, Obsolescence, Financial Supply Chain, Transparency, Lean, Lean Manufacturing, Outsourcing, GE VeriWise, GPS, High Volume Data, High Frequency Data, Real-Time Data, Right Time Information, Logistics, Security, Security Risk Analysis, Logistics Network, Customs, Customs Security, Biometrics, Ontology, Intelligent Decision Systems, Agents, AI Agents, Logistics Network, Value Chain, C-TPAT, Customs-Trade Partnership Act Against Terrorism, Homeland Security, Non-obvious Relationship Analysis, NORA

1. Background

Forecasting is an ancient activity and has become more sophisticated in recent years. For a long time steady steps in a time series data set, such as simple trends or cycles (such as seasonals), were observed and extended into the future. However, now a mixture of time series, econometrics and economic theory models can be employed to produce several forecasts which can then be interpreted jointly or combined in sensible fashions to generate a superior value.

The variable being forecast is a random variable. Originally attention was largely directed towards the mean of this variable; later to the variance, and now to the whole marginal distribution. Pre-testing of the data to find its essential features has become important and that has produced modern techniques such as cointegration.

The horizon over which the forecast is attempted is also important, and longer-run forecasts are now being considered as well as forecasts of "breaks" in the series.

The question of evaluation of forecasts has also been greatly developed. Most forecasts are quite easy to evaluate but others, coming from the Global Models (which attempt to model the global economy), are more difficult. Business, commerce, global organizations and governments may find that these models, if explored, may offer valuable guidance for their forecasting activities or their attempts to improve accuracy of forecasts.

Thus, forecasting is a necessity almost in any operation. However, the tools of forecasting (software) in general business use are still primitive in view of the strides made by research. Hence, promoting advances in forecasting to aid predictive analytics is deemed a worthwhile endeavour and is the purpose of this paper. Such tools may further reduce uncertainty and volatility characteristic of global trade. The relationship of various business parameters that may change and impact decisions are so abundant that any credible attempt to drive meaningful associations are in demand by global businesses. This paper proposes some modifications to adapt an already advanced forecasting technique with the aim to develop it as a decision support tool applicable to a wide variety of operations including supply chain management.

2. Introduction

Total quality management (TQM) gained prominence in the 1970's by claiming to boost quality at a lower cost through proper management and operational design. Lean (manufacturing) was the euphoria in the 1980's following Toyota's exemplary adoption of Just In Time (JIT) processes to enable flexible manufacturing and minimize costs by reducing inventory level. However, it soon became clear that manufacturing costs could not be reduced further by

pursuing variations of TQM and JIT simply through classical operations research. Globalization of markets in the 1990's combined with improvements in ICT (information communication technologies) and short product life cycles shifted the focus on supply chain management (SCM) that could adapt to demand or reduce costs through improvement in efficiency.

SCM is a set of approaches to efficiently integrate suppliers, manufacturers, distributors, warehouses and retail stores so that merchandise is produced and distributed in the right quantities, to the right locations, at the right time in order to minimize system wide costs while satisfying (customer) service-level requirements (Simchi-Levi *et al*, 2003). Viewed from this perspective, similarities exist between SCM practices and a competitive market economy. A market economy ensures that right mix of goods and services get produced (those that are most wanted by consumers) in the right way (i.e. least cost) and eventually distributed to the right people (those who are willing to pay the most). Therein lies the attractiveness of a market based economy, that it gives rise to most efficient allocation of resources. Likewise, SCM, if appropriately designed and executed, may offer efficient business solutions, thereby minimizing costs and improving readiness or competitiveness.

Despite rapid advances in SCM and logistics, inefficiencies still persist and are reflected in related costs. During 2000, supply chain related costs in the United States alone exceeded \$1 trillion (10% of GDP), which is close to the 2005 GDP of Russia and Canada or the combined GDP of the 22 nations who are members of the oil-rich League of Arab Nations. A mere 10% savings of supply chain costs in the United States is close to the 2005 GDP of Ireland (Datta *et al*, 2004). More than US\$3 trillion have been spent on global logistics in 2004 and this represents almost 5% of the global GDP or more than the GDP of Germany and just less than the GDP of India in 2005. Inefficiencies in the global logistics network estimated at an approximate of US\$600 billion (close to the 2005 GDP of Australia) offers untapped opportunities for organisations to optimise or adapt to improve sustainable profitability. Hence serious questions have been raised as to how to make decision systems more efficient in order to reduce cost of transaction (Coase, 1960 and Coase, 1992). This, in turn, requires a thorough understanding of the factors that make design and operation of effective SCM strategy a challenging task due to the volatility of supply and demand.

It is challenging enough to design and operate a supply chain for one facility, in order that costs are minimized and service levels are maintained. The difficulty increases exponentially when the system as a whole is considered and system-wide costs must be minimized, i.e., optimizing the interactions between various intermediaries, such as retailer, wholesaler, distributor, manufacturer and supplier of materials. This is mathematically equivalent to finding a global optimal solution as opposed to local optimization, the predominant business practise. Global optimization, involving several stages in the decision making process, is far more complicated. It is also much broader in scope and encompasses local optimization, but only as a special case.

Some may argue, justifiably, that optimization itself is to be blamed for the inefficiencies in global SCM practices. Perhaps optimization suggests an innate assumption that operations are capable of reaching a steady state or equilibrium, once "optimal" conditions are determined and executed. Global volatility, even in peaceful or stable political economies, may disprove this assumption. Hence, dynamic or recurrent real-time optimization is required and reflects the fundamental necessity of global supply chains to continuously adapt.

The task of global optimization is rendered difficult by the uncertainty of the business environment. First, businesses need to continually adapt to demand uncertainty and its impact on inventory management. In a market based economy, production decision is primarily demand driven and must be made *ex ante* (before customer demand is realized). Furthermore, due to lack of information sharing *ex post* (after actual customer demand is realized) between partners, the variability in orders is amplified upstream, along the supply chain. This phenomenon is commonly referred to as the 'Bullwhip Effect' and it is a key driver of inefficiencies associated with SCM. It distorts the demand signals, resulting in costs in the form of excess capacity and inventory, need for increased storage, and transportation cost increases (due to less-than-truckload or LTL scenarios), to name a few (Lee *et al*, 1997).

The Bullwhip Effect and the resulting inefficiencies associated with traditional supply chains may be reduced, in theory, by centralizing information relating to supply and demand (Datta, S., *et al*, 2004). In other words, a "centralized" supply chain model is one where such information is made available to all participating businesses at various stages of the supply chain or network of partners. Advances in information and communication technologies in the past decade has made it easier to acquire, share, access and analyze data in a manner that is increasingly feasible for "sense and response" systems. In the context of SCM, the idea is to enable intermediaries in the supply chain process to act as "infomediaries" or serve as agents for sharing and accessing the real-time data flow through common interfaces, such as web-based services (Datta, 2006).

Acquisition of or access to data is not equivalent to use of decisionable information that can be extracted from data. Differences in forecasting methodologies applied (to the same data) at different stages of SCM by the participants (process owners) may yield varying types of information that may further obscure the value of data or give rise to increased fluctuations, thus distorting the signals, such as demand (Lee, 1997). To rein in the Bullwhip Effect, one contribution may stem from a standardized forecasting model, that may be used by the supply chain partners, as an analytical tool to extract value from the data that is accessible to all the partners. Sharing of such an analytical engine by a group of businesses is possible through the use of grid computing (Datta, 2004). Although we have the tools and technologies at our disposal, the sluggish growth of collaborative systems such as CPFR (collaborative planning, forecasting and replenishment) may be indicative of only a mild interest in the benefits of

collaborative information processing. It is quite possible that lack of trust between businesses and heightened data security risks may be slowing real-world implementations of valuable strategies such as CPFR.

While a standardized forecasting model applied to near real-time data in a shared or centralized database may try to tame the Bullwhip Effect, it may never be eliminated due to outlier events and inherent or unexplained variability. In SCM, innumerable sources of variability exist, including factors such as demand forecasting, variability in lead time, batch processing or bulk ordering to take advantage of transportation discounts, price variability due to product promotion or discount, to name a few.

Hence, the objective of this paper is to propose the potential use of an advanced statistical modeling technique for the purpose of forecasting (originally proposed by Datta, 2003 and Datta *et al*, 2004). Based on the pioneering work on time series econometrics by Clive W. J. Granger and Robert F. Engle (Engle and Granger, 1987 & Engle and Granger, 1991), this paper proposes a few modifications to the statistical model proposed by Robert F. Engle based on advances in time series econometrics. The modifications were introduced to make the model more amenable for use in decision support systems, such as, supply chain management. If the proposed modifications are indeed viable, it is expected to explicitly model the interactions between various intermediaries of SCM as well as the time varying (non-constant) variability that manifests, at least in part, as the Bullwhip Effect. For example, our proposed model captures the cross-variable dynamics as reflected in interaction between supply chain nodes or stages (retailers, wholesalers, distributors) using vector auto regression (VAR) methodology which is essentially a model for the means of a vector process. The framework also explicitly models the time varying volatility (perhaps observed, in part, as the Bullwhip effect) by using a Generalized Autoregressive Conditional Heteroskedasticity (GARCH) technique (Engle and Kroner, 1995). GARCH is a model for volatility of a single series whereas multi-variate GARCH (MGARCH) is a model for volatility (variances and covariances) for a vector. Therefore, the proposed model may also be denoted as a VAR-MGARCH model.

While these techniques have been widely used in finance (and economics) in the past few decades (and also earned Engle and Granger the 2003 Nobel Prize in Economics), to our knowledge, they have not been applied or explored as decision support tools by supply chain planners or analysts in the area of supply chain management.

By using a dynamic model of volatility (defined as standard deviation of variance), a GARCH type model has the added advantage of providing a forecast of volatility in near term. Such a forecast may be useful in calculating value at risk (VaR). However, VaR is estimated with a simplifying assumption, such as (joint) normality. Consequently, ARCH technique has become an indispensable tool in risk assessment and management in the financial sector. Globalization of the supply chain has concomitantly increased the risk in the supply chain due to potential for loss of

profits from over-capacity (cost of excess inventory) or opportunity lost due to out-of-stock (OOS) situations. Hence, it is our contention that use of similar methodology in supply chain processes may enable businesses to better manage or even quantify the risk in the process.

VAR-GARCH type models require estimating a large number of parameters and hence cannot be used in practice unless a large sample of data is available. The lack of availability of high volume granular data may explain the scarce interest in applying this modeling technique as a forecasting tool in decision support systems. High volume accurate data is the single most important driver for forecasting accuracy. The recent rejuvenation of the use and adoption of automatic identification technologies may partly ameliorate the lack of high volume data. The surge in the use of radio frequency identification (RFID) or ultrawideband (UWB) tags that may be embedded or attached with physical objects, will make it possible to track and locate objects along the entire supply chain, if the systems used by manufacturers, distributors, logistics providers and retailers are able to take advantage of middleware and hardware interoperability (software defined radio or SDR) to monitor, access and share near real-time RFID data.

Thus pervasive use of automatic identification tags may provide high volume object data in near real time with the maturing trend toward ubiquitous computing. Businesses may not have a clear understanding of how to use this data efficiently to extract decisionable and actionable information that offers business value not merely through savings but may actually increase profitability. We propose that businesses explore advanced techniques such as multivariate GARCH that requires high volume of data for estimation but offers the potential to deliver increasingly accurate forecasts along with a measure of Value at Risk. Success in applying similar models to analyze financial market returns is well documented. Global supply chain management and any operation in need of planning for the future (healthcare, military, emergency) offers interesting applications for VAR-MGARCH techniques.

In the next section, we develop this statistical model for forecasting on a sequential, step by step basis, with the idea that independent variables represent operational 'nodes' (for example, the 'stages' or entities in supply chain). Section 4, discusses data requirements for model validation including the significance of automatic identification (RFID) data. Risk in the global supply chain is qualitatively discussed in section 5. Concluding thoughts are offered in section 6 including comments about preliminary results obtained in (only) one study that explored the use of the modification proposed in this paper to simulate improvements in forecasting based on (only) one data source from an ongoing real-world operation.

3. Statistical Model: VAR-MGARCH

Forecasting demand is a key tool in managing uncertainty. Forecast accuracy may depend on the understanding and coverage of parameters taken into account and the accuracy of historic data available for each variable that

may have an impact on the prediction. In this section, we propose a statistical model that combines classical regression analysis with advanced time series techniques, hopefully to improve accuracy of forecasts.

3.1 CLRM

Classic linear regression models (CLRM) have been around for a century (Studenmund, 2000) and used for a variety of purposes including traditional supply chain planning software. CLRM may be expressed as follows:

$$y_t = \beta_0 + \beta_1 x_t + \varepsilon_t \quad (1)$$

where,

y = dependent variable of interest to be modeled for forecast (e.g., sales of a product, say aspirin)

t = time period (frequency of observation, for example, t-1 may indicate prior week 1, t-2 → week 2)

β = coefficients to be estimated (based on values of y and x)

x = explanatory variable that is used to 'explain' variations in the dependent variable y (for example, low sales of aspirin may be explained by low in-store inventory {x} of aspirin)

ε = random (stochastic) error term

This simple technique can model multiple independent or explanatory variables, that is, multiple x's, since the variation in y, say, sales of aspirin, is dependent on multiple parameters, such as inventory (x_1), price (x_2), expiration date (x_3). The choice of x's (number of explanatory variables) will drive the validity and accuracy of the model. X's may be based on underlying economic principles (theoretical) or business logic (practical underpinnings). However, no matter how many x's are included, there may be an inherent randomness in y that cannot be explained. Thus, the random error term (ε) is included in the equation (admission of the fact that the dependent variable (y) cannot be modeled perfectly). The corresponding mathematical equation is given by equation (2):

$$y_t = \beta_0 + \beta_1 x_{1t} + \beta_2 x_{2t} + \dots + \beta_k x_{kt} + \varepsilon_t \quad (2)$$

Objective of CLRM is to estimate the parameters ($\beta_0, \beta_1, \dots, \beta_k$) of the model based on a *sample* of observations on y and x, assuming that ε is characterized by a normal distribution with mean = 0 and variance = σ^2 for all time periods (t).¹

¹ Normality assumption is needed for hypothesis testing with respect to β 's based on sample of data, unless the sample size is large.

$$\varepsilon_t \sim N(0, \sigma^2)$$

Given the multiple sets of $(\beta_0, \beta_1, \dots, \beta_k)$ may be estimated, the objective of CLRM is to choose that set of $(\beta_0, \beta_1, \dots, \beta_k)$ which minimizes the sum of squared residuals $(e_1^2, e_2^2, \dots, e_n^2)$:

$$\sum_{t=1}^n e_t^2$$

where e_t = empirical counterpart of ε (and is estimated based on sample data). Intuitively, this amounts to finding a line that best fits the data points by minimizing the sum of squared vertical distances of the actual data points from the fitted line. Thus residuals are essentially in-sample forecast errors as they measure the difference between actual y and fitted y . This technique is commonly referred to as the principle of ordinary least squares (OLS) and widely used due to its simplicity. The attractiveness of CLRM based OLS forecasting stems from the fact that we can model cross variable linkages. This feature is especially useful to carry out 'what-if' analysis. For example, what may happen to sales (y , the dependent variable) of aspirin-based pain killers in retail sales if the in-store inventory of non-aspirin pain killers were increased by 10%? Clearly, 'what if' analysis is conditional upon assumptions we make about x 's in the model. Therefore, in building this model, the choice of x is a *process* decision based on the model builder's knowledge about an operation or business or industry.

One may wonder if we are playing a 'what if' game or is 10% increase, cited above, a real-world scenario. The retail outlet surely knows what has happened in the past. This segues to the next phase in the development of our statistical model where it is no longer necessary to assume values of the explanatory variable to forecast y (the dependent variable). Instead of inserting arbitrary values for future x 's (such as a 10% increase), we start by forecasting the values of x based on its own past data to obtain an unconditional forecast for y . In this stage of model development, the regression technique gets intertwined with time series techniques. By fitting a univariate autoregressive model to x where we use past (lagged) values of x to forecast x , we obtain the following equations (for X_{1t}, \dots, X_{kt}):

$$X_{1t} = \alpha_{10} + \alpha_{11} X_{1t-1} + \alpha_{12} X_{1t-2} + \dots + \alpha_{1N} X_{1t-N} + u_{x1t}$$

$$X_{kt} = \alpha_{k0} + \alpha_{k1} X_{kt-1} + \alpha_{k2} X_{kt-2} + \dots + \alpha_{kN} X_{kt-N} + u_{xkt} \quad (3)$$

Rewriting using general notation:

$$y_t = \beta_0 + \sum_{i=1}^{N_{x1t}} \alpha_{1i} X_{1t-i} + \dots + \sum_{i=1}^{N_{xkt}} \alpha_{ki} X_{kt-i} + \varepsilon_t \quad (4)$$

or

$$y_t = \beta_0 + \sum_{k=1}^K \sum_{i=1}^{N_{xkt}} \alpha_{ki} X_{kt-i} + \varepsilon_t \quad (4a)$$

where,

X_{1t} = variable x_1 at time t (for example, we used x_1 for inventory, thus x_{1t} is inventory at time t)

X_{kt} = variable x_k at time t (up to K number of x 's)

X_{1t-1} = value of x_1 at time $t-1$ (referred to as the lagged value by one period)

N = period up to which the lagged values of x_{1t} will be used in the equation

U = random error term

Note that β_0 in equation (4) is a combination of constants from equation (2) and (3) respectively.

In equation 3, α_{11} , α_{12} are coefficients of X_{1t-1} , X_{1t-2} and are referred to as lagged weights. An important distinction is that instead of arbitrarily assigning weights, these coefficients are estimated using OLS. The error term in equation 3 represented by u is analogous to ε in equation 1. Depending on the number of x 's (X_1, \dots, X_K) that adequately represents the process being modeled in equation 1, there will be K number of equations as given by (3) that must be estimated to forecast the x 's (X_1, \dots, X_K) which will then be used to obtain an unconditional forecast of y . Thus, to simplify the task, we can estimate all the parameters (α, β) simultaneously by re-writing equation 1, the basic CLRM equation, as equation (4) or its shortened version, as in equation (4a).

Equation 4 is a step toward forecasting the dependent variable (y) with greater accuracy using forecasts of x 's based on historical data of x 's (lagged values). But, it is also clear that equation 4 ignores the impact on y of the

past values of y itself (lagged values). Consequently, a preferable model will include not only lagged values of x but also lagged values of y , as shown in equation (5).

$$y_t = \beta_0 + \sum_{j=1}^{N_{yt}} \phi_j y_{t-j} + \sum_{K=1}^K \sum_{i=1}^{N_{xkt}} \alpha_{ki} X_{kt-i} + \varepsilon_t \quad (5)$$

In moving from conditional to unconditional forecasts of y using a time series model, we are increasing the number of parameters to be estimated. In equation 2, we estimate K parameters (β_1, \dots, β_K) excluding (β_0). In equation 3, we estimate n parameters ($\alpha_1, \dots, \alpha_N$) excluding the intercept (α_0) for each of the K number of x 's (X_1, \dots, X_K). In equation 5 we estimate j parameters for lagged values of y_{t-j} (ϕ_1, \dots, ϕ_j) in addition to all the parameters for equation 4. If we set $K=5$ (5 explanatory variables, the x 's), $N_x = 10$ (number of lagged values to forecast the x 's) and $N_y = 10$ (number of lagged values of y_t), then, we have increased the number of parameters to be estimated from 5 in equation (2) to 50 in equation (4) to 60 in equation 5 (excluding intercept).²

3.2 GARCH

Thus far, our discussions have centered on CLRM in conjunction with time series techniques. CLRM is based on a set of assumptions mainly about ε , that, when satisfied, gives rise to desirable properties of the OLS estimates. Needless to emphasize, in the real world, these assumptions are almost always violated. Developments in time series, over the past couple of decades, have addressed the challenges that stem from the violation of some of these classical assumptions leading to inaccurate forecasts.

One of the assumptions often violated in practice relates to homoskedasticity (homo \approx equal, skedasticity \approx variance or mean squared deviation (σ^2), a measure of volatility) or constant variance for different observations of the error term. Forecast errors are frequently found to be heteroskedastic (unequal or non-constant variance). For example, in multi-stage supply chains, the error associated with manufacturer's forecast of sales of finished goods may have a much larger variance than the error associated with retailer's projections (the assumption being that

² To drive precision to the next (logical) step, equation 5 may be expanded further to include the important real-world observations regarding trend, seasonality and other cyclical dynamics. Businesses struggle to uncover 'trends' and once found, they are avidly pursued, often for short term gains but increasingly with less than stellar results due to fickle customer preferences.

the proximity of the retailer to the end consumer makes the retailer offer a better or more informed forecast of future sales through improved understanding of end-consumer preferences). The upstream variability reflected in the Bullwhip Effect violates the basic premise of CLRM, the assumption of homoskedasticity. CLRM ignores the real-world heteroskedastic behavior of the error term ϵ_t and generates forecasts which may provide a false sense of precision by underestimating the volatility of forecast error.

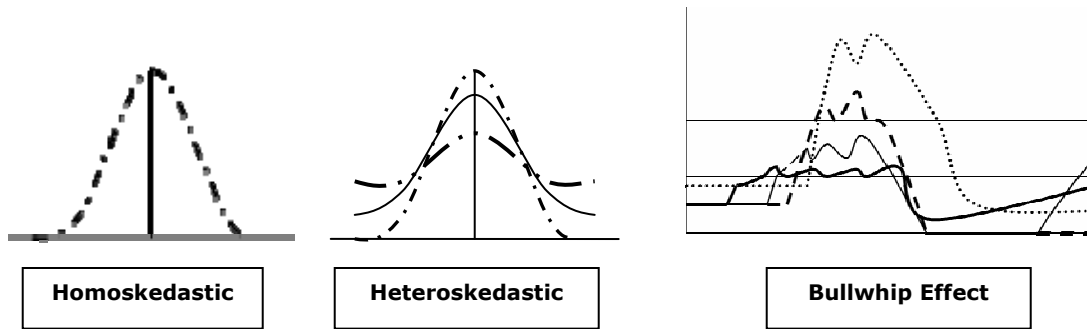


Figure 1: Homoskedasticity, Heteroskedasticity and the Bullwhip Effect

Homoskedastic and heteroskedastic error term distributions are illustrated in Figure 1. In a homoskedastic distribution, all the observations of the error term can be thought of as being drawn from the same distribution with mean = 0 and variance = σ^2 for all time periods (t). A distribution is described as heteroskedastic when the observations of the error term may be thought of as coming from different distributions with differing widths (measure of variance). In supply chains, the variance of orders is usually larger than that of sales. This distortion tends to increase as one move upstream from retailer to manufacturer to supplier. Therefore, the assumption of heteroskedasticity seems more appropriate as a characteristic that may be associated with the Bullwhip Effect.

While variance of error term may change across cross sectional units at any point in time, it may also change over time. This notion of time varying volatility is frequently observed in financial markets and has been the driving force behind recent advancements in time series techniques. Robert Engle is credited with the observation that not only is volatility non-constant (of financial asset returns), it also tends to appear in bursts or clusters. Instead of considering heteroskedasticity as a problem to be corrected (approach taken by CLRM practitioners in assuming homoskedasticity of error term), Robert Engle seized this opportunity to model this non-constant time dependent variance (heteroskedasticity) using an autoregressive moving average (ARMA) technique.

ARMA has been in use for several decades and is a combination of AR (autoregression) and MA (moving average) techniques. We have already invoked autoregressive (AR) representation in equations (4) and (5). AR links the present observation of a variable to its past history, for example:

$$y_t \text{ to } y_{t-1}, y_{t-2}, \dots, y_{t-p}$$

where p = the order of the autoregressive process $AR(p)$ or the period up to which the historical data will be used (a determination made by using other statistical tools).

Thus, AR is a technique by which a variable can be regressed on its own lagged values. For example, today's sales (y_t) may depend on sales from yesterday (y_{t-1}) and the day before (y_{t-2}). $AR(p)$ is appealing since it links the present to the past. MA expresses observations of a variable in terms of current and lagged values of squared random error terms $\varepsilon_t, \varepsilon_{t-1}, \varepsilon_{t-2}, \dots, \varepsilon_{t-q}$ where q is the order of the moving average process $MA(q)$. Combining $AR(p)$ and $MA(q)$ we get $ARMA(p,q)$ where p and q represent the lagging order of AR and MA, respectively.

Robert Engle used the MA technique to model the time varying volatility in a series and proposed the so called AutoRegressive Conditional Heteroskedasticity model or ARCH. The 'conditional' nature of non-constant variance (heteroskedasticity) refers to forecasting of variance *conditional* upon the information set available up to a time period (t). Using ARCH, the variance of the random error term (ε_t) in equation (5) can be expanded in terms of current and lagged values of squared ε ($\varepsilon_{t-1}^2, \varepsilon_{t-2}^2, \dots, \varepsilon_{t-q}^2$) as follows:

$$\sigma_t^2 = \theta_0 + \theta_1 \varepsilon_{t-1}^2 + \theta_2 \varepsilon_{t-2}^2 + \dots + \theta_q \varepsilon_{t-q}^2 \quad (6)$$

where σ_t^2 = variance of ε_t [$\text{var}(\varepsilon_t)$].

This $MA(q)$ representation of σ_t^2 was later generalized to an ARMA representation of σ_t^2 and is referred to as the Generalized AutoRegressive Conditional Heteroskedasticity model or GARCH.³

³ The GARCH technique represents a parsimonious model than ARCH, while allowing for an infinite number of past error terms to influence current conditional variance. Hence GARCH is widely used than ARCH.

GARCH evolved when Tim Bollerslev extended the MA(q) representation of σ_t^2 (the ARCH model) to include an AR(p) process, that is, regressing a variable (σ_t^2) on its own (past) lagged values ($\sigma_{t-1}^2, \sigma_{t-2}^2, \dots, \sigma_{t-p}^2$) as well. Thus, variance of the random error term in a certain period (ε_t) can be modeled to depend not only on squared past errors ($\varepsilon_{t-1}^2, \dots, \varepsilon_{t-q}^2$) but also on the lagged value of the variance ($\sigma_{t-1}^2, \sigma_{t-2}^2, \dots, \sigma_{t-p}^2$) as shown in equation (7) below.

$$y_t = \beta_0 + \sum_{j=1}^{N_{yt}} \varphi_j y_{t-j} + \sum_{k=1}^K \sum_{i=1}^{N_{xkt}} \alpha_{ki} X_{kt-i} + \varepsilon_t$$

$$\sigma_t^2 = \theta_0 + \sum_{i=1}^q \theta_i \varepsilon_{t-i}^2 + \sum_{j=1}^p \tau_j \sigma_{t-j}^2 \quad (7)$$

Thus, GARCH may enable supply chain practitioners to model the volatility in the supply chain, a phenomenon documented by the Bullwhip Effect. How GARCH may help calculate the value at risk for various supply chain stages deserves deeper investigation. Future research may reveal a mechanism to quantitatively determine the risk associated with various supply chains. The latter tool, when developed, may be of considerable value in general risk management in the globalized world of international commerce.

3.3 VAR-GARCH

In developing the GARCH model, equation (7) takes into account the lagged values of the dependent variable (sales), the impact of multiple explanatory variables (K number of x 's that influence sales such as inventory, price) and their respective lagged values, as well as time dependent heteroskedasticity of the error term. But, thus far, we have not considered the fact that to predict sales h periods ahead, it is also crucial to model the interaction between the entity level nodes (manufacturer, supplier, distributor in supply chain) which can impact sales.

In any operation, including supply chains, interaction between partners can influence any outcome (profit, service, readiness, response). The strikingly different business "clockspeed" and dynamics of the supply chains partners is what partly fuels the Bullwhip Effect. Thus, to incorporate the dynamics of interaction between players, it

is essential to explicitly model the dynamics between the entities to be a useful real-world model. A combination of vector autoregression technique with GARCH captures this dynamics. Vector autoregression (VAR) is a model for the means of a vector process and was developed over a quarter century ago by Sims (1980). Previously we discussed $AR(p)$ with respect to equation (5), which is a univariate model. In contrast, $VAR(p)$ is a n -variate (multivariate) model where we estimate n different equations (for $Y_1, Y_2, Y_3, \dots, Y_n$). In each equation, we regress a variable on p lags of itself as well as p lags of every other variable in the system. Thus, the right hand side variables are the same for every equation in the system.

The key advantage of VAR lies in its ability to capture cross-variable dynamics (vector process). For example, future sales (prediction) of Michelin brand tyres may not be precisely forecasted by Sears unless the store takes into consideration the events or sales (vector) at the distributor. Thus, there are at least two parties (vectors) in this example (interaction between retail store and distributor). To model this cross variable dynamics of $n=2$ using $VAR(p)$, let us assume that $p=1$ (lagged by 1 period). Equation (7) may be extended to the VAR-GARCH type model for two entities with $(n=2, p=1, q=1)$ as shown in equation (8).

$$y_{1t} = \beta_0 + \sum_{k=1}^K \sum_{i=1}^{N_{xkt}} \alpha_{ki} X_{kt-i} + \varphi_{11} y_{1t-1} + \varphi_{12} y_{2t-1} + \varepsilon_{1t}$$

$$y_{2t} = \beta_0 + \sum_{k=1}^K \sum_{i=1}^{N_{xkt}} \alpha_{ki} X_{kt-i} + \varphi_{21} y_{1t-1} + \varphi_{22} y_{2t-1} + \varepsilon_{2t}$$

$$\sigma_{1t}^2 = \mathbf{c}_{11} + \theta_{11} \varepsilon_{1t-1}^2 + \tau_{11} \sigma_{1t-1}^2$$

$$\sigma_{2t}^2 = \mathbf{c}_{22} + \theta_{22} \varepsilon_{2t-1}^2 + \tau_{22} \sigma_{2t-1}^2 \quad (8)$$

In the VAR-GARCH model represented by equation (8), this dynamics is captured by estimating the coefficient Φ_{ij} which refers to changes in y_i with respect to y_j . For example, if y_1 represents Michelin tyre sales at Sears retail store and y_2 represents Michelin tyre sales at the distributor, then the parameter Φ_{12} refers to changes in sales at retail store (y_1) with respect to sales at the distributor (y_2). If any one of the two random error terms (ϵ_{1t} and ϵ_{2t}) changes, it will impact both the dependent variables (y_1 and y_2). In terms of equation (8) above, if ϵ_{1t} changes, it will change y_{1t} and since y_{1t} also appears as one of the explanatory variables for y_{2t} in the equation, the change in any error term impacts both dependent variables in this VAR representation. This cross variable dynamic interaction has thus far been ignored by current modeling practices for forecasting. The VAR component of the proposal in this paper is closer to the real-world scenario and VAR-GARCH may make it possible to quantify such cross-variable dynamics.

3.4 Multivariate GARCH (MGARCH)

To move beyond the realm of univariate autoregression to a vector autoregression system, for further precision of forecast, it is necessary to model time varying conditional covariance (measuring the degree of association between any two variables) between ϵ_1 and ϵ_2 in addition to time varying conditional variance of the error term. In other words, the error terms associated with the retailer's sales forecast and the distributor's inventory level may be correlated. This type of multivariate interaction is not explicitly captured by the VAR-GARCH model (section 3.3) yet in the business world the association between, say, sales forecast and inventory level, is crucial for the overall efficiency and profitability of the supply chain. Thus, the next task is to combine the VAR representation with a multivariate GARCH component. Assuming $p=q=1$, MGARCH specification can be expressed as follows:

$$Y_{mt} = \beta_0 + \sum_{K=1}^k \sum_{i=1}^{N_{xkt}} \alpha_{Ki} X_{ikt-1} + \sum_{l=1}^2 \phi_{ml} y_{lt-1} + \epsilon_{mt}, \forall m=1, 2$$

$$\sigma_{1,t}^2 = C_{11} + \theta_{11} \epsilon_{1,t-1}^2 + \tau_{11} \sigma_{1,t-1}^2$$

$$\sigma_{12,t} = C_{12} + \theta_{12} \epsilon_{1,t-1} \epsilon_{2,t-1} + \tau_{12} \sigma_{12,t-1}$$

$$\sigma_{2,t}^2 = C_{22} + \theta_{22} \epsilon_{2,t-1}^2 + \tau_{22} \sigma_{2,t-1}^2 \quad (9)$$

where $\sigma_{12,t}$ indicates conditional covariance between ϵ_1 and ϵ_2 in time period t , based on information set available up to period $(t-1)$.

Thus, the conditional variances and conditional covariances will depend on their respective lagged values, as well as the lagged squared errors and the error cross products. Clearly, estimating such a model may be a formidable task, even in a bi-nodal scenario, for example, a retailer and distributor.⁴

3.5 Is there a link between Bullwhip Effect and GARCH Processes?

We have often used "volatility" to indicate the observation of fluctuation represented by the Bullwhip effect but it is unclear if there is an actual link between Bullwhip Effect and GARCH processes. Simply going "along" the supply chain, there may not be an use for GARCH but going over "time" there might be, as explained below.

Consider a supply chain with a sequence of stages or locations: L_0 (origin), L_1 (stage one or first location), L_2 (second), ..., L_f (final stage or end). Goods moving along the chain are associated with a number of delivery times between these locations. Let us denote $T_{j \rightarrow k}(t)$ as the time taken to deliver a good from location j to location k , the goods having started at time t at L_0 (origin). The 1st leg of the chain takes time $T_{0,1}(t)$, the 2nd leg $T_{1,2}(t)$ and so forth. These L values are positive random variables, possibly auto correlated, but initially considered as an independent sequence. Note that,

$$T_{0,k}(t) = \sum_{j=0}^k T_{j,j+1}(t)$$

is, essentially, a random walk, with an increasing mean and variance. If all the $T_{j,j+1}(t)$ are uncorrelated with mean $m > 0$ and variance v , then $T_{0,k}(t)$ will have mean km and variance $k v$. As k increases, volatility will increase, which is the Bullwhip Effect (there is no need to use GARCH models to fit this process).

⁴ If the GARCH system is functional, it may be used to better analyze Impulse Response Function (IRF). At present, IRFs values are of limited use because it is difficult to provide confidence intervals for the values. Confidence intervals are necessary for forecasts. GARCH values may provide these confidence intervals. IRF traces the impact of changes ('shock') in error terms on the dependent variable for several periods in the future. Applied to operational planning, IRF may offer insight about 'sense and respond' scenarios. IRF simulation may enable exploration of multi-component "what if" scenarios by creating challenges and learning (from simulation) how to prepare (readiness) for such challenges (hurricane, fire, flood, earthquake, epidemics, pandemics, military escalations).

The total time taken for the supply chain $T_{o, f}(t)$ will, as t varies, generate a time series which can be analyzed. In the unlikely event that the chain does not change, this will be a stationary series, but it is likely that volatility (Bullwhip Effect) will be experienced by the chain. Thus, an AR-GARCH model may be appropriate.

4. Data

The modeling technique proposed above, may represent an opportunity to apply advanced statistical and econometric tools to improve the quality of predictive analytics in general and supply chain forecasting, in particular. However, validating such a model requires high volume data and involves estimating a large number of parameters. It is possible that advanced organizations, such as the military establishments, may have considered using these techniques but could not substantiate the models due to fewer than necessary reliable data points (degrees of freedom).

However, data "points" may no longer be the limiting factor if the increasing interest in adoption of Automatic Identification Technology (AIT) is transformed to reality. Widespread adoption of AIT (such as radio frequency identification or ultrawideband tags and sensor data) may pave the way for use of real time data to validate a model such as the one proposed in this paper. The innovative convergence of fields as diverse as AIT and time series econometrics may improve decision support systems in domains beyond finance and economics (Datta, 2004).

AIT and progress toward embedding intelligence into physical objects may allow them to communicate with each other (thing-to-thing) as well as with business systems or users (consumers) in near real-time. Hence, businesses may soon be faced with ultra high volume multi-gigabit data streams that may be expressed succinctly only in terms of exabytes per second (1 exabyte = 10^{18} bytes or 10^9 gigabytes). Infrastructure necessary to acquire such data may not offer a satisfactory return on investment (ROI) unless decisionable information derived from this data offers value or profitability. The question of value from high volume data may be considerably enhanced by using data in advanced statistical models (as proposed above) to yield useful analytics.

Availability of near real-time data at the right time may be especially useful for industries where historical data is an agonizing cliché due to short product life cycles, such as mobile phones, digital cameras and laptop computers, which are characteristic of high 'clockspeed' industries (Fine, 1998). For a product with a sales life cycle of 200 days (about 6 months), if we use data from the past 100 days (more than 3 months) in the time series model, it may be difficult to 'change course' and respond or adapt (based on forecasts or predictions from such models). This is where the granularity of high volume AIT data from RFID tags offers the potential to deliver real business value and ROI.

Re-consider the above example but assume the availability of high volume accurate AIT data (from RFID tags on high value products with rapid obsolescence). The data from RFID tags may be modeled with $N=100$ where data is lagged every hour ($N=100$ hours instead of $N=100$ days). However, whether the quality of the information that may be extracted from such data, may change if $N=100$ is in hours or days, is a business question, not a technology or analytics issue. Consequently, whether high volume data of a certain granularity is sufficient for reliable forecasts will depend on process. If the hourly data is used ($N=100$), then predictive analysis can be made available within 5 days from launch of a product with 195 days (97.5%) of its sales life cycle still viable, in case it is necessary to re-engineer the product in order to respond to or meet customer preferences. If compared to daily batch data with $N=100$, analytics may be available after 100 days or with only 50% of the product sales life cycle still viable.

Thus, use of high volume real-time data in these models may make it possible and feasible for sales, marketing, production or distribution to adapt in real-time or at the right-time. Changes can be initiated, based on forecasts, earlier in the (sales) cycle of the product or even at the production stage, by using delayed product differentiation strategies, if products were designed with modular architecture or if the product lifecycle was carefully optimized by balancing the demands of development vs fulfillment supply chain parameters.

Regarding estimation technique, the OLS technique, although simple, may not be preferred for use with GARCH. OLS technique proceeds by minimizing sum of squared residuals but residuals, by definition, do not depend on the parameters of the conditional variance equation. Thus, in the presence of GARCH specification, minimizing residual sum of squares is no longer an appropriate objective. Instead, to estimate models from the GARCH family, the Maximum Likelihood Estimation (MLE) is the technique of choice. However, under an assumption of normality, MLE is simply generalized OLS.

MLE works by finding the most likely values of the parameters given the actual data. Multivariate GARCH models are similar to their univariate counterparts and thus MLE technique can be used. However, due to explicit modeling of conditional covariances over time in MGARCH, the number of parameters to be estimated increases exponentially. A few different MGARCH specifications have been proposed, such as the VEC model proposed by Bollerslev, Engle and Woolridge (1988) and the BEKK model proposed by Engle and Kroner (1995). This is an area that warrants deeper exploration keeping in mind increased data availability through use of AIT data acquisition tools.

5. Implications for Risk Management

Risk in supply chain management originates from two key areas: supply and demand. At the next level of equal importance are environmental, political, process and security risks. Political and environmental risks may always

remain amorphous and refractory to adequate quantification. Security risks are even more volatile but on a higher priority level that demands advanced risk management tools and analysis for targeting operations in global trade.

Too often, risk is viewed as simplistic as merely the product of frequency and consequence. A high-frequency but low-consequence event (currency exchange rates) is viewed as similar to a low-frequency but high-consequence event (sinking of a cargo ship laden with spare parts). In reality, such apparently "similar risks" may have vastly different effects. Sensational risks grab attention and beg for resource-consuming mitigation while risk managers tend to ignore the smaller risks that create the real friction in the supply chain. With the increasingly complex business environment that is the hallmark of globalization, today's supply chain presents a myriad of specific risks ranging from external sources (such as, terrorist strikes or vulnerability to political instability in developing countries due to global outsourcing) to internal sources (pressure to enhance productivity and reduce costs by eliminating waste, removing duplication through use of single source supplier). If accounted as parameters in traditional optimization equations, the sheer number of factors will exponentially increase the state space and as a result may grind the computation of the optimization algorithms to a pace that may become unacceptable for decision support systems to aid in the management of supply chain adaptability.

The VAR-MGARCH model proposed here may be well suited to take into account the details of the operational nodes (assuming we have data available from each of these nodes/processes). Recurring analysis performed in near real-time (assuming real-time data is available to the analytical engine) may offer results that predicts or detects risks in the operational model (supply chain) far in advance of what is possible at present. The validity of the proposed model as a tool for risk analysis may be tested by simulating a model of a real world business operation and running the simulation with real-time data (observed or simulated).

Availability of abundant data from various supply chain nodes (supplier, distributor, logistics provider) will reduce risk, if the data is analyzed and its impact sufficiently understood to deploy risk mitigation steps, at the right time. Operational transparency at or within supply chain nodes is likely to improve with the increase in object associated data acquisition that may be possible through pervasive adoption of automatic identification (RFID, UWB, GPS, sensors, GE VeriWise System). The use and analysis of this data in a model that captures the end-to-end business network (as well as links to other factors that may impact the function of a specific node) may help to reduce risk. It is in this context that a combination of MGARCH and VAR techniques may offer value hitherto unimaginable.

This model is also relevant to businesses increasingly using "lean" principles and depends on global outsourcing practices which may compromise the visibility of the supply chain. Transparency of operations within the corporation (internal risk drivers) is as critical as data from business partners in "lean" and "global" operations to evaluate

external risk drivers. In some cases, outlier events may be even more influential given that uncertainty is far greater than risk and it is very difficult to assign proper weights to distant elephants.

Use of GARCH in supply chain to estimate risk through VaR (value at risk) analysis may also help create a merger of financial and physical supply chains. The financial supply chain, which drives financial settlement, takes over where the physical supply chain ends. Exporters want rapid payment while importers demand accurate data on goods received to better manage inventory and cash-flow to optimize working capital management. Thus, capital efficiency (the traditional domain of the chief financial officer or CFO) depends on data and sharing of information (traditional domain of the chief information or chief technology officer, CIO or CTO) about cross-border movement of goods (customs and excise), transfer of title, risk mitigation and payment. Facilitation of the flow of (decisionable, actionable) information across physical and financial supply chains has a direct impact on working capital.

From a risk management perspective, the supply chain, therefore, appears to evolve as a component of the CFO's responsibility. Adapting the GARCH model to serve as a tool in supply chain risk analysis may offer financial managers a familiar tool that may yield clues to effective supply chain risk mitigation strategies. In general, comprehensive solutions are necessary over the life of a transaction cycle that may integrate cash management, trade settlement, finance, logistics, supply nodes, procurement, demand projections, inventory, human resources, regulatory compliance and management of information across physical and financial supply chain boundaries. Creating one or more models that may work in synergy and integrating such real-world scenarios is a challenge.

However challenging, risk management may soon become a "household" issue for business and industry. Cost of doing business with and in the US may soon have to figure in the cost necessary to implement transparency in order to mitigate risk. Businesses must share data with US Department of Homeland Security if their goods originate overseas. This model of data sharing may soon be adopted by other countries, determined to counter terrorism. The move toward global supply chain transparency is not a matter of if but a question of when, due to the great uncertainty posed by terrorists that heighten security risks. The lack of analytical tools to make sense of this data may create many more problems before it starts providing solutions. If even a tiny fraction of the 25,000 containers that arrive in US ports each day require inspection, then businesses will face costly delays in receiving customs clearance. In October 2002, a war game that mimicked this delay found that closing US ports for only 12 days created a 60-day container backlog and cost the economy roughly \$58 billion (Worthen, 2006).

The proven success of GARCH in finance and the potential to adapt GARCH for business operations may be viewed as one of the promising solutions to offer a synergistic multi-faceted tool for risk-adjusted supply chain management by acting as a bridge for some of the interdependent issues in global business: finance, supply chain and security risk analysis.

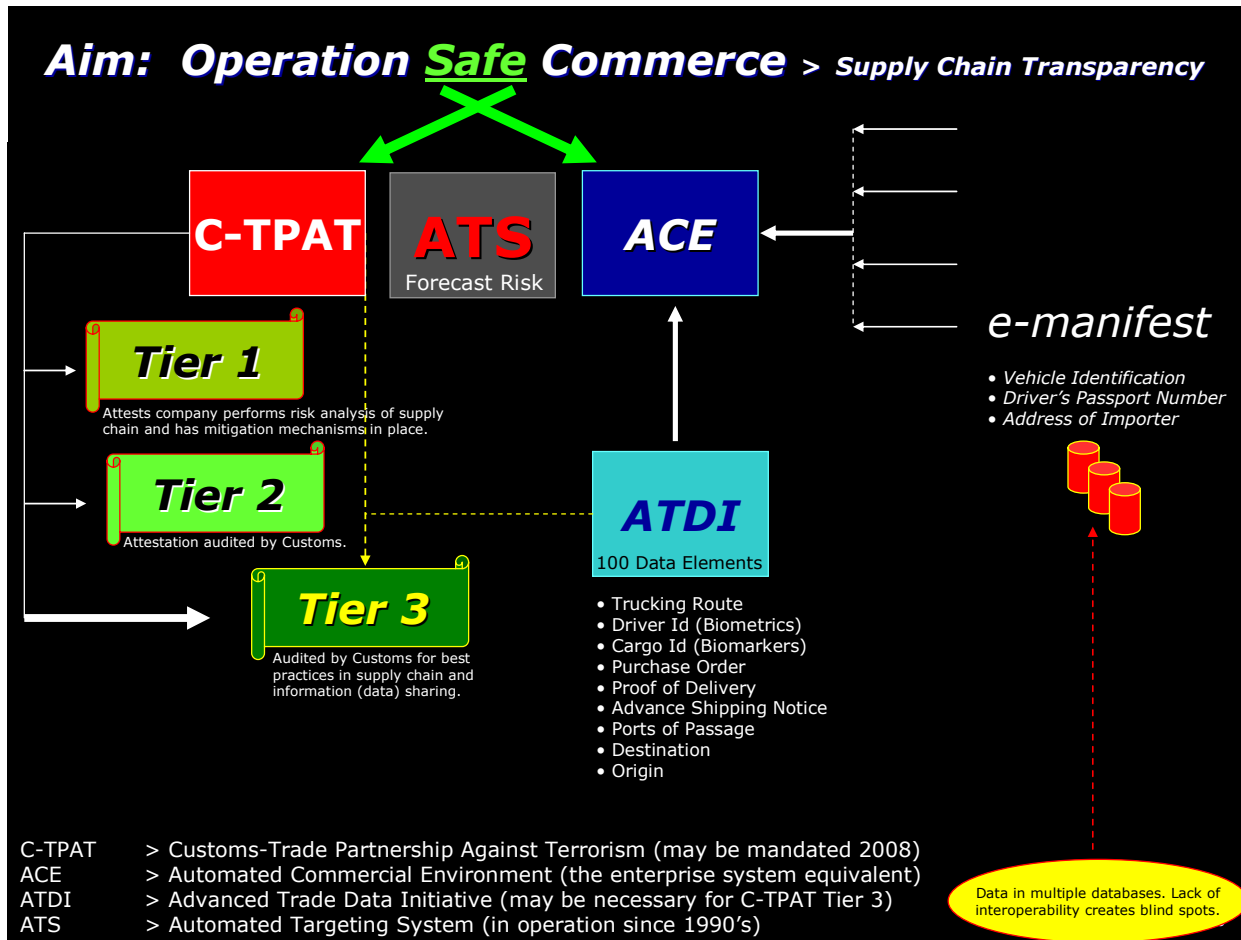


Illustration 1: GARCH and Global Risk Management?

Illustration outlines some of the pilot projects in progress in the US. There exists a possibility of a mandate by the US in the form of Customs-Trade Partnership Against Terrorism (C-TPAT). To qualify for C-TPAT Tier 3 certification, business must share data through the Advanced Trade Data Initiative (ATDI). Sharing sensitive data will add layers of data security. With data from ATDI, the customs "enterprise" system or Automated Commercial Environment (ACE) is expected to run analysis to spot anomalies, integrate biometric information (individuals, meat and agricultural products), perform non-obvious relationship analysis (NORA) and forecast risk profile associated with containers or shipments. Armed with this information, customs aims to selectively "target" cargo for inspections.

6. Concluding Remarks

In this paper, we propose a model for forecasting with potential broad spectrum applications that include supply chain management. The model is based on advances in time series econometrics. GARCH technique is used to explicitly model the volatility generally associated with supply chains. A VAR framework captures the dynamics of interactions that characterize multi-stage SCM. From a theoretical point of view, such a model is expected to yield an accurate forecast, thereby reducing some of the operational inefficiencies. In addition, businesses and security organizations may benefit from GARCH because it may enable the quantification of value at risk associated with a wide variety of processes that require better tools for management of risk.

The proposed model, by its very construction, requires high volume data to estimate a large number of coefficients. Availability of high volume data may not be the limiting factor in view of the renewed interest in automatic identification technologies (AIT) that may facilitate acquisition of real-time data from products or objects affixed with RFID tags. Although speculative, it stands to reason that use of a GARCH type model may enhance the ROI from AIT infrastructure by delivering value from acquired data. However, understanding the "meaning" of the information from data is an area still steeped in quagmire but may soon begin to experience some clarity if the operational processes take advantage of the increasing diffusion of the semantic web and organic growth of ontological frameworks to support intelligent decision systems coupled to agent networks (Datta, 2006).

Rigorous validation of the proposed model with real world data is the next step. In one isolated experiment, the model proposed in this paper was tested to compare forecasting accuracy. When simulated using real world data and compared to traditional CLRM type techniques, the GARCH type model provided a forecast that was appreciably closer to the observed or realized value (Don Graham, personal communication). This observation is immature. Several more experiments with rigorous controls must be performed before this result may be even considered to offer "preliminary" evidence that the GARCH type model proposed in this paper may represent an advanced tool.

In this paper, we have attempted to coalesce a few ideas toward a 'solutions' approach aimed to model volatility in supply chain and in the process, perhaps, better manage risk. It is possible that business, industry, governments, consultants and academics with deep knowledge in one or more fields, may spend the next few decades striving to synthesize one or more models of effective *modus operandi* to combine these ideas with other emerging concepts, tools, technologies and standards to collectively better understand, analyze and respond to uncertainty. However, the inclination to reject deep rooted ideas based on inconclusive results from pilot projects is a detrimental trend and begs to ask the question whether one can aspire to build an elephant using a mouse as a model.

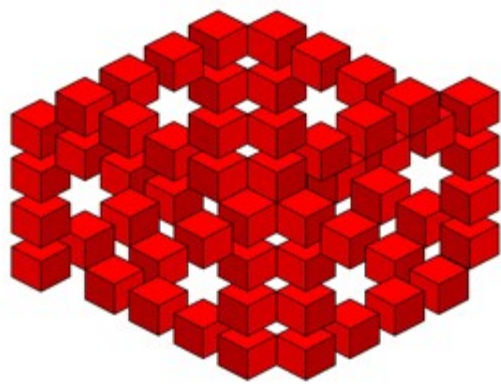
Acknowledgements

This work was made possible by the financial support from the sponsors of the MIT Forum for Supply Chain Innovation. The corresponding author benefited from numerous discussions with industry and government thought leaders, worldwide. Special thanks are due to Robert Engle (New York University), Jon Stine (Intel Corporation), Bob Betts (MainStreet Applications), Joseph Salvo (GE Global Research), Franz Dill (Procter & Gamble), Andy Mulholland (Capgemini), Peter Koudal (Deloitte Research), Reuben Slone (OfficeMax), Jeff Wilke & Micah Samuels (Amazon), Jeffrey Tew (General Motors), Paul Kern (The Cohen Group), Greg Parlier (SAIC), Kevin Larson (AAR), Stan Horowitz (Institute for Defense Analysis), Robert Ciskowski, Grace Lin and Robert Mayberry (IBM), Alexander Renz (Microsoft - Copenhagen, Denmark), Franz Hero (SAP AG - Walldorf, Germany), Hideki Sakai (SAP - Tokyo, Japan), Satoshi Arizumi (Sony - Tokyo, Japan), Masami Kinugasa and Sam Nakane (PoweredCom - Tokyo, Japan), Susumu Takahashi (Agnie - Tokyo, Japan), Eelco de Jong (LogicaCMG - Hoofddorp, Netherlands), Michel Danet, Ray McDonagh & Dietmar Jost (World Customs Organization - Brussels, Belgium), Roongrote Rangsiyopash, Bhanumas Srisukh, Bunn Kasemsup & Pimchanok Chuengcharoen (Siam Cement Group - Bangkok, Thailand), Rajanish Dass (Indian Institute of Management - Ahmedabad, India), Louis Brennan, Kate Phillip Connolly & John Murray (Trinity College - Dublin, Ireland), Petri Kalliokoski & Santu Toivonen (VTT - Espoo, Finland), Raimo Pulkkinen & Heidi Lindroth (TEKES - Helsinki, Finland), Vesa Salminen (Lappeenranta University of Technology - Lappeenranta, Finland), Tarja Pursiainen (Aker Kvaerner - Vantaa, Finland), Pekka Malinen (Helsinki University of Technology - Helsinki, Finland), Kenth Lumsden & Gunnar Stefansson (Chalmers University of Technology - Goteborg, Sweden), Yichen Lin (National University of Tainan, Taiwan), JrJung Lyu (National Cheng Kung University, Taiwan), Han Pang Hwang (National Taiwan University, Taipei, Taiwan), Dominique Estampe (ISLI - Bordeaux, France), Alain Lempereur & Michele Pekar (ESSEC - Paris, France), Gerry Frizelle (University of Cambridge, Cambridge, UK), Yoon Chang (Hankuk Aviation University, Goyang-City, Korea), Alexander Zier (The Hasso Plattner Institute - Berlin, Germany), Michael Barr (California Agricultural Leadership Foundation), Ozalp Ozer (Stanford University), Gita Swamy & Ananth Raman (Harvard Business School), Nicole DeHoratius (University of Chicago School of Business), Mahua Barari (Missouri State University), Sanjay Sarma, David Brock, Charles Fine, Hui Li, Mike Li, David Simchi-Levi & Joseph Sussman of Massachusetts Institute of Technology.

References

- Albertson, K and J. Aylen. (2003). Forecasting the Behavior of Manufacturing Inventory. *International Journal of Forecasting* **19**
- Bollerslev, T., Engle, R. and Woolridge, J. (1988) Capital Asset Pricing Model With Time Varying Covariances. *Journal of Political Economy* **96**
- Coase, R. H. (1960) The Problem of Social Cost. *Journal of Law and Economics* **3** 1-44
- Coase, R. H. (1992) The Institutional Structure of Production. *American Economic Review* **82** 713-19
- Datta, S. (2003) Future Tools for Real Time Data: Can Econometric Tools Model Real-Time RFID Data? http://supplychain.mit.edu/innovation/docs/MIT_STARCH_Shoumen_Datta_09_DEC_2003.doc

- Datta, S., et al (2004) Adaptive Value Networks in *Evolution of Supply Chain Management*. Kluwer Academic Publishers.
- Datta, S. (2004) Adapting Decisions, Optimizing Facts, Predicting Figures. Working Paper, Engineering Systems Division, Massachusetts Institute of Technology <http://supplychain.mit.edu/innovation/shoumen.htm>
- Datta, S. (2006) Potential for Improving Decision Support Catalysed by Semantic Interoperability between Systems. (<http://esd.mit.edu/WPS/esd-wp-2006-10.pdf>) Working Paper. Engineering Systems Division, MIT
- Engle, R. F. and Kroner, K. F. (1995) Multivariate Simultaneous Generalized ARCH. *Econometric Theory* **11** 122-150
- Engle, R. F. and Bollerslev, T. (1986) Modeling persistence of conditional variances. *Econometric Reviews* **5** 1-50.
- Engle, R.F. (1995) ARCH: Selected Readings. OUP
- Engle, R. F. and Granger, C. W. J. (1987) Co-integration and error-correction: Representation, estimation and testing. *Econometrica* **55** 251—276.
- Engle, R. F. and Granger, C. W. J. (1991) Long-Run Economic Relationships: Readings in Cointegration. OUP
- Engle, R. F., Lilien, D. M. and Robins, R. P. (1987) Estimating time-varying risk premia in the term structure: The ARCH-M model. *Econometrica* **55** 391-407
- Engle, R. F. and Manganelli, S. (1999) CAViaR: Conditional autoregressive value at risk by regression quantiles. Working paper 99-20. Department of Economics, University of California, San Diego.
- Fine, C. (1998) Clockspeed. Perseus Books
- Granger, C. W. J. and Swanson, N. R. (1996) Further developments in the study of cointegrated variables. *Oxford Bulletin of Economics and Statistics* **58** 374-386
- Lee, H.L., Padmanabhan, P. and Whang, S. (1997) The Bullwhip Effect in Supply Chains. *Sloan Management Review* **38** 93-102
- Lee, H.L. (2001) Ultimate Enterprise Value Creation Using Demand-Based Management. SGSCMF-W1-2001
- Simchi-Levi, D., Kaminsky, P. & Simchi-Levi, E. (2003) *Designing and Managing The Supply Chain*. McGraw Hill.
- Sims, C. A. (1980) Macroeconomics and Reality. *Econometrica* **48** 1-48
- Studenmund A. H. (2001) *Using Econometrics: A Practical Guide*. Addison Wesley Longman Publishers
- Worthen, B. (2006) Customs Rattles the Supply Chain. www.cio.com/archive/030106/supply_security.html



Chapter 10

Forecasting and Risk Analysis in Supply Chain Management: GARCH Proof of Concept

Shoumen Datta, Don P. Graham, Nikhil Sagar, Pat Doody, Reuben Slone
and Olli-Pekka Hilmola

Abstract Forecasting is an underestimated field of research in supply chain management. Recently advanced methods are coming into use. Initial results presented in this chapter are encouraging, but may require changes in policies for collaboration and transparency. In this chapter we explore advanced forecasting tools for decision support in supply chain scenarios and provide preliminary simulation results from their impact on demand amplification. Preliminary results presented in this chapter, suggests that advanced methods may be useful to predict oscillated demand but their performance may be constrained by current structural and operating policies as well as limited availability of data. Improvements to reduce demand amplification, for example, may decrease the risk of out of stock but increase operating cost or risk of excess inventory.

Key words: Forecasting; SCM; demand amplification; risk management; intelligent decision systems; auto-id data; GARCH; RFID; operations management

10.1 Introduction

Uncertainty fuels the need for risk management although risk, if adequately measured, may be less than uncertainty, if measurable. Forecasting may be viewed as a bridge between uncertainty and risk, if a forecast peels away some degrees of uncertainty but on the other hand, for example, may increase the risk of inventory. Therefore, forecasting continues to present significant challenges. Boyle et al. (2008) presented findings from electronics industry, where original equipment manufacturers (OEM) could not predict demand beyond a 4 week horizon. Moon et al. (2000) presented demand forecasting from Lucent (Alcatel-Lucent), demonstrating improvement in forecasting accuracy (60 % to 80–85 %). Related observations (Datta, 2008a) resulted in inventory markdowns.

Availability of increasing volumes of data (Reyes et al., 2007; Reyes and Frazier 2008) demands tools that can extract value from data. Recent research has shown that advanced forecasting tools enable improvements in supply chain performance (Zhao et al., 2001; Zhao et al., 2002; Bayraktar et al., 2008; Wright and Yuan, 2008), if certain pre-requisites are optimized (ordering policies, inventory collaboration). Autoregressive models have been effective in macroeconomic inventory forecasts (Albertson and Ayles, 2003). Zhao et al. (2002) and Bayraktar et al. (2008) emphasize that the role of forecasting in supply chain is to indicate the right direction for the actors rather than being exactly right, at every moment. Choosing the correct forecasting method is often a complex issue (Chatfield and Yar, 1988).

The purpose of this work is to explore how advanced forecasting methods could be applied in global supply chain management and their requirements. We present real world results and use simulation of a 4-stage supply chain model, beer-game (Vensim simulation). We have also used SPSS statistical analysis software to construct autoregressive forecasting models. The problems may be described as: (1) how to construct autoregressive forecasting models for a supply chain environment and (2) what changes may be needed in supply chain design to apply these advanced forecasting models? In the next section, we introduce a few challenges and Sect. 10.3 discusses demand amplification in supply chain management. In Sect. 10.4 we discuss features of autoregressive models and generalized autoregressive conditional heteroskedasticity (GARCH). Data and analysis from a supply chain inventory model using GARCH is presented and although the results are preliminary, they are encouraging. Concluding thoughts and further research issues are proposed in Sect. 10.5.

10.2 Supply Chain Management and Demand Amplification

Despite rapid advances in SCM and logistics, inefficiencies still persist and are reflected in related costs (Datta et al., 2004). In developing nations the actual amounts are lower, but proportional share is higher (Barros and Hilmola, 2007). One of the logistically unfriendly country groups are oil producers (Arvis et al., 2007).

The high cost for operations offer prosperity for the service providers. In 2006, AP Moller-Maersk raked in US\$ 46.8 billion in revenues (Hilmola and Szekely 2008). Deutsche Post reported revenues of € 63.5 billion in 2007 (Annual Report, 2007). Profitability and growth of these services are increasing, fueled by globalization. Global transportation growth exceeds global GDP growth (United Nations, 2005, 2007), since trade grows twice as fast as GDP. For decades companies emphasized lower inventories and streamlined supply chains but it has resulted in a situation (Chen et al., 2005; Kros et al., 2006) where material handling in distribution centers has increased (transportation growth combined with lower lot sizes). Management science and practice continues to explore ways to decrease transaction costs (Coase 1937, 1960, 1972, 1992) through real-time information arbitrage. Cooper and Tracey (2005) reported that in the 1990's Wal-Mart had an informa-

tion exchange capacity of 24 terabytes. While massive investments in information technology (IT) may be prudent, the sheer volume of data begs to ask the question whether we have the tools to separate data from noise and if we have systems that can transform data into decisionable information.

In supply chain management, the issue of demand amplification or Bullwhip effect has been in the forefront for some time (Forrester, 1958; Lee et al., 1997) but it took decades before its importance was recognized. The development of supply chain management (Oliver and Webber, 1982; Houlihan, 1985) catalysed by globalization, highlighted the strategic importance of logistics and pivotal role of information technology. Small demand changes in the consumer phase resulted in situations, where factories and other value chain partners faced sudden peaks and down turns in demand, inventory holdings and a corresponding impact on production and delivery (delivery structure phenomenon due to Bullwhip effect is referred to as “reverse amplification” by Holweg and Bicheno (2000) and Hines et al. (2000) referred to it as “splash back”). Human intervention to tame the Bullwhip effect, compared to simple heuristics, leads to higher demand amplification (Sterman 1989).

It follows that demand amplification may have serious consequences due to increased uncertainty and increases the significance of risk management. During a down turn, Towill (2005) showed that amplification causes possible shortages on product volume (products are not ordered, even if demand is undiminished) and variety as well as on idle capacity in operations and involves potential layoff costs. In the case of positive demand, Towill (2005) identifies that stock deterioration and sales cannibalization produces lost income.

Consumers purchase products lured by discounts and that diminishes sales in the following time periods or seasons (Warburton and Stratton, 2002). During up-swings, operations cost a premium for manufacturing and distribution (orders increase rapidly), but also decreases productivity development and increases waste levels. Recent emphasis on outsourcing and large-scale utilization of low cost sourcing has worsened demand amplification (Lowson, 2001; Warburton and Stratton, 2002; Stratton and Warburton, 2003; Hilletoft and Hilmola, 2008). Risks associated with production and transportation delays are considerably higher. To mitigate such risks, some corporations are using responsiveness as a strategic differentiator and have built their supply chains to react on market changes through more localized supply networks, for example, Benetton (Dapiran, 1992), Zara (Fraiman and Singh, 2002), Griffin (Warburton and Stratton, 2002; Stratton and Warburton, 2003), Obermeyer (Fisher et al., 1994) and NEXT (Towill, 2005). The carbon footprint of sourcing strategies will become increasingly relevant in view of future legislation. Logistics may ultimately benefit from a disruptive innovation (Datta, 2008b) in energy sourcing and management using wireless sensors networks (Datta, 2008e).

In recent decades, even macroeconomists are including inventory as a key indicator of economic decline of national economies (Ramey, 1989; Albertson and Aylen, 2003). Ramey (1989) argued that manufacturing input inventories, raw materials and work in process (WIP), fluctuated most in recession, while end-item or finished goods inventories fluctuate less (Table 10.1). However, the labour market volatility is also an issue in changing economic environments (Ramey, 1989). Although,

Table 10.1 All numbers billions of US-dollars (1972), annual rates of change

Recessions	Retail	Wholesale	Manufact. Finished Inventories	Manufact. Input Inventories
1960: 1–1960: 4	-6.3	-1.7	-3.1	-6.3
1969: 3–1970: 4	-8.2	1.2	-0.4	-5.2
1973: 4–1975: 1	-16.0	-5.8	2.4	-13.2
1980: 1–1980: 2	3.6	1.9	-0.3	-4.1
1981: 3–1982: 4	-7.6	-2.3	-7.8	-11.1

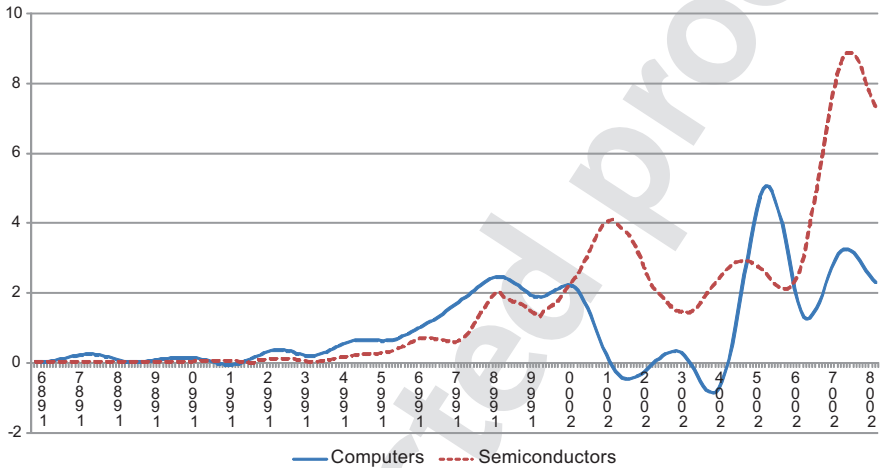


Fig. 10.1 Capacity addition change in US computer and semiconductor 1986–2008 (Federal Reserve 2008)

inventory positions seem to fluctuate, Albertson and Aylene (2003) argue that autoregressive forecasting models are able to forecast next period situation with a 50% accuracy. While autoregressive techniques have been widely used in finance (and economics) in the past few decades, they may not have been applied or explored as decision support tools by supply chain planners or analysts in the area of supply chain management (Datta et al., 2007) or in other verticals (healthcare, energy).

Logic of demand amplification is evident in economic cycles (Forrester, 1976; Sterman, 1985). Order backlog, existing inventory holdings, amount of production, amount of employment and capacity additions were used in simulation trials to forecast different levels of economic cycles. In long-term changes, both Forrester (1976) and Sterman (1985) have emphasized the importance of capacity additions. A similar methodology has been used in maritime economics to estimate price level changes (Dikos et al., 2006) and investment cycle lengths in capital intensive industries (Berends and Romme, 2001). Hilmola (2007) has shown that capacity additions in US in semiconductors and computers industries may explain the behavior of stock market indices.

10.3 Beer Game and Role of Advanced Forecasting Methods

Forrester (1958) introduced a classical 4-stage beer-game simulation and revealed that demand information amplifies within the supply chain as we move further up-stream. Figure 10.2 shows, customer demand is flat at 8 units per time period (it increased from 4 to 8 during time period of 100), but over-under reaction appears when supply chain is moved further with respect to time. Production orders spike to over 40 units per period, while waiting collapses to 0 units only 15 time units later. This occurs mostly due to time-delayed supply process in each stage, which is following make-to-stock (MTS) inventory principles (each phase has “target” for end-item inventory levels, which they try to reach with order algorithms).

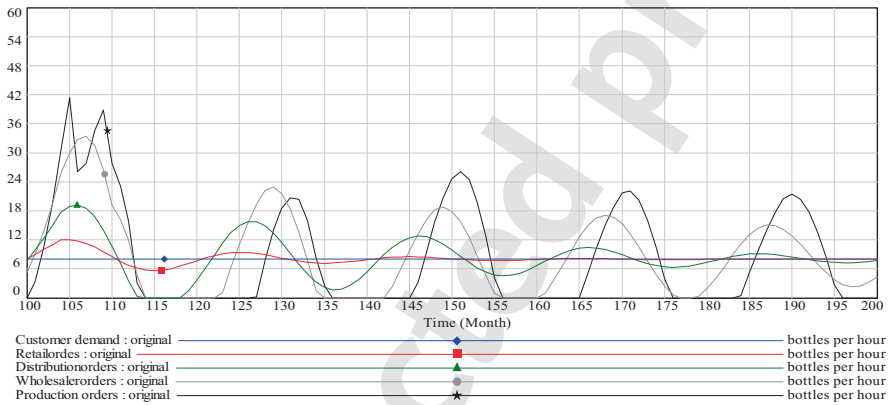


Fig. 10.2 Forrester effect (delay = 4, step-wise demand change from 4 to 8 units during time unit 100)

It may be observed from previous research that conventional forecasting methods do not reduce negative impact from demand amplification. As shown in Fig. 10.3, classical forecasting techniques such as exponential smoothed moving average (EWMA) only heightens demand amplification (highest value reaches above 50 units per time period) due to the assumption that all previous values should be used to predict demand. Although, use of EWMA may be justified under certain circumstances, the non-discriminatory or mandatory use of past data to predict future demand may often generate an undesirable over-reaction.

Figure 10.4 reveals implementation problems for sharing of demand information. Often different supply chain phases use different competing suppliers to gain cost efficiency and true demand is often confidential. Lam and Pestle (2006) describe 60% of respondents in a survey (in China) indicating that their customers are not willing to exchange information. Sharing data about high demand periods could result in inflated purchase price if suppliers decide to form cartels. However, it has been shown in a signaling game theoretic approach that sharing of information increases total supply chain profit (Datta, 2004).

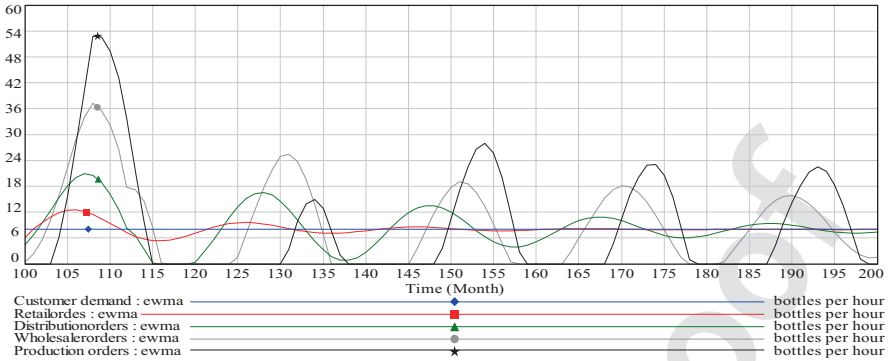


Fig. 10.3 Forrester effect in a supply chain as it tries to use EWMA at local level (0.5 weight) within original setting (delay = 4, step-wise demand change from 4 to 8 units during time unit 100)¹

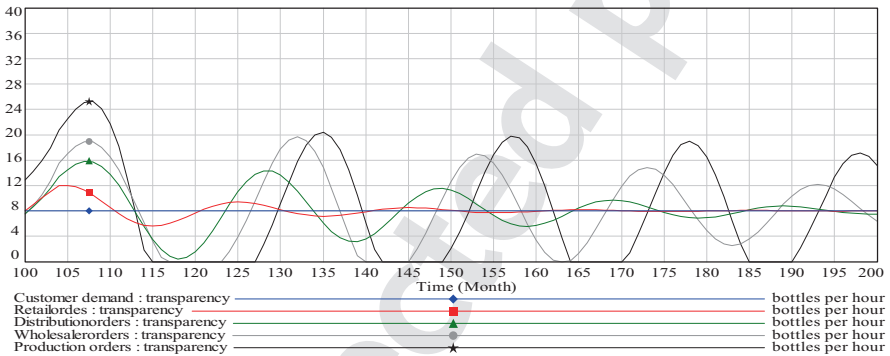


Fig. 10.4 Forrester effect in four stage supply chain, where we have transparency for the next stage (delay = 4, step-wise demand change from 4 to 8 units during time unit 100)

In previous and current work, we suggest that improving forecasting accuracy could be profitable by using advanced forecasting methods, such as autoregressive moving average (ARMA) models. Figure 10.5 shows that demand forecasting in an amplified environment may be completed by assigning a positive value for last observed demand and a negative co-efficient for older observations (for simplicity we have used lag of one and two).

Table 10.2 shows co-efficient of two lagging parameters are within the neighborhood of ARMA models built with a larger amount of data. However, the differences among different models are rather minimal.

Applying advanced forecasting models to tame the Bullwhip effect is challenging because it calls for process transformation (Zhao et al., 2002; Bayraktar et al., 2008). In Figure 10.6 the manufacturing unit reserves forecasted amount of inventory one

¹ Juha Saranen, Lappeenranta University of Technology, Finland

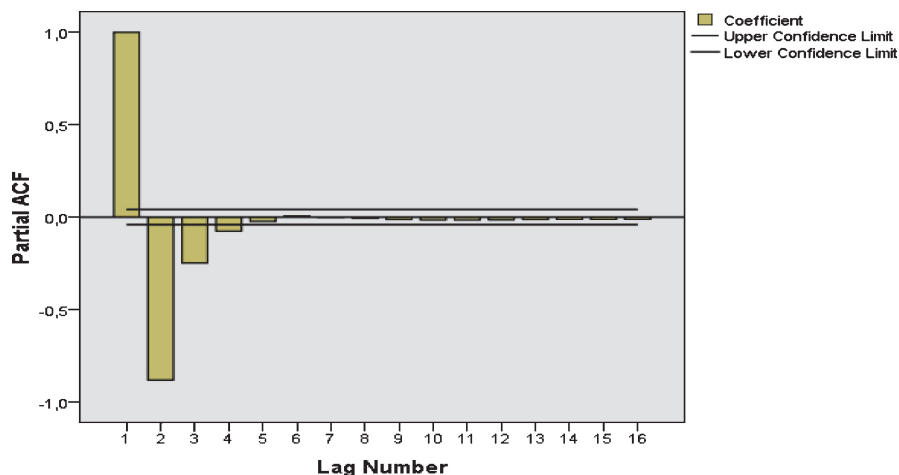
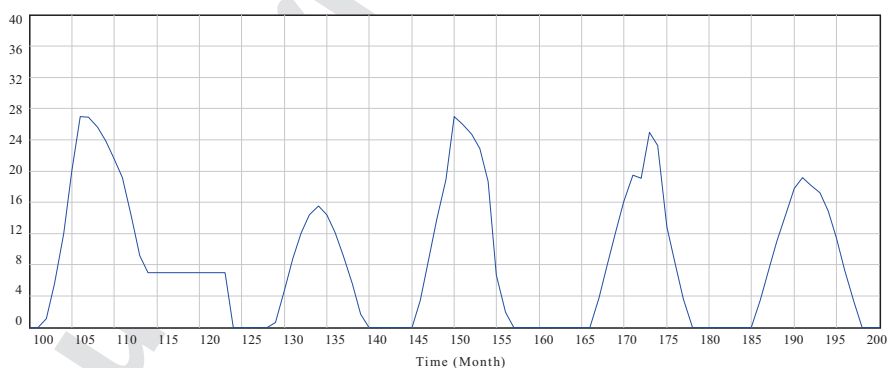


Fig. 10.5 Partial autocorrelation of four stage supply chain data from production phase (2401 observations from 300 time units)

Table 10.2 ARMA models built with 0.125 interval data from original beer-game setting for production phase (number of observations in integer time units given in parenthesis)

Number of observations	Co-efficient $t - 1$	$t - 2$	Goodness of fit R2 (%)	R2 (%) whole sample
100 (12.5)	1.936	-0.938	99.8	99.97
200 (25)	1.937	-0.939	99.9	99.97
300 (37.5)	1.937	-0.939	99.9	99.97
2401 (300.1)	1.918	-0.919	100.0	-



Prod orders TO TAL : original

Fig. 10.6 Production orders as ARMA model of wholesaler demand is used in production orders with modifications on operating structure

period before-hand (in order to distribute knowledge from future demand into operative decisions). However, this is not enough. We have used another manufacturing unit, which serves as an emergency inventory, dedicated for sudden upswings of demand. This emergency inventory is served with local short response manufacturing, which continuously replenishes emergency inventory with low lot size (in this case lot size is 7 units, lead time to emergency inventory is 1 time unit, instead of 4). During simulation trials we explored how ARMA model may be built within dynamic environments with respect to time.

10.4 Advanced Statistical Models

Forecasting demand is a key tool in managing uncertainty. Forecast accuracy depends on the understanding and coverage of parameters as well as the accuracy of historic data available for each variable that may have an impact on the forecast or predictive analytics. The broad spectrum applicability of forecasting includes such diverse verticals as healthcare and energy² utilization (Datta 2008e, 2008f).

One of the assumptions in the Classical Linear Regression Models relates to homoskedasticity (homo \approx equal, skedasticity \approx variance or mean squared deviation (σ^2), a measure of volatility) or constant variance for different observations of the error term. Forecast errors are heteroskedastic (unequal or non-constant variance). For example, in multi-stage supply chains, the error associated with manufacturer's forecast of sales of finished goods may have a much larger variance than the error associated with retailer's projections (the assumption being that the proximity of the retailer to the end consumer makes the retailer offer a better or more informed forecast of future sales through improved understanding of end-consumer preferences). The upstream variability reflected in the Bullwhip Effect violates the basic premise of CLRM, the assumption of homoskedasticity. CLRM ignores the real-world heteroskedastic behavior of the error term ε_t and generates forecasts, which may provide a false sense of precision by underestimating the volatility of the error terms.

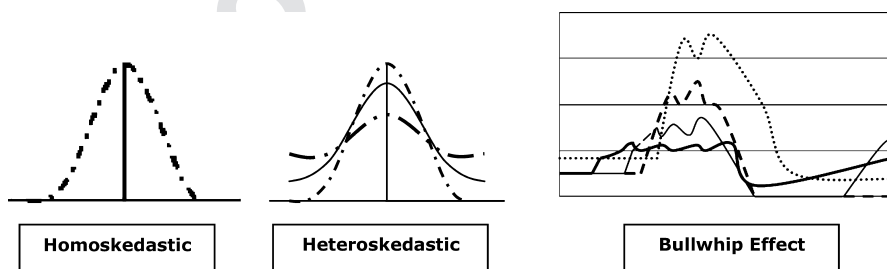


Fig. 10.7 Illustrations of homoskedasticity, heteroskedasticity and the Bullwhip Effect

² See www.cids.ie/Research/DCSES.html and www.dcsenergysavings.com

In a homoskedastic distribution, observations of the error term can be thought of as being drawn from the same distribution with mean = 0 and variance = σ^2 for all time periods (t).

A distribution is described as heteroskedastic when observations of the error term originate from different distributions with differing widths (measure of variance). In supply chains, the variance of orders is usually larger than that of sales and the distortion increases as one moves upstream from retailer to manufacturer to supplier. Therefore, the assumption of heteroskedasticity, over time, seems appropriate as a characteristic that may be associated with demand amplification or the Bullwhip effect.

While variance of error term may change across cross sectional units at any point in time, it may also change over time. This notion of time varying volatility is frequently observed in financial markets and has been the driving force behind recent advancements in time series techniques. Instead of considering heteroskedasticity as a problem to be corrected (approach taken by CLRM practitioners in assuming homoskedasticity of error term), Robert Engle modelled non-constant time dependent variance (heteroskedasticity) using an autoregressive moving average (ARMA) technique.

ARMA consists of two components, an autoregressive (AR) component and a moving average (MA) component. AR is a technique by which a variable can be regressed on its own lagged values and thus link the present observation of a variable to its past history. For example, today's sales may depend on sales from yesterday and the day before. MA expresses observations of a variable in terms of current and lagged values of squared random error terms using a moving average.

Robert Engle used the MA approach to propose AutoRegressive Conditional Heteroskedasticity or ARCH to model the time varying volatility in a series. The 'conditional' nature of non-constant variance (heteroskedasticity) refers to forecasting of variance *conditional* upon the information set available. This MA representation was later generalized to an ARMA representation referred to as Generalized AutoRegressive Conditional Heteroskedasticity model or GARCH. The GARCH technique represents a parsimonious model than ARCH, while allowing for an infinite number of past error terms to influence current conditional variance.

These advances from econometrics may be developed into tools for forecasting and risks analytics with a broad spectrum of applications in business, energy, industry, security and healthcare (Datta, 2008d), as well as decision support systems and operations management, for example, supply chain management (Datta et al., 2007).

Impact of Real-Time High-Volume Data from Automatic Identification Technologies (AIT)

Tracking technologies evolved from the discovery of the RADAR at MIT in the 1940's. AIT is slowly beginning to impact information flow in the modern value chain network. Tracking products from manufacturers to retailers may have its ori-

gins in the 1970's with the introduction of the bar code to identify stock-keeping units (SKU). Now it is embracing AIT or auto id, for example, use of radio frequency identification (RFID). AIT makes it possible to electronically log product movement in the "digital" supply chain. This information may be available in real-time. However, the standards, such as the electronic product code (EPC), to capture unique identification of physical objects and processes (Datta, 2007a) calls for a paradigm shift (Datta, 2008c).

Since RFID updates reports every time an individual item or SKU moves from one stage to another stage in the supply chain, or when the item is sold, it is possible to determine the demand for an item in *real-time* rather than wait for batch updates or weekly or monthly buckets to generate a forecast. The granularity of the data from auto id systems may result in very high volume data which may reveal peaks and troughs of demand for the product, hourly or daily. This volatility is lost when data is aggregated in buckets or batch.

Extracting the value from this high volume near real-time data and deciphering the meaning of the implicit volatility may be a boon to business intelligence and predictive analytics, including forecasting.

Indeed many warehouses adopt an inventory policy of ordering products when stock levels fall below a certain minimum amount s and order up to a maximum amount S [the (s, S) policy]. With auto id it is possible to ascertain this at the instant the threshold is attained, thereby, eliminating the likelihood of out of stock (OOS). Hence, it follows that capitalizing on the increased volume of near real-time demand data from auto id may have profound impact on supply chain forecasting.

However, current software with its CLRM engines and clustering approach, does not improve forecasts even with high volume data. The assumption of error terms implicit in CLRM limits the gains in forecast accuracy from high volume data and fails to show return on investment (ROI) from adoption of (new) auto id tools.

It is our objective to justify why deployment of new tools, for example, auto id, calls for adoption of new techniques for data analytics, for example, advanced techniques from financial econometrics. It is safe to state that new streams of data emerging from a multitude of sources, for example, auto id and sensors, cannot yield value or ROI if used in conjunction with archaic software systems running ancient forms of analytical engines that are typically CLRM based, at least, in the forecasting domain.

To extract decisionable information from high volume near real-time auto id and sensor data, the use of techniques like GARCH deserves intense exploration. The fact that GARCH may be a clue to generating ROI from auto id and RFID data is no accident because GARCH requires high volume data to be effectively utilized and generate results with higher accuracy levels. Hence, this convergence of auto id data with tools from econometrics may be an innovative confluence that may be useful in any vertical in any operation including security and healthcare, as well as obvious and immediate use in supply chain management. Datta et al. (2007) and this chapter, has attempted to highlight how to extract the advances in econometrics from the world of finance and generalize their valuable use in decision systems, with a broad spectrum of general applications.

Evolution of such a tool may help analysts and planning managers since a key concern of any manager is the accuracy of the predictions on which their budget is based. The proper allocation of resources for acquisition of personnel and equipment has long been plagued by errors in traditional forecasting. A part of the answer to this problem may be latent in the potential for the combined use of VAR (vector autoregression) with other forecasting techniques. The primary VAR model best suited for the planning function in resource allocation is the standard GARCH model. It is well suited for pragmatic studies involving supply chain, army personnel requirements and defense equipment requirements. Any system that may be modeled using time-series data, may explore how to include GARCH based on the error correction innovation that may improve forecasts. Forecast accuracy of GARCH model may be quantified in a number of different ways. Traditional methods are:

1. Mean Square Error.
2. Mean Average Percentage Error.
3. Aikiki Information.

Once the forecast is developed, the accuracy can be measured by comparing the actual observed values with the predicted values. If the collected data falls within the confidence interval of the forecast model, then the model provides a good fit for the system. Although GARCH is useful in forecasting it is important to realize that it was designed to model volatility and can be applied to positive series but not to economic series.

GARCH Proof of Concept Demonstrated Using an Example from Spare Parts Inventory Management

Although GARCH models have been almost exclusively used for financial forecasting in the past, we propose (Datta et al. 2007b) that with appropriate modifications, it may be applicable to other areas. An operation exhibiting volatility may benefit from VAR-GARCH in addition to other techniques, either in isolation or in combination. It is known that in times of conflict military supply chains experience spikes in demand. These spikes and troughs occur over a short period of time and result in losses due to OOS (out of stock) or surplus. GARCH may minimize forecast errors and fiscal losses in some of the following domains:

1. Cost of personnel, supplies, support;
2. Planning, programming and budgeting;
3. Defense program and fiscal guidance development;
4. Force planning and financial program development.

In one preliminary study (supported by the US DoD, Institute for Defense Analysis, Washington DC and also mentioned in Datta et al., 2007) the spare parts supply chain of a military base was examined for inefficiencies. The data for a 9 month period was collected for a spare part for a military vehicle (HumV). Because the

US Department of Defense affixes RFID tags on some spare parts from some of its suppliers, the hourly auto id demand data was available for analysis. The historical data was used to develop CLRM and GARCH (1,1) model. In this case, the linear regression model was found to have Mean Square Error (MSE) of 0.20 (20 %). By comparison, the GARCH (1,1) model produced a MSE of 0.06 (6.7 %). These results are encouraging and the US DoD case lends credibility for exploration of GARCH in forecasting analytics. Although this finding is promising, it needs to be repeated with other forms of data and subjected to rigorous mathematical analysis.

Financial Profit from Application of GARCH Technique in Retail Inventory Management

A pilot implementation using GARCH in a commercial supply chain has been undertaken with real-world retail data from a major US retailer. Preliminary results reveal that using GARCH as a forecasting technique offers some advantages (even with limited data volume) compared to CLRM and ARMA. The retail data are from office supply products for business and home customers. Thousands of product lines are sourced from different suppliers, globally. In this study, nine different SKU's from three different product classes were chosen for analysis. It is not known whether some of the products may suffer from seasonality effects. For each of the 9 products the historical demand data is available for 70 continuous weeks. 52 weeks of history was used to develop projections of demand variability for the subsequent 18 weeks. This projection was compared to the actual observations of demand variability over the 18 week test horizon. Three different techniques were used to forecast the standard deviation. The methods used were CLRM, ARMA and GARCH.

Figure 10.8 shows the performance of each of the three forecasting techniques based on retail data on the 9 products. The error of the forecasted standard deviation is calculated as an average over the final 16 weeks of forecast data. CLRM is outperformed by ARMA and GARCH models for almost all SKU's.

The results suggest that GARCH may be better (or as good as) across different SKU's. GARCH outperforms ARMA for a number of products. For the eight favorable tests, an average improvement of 800 basis points was observed. That translates to 1.1 % in-stock improvement from a preliminary application of GARCH. In this real-world case, that amounts to about \$ 13 million in additional revenue in terms of recovered lost sales. The product-dependent variability of GARCH performance may be linked to seasonality or other factors (accuracy of input data). Further testing with granular data (hourly or daily) and higher volume data per SKU may increase the accuracy and benefits from using the GARCH technique in forecasting. It may be apparent that systemic use of GARCH type techniques in forecasting, therefore, may substantially improve corporate profit.

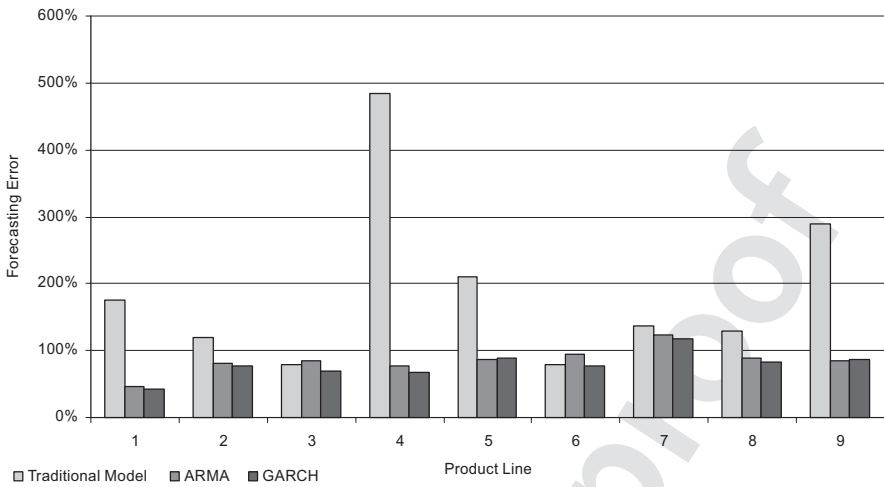


Fig. 10.8 Classic Linear Regression Model (CLRM) is almost always outperformed by ARMA and GARCH

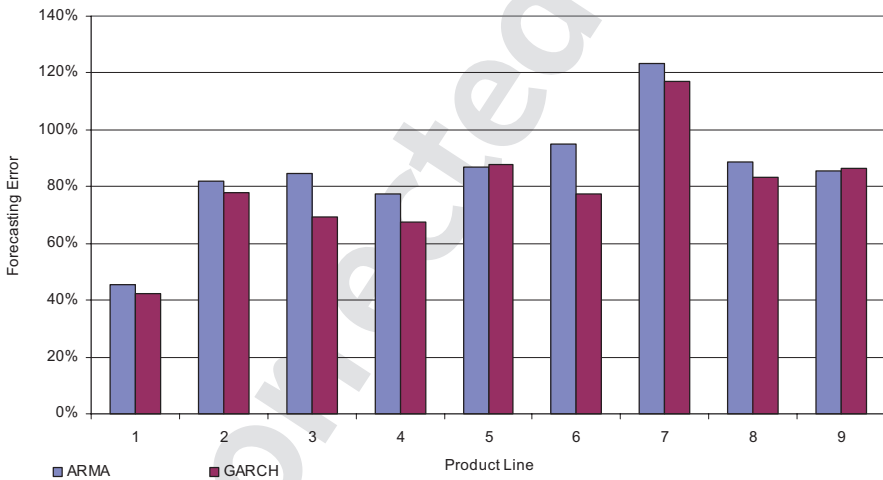


Fig. 10.9 Comparing autoregressive techniques: ARMA vs. GARCH (same data set but excluding CLRM)

It is not difficult to extrapolate that high volume item level retail sales or inventory data (per minute or by the hour) may be available with the diffusion of item level tagging using RFID or radio frequency identification tags. The volume of the data may increase exponentially if embedded sensors are deployed to enhance security and/or detect movement of any physical object from any location. Businesses dealing with short life cycle products (electronics, semi-conductors industries) may explore how these advanced techniques may help to reduce the volatility of supply-

demand since the ability to re-address sales or marketing issues are often limited if the shelf-life of the product is merely a few months (laptops, MP3 players, cell phones).

10.5 Temporary Conclusion

Making sense of data may benefit from high volume data acquisition and analysis using GARCH and VAR-MGARCH (Datta et al., 2007) techniques in addition to and in combination with other tools for forecasting and risk analysis in diverse verticals that may span from healthcare to energy (Datta, 2008e). In this work, we explored the possibility of using advanced forecasting methods in context of supply chains and demonstrated financial profitability from use of the GARCH technique. It remains unexplored if concomitant business process transformation may be necessary to obtain even better results. The proposed advanced forecasting models, by their very construction require high volume data. Availability of high volume data may not be the limiting factor in view of the renewed interest in automatic identification technologies (AIT) that may facilitate acquisition of real-time data from products or objects with RFID tags or embedded sensors. It is no longer a speculation but based on proof that use of advanced forecasting methods may enhance profitability and ICT investments required to acquire real-time data may generate significant return on investment (ROI). However, understanding the “meaning” of the information from data is an area still steeped in quagmire but may soon begin to experience some clarity if the operational processes take advantage of the increasing diffusion of the semantic web and organic growth of ontological frameworks to support ambient intelligence in decision systems coupled to intelligent agent networks (Datta, 2006). To move ahead, we propose to bolster the GARCH proof of concepts through pilot implementations of analytical engines in diverse verticals and explore advanced forecasting models as an integrated part and parcel of real-world business processes and systems including the emerging field of carbonomics (Datta, 2008f).

Acknowledgements The corresponding author (SD) is deeply indebted to Prof. Clive Granger (UCSD) for his guidance, critical reading and review of the manuscript. The author (SD) is grateful to Professor Robert Engle (NYU) for his advice. The detailed editing of this document was accomplished by Brigid Crowley at the School of Science and Computing at ITT, Ireland. Comments from General Paul Kern of The Cohen Group (Washington DC) and Dr. Stan Horowitz of the Institute for Defense Analysis (Washington DC) were very helpful to the corresponding author (SD). The encouragement from Mr Kazunori Miyabayashi, Senior Vice President of Hitachi (Tokyo, Japan) and Professor Joseph Sussman, MIT is acknowledged. This work was partially supported by the members and sponsors of the MIT Forum for Supply Chain Innovation, Massachusetts Institute of Technology (Cambridge, Massachusetts) and the Centre for Innovation in Distributed Systems.

References

- Arvis J.-F., Mustra M.A., Panzer J., Ojala L., and Naula T. (2007). *Connecting to Compete – Trade Logistics in the Global Economy*. World Bank Publications, New York
- Albertson K. and Ayles J. (2003). Forecasting the behavior of manufacturing inventory. *Int J Forecasting* 19:299–311
- Bayraktar E., Lenny Koh S.C., Gunasekaran A., Sari K., and Tatoglu E. (2008). The role of forecasting on Bullwhip effect for E-SCM applications. *International Journal of Production Economics* 113:193–204
- Berends P.A.J. and Romme A.G.L. (2001). Cyclicalities of capital intensive industries: A system dynamics simulation study of the paper industry. *Omega: International Journal of Management Science* 29:543–552
- Boyle E., Humphreys P., and McIvor R. (2008). Reducing supply chain environmental uncertainty through e-intermediation: An organization theory perspective. *International Journal of Production Economics* 114:347–362
- Chatfield C. and Yar M. (1988). Holt-Winters forecasting: Some practical issues. *The Statistician* 37(2):129–140
- Hong C., Frank M.Z., and Wu Q.Q. (2005). What actually happened to the inventories of American companies between 1981 and 2000? *Management Science* 51(7):1015–1031
- Coase R.H. 1937. “The Nature of the Firm” *Economica* N.S. 4:386–405. Reprinted in Williamson O.E. and Winter S., eds., 1991. *The Nature of the Firm: Origins, Evolution, Development*. NY: Oxford University Press, pp. 18–33
- Coase R.H. (1960). The problem of social cost. *J Law Econ* 3:1–44
- Coase R.H. 1972. *Industrial Organization: A Proposal for Research* in Fuchs V.R., ed., *Policy Issues & Research Opportunities in Industrial Organization*. NY: National Bureau of Economic Research, pp. 59–73
- Coase R.H. 1992. The Institutional Structure of Production. *American Economic Rev* 82:713–719
- Cooper D.P. and Michael T. (2005). Supply chain integration via information technology: strategic implications and future trends. *International Journal of Integrated Supply Management*, 1(3):237–257
- Dapiran P. (1992). Benetton: global logistics in action. *International Journal of Physical Distribution & Logistics Management* 22(6):7–11
- Datta S., et al. (2004). “Adaptive value networks: emerging tools and technology as catalysts” in Y.S. Chang, H.C. Makatsoris, and H.D. Richards (eds). *Evolution of Supply Chain Management: Symbiosis of Adaptive Value Networks and ICT*. Kluwer Academic Publishers, Amsterdam-Boston
- Datta S. (2006). *Potential for improving decision support catalysed by semantic interoperability between systems*. Working Paper, Engineering Systems Division, Massachusetts Institute of Technology. <http://esd.mit.edu/WPS/esd-wp-2006-10.pdf> & <http://dspace.mit.edu/handle/1721.1/41903>
- Datta S., Granger C.W.J., Barari M., and Gibbs T. (2007). Management of supply chain: an alternative modelling technique for forecasting. *Journal of the Operational Research Society* 58:1459–1469 <http://dspace.mit.edu/handle/1721.1/41906> and <http://esd.mit.edu/WPS/esd-wp-2006-11.pdf>
- Datta S. (2007a) Unified Theory of Relativistic Identification of Information in a Systems Age: *Convergence of Unique Identification with Syntax and Semantics through Internet Protocol version 6 (IPv6)*. Engineering Systems Division Working Paper Series, Massachusetts Institute of Technology <http://esd.mit.edu/WPS/2007/esd-wp-2007-17.pdf> & <http://dspace.mit.edu/handle/1721.1/41902>
- Datta S. (2008a). *Forecasting and Risk Simulation: Proposed Analytical Tool*. Working Paper, Engineering Systems Division, Massachusetts Institute of Technology <http://dspace.mit.edu/handle/1721.1/41913>

- Datta S. (2008b) WiFi Meet FuFi: Disruptive Innovation in Logistics Catalysed by Energy. *International Journal of Electronic Business Management* 6 117-119 <http://dspace.mit.edu/handle/1721.1/41897>
- Datta S. (2008c) Auto ID Paradigm Shifts from Internet of Things to Unique Identification of Individual Decisions in System of Systems. MIT ESD Working Paper Series and *Supply Chain Europe*, 2008 <http://esd.mit.edu/WPS/2008/esd-wp-2008-09.pdf> and <http://dspace.mit.edu/handle/1721.1/41900>
- Datta S. (2008d) Will Nano-Butlers Work for Micro-payments? Innovation in Business Services Model may Reduce Cost of Delivering Global Healthcare Services. MIT Engineering Systems Division WP <http://esd.mit.edu/WPS/2008/esd-wp-2008-17.pdf> and <http://dspace.mit.edu/handle/1721.1/41901>
- Datta S. (2008e) Tutorial on Sensor Networks in Energy Management Solution <http://dspace.mit.edu/handle/1721.1/43941>
- Datta S. (2008f) Nano-sensoromics: Is it Conceptually Similar to Carbonomics? <http://dspace.mit.edu/handle/1721.1/439415>
- Deutsche Post (2007). Annual Report of 2007. Germany
- George D., Marcus H.S., Papadatos M.P., and Papakonstantinou V. (2006). Niver Lines: A system-dynamics approach to tanker freight modeling. *Interfaces*, 36(4):326–341
- Fisher M.L., Hammond J.H., Obermeyer W.R., and Raman A. (1994). Making Supply Meet Demand In an Uncertain World. *Harvard Business Review* 72(3):83–93
- Fraiman N. and Singh M. (2002). Zara: Case Study. Columbia University School of Business, New York
- Forrester J.W. (1958). Industrial dynamics – a major breakthrough for decision makers. *Harvard Business Review* 36(4):37–66
- Forrester J.W. (1976). Business structure, economic cycles, and national policy. *Futures* 8(3):195–214
- Hilletofth P. and Hilmola O.-P. (2008). Supply chain management in fashion and textile industry. *International Journal of Services Sciences* 1(2):127–147
- Hilmola O.-P. (2007). Stock market performance and manufacturing capability of the fifth long-cycle industries. *Futures* 39(4):393–407
- Hilmola O.-P. and Szekely B (2008). *Railways, Airports and Sea Container Operators as Publicly Listed Companies – Financial Performance and Shareholder Value Creation Perspective*. Lappeenranta University of Technology, Department of Industrial Management. Research Report 196
- Hines P., Holweg M., and Sullivan J. (2000). Waves, beaches, breakwaters and rip currents – A three-dimensional view of supply chain dynamics. *International Journal of Physical Distribution & Logistics Management* 30(10):827–846
- Holweg M. and Bicheno J. (2000). The reverse amplification effect in supply chains. In: Katayama, H. (ed.): *Global Logistics for the New Millennium – 5th International Symposium on Logistics*, pp. 549–554. Tokyo
- Kros J.F., Falasca M., and Nadler S.S. (2006). Impact of just-in-time inventory systems on OEM suppliers. *Industrial Management and Data Systems* 106(2):224–241
- Lam J.K.C. and Postle R. (2006). Textile and apparel supply chain management in Hong Kong. *International Journal of Clothing Science and Technology* 18(4):265–277
- Lee H.L., Padmanabhan P., and Whang, S (1997). The Bullwhip Effect in Supply Chains. *MIT Sloan Management Review* 38:93–102
- Lowson R. (2001). Analysing the effectiveness of European retail sourcing strategies. *European Management Journal* 19(5):543–551
- Moon M.A., Mentzer J.T., and Thomas D.E. (2000) Customer demand planning at Lucent Technologies – A case study in continuous improvement through sales forecast auditing. *Industrial Marketing Management* 29:19–26
- Oliver R.K. and Webber M.D. (1982) Supply-chain management: logistics catches up with strategy. In Christopher M (ed.): *Logistics: Strategic Issues*, Chapman & Hall, London

- Ramey V.A. (1989). Inventories as factors of production and economic fluctuations. *The American Economic Review* 79(3):338–354
- Reyes P.M. and Frazier G.V. (2007) Radio frequency identification: Past, present and future business applications. *International Journal of Integrated Supply Management* 3(2):125–134
- Reyes P.M., Frazier G.V., Prater E.L., and Cannon A.R. (2007) RFID: The state of the union between promise and practice. *International Journal of Integrated Supply Management* 3(2):192–206
- Stratton R. and Warburton R.D.H. (2003) The strategic integration of agile and lean supply. *International Journal of Production Economics* 85(2):183–298
- Sterman J.D. (1985) An integrated theory of the economic long wave, *Futures* 17(2):104–131
- Sterman J.D. (1989). Modeling managerial behavior: Misperceptions of feedback in a dynamic decision making experiment. *Management Science* 35(3):321–339
- Towill D.R. (2005) The impact of business policy on bullwhip induced risk in supply chain management. *International Journal of Physical Distribution and Logistics Management* 35(8):555–575
- United Nations (2007). *Regional Shipping and Port Development Strategies – Container Traffic Forecast 2007 Update*. Economic and Social Commission for Asia and the Pacific
- United Nations (2005) *Regional Shipping and Port Development Strategies (Container Traffic Forecast)*. Economic and Social Commission for Asia and the Pacific
- Warburton R.D.H. and Stratton R. (2002). Questioning the relentless shift to offshore manufacturing. *Supply Chain Management: An International Journal* 7(2):101–108
- Wright D. and Yuan X. (2008) Mitigating the bullwhip effect by ordering policies and forecasting methods. *International Journal of Production Economics* 113:587–597
- Zhao X., Xie J., and Lau R.S.M. (2001) Improving the supply chain performance: Use of forecasting models versus early order commitments. *International Journal of Production Research* 39(17):3923–3939
- Zhao X., Xie J., and Leung J. (2002) The impact of forecasting model selection on the value of information sharing in a supply chain. *International Journal of Production Economics* 142:321–344

uncorrected proof

APPENDIX III

Shoumen Datta

HAPHAZARD REALITY – IOT IS A METAPHOR

THIS PAGE IS LEFT BLANK

Chapter 1

ADAPTIVE VALUE NETWORKS

*Convergence of Emerging Tools, Technologies and Standards as Catalytic Drivers**

Shoumen Datta¹, Bob Betts², Mark Dinning³, Feryal Erhun⁴, Tom Gibbs⁵, Pinar Keskinocak⁶, Hui Li¹, Mike Li¹, Micah Samuels⁷
Massachusetts Institute of Technology¹, Timogen Inc.², Dell Corporation³, Stanford University⁴, Intel Corporation⁵, Georgia Institute of Technology⁶, Amazon.com⁷

Abstract: If a typhoon in the South China Sea impacts the shipment and delivery of memory chips to an assembly plant in Mexico City, you can count on the ripple effect to impact financial service providers, manufacturers and suppliers, shippers in charge of logistics and of course, the end-consumer. Can we plan to reduce the risk arising from such uncertainties? Can businesses (semiconductor plants, banks, logistics providers) cooperate to minimize uncertainties? Conventional wisdom states that uncertainties are equivalent to accidents and hence by nature remain unpredictable. However, application of tools and technologies based on emerging standards may partially disprove such wisdom. Focus on demand management may be the guiding light for supply chain practitioners. Can we collapse information asymmetries (between manufacturers and their lending institutions, for example) and add far more value to networks or demand webs? Real-time operational adaptability is key, especially in fast 'clockspeed' industries. Confluence of emerging tools, technologies and standards are required to converge to catalyze the evolution of such adaptable enterprise. Can real-time distributed data, in-network processing, Agent-based autonomy, taken together, tame the Bullwhip Effect? Can the (semantic) web catalyze the "Nash Equilibrium" of people (games) and information (theory) in our quest for real time "predictive" decision support systems? We will explore a few of these issues and how they may coalesce to enable the adaptive value network of the future.

Key words: Adaptive value networks, Game theory, Bullwhip effect, Agent, Automatic Identification Technologies

New technologies for supply chain management and flexible manufacturing imply that businesses can perceive imbalances in inventories at an early stage — virtually in real time — and can cut production promptly in response to the developing signs of unintended inventory build up.

Alan Greenspan
Testimony to the U.S. Senate Committee on Banking,
Housing and Urban Affairs (13 February 2001)

*Disclaimer: This article is an over-simplified and incomplete exploration of a few tools and technologies that may converge to influence decision support systems in a manner that may catalyze the transformation of current-day supply chains toward an adaptive value network. In addition to named contributions, the corresponding author has used several sources of information in an effort to ‘connect the dots’ to suggest how apparently distant disciplines, if coalesced, may be complementary. Although the list of references is seriously incomplete, it should be amply clear that the original research is not due to the corresponding author. However, quotes, opinions, comments expressed in this article are solely attributable to the corresponding author and do not represent the views of MIT as an institution or the co-authors or their institutions or organizations. Some terms, for example, information asymmetry, may be used in a generic sense to imply lack of information or information visibility. This article is not an original research document but rather a synthesis of a few ideas, which, if taken together, may be catalytic in the transformation of supply chain management to become adaptive or perhaps even predictive. In this chapter we suggest that adaptive may morph into ‘predictive’ through a confluence of principles. We advocate inclusion of ARCH (autoregressive conditional heteroskedasticity) and GARCH (generalized ARCH) in the context of supply chains to model high frequency (volume) real-time data (from RFID tags) that may also exhibit volatility (<http://pages.stern.nyu.edu/~rengle/>). All errors of content or coherence are solely due to the corresponding author.

1. INTRODUCTION

“At the science museum in Barcelona, I saw an exhibit that beautifully illustrated ‘chaos.’ A nonlinear version of a pendulum was set up so that a visitor could hold the bob and start out in a chosen position with a chosen velocity. One could then watch the subsequent motion, which was also recorded with a pen on a sheet of paper. The visitor was then invited to seize the bob again and try to imitate exactly the previous initial position and velocity. No matter how carefully it was done, the subsequent motion was quite different from what it was the first time. I asked the museum director what the two men were doing who were standing in a corner, watching us. He replied, “Oh, those are two Dutchmen waiting to take away the “chaos.” Apparently, the exhibit was about to be dismantled and taken to Amsterdam. I have wondered ever since whether the services of those two Dutchmen would not be in great demand across the globe, by organizations that wanted their chaos taken away.” (Gell-Mann 1994).

The holy grail of industry is to remove “chaos” from the supply chain in order to better adapt to demand fluctuations. Managing uncertainty is compounded by the increasing degree of information asymmetry¹ between the supply “chain” (value network²) partners (designers, suppliers, distributors, retailers, consumers) who have different and often conflicting objectives, that threaten to create barriers on the road to adaptive business networks of the future (Heinrich and Betts, 2003).

Ampex pioneered the video recorder market in 1956. Each unit was priced at \$50,000 and the only competitors, RCA and Toshiba, were way behind. Sony, JVC and Matsushita were mere observers. Masaru Ibuka, co-founder of Sony and Yuma Shiraishi at JVC, issued directives for their respective engineers to produce an unit that would cost \$500, a mere 1% of Ampex’s price. In the 1980’s, video recorder sales went from \$17 million to \$2 billion at Sony, \$2 million to \$2 billion at JVC, \$6 million to \$3 billion at Matsushita and \$296 million to \$480 million at Ampex. Failure to adapt eclipsed Ampex. (Tellis and Golder, 1996).

One business objective of suppliers is to secure large volume purchase commitments (with delivery flexibility) from manufacturers. It conflicts with the manufacturer’s objective that must include rapid response to demand fluctuation yet the manufacturer must mass produce (to take advantage of economies of scale) yet production runs must adapt to fluctuations even though a certain run may have been planned based on demand forecast. Thus, manufacturers may need more or less raw materials and therefore seek flexibility in purchasing raw materials, which conflicts with the supplier’s objective. Manufacturer’s desire to run long production batches are in

conflict with the warehouse and distribution centers that aim to reduce inventory due to storage capacity constraints. The latter increases cost of transportation for all the players.

During 2000, supply chain related costs in USA alone exceeded \$1 trillion (10% of GDP), which is close to the entire GDP of Russia, is more than the GDP of Canada or Spain or the *combined* GDP of all the 22 nations who are members of the League of Arab Nations. The combined GDP of all 22 Arab nations is less than that of Spain (www.wrmea.com/archives/sept-oct02/0209044-2.html; www.bea.doc.gov; www.cia.gov). A mere 10% savings of supply chain costs in USA is nearly equal to the GDP of Ireland. Therefore, tools and processes that may reduce supply chain inefficiencies and help it better adapt to demand changes, are valuable. We will briefly explore some of the tools that may catalyze the adaptive value network.

Some emerging technologies may take leading catalytic roles but technology is *not* the solution. Ability to adapt supply chains will depend on continuous business process innovation led by management capable of envisioning use of technology as a tool to reduce (1) inefficiencies, (2) uncertainties and (3) information asymmetry within the value network. In essence, decision making processes should respond to (dynamic) information such that the system (enterprise) is able to rapidly adapt and/or respond.

One driver of this transformation (from ‘push’ based supply chain management to ‘pull’ based adaptive value networks) is the potential use of real-time information to catalyze or trigger autonomous decision steps capable of re-planning and execution. By some estimates, business in 2003 generated more than 1 terabyte of data per second (excludes data gathered by automatic identification technologies). Is this equivalent to information? It is unlikely that this data, as is, can be considered as information. Even when we extract the information, will it offer a “transactional” value? The ability to extract intelligence from data to manage information may be the differentiator between companies who will profit from data (such as automatic identification or sensors) versus those who will not. Data that is stored in business systems (such as ERP) may suffer from problems that reduces the value of their information. ERP systems may also compromise the efficacy of dynamic data if the data feeds static systems unable to respond in near real-time. When such ERP data and/or information sources are used by strategic planners for forecasting and optimization, it leaves room for speculation about the validity of the outcome since the process may have been optimized, or forecast delivered, based on “noise” rather than robust dynamic data. Stemming from poor data quality and information asymmetry between supply chain partners, these errors (of optimization, forecasting) accumulate at successive stages of a supply chain and manifests

itself as the generic Bullwhip Effect (Forrester 1961, Sterman 1989, Lee et al., 1997) (Figure 1-1 and Figure 1-2).

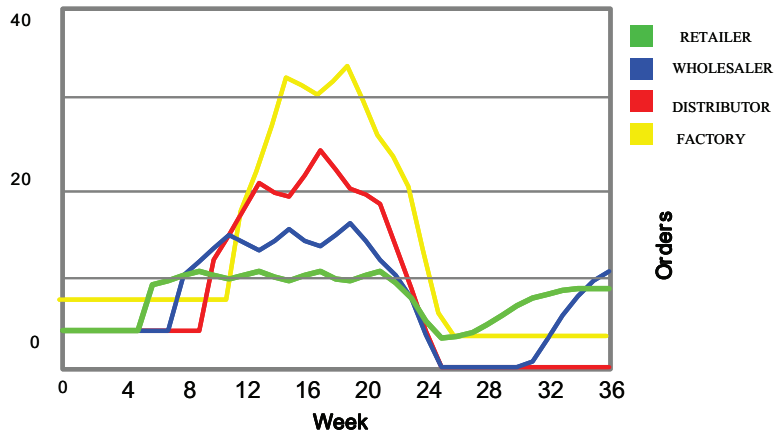


Figure 1-1. The Bullwhip Effect (Source: Joshi 2000)

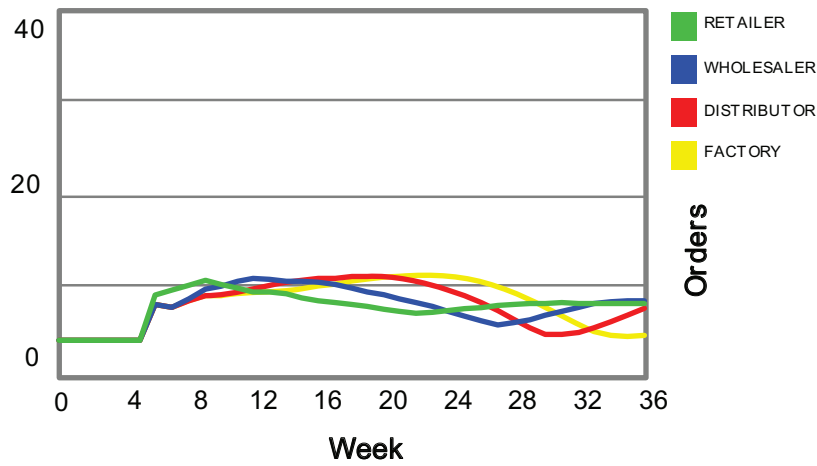


Figure 1-2. How do we taming the Bullwhip Effect? (Source: Joshi 2000)

Example from the semiconductor equipment supply chain shows demand forecast versus actual purchase of equipment by Intel Corporation (Figure 1-3).

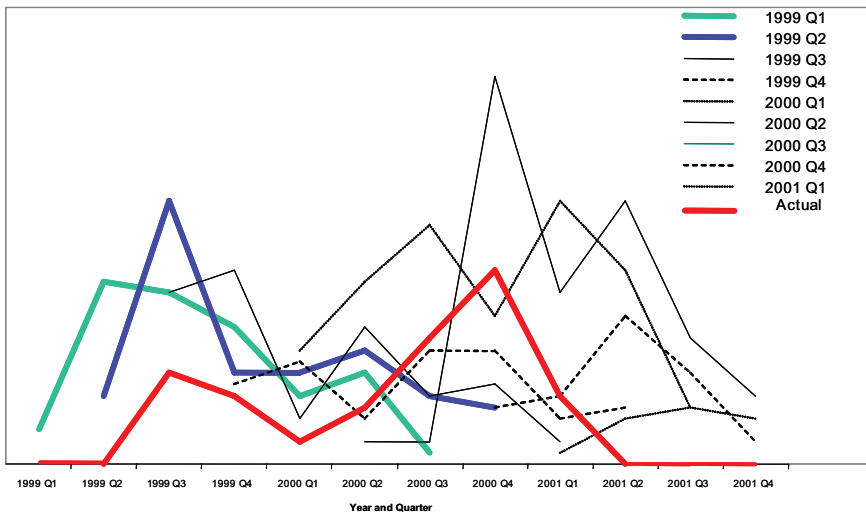


Figure 1-3. Intel Tool Order Data 1999-2001 (Source: Cohen, Ho, Ren and Terwiesch, 2003)

2. TOWARD ADAPTIVE VALUE NETWORKS: INFORMATION VISIBILITY (TRANSPARENCY)

Tools and technologies that may be catalytic in taming the Bullwhip Effect may also have an impact on making supply chains more adaptive by ushering in adaptive decision support systems. However, both assume the success of business process innovation to improve intra- and inter-enterprise information exchange as well as efforts to break down data silos as a segue to distributed data infrastructure. In thinking about adaptive supply chain management, it is helpful to analyze how the tools and technology catalysts may help connect *objects to processes* and *processes to decision systems*. Some of these “catalysts” may be classified into two broad (albeit arbitrary) categories. We will make an attempt to show how a few of these catalysts may (converge to) transform current supply chains to become more adaptive (Table 1-1).

Table 1-1. Tools and Concepts versus Data Mobility

Tools and Concepts	Data Mobility
Operations Research and Game Theory	Automatic identification technologies (RFID, UWB, GPS)
Distributed Artificial Intelligence and Agents	Wireless protocols (802.11, 802.16)
'Clockspeed' as defined by Charles Fine, MIT	Sensor networks
Semantic Web	
Simulation	

3. OPERATIONS RESEARCH AND GAME THEORY³

The workhorse of optimization (algorithms) is based on operations research. It is an area of intense research and innumerable sources of information are available. However, Game Theory was not such a "household" name until 1994 when John Nash, and later the movie about him, changed the public's perception so much so that generic business journals began touting the virtues of Game Theory.

Having game theory in your corporate 'bag of tricks' can mean the difference between success and failure. (Investor's Business Daily, 25 January 1996).

Managers have much to learn from game theory - provided they use it to clarify their thinking, not as a substitute for business experience (The Economist, 15 June 1996).

Game theory helps us model, analyze and understand the behavior of multiple self-interested parties who interact while making decisions. As such, Game Theory deals with interactive optimization problems. In particular, it is a tool for analyzing situations where the parties strive to maximize their (expected) pay-offs while choosing their strategies. Each party's final pay-off depends on the profile of strategies chosen by all parties. Most business situations can be modeled by a "game" since in any business interaction, involving two or more parties, the pay-off of each party depends on the other party's actions.

For centuries economists have worked on various game-theoretic models but Neumann and Morgenstern (1944) are credited as the fathers of modern Game Theory. Game Theory has since enjoyed an explosion of developments, including the concept of equilibrium (Nash, 1950), games

with imperfect information (Kuhn, 1953), cooperative games (Aumann, 1959; Shubik, 1962) and auctions (Vickrey, 1961).

3.1 Let the Game Begin

The overarching theme in Game Theory is “interactions.” In business, each decision maker is a player making a decision or choosing a strategy that will be impacted by the competitor.

“A chip manufacturer slashed prices of its desktop and mobile processors just days after a similar move by a rival. We’re going to do what it takes to stay competitive’ on prices, said representative. The companies aggressive price-chopping means the company doesn’t want to give up market share gains, even at the cost of losses on the bottom line (CNet News.com, May 30, 2002)”

In this example, companies compete on price to gain market share. During Q1 of 2002, this semiconductor company increased processor shipments (compared to Q4 of 2001) worth \$8 million but processor revenue declined by 3% (sold more chips for less money). Companies engaged in price wars rarely, if ever, benefit from such competition. Reducing prices slightly might increase the overall market potential but decreasing prices beyond a certain limit has a diminishing impact. Eventually the size of the “pie” does not increase anymore and firms fight harder to get a bigger “pie” by slashing prices and profits. Why do firms behave this way? In this situation and in some others, firms are caught in what is known in Game Theory as the “Prisoner’s Dilemma” where the rational response may not be the optimal.

3.1.1 Prisoner’s Dilemma

Two burglars, Alice and Bob, are arrested near the scene of a burglary and interrogated separately. Each suspect can either confess with a hope of a lighter sentence or may refuse to talk (does not confess). The police do not have sufficient information to convict the suspects, unless at least one of them confesses. Each must choose without knowing what the other will do. In other words, each has to choose whether or not to confess and implicate the other. If neither confesses, then both will serve one year on a charge of carrying a concealed weapon (Table 1-2). If both confess and implicate each other, both will go to prison for 10 years. However, if one burglar confesses and implicates the other but the other burglar does not confess, then the one who cooperates with the police will go free, while the other burglar will go

to prison for 20 years on the maximum charge. The “strategy space” in this case is simple: confess or don't confess (each chooses one of the two strategies). The payoffs (penalties) are the sentences served. In effect, Alice chooses a column and Bob chooses a row.

Table 1-2. Prisoner's Dilemma

		Alice	Alice
		<i>Confess</i>	<i>Does not</i>
Bob	<i>Confess</i>	10, 10	0, 20
Bob	<i>Does not</i>	20, 0	1, 1

The two numbers in each cell show the outcomes for the two prisoners when the corresponding pair of strategies are chosen. The number to the left shows the payoff to the person who chooses the rows (Bob) while the number to the right tells the payoff to the person who chooses the columns (Alice). Thus (reading down the first column) if they both confess, each gets 10 years, but if Alice confesses and Bob does not, Bob gets 20 and Alice goes free. Therefore, what strategies are "rational" in this game if both of them want to minimize their sentences? Alice might reason: *"Two things can happen: Bob can confess or Bob can keep quiet. If Bob confesses, I get 20 years (if I don't confess) and 10 years if I do confess (cooperate), so in that case it is better to confess. On the other hand, if Bob doesn't confess and I don't either, I get a year but in that case, if I confess I can go free. Either way, it is better if I confess. Therefore, I will confess."*

But Bob can and presumably will reason in the same way. So they both reason rationally to confess and go to prison for 10 years each. But, if they had acted "irrationally" and did not confess, they each could have gotten off with a year (<http://william-king.www.drexel.edu/top/eco/game/ game.html>).

Prisoner's Dilemma⁴ is an example of a non-cooperative static game where the players choose strategies simultaneously and are thereafter committed to their chosen strategies. The main issue of such games is the existence and uniqueness of Nash equilibrium (NE). NE is the point where no player has incentive to change her strategy since each player has chosen a strategy that maximizes his or her own payoff given the strategies of the other players. It may be prudent to point out that the fundamental distinction between cooperative and non-cooperative games is that cooperative games allow binding agreements while non-cooperative games do not. Study of cooperative games focuses on the outcome of the game in terms of the value

created through cooperation of players, but does not specify the actions that each player will take. The study of non-cooperative games is more concerned with the specific actions of the players. Hence the former allows us to model outcomes of more complex business processes.

3.1.2 Dilemma in Prisoner's Dilemma

A key concept not captured in "Prisoner's Dilemma" is the repetition of interactions. In business, most players know they will be in the "game" for awhile. Hence, they may choose to cooperate, especially if they deem that cooperation today may increase the chances of cooperation, or even collaboration, in the future. With repeated actions, companies build a reputation, which influences the actions of others. For example, a restaurant might make a higher profit today by selling slightly less fresh food (prepared yesterday), but will it be worth the possible consequence of losing customers in the future? Thus, rationally speaking, companies aim to act strategically with competitors and partners. In practice the behemoths continually try to squeeze their suppliers (blinded by "cost" reduction) and could lose critical partners.

Intel uses its much envied supplier ranking and rating program - which tracks a supplier's total cost, availability, service, supports responsiveness and quality - to keep its top suppliers on a course for better quality. 'We reward suppliers who have the best rankings and ratings with more business,' says Keith Erickson, Director of Purchasing.

As an added incentive, Intel occasionally plugs high-quality suppliers in magazine and newspaper advertisements. The company even lets its top performing suppliers publicize their relationship with Intel. That's a major marketing coup, considering that Intel supplies 80% of chips used in PCs today and is one of the most recognized brand names in the world.

Given that each party in a supply chain acts entirely on self interest, individual choices collectively do not lead to an "optimal" outcome for the supply chain. Thus, supply chain profit of a "decentralized" supply chain composed of multiple, independently managed companies, is less than the total supply chain profit of the "centralized" version of the same chain where the partner interactions (suppliers, manufacturers, retailers) are managed by a single decision-maker (information symmetry) to optimize total supply chain profits. Sharing of information in centralized supply chains reduces inefficiencies that are obvious in decentralized supply chains due to "double marginalization" stemming from self-centered decision making.

3.1.3 Optimal Profit is Higher in Centralized Supply Chains with Information Sharing (Symmetry)

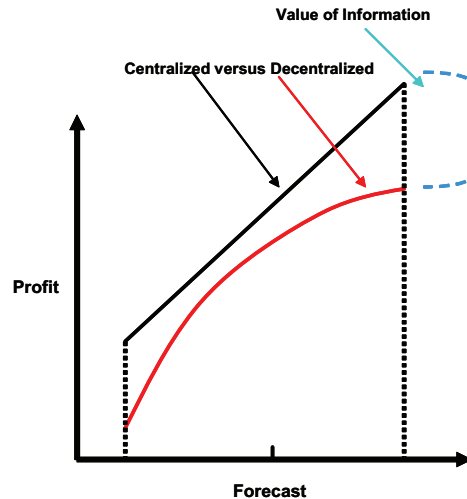


Figure 1-4. Optimal Profit versus Forecast (personal communication; Ozalp Ozer, Stanford University)

One strategy for reducing inefficiencies in decentralized supply chain (and consequent loss of profit) is “vertical integration” where a company owns every part of its supply chain. An example of vertical integration is Ford Motor Company. Earlier in the 20th century, in addition to automobile factories, Henry Ford owned a steel mill, glass factory, rubber plantation and iron mines. Ford’s focus was on (mass production) making the same car, the Model T, cheaper. This approach initially worked well. The price of a Ford Model T fell from \$825 in 1908 to \$290 in 1924. By 1914, Ford had a 48% share of the US market. By 1920, Ford was manufacturing half the cars made worldwide. Vertical integration allows a company to obtain materials at a low cost and control the entire supply chain.

In today’s economy, customer demand and preferences change rapidly. Companies that focus on core competencies are more likely to be nimble in order to stay ahead of competition and succeed. Hence, we see a trend towards “virtual integration” where supply chains are composed of independently managed but tightly partnered companies. Information sharing and vendor managed inventory (VMI) are strategies successfully used by some companies (such as Dell Corporation) for higher degree of

virtual integration. However, most companies still find it difficult or face internal reluctance to usher changes in their supply chain practices. Similar issues apply to independently managed intra-company divisions, such as marketing, production, and sales.

Game Theory makes some assumptions in its study of the impact of interactions of multiple players and the resulting dynamics in a market environment. Two key assumptions are:

- Each player in the market acts on self-interest, but they pursue well-defined exogenous objectives, that is, they are rational;
- In choosing a strategy, a player considers the potential reaction of other players and takes into account his or her knowledge of other decision makers' behavior, that is, he or she reasons strategically.

These assumptions rule out games of pure chance, such as lotteries and slot machines, where strategies do not matter and games without strategic interaction between players, such as Solitaire. Credibility is a central issue in games.

Coca-Cola is developing a vanilla-flavored version of its best-selling flagship cola, a report says, extending the company's palette of flavorings from Cherry Coke and Diet Coke with lemon. But don't expect to see a vanilla-flavored Pepsi anytime soon. 'It's not something we're looking at,' said spokesman Larry Jabbonsky of Pepsi. 'We think it's a bit vanilla.' (USA Today, 1 April 2002).

PepsiCo is launching Pepsi Vanilla and its diet version in stores across the country this weekend. Coke came out with Vanilla Coke in May 2002 and it was a resounding success, selling 90 million cases. 'We're a little surprised that Pepsi decided to enter the vanilla segment,' said Mart Martin of Coca-Cola. 'When we came out with Vanilla Coke, Pepsi originally said the idea sounded 'a bit vanilla.' (CNN/Money August 8, 2003).

3.2 Game Theory in Quantity and Price Competition

Business decisions include what to produce/procure, sell, how much, and at what price. Study of competitive interactions around these issues can be addressed using game theoretic models that focus on price and quantity decisions (several excellent papers including that of Albeniz and Simchi-Levi, 2003).

Quantity competition (Cournot Game) is especially important for commodities where there is an inverse relationship between quantity and market price. Price competition (Bertrand Game), on the other hand, occurs in every market, as competing companies try to maintain or increase market share.

OPEC decided to slash its crude oil production by 1.5 million barrels a day (6%). The issue came to a head this autumn with weakening world economy, together with the uncertainty caused by the Sep 11 attacks on the US, dragged down prices some 30%. The cut is expected to lift OPEC's benchmark price to \$22 a barrel, the group's minimum target price (CBS News, December 28, 2001).

Burger King will put its Whopper on sale for 99 cents. The move is likely to intensify and prolong the burger price wars that have been roiling the US fast-food industry in recent months. Burger King Officials had said earlier they had little choice given a \$1 menu at McDonald's that included a Whopper-like hamburger called the Big 'N Tasty." (Chicago Sun-Times, January 3, 2003).

Tesco announced plans to slash £80 million from prices of more than 1,000 products, with some prices falling by more than 30%. The cuts came as rival Asda also said it was slashing selected prices. The cuts echo memories of the supermarket price wars in 1999 as stores fought to capture more customers and increased market share (Sunday Telegraph, January 5, 2003).

Cournot Game

A market with two competing firms, selling homogeneous goods, where the two firms choose production quantities simultaneously, is known as a Cournot Game. It is a static game where the player's action sets are continuous (each player can produce any non-negative quantity). This is a tacit collusion to raise prices to a jointly optimal level and thus is a "cartel." A cartel is defined as a combination of producers of any product joined together to control its production, sale and price, so as to obtain a monopoly and restrict competition in any particular industry or commodity (www.legal-database.com). Cartels can be quite unstable. At each stage, the players have a huge incentive to cheat.

On Tuesday, 23 September 2003, an agreement was submitted to the US District Court in Philadelphia for an out-of-court settlement for a suit filed by industrial purchasers in 1999. According to this agreement, International Paper, Weyerhaeuser and Georgia-Pacific will pay US\$68

million to avoid litigation related to class-action lawsuits that accused them of conspiring to fix prices for container-board (packaging material).

The oil market is notoriously difficult to balance - demonstrated by the rollercoaster of prices over the last few years. Member states of OPEC do not have identical interests and find it difficult to reach consensus on strategy. Countries with relatively small oil reserves are often seen as 'hawks' pushing for higher prices. Meanwhile, producers with massive reserves and small populations fear that high prices will accelerate technological change and the development of new deposits, reducing the value of their oil in the ground (BBC News, February 12, 2003).

Bertrand Game

Models situations where firms choose prices rather than quantities. Assume two firms produce identical goods which are perfect substitutes from the consumers' perspective (consumers will buy from the producer who charges the lowest price). If the firms charge the same price, they will split the market evenly. There are no fixed costs of production and the marginal costs are constant. As in the Cournot Game, the firms act simultaneously. Therefore, when the costs and the products are identical, there exists a unique equilibrium in which all output is sold at the price equal to the marginal cost. Thus, the Bertrand Game suggests that when firms compete on price, and the costs are symmetric, we obtain a perfectly competitive market even in a duopoly situation. However, in real life, customers do not choose based on price alone. For example, Wendy's fast food chain decided to stay out of the Burger King and McDonald's price war (for a while) by aiming to gain market share by offering high quality food.

Stackelberg Game

In most business situations, firms choose their actions sequentially rather than simultaneously. In price wars, one firm responds after it observes another firm's actions. For our discussion, consider that firm 1 moves first and firm 2 responds. We call firm 1 the Stackelberg "leader," and the "follower" is firm 2.

3.3 Game Theory in Inventory Optimization

In time-dependent multi-period games, the players' payoff in each period depends on the actions in the previous, as well as, current periods. The payoff structure may not change from period to period (so called stationary payoffs). This resembles multi-period inventory models in which time periods are connected through the transfer of inventories and backlogs. Due

to this similarity, time-dependent games have applications in supply chain management, for example, Stochastic Games. (For detailed mathematical review, see Cachon and Netessine, 2003).

Stochastic Games may help in analyzing:

- two-echelon game with the wholesaler and retailer making stocking decisions;
- price and service competition;
- game with the retailer exerting sales effort and wholesaler stocking inventory and van;
- two-period game with capacity choice in 1st period and production decision under capacity constraint in 2nd period.

These games involve a sequence of decisions that are separated in time, but many supply chain models rely on continuous-time processes. Such applications of Differential Games are especially valuable in the area of dynamic pricing and in marketing-production games with manufacturer and distributor.

Biform Games have been successfully adopted in supply chain management (Anupindi et al., 2001). Consider a game where multiple retailers stock at their own locations, as well as, at several centralized warehouses. In the first (non-cooperative) stage, retailers make stocking decisions. In the second (cooperative) stage, retailers observe demand and decide how much inventory to trans-ship (cross-dock) among locations to better match supply and demand and how to appropriate the resulting additional profits. Variations on this theme are:

- allow retailers to hold back residual inventory. This model has three stages: inventory procurement, decision about how much inventory to share with others and, finally, the trans-shipment stage;
- option of pooling their capacity and investments to maximize the total value. In the first stage, firms choose investment into effort that affects market size. In the second stage, firms bargain over division of market and profits.

3.4 Game Theory in Contracts (Revenue Sharing)

This model is motivated by revenue sharing contracts implemented in practice. Blockbuster purchases movies from studios (suppliers) and rents them to customers. The supplier's wholesale price impacts how many videos Blockbuster orders and hence, how many units are available for rent. Before 1998, purchase price of a video tape from the studio was around \$65. Given that video rental fees are \$3-\$4 per tape, Blockbuster could purchase only a

limited number of videos and suffered lost demand during the initial release period (peak demand <10 weeks). About 20% of customers could not find the desired tape to rent. The studio's high wholesale price impacted on the quantity purchased by Blockbuster and in turn, revenues and profitability of both firms. Thus, Blockbuster and the studios crafted a revenue sharing agreement such that Blockbuster pays only \$8 per tape initially but then gives a portion (30 to 45%) of rental revenues to the studio (supplier). Since this agreement reduced Blockbuster's initial investment, it could order more tapes to meet peak demand and generate more revenues even with contracted revenue sharing with the studio (supplier). Blockbuster increased its overall market share from 25% to 31% and improved its cash flow by 61% (CNet News.com, October 18, 2000).

3.5 Games with Incomplete Information (Game Theory and Information Asymmetry)

Ubiquitous knowledge about players and decisions or payoffs is rarely a reality in real world supply chains. It is common that one firm may have a better demand forecast than another or a firm may possess superior information regarding its own costs and operating procedures. If a firm knows that another firm may have better information, it may choose actions that take this into account. Game Theory provides tools to study cases with information asymmetry with increasing analytical complexity.

Signaling Game

In its simplest form, a Signaling Game has two players, one of which has better information than the other. The player with the better information makes the first move. For example, a supplier must build capacity for a key component for a manufacturer's product. The manufacturer has a better demand forecast than the supplier. In an ideal world, the manufacturer may truthfully share his or her demand forecast with the supplier so that the supplier could build the appropriate capacity. But the manufacturer benefits from a larger capacity at the supplier in case of higher demand. Hence, the manufacturer has an incentive to inflate his or her forecast. However, the supplier will bear the cost of building capacity if it believes the manufacturer's (inflated) forecast. The manufacturer hopes the supplier believes the (inflated) forecast and builds capacity. Fortunately, the supplier is aware of the manufacturer's "game" to inflate (distort) forecast. What move (signal) from the manufacturer may induce the supplier to believe the forecast is credible? Consider the example below (from Ozalp Ozer of Stanford University).

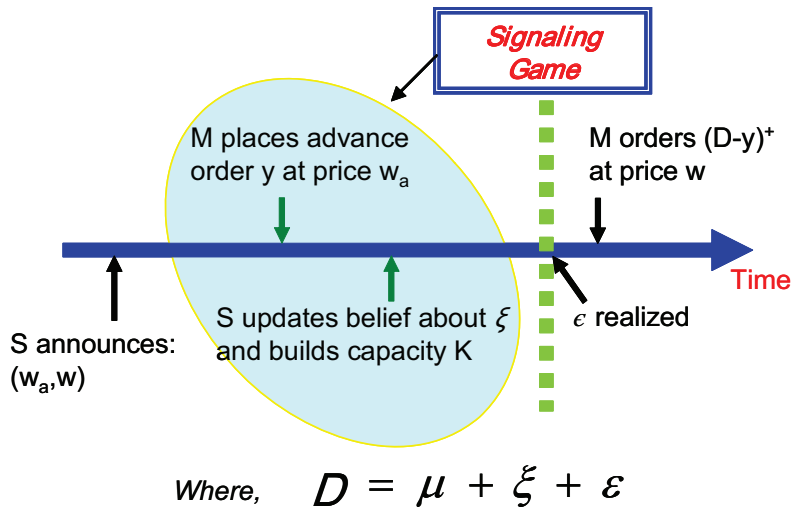


Figure 1-5. Signaling Game

In its simplest form, in this example, Demand (D) is represented as a sum of three forecasts (Figure 1-5). A market forecast μ (μ) is common information and published by commercial analysts. The manufacturer has sources and/or experience to derive private forecast information ξ (ξ) which is unknown to the supplier in a decentralized system (information asymmetry). However, the supplier can categorize the manufacturer into certain “types” based on prior actions or credibility of the manufacturer. Thus, the supplier updates its “belief” about the “type” of the manufacturer’s forecast information and may select some value of ξ that is spread over a distribution (function). This introduces a random variable. The general market uncertainty is given by epsilon (ϵ) and neither the manufacturer nor the supplier can control its value, although using appropriate tools, a closer to reality approximation of ϵ is possible. This introduces another random variable which is also spread over a distribution (function).

The Signaling Game, shown here, commences with a price announcement by the supplier: w (regular) and w_a (advance purchase) price. The manufacturer creates a demand (D) forecast and based on the strength of forecast, reacts to the supplier’s price package by placing an advanced order (y) to be purchased at w_a . The volume of y sends a “signal” to the supplier. The “signal” is used to update the supplier’s “belief” about the credibility of manufacturer’s forecast (D). Based on this, the supplier can determine how much capacity to build (K) to optimize his or her profits (inventory risk). Down the timeline, the market uncertainty is realized and using this value of ϵ the manufacturer may update its forecast. The volume of the D minus y is

the remaining volume the manufacturer orders from the supplier at a price w . While optimization based on Signaling Games may increase profits for manufacturer and supplier, it will still remain vulnerable to the value chosen for the variables ξ and ϵ . But, this may be further reduced using near real-time data (from automatic identification technologies, as we shall discuss in a later section), which offers greater adaptability to demand.

If signaling favors optimization of the supplier's capacity planning, then what is the manufacturer's incentive to signal? Does the manufacturer incur a cost to signal? Is the manufacturer's expected profit in the signaling equilibrium lower than what it would be if the manufacturer's type were known to the supplier to update his or her "belief" with certainty?

An ideal action for a high demand manufacturer is one that sends the signal of his or her high demand forecast at no cost. If a costless signal does not exist, then the goal is to seek the lowest cost to signal. Whether or not a costless signal exists depends upon what commitments the manufacturer can impose on the supplier. Suppose the manufacturer dictates (contractually) to the supplier a particular capacity level and the supplier accepts the terms. By accepting the contract, the supplier has essentially no choice but to build that level of capacity (severe penalty for non-compliance). This is referred to as "forced compliance" and in this case many costless signals exist for the manufacturer. However, if the supplier could potentially deviate without penalty, referred to as voluntary compliance, then the manufacturer's signaling task becomes more complex. One solution for a high demand manufacturer is to give a sufficiently large advance payment to the supplier. Since the high demand manufacturer's profit is higher than the low demand manufacturer's profit, only a high demand manufacturer could offer such an advance payment. This is referred to as signaling by "burning money" (who can afford to burn money?). A better signal is a contract that is costless to a high demand manufacturer, but expensive to a low demand manufacturer. An example of such a signal is a minimum commitment. The latter is costly only if realized demand is lower than the commitment and the manufacturer is forced by contract to purchase excess inventory. That scenario is less likely for a high demand manufacturer but a minimum commitment may be costly for a low demand manufacturer. Should a manufacturer agree to a minimum commitment if it possesses perfect information? Likely, because these contracts could be used solely for the purpose of signaling information.

Screening Game

In this game the player who lacks information makes the first move. For example, a supplier offers a menu of contracts with the intention of getting the manufacturer to reveal his or her type via the contract selected (in

economics this is referred to as mechanism design). The supplier is in charge of designing a mechanism to extrapolate the manufacturer's information.

The space of potential contract menus may be large. How many contracts should be offered and what form should they take? Furthermore, for any given menu, the supplier needs to infer for each manufacturer type which contract that manufacturer will choose. The revelation principle begins with the presumption that a set of optimal mechanisms exists. Associated with each of these mechanisms is a Nash Equilibrium (NE) that specifies which contract each manufacturer type chooses and the supplier's action given the chosen contract. (NE is the point where no player has incentive to change her strategy since each player has chosen a strategy that maximizes her own payoff given the strategies of the other players.) However, it is possible that some manufacturer type chooses a contract that is not designated for that type. For example, a high demand manufacturer chooses an option that the supplier had designed for the low demand manufacturer. Therefore, even though this game does not seem desirable, it is possible that this mechanism is still optimal in the sense that the supplier may not be able to do better on average because the supplier ultimately only cares about optimizing expected profit (not the means by which that profit is achieved). Auction design in the context of supplier procurement contracts and inventory contract design are two of the potential applications of the revelation principle in supply chain management.

Even though an optimal mechanism may exist for the supplier, this does not mean that the supplier earns as much profit as he or she would if he or she knew the manufacturer's type. The gap between what a manufacturer earns with the menu of contracts and what the same manufacturer would earn if the supplier knew her type is called an information rent. The separation of manufacturer types goes hand in hand with a positive information rent, that is, a manufacturer's private information allows the manufacturer to keep some rent that the manufacturer would not be able to keep if the supplier knew his or her type. Hence, even though there may not be any cost involved in information revelation with a Signaling Game, the same is not true with a Screening Game.

Bayesian Games

With a Signaling or Screening Game, actions occur sequentially, such that information may be revealed through observation of actions. There also exist games with private information that do not involve signaling or screening. Consider that a single supplier has a finite amount of capacity. There are multiple retailers and each knows his or her demand, but not the demand of other retailers. The supplier announces an allocation rule, the retailers submit their orders. Then, the supplier produces and allocates units.

If the retailer's total order is less than the supplier's capacity, then each retailer receives his or her entire order. If the retailer's total order exceeds the supplier's capacity, the supplier's allocation rule is implemented to allocate the capacity. To what extent does the supplier's allocation rule influence the supplier's profit, retailer's profit and the supply chain profit? In this setting the firms (retailers) that have the private information choose their actions simultaneously (no information exchange among retailers). If the supplier's capacity is fixed before the game starts, the supplier is unable to use any information from retailers (demand) to adapt capacity planning. However, it is possible that correlation exists in the retailers demand information, that is, if a retailer observes his or her demand type to be high, then he or she might assess that other retailers may have high demand types as well (if there is a positive correlation). Thus, each player uses Bayes' rule to update his or her belief regarding the types of the other players in a Bayesian Game. Bayesian Equilibrium is a set of strategies for each type that is optimal given the updated beliefs with that type and the actions of all other types. If a player deceptively inflates demand (high type) and other players use this information to update their "beliefs" then this effect may contribute to the observed Bullwhip Effect.

3.6 Temporary Conclusion

God definitely plays dice! Combined GT/OR may offer approaches to use (data) dynamic information for continuous optimization in terms of location and real-time availability (improve from visibility to transparency, among players) as a step toward an adaptive value network.

4. AGENTS

Linearization of real world conditions to fit mathematical models, such as Game Theory, may stifle real-time adaptability of value networks. As an example (see preceding section), a Bayesian Game potentially could contribute to the Bullwhip Effect representing wide fluctuations in supply chain. The discrete, dynamic and distributed nature of data and applications require that supply chain solutions do not merely respond to requests for information but anticipate, adapt and (support users to) predict. In that vein, 'intelligent' autonomous Agents are an essential tool for adaptive value networks to emerge.

The idea of Agent originated with John McCarthy in the 1950's at MIT. The term "Agent" was coined by Oliver Selfridge, a colleague of McCarthy's at MIT. Recent trends, beginning 1977, in Agent systems are

based on research in distributed artificial intelligence. Research from MIT, DARPA, Carnegie-Mellon University and University of Michigan at Ann Arbor has made significant contributions.

We define an autonomous Agent as a software entity that functions continuously in an environment, often inhabited by other Agents. Continuity and autonomy empower Agents to (plan) execute processes in response to changes in the environment without requiring constant human guidance, intervention or top-down control from a system operator. Thus, Agents offer the ability to rapidly adapt. An Agent that functions continuously in an environment over a period of time also learns from experience (patterns). In addition, Agents that inhabit an environment with other Agents in a Multi-Agent System (MAS) are able to communicate, cooperate and are mobile between environments. Agents work best for clearly discernible tasks or processes, such as, to monitor data from, for example, automatic identification technologies (radio frequency identification or RFID), ultrawideband (UWB) transponders, global positioning system (GPS), WiFi and sensors. Data Agents can share this data with high level Information Agents and offer real-time information to Process Agents (Inventory Agent, Purchasing Agent). The emergence of Multi-Agent Systems (MAS) may be slow to take-off unless the Semantic Web sufficiently permeates the environment for ubiquitous deployment of Agents.

Design of Agent-Based Modeling (ABM) draws clues from natural behavior of biological communities. Although it still remains a paradox, it is increasingly undeniable that simple individual behaviors of bugs like ants and wasps, *collectively*, may offer intelligent models of complicated overall behavior. In fact, this may have been known for centuries. One ancient observer, King Solomon, knew from his father, David, of the elaborate court organizations of oriental kings and preparations needed for military campaigns. He marveled that insects could accomplish both these tasks without any central control. Thinking of the complex systems needed to maintain the palace commissary, he wrote, "Go to the ant, consider her ways and be wise. Having no guide, overseer or ruler, she prepares her bread in summer and gathers her food at harvest time." He knew the complexity of a military organization and was impressed that "locusts have no king, yet all of them go forth by companies." Nearly 3000 years later, a participant in the NCMS Virtual Enterprise Workshop (1994) commented, "we used to think that bugs were the problem. Now we suspect they may be the solution!" (Parunak 1997)

Adaptability in biological systems is a fundamental characteristic of nature, and thus, models based on and inspired by such superior systems can contribute significantly to reduce key inefficiencies (and stem the loss of profit) between centralized and decentralized supply chains. Most software

is based on equations that link rates and flows (consumption, production). Variables (cost, rebates, transportation time, and out-of-stock) evaluate or integrate sets of ordinary differential equations (ODE) or partial differential equations (PDE) relating these variables. Operations research provides the framework to optimize for the “best” result. What if the “best” result is not necessarily the optimal “best” for that situation? Shortest lead time could plan a route through an area with a high probability of flash flood due to a brewing storm or threat of sniper attack on a portion of the highway. Planning software (today) fails to, or is incapable of, modeling such random events that may have profound implications for business, at that time. Thus, the “best” solution may not be adaptive to supply chain events at hand.

Even excluding random events or decisions that require integration with other models (weather, road construction), what is the half-life of ‘best’ solution in a fickle economy or high “clockspeed” industry? Compared to ABMs, a significant shortcoming of such Equation-based (ODE, PDE) models (EBM) is that EBM based software processes assume that these parameters are linear in nature and relevant data is available (for optimization). In the real world, events are non-linear, actions are discrete, information about data is distributed (CRM, PLM, SCM data silos) and data is corrupted with “noise” (according to a study by Ananth Raman of Harvard Business School and Nicole DeHoratius of the University of Chicago, for a global retailer, in some cases, 65% of SKUs (bar coded) were found to be inaccurately represented between system data, back-store and availability on store shelf, see Dehoratius, 2002).

Virtually all computer-based modeling, up to this point has used system dynamics, an EBM approach. But the struggle to adapt and respond in real-time will eventually and collectively fuel a paradigm shift that will make it imperative to model business software based *both* with Agents and equations. The question is no longer whether to select one or the other approach, but to establish a business-wise mix of both and develop criteria for selecting composition of software-based on one or the other approach that can offer valuable combinatorial solutions. The “balance” is subject to dynamic change (seek analogy with Screening Games). For traditionalists in supply chain management, the situation is analogous to a “push-pull” strategy where the dynamic push-pull boundary shifts with changing demand (pull).

ABM and EBM, both simulate the system by constructing a model and executing it on a computer. The differences are in the form of the model and how it is executed. In ABM, the model consists of a set of Agents that encapsulate the behaviors of the various individuals that make up the system, and execution consists of emulating these behaviors, which is essentially dynamic. In Equation-Based Modeling (EBM), the model is a set of

equations (pre-determined, static) and execution consists of evaluating them. Thus “simulation” is a generic term that applies to both methods, which are distinguished as Agent-based *emulation* and equation-based *evaluation*.

Thus, the need for supply chains to be adaptive should rapidly trigger demand for Agent integration with existing EBM systems. But the demand for Agents software is slow to materialize. One reason may be gleaned from the observation by Norman Poire, an economist (Figure 1-6, blue lines, http://www.smalltimes.com/document_display.cfm?document_id=2141). As shown in figure 1-6, it takes about a quarter of a century for a technology to gain acceptance. Then it fuels a period of rapid growth lasting an additional half a century. Almost after a century since “invention” or introduction, the innovation may become a commodity and grows in line with fluctuations in macroeconomic forces. We propose that Agents, in principle linked to some of the fundamentals from distributed artificial intelligence (DAI), may follow a similar trajectory which suggests increasing adoption beginning about 2005 (Figure 1-6, red line). These Agents are the types that are capable of machine learning and utilize learning algorithms, such as (ant-based) swarm intelligence, genetic algorithms, and neural networks (single and multilayer perceptions, Hopfield networks, Kohonen networks, radial basis function networks).

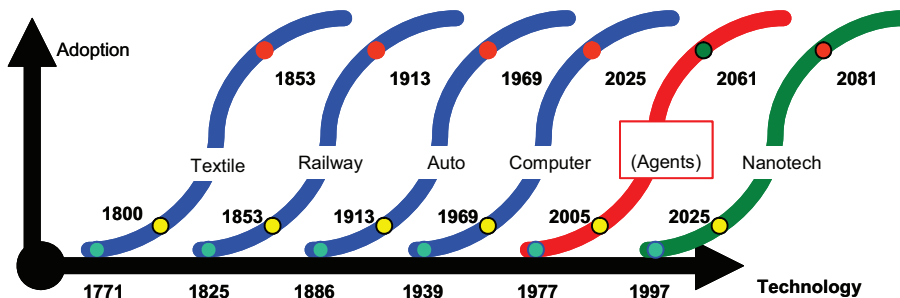


Figure 1-6. How Conceptual Advances Lead to the Wealth of Nations

Continuity and autonomy of biology offer behavior patterns that are flexible, adaptive and responsive to change. Thus, the mobile, networked, autonomous, self-learning, adaptive Agent may have different principles compared to those that were developed for monolithic systems. Examination of naturally occurring Agent-based systems suggests design principles for Agents. While some circumstances may warrant deliberate exceptions, in general, Agents are aligned with the concepts listed below from Parunak (1997) and Parunak et al., (1998):

1. Agents should correspond to “things” in the problem domain rather than to abstract functions;
2. Agents should be small in mass, time (able to forget), and scope (avoid global knowledge action);
3. Multi-Agent Systems should be decentralized (no single point of control/failure);
4. Agents should be neither homogeneous nor incompatible but diverse;
5. Agent communities should include a dissipative mechanism (entropy leak);
6. Agents should have ways of caching and sharing what they learn about their environment;
7. Agents should plan and execute concurrently rather than sequentially.

4.1 Agents versus Equations: Conceptual and Practical Considerations

The difference in representational focus between ABM and EBM has consequences for how models are modularized. EBM represents the system as a set of equations that relate observables to one another. The basic unit of the model, the equation, typically relates observables whose values are affected by the actions of multiple individuals. ABM represents the internal behavior of each individual. An Agent’s behavior may depend on observables generated by other (Agents) individuals, but does not directly *access* the representation of those individual behaviors, thus, maintains boundaries among individuals. This fundamental difference in model structure gives ABM a key advantage in commercial applications such as an adaptable value network where partners may interact over an e-marketplace.

First, in an ABM, each firm has its own set of Agents. An Agent’s internal behaviors are not required to be visible to the rest of the system, so firms can *maintain proprietary information* about their internal operations. Groups of firms can conduct joint modeling exercises (Public MarketPlaces) while keeping their individual Agents on their own computers, maintaining whatever controls are needed. Construction of EBM requires disclosure of the relationships that each firm maintains on observables so that the equations can be formulated and evaluated. Distributed execution of EBM is not impossible, but does not naturally respect commercially important boundaries (why the early wave of e-MarketPlaces failed to survive).

Second, in many cases, simulation of a system is part of a larger project whose desired outcome is a control scheme that more or less automatically regulates the behavior of the entire system. Agent systems may correspond 1-to-1 with the individuals (firms or divisions) in the system being modeled, and the behaviors are analogs of real behaviors. These characteristics make

Agents a natural locus for the application of adaptive techniques that can modify their behaviors as the Agents execute, so as to control the *emergent behavior* of the system. Migration from simulation model to adaptive control model is more straightforward in ABM than in EBM. One can imagine a member of adaptable business network using its simulation Agent as the basis for an automated control Agent that handles routine interactions with trading partners. It is unlikely that such a firm would submit aspects of its operation to an external “equation manager” that maintains specified relationships among observables from several firms.

EBM most naturally represents the process being analyzed as a set of flow rates and levels. ABM most naturally represents the process as a set of behaviors, which may include features difficult to represent as rates and levels, such as step-by-step processes and conditional decisions. ODEs are well-suited to represent purely physical processes. However, business processes are dominated by non-linear, discrete decision-making.

Both ABMs and EBMs can be validated at the system level by comparing model output with real system behavior. In addition, ABM’s can be validated at the individual level, since the behaviors encoded for each Agent can be compared with local observations on the actual behavior of the domain individuals. ABMs support direct experimentation. Managers playing ‘what-if’ games with the model can think directly in terms of business processes, rather than translate them into equations relating observables. A purpose of what-if experiments is to identify improved business practices that can be implemented. If the model is expressed and modified in terms of behaviors, implementation of its recommendations is a matter of transcribing the modified behaviors of Agents into task descriptions for the underlying physical entities in the real world.

In many domains, ABM gives more realistic results than EBM, for manageable levels of representational detail. The qualification about the level of detail is important. Since PDEs are computationally complete, in principle, one can construct a set of PDEs that completely mimics the behavior of any ABM (thus produce the same results). However, the PDE model may be much too complex for reasonable manipulation and comprehension (for example what we observe in repetitive Stochastic Games with incomplete information). EBMs (like system dynamics) based on simpler formalisms than PDEs may yield less realistic results regardless of the level of detail in the representation. For example, the dynamics of traffic networks achieved more realistic results from traffic models that emulate the behaviors of individual drivers and vehicles, compared with the previous generation of models that simulate traffic as flow of a fluid through a network. The latter example bears strong similarities to the flow-and-stock approach to supply chain simulation.

The disadvantages of EBM in this and other examples result largely from the use of averages of critical system variables over time and space. EBM assumes homogeneity among individuals but individuals in real systems are often highly heterogeneous. When the dynamics are non-linear, local variations from the averages can lead to significant deviations in overall system behavior (outcome). Refer back to the section on Game Theory and in light of ABM vs. EBM, re-consider the example of the Signaling Game: the choice of values (of ξ and ε from the distribution) can significantly impact capacity planning (inventory risk) and profit optimization (price risk). In such business applications, driven by “if-then” decisions, non-linearity is the rule. Because ABM’s are inherently local and can adapt to changes, it is beneficial to let each Agent monitor the value of system variables locally (for example, real-time data for ε , in the Signaling Game), without averaging over time and space.

Ant-based algorithms based on naturally occurring systems, enables the Agent to forget (ant pheromones evaporate and obsolete paths leading to depleted food sources disappear rather than misleading members of the colony). The mechanism of forgetting is an important supplement to the emphasis in conventional artificial intelligence (AI) systems on mechanisms for learning. In a discrete-event system, forgetting can be as complex as learning since both represent discrete state transitions. In a time-based system, forgetting can take place “automatically” through the attenuation of a state variable that is not explicitly reinforced. The Agents ability to “forget” is a boon to real-world adaptable business networks. EBM based demand forecasting generally uses a weighted-average of past consumption data. If there was a marked variation (for example, spike in sales, 20 weeks ago) the planning algorithm continues to consider that value because equation-based modeling cannot “forget” facts, although the weight will decrease successively in each planning cycle unless manual intervention or program insertion specifies a “forget” rule. The forecasting engine, therefore, may continue to reflect the effect in its subsequent forecast for weeks or months. Consider the cumulative error from such events, if aggregated over geographies prior to generating a global forecast that may guide procurement or production. Such events produce the Bullwhip Effect. Agents can improve forecasting and with real-time data, accuracy may be further enhanced. As a result, for example, the manufacturer may adjust production to manage inventory better and reduce waste. Reduced inventory decreases working capital charges which improves return on assets because manufacturing the cash cycle gets shorter.

In a traditional system, forecast determines production planning and subsequently, execution of the plan. Some manufacturers develop a schedule each night that optimizes manufacturing the next day, a process not much

different from grocery chains that order perishables the day before it is displayed in stores. Engineers in industries as diverse as auto, semiconductors, aerospace, and agricultural equipment will agree that a daily schedule is obsolete less than an hour after the day begins. But Agents seek to avoid the “plan *then* execute” mode of operation and instead responds dynamically to changes in the environment. In concurrent planning and execution, the actual time at which a job will execute may not be known until the job starts. The resource does not schedule a newly-arrived job at a fixed point in time but estimates probabilistically the job’s impact on its utilization over time, based on information from the customer about acceptable delivery times. The width of the window within which the job can be executed is incrementally reduced over time, as needed, to add other jobs (may be rated by priority, at that time) to the resource’s list of tasks. If the resource is heavily loaded, the jobs organize themselves into a linear sequence but if it is lightly loaded, the actual order in which jobs are executed is decided at the moment the resource becomes available, depending on the circumstances that exist at that time. Figure 1-7 shows simplified view of agent in system architecture.

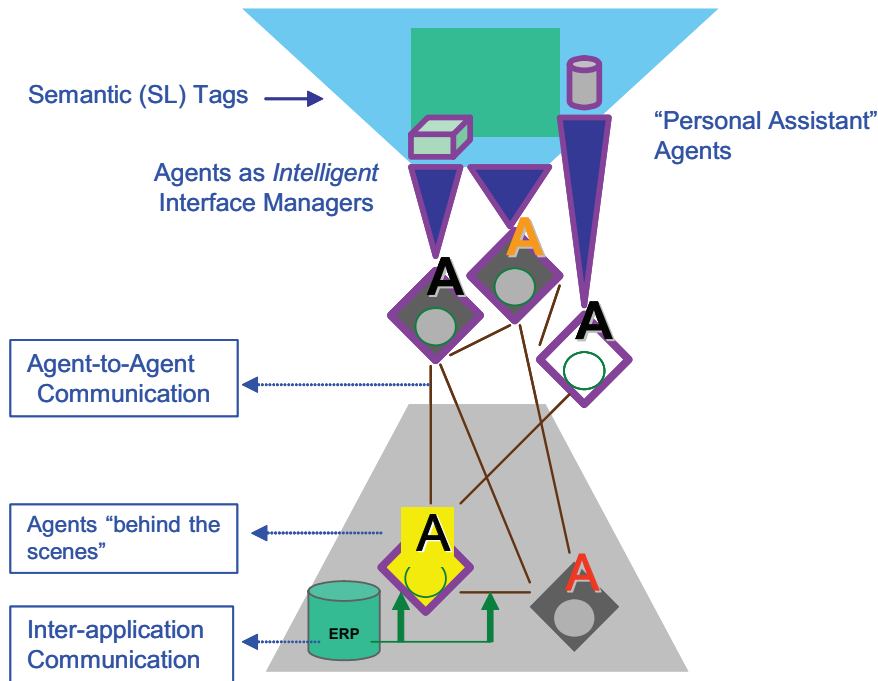


Figure 1-7. A simplified View of Agents within the System Architecture

4.2 Agents in Maintenance (US Air Force Case Study)

This example of a multi-Agent framework (and this case study) was developed by Shehory, Sycara and Sukthankar in 1999 (Agent aided aircraft maintenance) at the Carnegie-Mellon University, Pittsburgh (Shehory et al., 1999). It provides information retrieval and analysis in support of decision making for aircraft maintenance and repair for the US Air Force (USAF). Although the solution was developed for a specific type of aircraft, the Agents and interactions were designed to apply to a range of similar maintenance scenarios.

Aircraft maintenance in the USAF is performed at different levels. Basic and intermediate levels are usually performed at the base where the aircraft is deployed, whereas periodic, comprehensive maintenance is performed at special depots. Initially, mechanics inspect the aircraft for discrepancies (and may also receive such information from pilots). For each discrepancy, the mechanic consults the technical manuals for a standard repair procedure. In case such a repair procedure is found and the resources (parts) are available, the mechanic proceeds with the repair. In cases where parts are not available or they are too expensive or require too much time and additional machinery for replacement or in cases where a procedure is not provided in the technical manual, a mechanic needs to consult an expert engineer. The engineer, in turn, may consult external sources of information. These include manuals, historical maintenance data and may even include consultation with experts.

Inventory of parts is based on traditional data input from goods received. Locating spares, therefore, could be a time consuming and arduous undertaking that can be automated to a significant extent by use of automatic identification technologies (UWB, RFID) and to link inventory object related data with service/maintenance processes to offer transparency of the spares supply chain.

Until recently, no automation was introduced to the consultation processes, either, of this information-rich environment. Hard-copy repair manuals are used by mechanics and engineers. Search for relevant information may be time consuming and incomplete. Historical data (records of previous similar repairs) is scarcely used, since it is stored in paper format with no search mechanisms and usually only kept for short periods (distributed along remotely located service centers). Expert engineers may be located remotely and their advice is available by voice or fax messages, usually delayed for hours or days. All of these factors contribute to a slow, inefficient maintenance that compromises readiness.

The inspection, consultation and repair process consists of the following steps:

1. Aircraft arrives at a maintenance center, either at its home base or depot (depending on the type of maintenance required). In both cases, the maintenance procedures must be completed within a limited time period. This period varies. Basic and intermediate maintenance must be completed within hours or a few days, whereas depot maintenance may be scheduled for several weeks (depends on aircraft).
2. Mechanics inspect the aircraft and locate discrepancies. For each discrepancy a mechanic performs the following:
 - a) browse the technical manual for repair procedures;
 - b) in case an appropriate procedure is located, mechanic needs to verify whether it can be completed given limitations on repair time and parts availability. Mechanic may also need to consider the price of repair. For example, the technical manual may require replacing a whole wing if a crack in the wing is greater than some given threshold. This may take too long and become too expensive thereby causing delay or compromise operational activity or readiness;
 - c) if the procedure found can be performed, the mechanic performs it. If not, mechanic proceeds to fill out form 202a, standard USAF form for reporting aircraft discrepancies and requesting advice. The mechanic may attach supporting information. The mechanic may consult Illustrated Part Breakdown (IPB) technical manuals and possibly other experienced mechanics. Form 202a is sent for advice and authorization for non-standard repair.
3. An engineer, upon receipt of a Form 202a, proceeds to:
 - a) use experience, historical repair information and manuals to design appropriate repair;
 - b) fill in a Form 202b, standard US Air Force form for discrepancy repair instructions. To this form the engineer may attach graphical illustration to clarify required repair procedure;
 - c) file 202a and 202b for future use as historical repair information.
4. When a standard repair procedure is found or on receipt of Form 202b from engineer, the mechanic performs the repair as instructed. The current inspection, consultation and repair processes, as described above, have several problems. The multi-Agent system (MAS) implementation reported here attempts to address these problems. The majority of the information, both historical repair information and technical manuals, is found in hard-copy format as well as hand-written pieces. Mechanics and engineers spend precious time on:
 - a) Browsing manuals and searching for historical repair information;
 - b) Drawing graphical discrepancy and repair illustrations;
 - c) Mechanics are idle, waiting for Form 202b to arrive from engineers in reply to their Form 202a;

- d) Historical information is unused when stored remotely or local hard-copy is difficult to browse.

For information needs of mechanics, using manuals during inspection for diagnosis is inefficient and at times impossible due to the physical constraints of the inspection environment. Scribbled information both from historical forms and the current Form 202 may have limited comprehensibility. The problem intensifies due to deterioration in the quality of such information when it is transmitted via fax or photo-copied. Historical forms are kept only for two years. Time and effort spent on paperwork and filing should be used instead for diagnosis and repair. Technical manuals (IPB) are not consistently updated.

The problem consists of decision support in a physically distributed, dynamically changing environment, rich in multi-modal information, where users have diverse (varying over time) information needs. This is the type of problem for which RETSINA (**RE**usable **T**ask-based **S**ystem of **I**ntelligent **N**etworked **A**gents) is a solution. It is a multi-Agent infrastructure that was developed for information gathering and integration from web-based sources and decision support tasks. It includes a distributed MAS organization, protocols for inter-Agent interaction as well as collaboration and a reusable set of software components for constructing Agents. Each Agent in RETSINA specializes in a special class of tasks. When Agents execute tasks or plan for task execution, they organize themselves to avoid processing bottlenecks and form teams to deal with dynamic changes in information, tasks, number of Agents and their capabilities.

In RETSINA, the Agents are distributed and execute on different machines. Based on models of users, an Agents and tasks, the Agents decide how to decompose tasks, whether to pass them to others, what information is needed at each decision point, and when to cooperate with other Agents. The Agents communicate with each other to delegate tasks, request or provide information, find information sources, filter or integrate information, negotiate to resolve inconsistencies in information and task models. The RETSINA infrastructure consists, by convention, of 3 broad types of Agents:

- Interface Agents;
- Task Agents;
- Information Agents.

In the RETSINA multi-Agent infrastructure, Interface Agents interact with users receiving specifications and delivering results. They acquire, model and utilize user preferences. The Interface Agents hide the underlying structural complexity of the Agent system. Main functions of an Interface Agent include:

- collecting relevant information from the user to initiate a task;
- presenting relevant intermediate and final results;
- requesting additional information during task execution;

Task Agents formulate and execute plans. They have knowledge of the task domain and which other Task Agents or Information Agents are relevant for performing various parts of a task. Task Agents have strategies for resolving conflicts and fusing information retrieved by Information Agents. A Task Agent:

- receives user delegated task specifications from an Interface Agent;
- interprets the specifications and extracts problem-solving goals;
- forms plans to satisfy these goals;
- identifies information-seeking sub-goals that are present in its plans;
- decomposes plans and cooperates with appropriate Task Agents or Information Agents for planning, execution, monitoring and results compilation.

Information agents provide intelligent access to heterogeneous collection of information sources. They have models of information resources and strategies for source selection, information access, conflict resolution, and information fusion. Information Agents can actively monitor information sources.

Middle agents collect and provide information about the location, availability and capabilities of other Agents (possibly additional information about them). They may also serve as mediators, hiding the identities of either service requester Agents or service provider Agents or both. Middle Agents (Matchmakers) provide RETSINA-based MAS with openness. That is, Agents may leave and enter the system dynamically. When an Agent appears, it advertises itself with a Middle Agent. When it leaves, it informs the Middle Agent, as well. Agent disappearance as a result of Agent or network failure is detected by a Middle Agent via a pinging mechanism. The RETSINA internal Agent architecture is based on a multi-module, multi-thread design. It consists of two component types: functional units and data stores. Given its properties, we found the RETSINA infrastructure appropriate to solve the USAF maintenance problem. By developing and using Agent architecture, we gain the following advantages:

1. The RETSINA architecture can be used to wrap legacy software systems by equipping them with a Communicator module. Thus the resulting system remains backwardly compatible with the older systems, without restricting future software development to an obsolete model. For instance, in 1999 the Warner Robins Air Force Base (AFB) engineers were experimenting with entering some of the data into an Access

database format, as a temporary measure while waiting for (the ITL-ALC) another system to become available. With this design, separate Information Agents can easily be designed to accommodate both data sources. Since the maintenance personnel only interact with Interface Agents, they are shielded from internal data discontinuities;

2. The information required by the maintenance engineers is likely to be distributed among several computers in different geographic locations. RETSINA architecture provides built-in networking support useful for developing distributed systems, in the form of the Communicator. The Agent Name Server (Matchmaker) allows service requesters to locate service providers. Although the current focus is on handling the repair operations described in Form 202A, which are performed locally in Warner Robins AFB, additional Agents can be added to the system to access collections of Form 00-107 (immediate repair requests), which can be filed from multiple locations. These Agents would be located on computers at the local Air Force base performing the repair and would communicate to agents at the central F-15 repair location (Warner Robins AFB);
3. The Warner-Robins Air Force Base is in a transitional phase of reorganizing their data and also training personnel. Rapid prototyping of a group of Agents are underway to address the current situation and slowly add to the "Agent population" as new information sources become available electronically. Since the Interface Agent is decoupled from the Information Agents, it is possible to replace older Information Agents without disruptions or disturbance to the users.

4.3 Agents in Manufacturing

Commercial aerospace industry makes fewer products and sells to a different set of customers than the retail industry (Figure 1-8 shows typical aerospace supply chains). Some (modular) parts and components are shared between different models (variants) of aircraft. Significant profit in this (and the automobile industry) is derived from the aftermarket sale of parts and service. The companies therefore have access to a large amount of usage data. Premature failure of two hydraulic pumps in different corners of the world prompts an Agent to explore the pattern. Both pumps came from the same manufacturing lot. The Agent prompts maintenance technicians to perform non-routine vibration analysis. Results indicated that the manufacturing lot had a defect. If vibration analyses data from manufacturer's test results were available to the Agent in this value network, a pattern may have emerged even before a single pump failed. Comparative

analysis involves access to massive data processing that is beyond human reach in a reasonable time frame. Agents could accomplish such tasks rapidly and be able to predict, thereby avert, a potential catastrophe. The information required for such Agent operations to recognize a pattern from manufacturer data, lot information, date of installation and hours of usage are possible in value networks with integrated points of access to distributed data, but impossible in silos of supply “chains” which are common today.

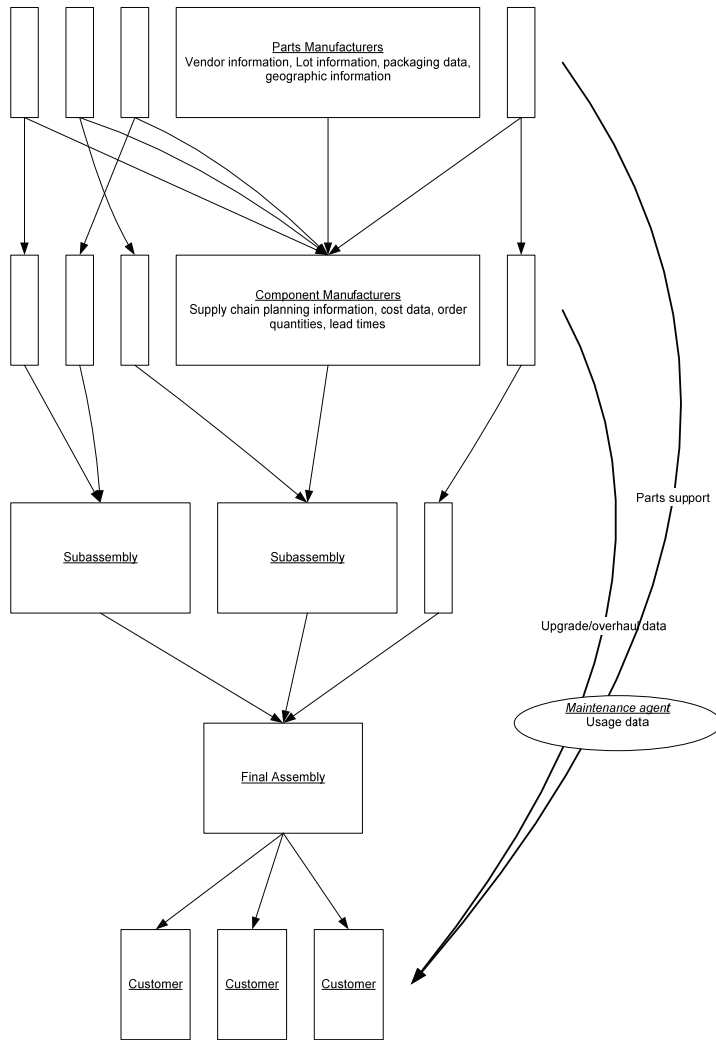


Figure 1-8. Commercial Aerospace Industry Supply Chain: Information Collection

4.4 Future Agents at Work?

Transistor Titikaka Promethium (TTP), a small electronics retailer, starts selling a digital camera (named, CELC) and soon runs out of inventory due to the popularity of the new product. TTP places another order. A week later some customers returned the cameras and others call with questions. TTP is unable to determine the cause and loses time and revenues. Think different.

You are Must-See-Borgium Corporation, the bleeding-edge retailing behemoth. You started selling CELC and soon your return center in Moose Jaw is flooded with CELC from unhappy customers. Fortunately, your ex-VP (exiled to Timbuktu) had created a liaison with a tiny institute around Boston. She quietly integrated a system called MY-CAH that offered no satisfactory ROI to your bean counters. Within a week of mounting CELC returns to Moose Jaw, Must-See-Borgium's MY-CAH Agent sends an e-mail alert (cc you) to N. E. Shee in Urawa (manufacturer's headquarter) that many US customers who returned CELC to Moose Jaw also bought a certain brand of BELL notebooks with Dumb-Bell Mobile Bambino. In your in-box you also find a response from Shee-san that the camera's software is incompatible with systems installed with Dumb-Bell Mobile Bambino without a special patch from MacroHard that can be downloaded from www.bosonic-hadrons.net and the CELC website will soon upload the link for customers. MY-CAH Agents already posted an update on the corporate website, informed Moose Jaw Center, CELC customers who registered or returned their products, sent e-mail to only those customers who bought CELC with Must-Have-Borgium credit-loyalty card and printed out an exact number of stickers (per inventory) with instructions to be affixed to CELC boxes in all your local mega-stores. You find a note of gratitude from Miss Fermionic Baryons at TTP who saw the notice about CELC on your website and could inform TTP's customers by phone. You had no problem getting out of a mess and a bad PR wrap because MY-CAH actually works! Didn't you vociferously object to the VP's proposal to sponsor research at that tiny institute around Boston? Anyway, you solved the problem.

What really happened? Your store was running an Agent system that analyses data for trends. The Agent was able to identify this trend in minimal time. The missing patch could have been identified without the use of an Agent, but it would have taken much longer and resulted in many more unhappy customers, which would generate bad publicity. Why did an Agent work in this situation? Data and information derived from data is the key enabler for decision systems to be agile. In this example, the Agents were autonomously collecting product, customer, and service related information.

Customer purchases were compared for people who bought and returned this new product (SKU). How does a company know what information to collect? Easily enough, companies should collect the same information that was needed to find previous patterns if the company had data mining capabilities. In this case, real-time data over short time windows were constantly under analysis and random associations were easier to track by multi-Agent systems monitoring multiple operations both within the company and its interactions in the value network. Concurrently, it was analyzing legacy data (ERP) to *learn* or create analytic parameters from past data patterns.

In another scenario, consider an Agent system that operates in a services business area (only) charged with the analysis of returns. The Agent spots that the rate of return for a certain manufacturer's products has risen above a certain level in recent weeks. Why? They are a relatively high value product, which weighs more than 15 pounds and the majority was shipped 500 miles or more. An alert from the Agent reaches the manager and she intuitively inspects the packaging and... Voila! It is different than the packaging for products that have a lower return rate. A phone call confirms the hunch that the manufacturer recently switched to a different packaging vendor in an effort to conserve costs. The Agent succeeded in creating the alert because the Agent system collects, processes, correlates and cross-references vendor data, shipping method data, shipping distance information data and other cradle-to-grave stages and any related ePC data that it can extract from the local data store connected with goods movement (RFID/UWB tags attached to this item). SKU information (only) still exists as a barcode on the outer packaging. The Agent also extracts the UPC code from the store master data (redundant information). If packaging type information was stored on RFID/UWB tags for each SKU sold, the Agent system may have been able to spot the trend without the aid of a human, the manager (Figure 1-9).

Agents can also help with marketing. Dell sells computers that consumers can configure. Bundling is a marketing technique that pairs two products together to sell at a single price, which is lower than the normal price of the two if sold individually. Single price gives a greater revenue and profit than if either item were sold alone. Dell stores exabytes of information on customer buying patterns. An "analytic" Agent is able to spot a pattern where 40% of customers who buy extra memory also buy a certain high-speed processor. A "marketing" Agent can "talk" to the "pricing" Agent to offer discounts if memory is bought together with the processor. As the trend of choices for combinations (memory vs. processor speed) changes or differs in demographics or geographies, the data from "analytic" Agent can be used for the "marketing" and "pricing" agent to adapt and offer new bundling

options (dynamic pricing). This can augment demand for the memory and increase total revenue and profit. Customers who are likely to buy a product may be targeted for marketing (may not buy without bundle discount).

The number of potential product combinations increases if three or more options are thrown into the mix, not to mention accessories like cameras, MP3 players or printers. It is simple for Agents to analyze gargantuan amounts of data and spot potential (multiple) bundling opportunities and adapt to the fluctuations in demand in near real-time much faster (by several orders of magnitude) than a human or software based on equation (EBM). Bundling strategies can be catalytic to sell slow moving inventory or end of life (EOL) product prior to new product introduction.

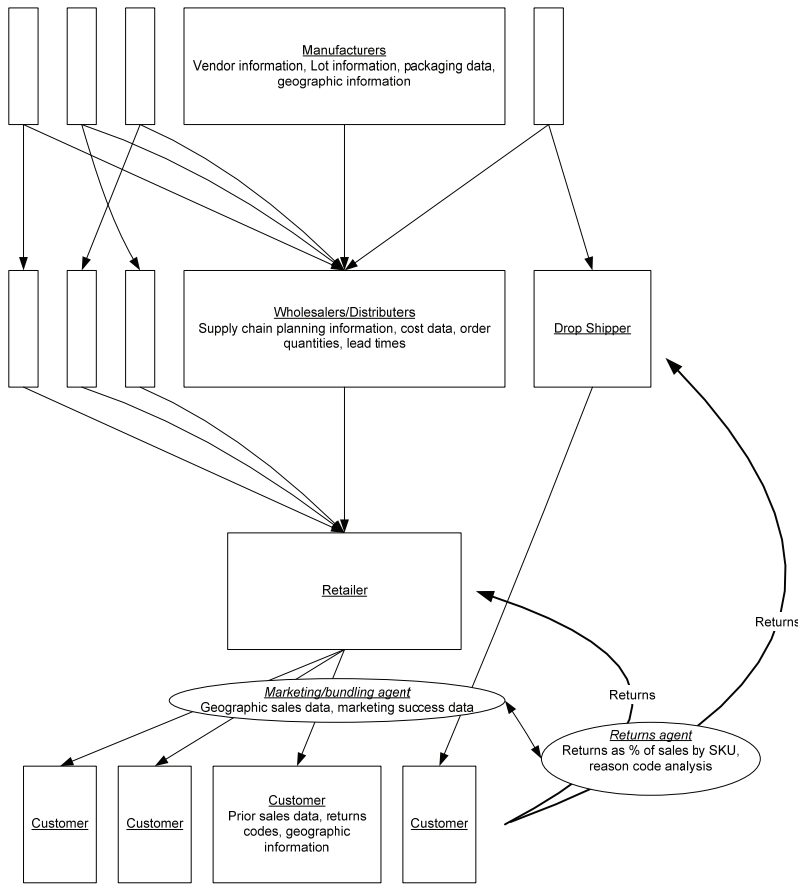


Figure 1-9. Agents in Retail Industry (also shows where “returns” and “bundling” Agents may integrate)

When I want to go out to the movies, rather than read reviews, I ask my sister-in-law. We all have an equivalent who is both an expert on movies and an expert on us. What we need to build is a digital sister-in-law ("Less Is More: Interface Agents as Digital Butlers" by Nicholas Negroponte, 1994).

4.5 WHY THINK DIFFERENTLY?

The approach to system design and management with Agents in the software landscape is at odds with the centralized top-down tradition in systems engineering. The question usually arises in terms of the contrast between local and global optimization. Decision-makers fear that by turning control of a system over to locally autonomous Agents without a central decision-making body, they will lose value that could have been captured by an integrated (enterprise) global approach.

Benefits of Agent-based architecture versus centralized ones are conditional, not absolute. In a stable environment, a centralized approach can be optimized to out-perform the efforts of an opportunistic distributed system of Agents. If the system has appropriate learning capabilities, it will eventually become as efficient. The appropriate comparison for systems designers of enterprise software is not between local and global optima but between static versus adaptable systems. Thus, evaluate the competing options (in any particular case) theoretically, strategically, tactically and practically.

Theoretically, there are decentralized mechanisms that can achieve global coordination. For example, economists have long studied how local decisions can yield globally reasonable effects. Recently these insights have been applied to a number of domains that were not traditionally considered as economic, such as network management, manufacturing scheduling and pollution control.

Strategically, managers must weigh the value of a system that is robust under continual change against one that can achieve a theoretical optimum in a steady-state equilibrium (that may never be realized). A company that anticipates a stable environment may well choose centralized optimization. One that *also* incorporates Agent-based software does so because it cannot afford to be taken by surprise.

Tactically, the life-cycle software costs may be lower for Agent-based systems than for centralized enterprise software. Agents can be modified and maintained individually at a fraction of the cost of opening up a complex enterprise software system. In systems that must be modified frequently, losses due to sub-optimal performance can be recovered in reduced system maintenance expenses.

Practically, Agent-based systems that follow these principles have been piloted or deployed operation (US Air Force case study by CMU). The Agents reflect the principles outlined rather than those of centralized systems. Growing acceptance of Agents in competitive business environments may be evidence of the benefit they bring to their adopters (Figure 1-10)

P&G's Agent-Enabled Supply Network in 2008

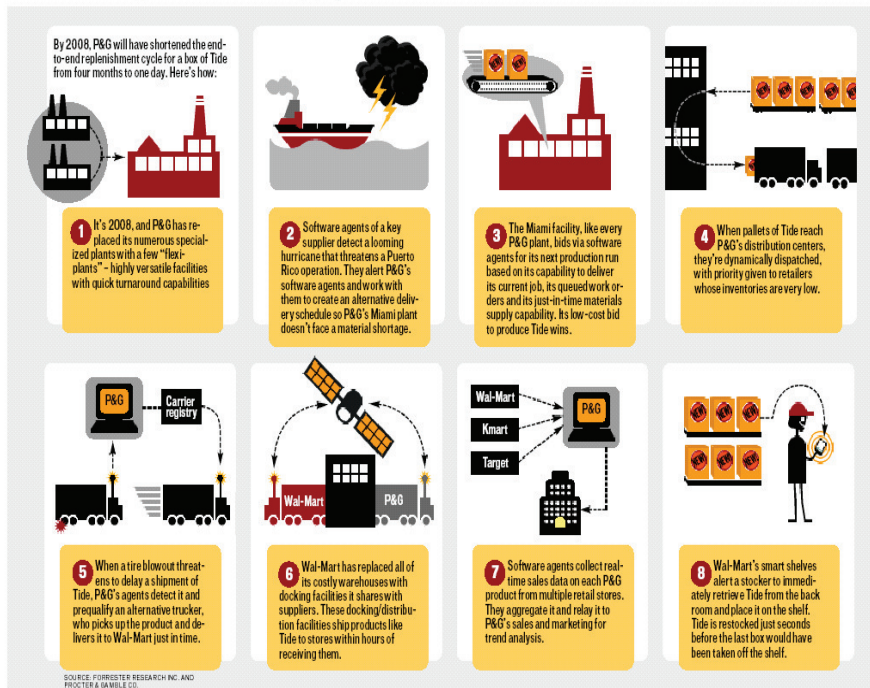


Figure 1-10. P&G's Agent-enabled Supply Network in 2008

5. AUTOMATIC IDENTIFICATION TECHNOLOGIES

Automatic identification technologies offer tools to acquire data about *objects* (e.g. IV pumps, toothpaste, and ammunition). Innovation and leadership lies in the effective use of the data, not in its acquisition.

In 1894, Oliver Lodge demonstrated how to communicate (data) using radio waves. Half a century later, with the discovery of the RADAR at MIT, it was likely that the natural frequency spectrum was going to "make waves"

for quite some time. Near the tail end of the last century, with the establishment of the MIT Auto ID Center (which morphed into Auto ID Center), once again, more than a century later, a radio frequency-based identification (RFID) and communication protocol created waves whose impact will be inescapable in the future and for the future of most businesses that were present in the past.

Neither the technology nor concepts are new but the two thinker-founders of the MIT Auto ID Center (Sarma and Brock, 1998) created a “storm in a tea cup” by reversing the conventional thinking (kilobytes of data on RFID tags) in their proposed standardization of a format for *minimal* data on RFID tags, referred to as electronic product code (ePC) that will serve only as a *reference* to a physical object, data about which may be stored on the internet (Figure 1-11). The generic organization of ePC was to extend the Universal Product Code (UPC) format currently used in bar codes. Thus, ePC was re-using an ‘old bag of tricks’ yet ‘disruptive’ to the *status quo* since the business of RFID usage had been around for half of the 20th century. A ‘killer’ ePC application may be a simple way to connect bits (information) with atoms (physical objects) in a manner that may make it feasible for *widespread* business adoption by offering low cost tags and use of the internet as the ‘data’ store. Low cost passive tags suffer from some limitations (signals absorbed by metal, such as beverage cans) which can be circumvented by a combinatorial approach to include emerging technologies, such as the active ultra wideband (UWB) tags. UWB tags transmit data at distances 30-300 meters using low power levels and the signals can penetrate metal barriers as well as concrete walls.

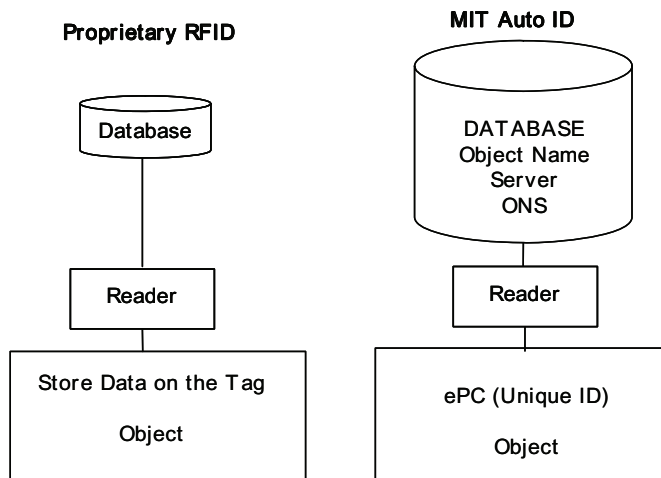


Figure 1-11. Evolution of ePC

The 96 bit electronic Product Code (ePC) as proposed by the Auto ID Center, is made up of Header, ePC manager (manufacturer's information, also in bar code), object class (product category similar to bar code) and serial number space that is expected to be unique for each unit, such as an individual can of Coke. The ePC manager is defined by 28 bits that can uniquely represent more than 268 million companies. Similarly 16 million different product classes (object) can be defined by 24 bits. Coke Classic and Diet Coke belong to 2 different object classes. The 36 bit serial number space refers to the maximum number of individual items in a specific product class that may be assigned a unique number. Thus, more than 68 billion individual Coke Classic cans may be individually identified if each can had a RFID tag encoded with ePC (Figure 1-12). In 2000, The Coca Cola Corporation, the largest bottler, sold 3.8 billion 'unit cases' each containing 192 ounces. About 42%, or 1.6 billion, 'unit cases' were Coke Classic (19.2 billion individual cans, assuming that all Coke was sold in 16 ounce cans). If each 16 oz. can had a unique identifier (19.2 billion cans per year), even then the ePC serial number space, as defined by the Auto ID Center, will accommodate individual numbering of Coke Classic cans for many years!

If the company made a sensible business process decision that the granularity of information at the level of each can was unnecessary, it could still track and trace 'unit cases' affixed with RFID tags encoded with ePC. If we use 2000 sales figures for Coke Classic (1.6 billion unit cases), the ePC serial number space will accommodate unique numbering of each Coke Classic 'unit case' for about 40 years. The 96 bit ePC serial number space will be sufficient for nearly a century for Perrier, the French bottling plant that produces 3 million bottles of Perrier per day.

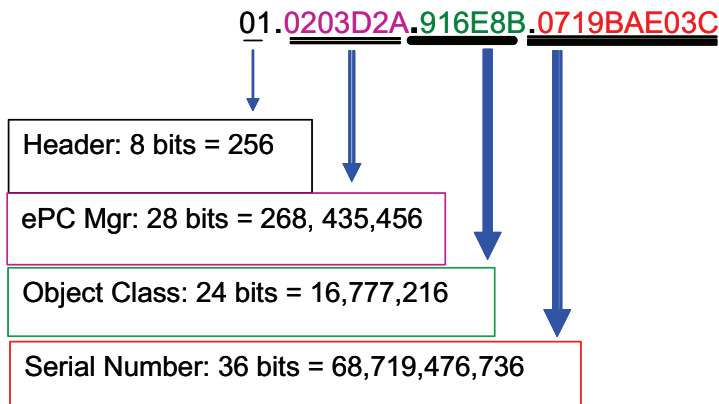


Figure 1-12. 96 bit Electronic Product Code (ePC) proposed by the Auto ID Center

But, these are only tools which may act as catalysts if thought leaders develop a vision to use this rich yet raw data. Businesses may manage uncertainty, reduce inefficiencies, and information asymmetry if corporate leaders are capable of utilizing real-time data to stimulate business process innovation. Can real-time information compress time between supply and demand? Auto identification technologies, as enablers of data acquisition about objects, to be valuable, must feed real-time information to update processes (maintenance, cross-docking) or decision systems (planning, execution) to trigger adaptive response(s). As an extension of adaptive decision support capabilities, real-time data can offer ‘transparency’ if pervasive and accessible via distributed data infrastructure among the value network. Transparency may be the key to further catalyze the practice of supply chain management to evolve toward an adaptive value network. Point A to B data visibility may augment a few operations and offer savings, but is far from the supply chain profits from real-time adaptability through pervasive real-time data (RFID) usage.

The impact of pervasive RFID (or UWB) deployment will create an avalanche of data, but can we extract the information from this data that will be valuable for business transactions? (Figure 1-13) In US alone, there are 1.5 million retail outlets, 160,000 grocery store chains, 400,000 factories and 115 million homes. The US consumer packaged goods (CPG) industry produces 1 billion items per year. If we read each item 10 times (in the supply chain) it translates to 300,000 “reads” per second. At 100 bytes to store each ‘read/event’ data, we will be faced with 1000 terabytes of static data storage each year, from CPG operation alone. The road to ubiquitous tagging of objects will dwarf the current internet that now holds about 1 billion web pages with only 10 petabytes of data. Current (year 2003) estimates suggest that we generate about 1 terabyte of data per second. The future requires a radically different mechanism of data and information handling, through Agents and use of semantic tags, to make sense of it all.

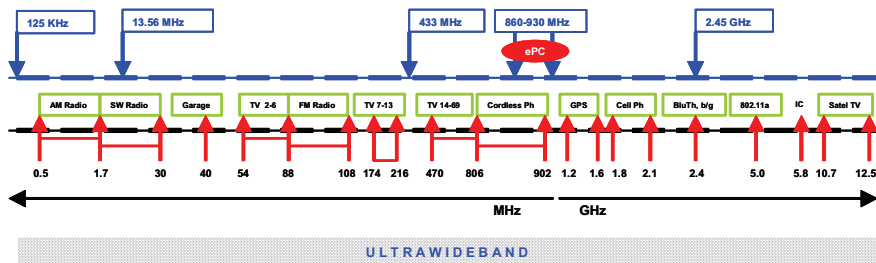


Figure 1-13. The Ultra High Frequency (UHF) Range for which an ePC Standard is Now Available

Given the potential impact, the ‘RFID’ market is, naturally, in quagmire, in part, spawned by unrealistic claims by some proponents of RFID who are focused on cost. Others discuss supply chain but understand less of its implication in terms of transparency in a value network. Still other contributors include vendors pushing products and consultants pushing services to offer you awe-inspiring ROI. Both groups want to “make hay while the sun shines.” Nay-sayers (with other commercial interests) are eager to point out shaky ROI because *their* methods still cannot prove the value. Another component has emerged in the form of individuals or groups (in search of media attention) who are quite vociferous about privacy of information but offers little substance to explain what constitutes violation of privacy in the context of an ePC alphanumeric string serving as a reference for Jiffy Peanut Butter or Wrigley’s Chewing Gum.

More than 5 billion bar codes are scanned each day, worldwide, but its potential for ubiquity may be cut short by the up-start ePC, but not anytime very soon. The inventors of the first linear bar code system were, naturally, decades ahead of their time. Bernard Silver and Norman Joseph Woodland applied to patent the system in 1949 and their patent was granted in 1952. Both were graduate students at the then Drexel Institute of Technology in Philadelphia and the idea was triggered by over-hearing a conversation in 1948 between the President of a grocery chain store imploring the Dean at DIT to develop an automated checkout system. Woodland took a job at IBM after graduation but IBM expressed limited interest in this work for bar codes. Disappointed, the duo sold their patent to Philco. Bernard Silver died in 1962. In the late 1960’s when their patent expired, several new technologies converged to make product scanning commercially feasible. In 1970, ten grocery companies formed a committee to choose a standard for encoding product data (the present day universal product code, UPC, the predecessor to ePC). By then IBM wanted “in” on the action and brought in Norman Woodland, still an employee at IBM, to help launch the bar code research effort. In 1973, Woodland’s leadership may have persuaded the standards committee to choose IBM’s symbol over six other competitors. On 26 June 1974, in a Marsh Supermarket in Troy, Ohio (USA) a package of Wrigley’s Chewing Gum was the first item scanned using the (universal product code) bar code (Scanlon, 2003).

“ In contrast, at highly successful firms such as McKinsey and Company [...] Hundreds of new MBAs join the firm every year and almost as many leave. But the company is able to crank out high-quality work year after year because its core capabilities are rooted in its processes and values rather than in its resources (vision). I sense, however, that these

capabilities of McKinsey also constitute its disabilities. The rigorously analytical, data-driven processes that help it create value for its clients in existing, relatively stable markets render it much less capable [...] in technology markets.” (Christensen, 2000).

Given the volume (some of dubious quality) of information already available on every facet of RFID and its applications in various industries, it is not necessary to add any technology or application review in this article. Our view of RFID deployment from a process perspective includes, albeit in stages, gradual integration with Agents in the system, for possible transition from real-time to adaptive to predictive states within the value network. The following figure outlines this convergence (Figure 1-14).

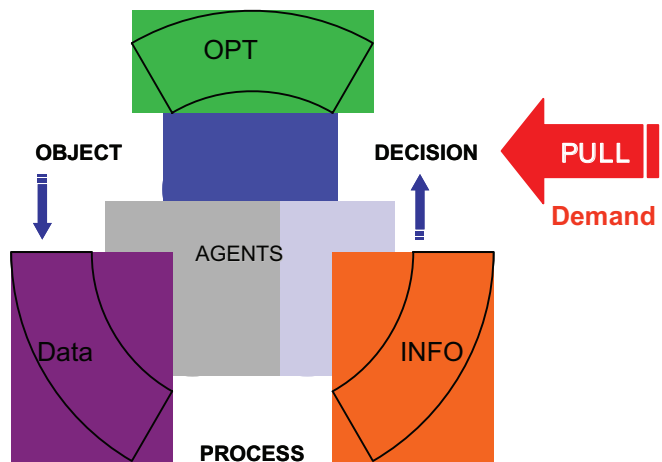


Figure 1-14. Convergence: Near Real-time Predictive Model

The version of the above illustration that may be forwarded as the “real-time model” can be viewed by removing the Agents and the ‘Pull’ signal from the above figure. Similarly, the “real-time adaptive model” may be visualized by excluding the “Pull” signal but including Agents. In general, the ability to identify any object in real-time (without errors and manual data entry), offers data that may be sieved through “intelligent” middleware to improve or adapt processes. High level or aggregated information and/or learnings may enable precision planning in the decision layers. Prior to execution, decision systems will be able to optimize how many objects may be distributed, displayed or destroyed. The ability of Agents to monitor and process vast surges of data in near real-time will enhance the adaptive

abilities implied in the model. However, what the customer “wants” to buy still remains the predominant market uncertainty, ε in the Signaling Game (see section on Game Theory and Operations Research). Are there mechanisms or innovative strategies that can “extract” this future demand signal to move the push-pull boundary? Actual “pull” data that is verifiably robust (value of ε) is at the core of the ‘predictive’ model since such customer “pull” data for future demand may be one pivotal factor in reducing supply chain inefficiencies by taming the Bullwhip Effect (Figure 1-15).

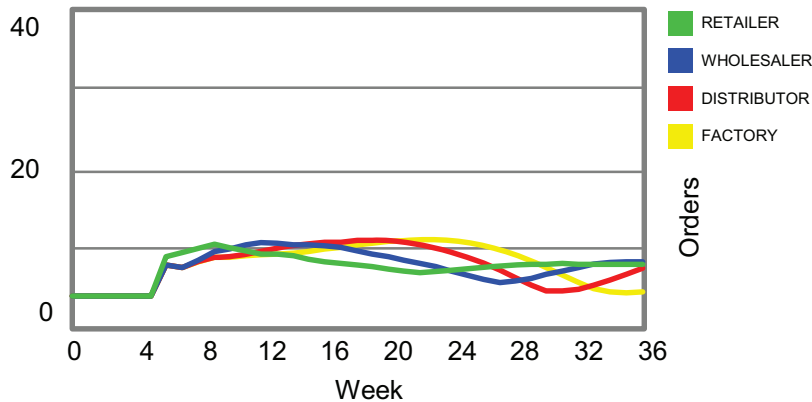


Figure 1-15. Bullwhip Effect after RFID? (Source: Yogesh V. Joshi, 2000. MIT Thesis)

The immense diversity of the “end” consumer makes it impossible to suggest any general mechanism. As an example, consider super-market type retailers who sell both dry goods and perishables. Retailers operating in single digit profit margins dream about improving accuracy of demand forecasting. Consider a down-to-earth scenario where a family of four living on San Silvestro in Venezia does *not* own an internet linked, Agent impregnated, ePC reader enabled refrigerator (from Being Digital Inc).

Instead, this family has a note pad on the refrigerator door. If Kathleen is using all the pesto, she writes Pesto (Butoni) on the super market shopping list, which keeps growing since the last shopping trip to Tesco. Charles wants fresh bananas and adds it to the list. Colin, manager of the Albertson’s Super Store, due to open next week near the Rialto Bridge, visits you. He is engaging and talks about his last job in Garden City. As a part of Albertson’s marketing campaign, Colin offers you a sleek tablet PC-like personal digital assistant (PDA). You are struck by the logo of Carleton urging all of us to

“invent” and it inspires you to think different. Colin explains that Albertson’s has teamed up with Moore Inc who bought Boingo Wireless from Sky Dayton. Colin is very convincing and you realize that this is not “a pie in the sky” scheme. You just may be on the road when the future arrives. The PDA is wireless internet accessible. You can use it at a T-Mobile “Hot Spot” such as one in the McDonald’s in San Marco. However, Colin would like you to use the magnetic holder of the PDA and slip it on the refrigerator door. Every time Matt is close to emptying the shampoo or Elaine finishes the Barilla tortellini, they should add these to the shopping list, as usual, but on the PDA with the sensor pen. What’s that to Albertson’s? Well, if you wrote down Barilla Pasta and bought Barilla Pasta the next time you shopped at Albertson’s with your Club Card, you shall receive a 2% discount, which also applies to all the items you scribbled on the PDA, if you actually bought those items at the store. What happens if you shopped online at Albertson’s virtual store, *A_Pea_in_the_Pod.com*? Colin explains that the PDA is still going to save you money. If you can plan ahead such that you can wait 24 hours before home delivery, then you get a discount. If you wait 48 hours, you receive 2.5% off your total bill. What if I can wait for 5 days? Colin explains that any wait longer than 48 hours is rewarded with a massive discount of 3%. But if you did go to the store with your PDA, it will wirelessly guide you to find things on your list and offer other tips or alert you to manufacturers or competitors e-coupons for things on your list. The first 100 people to sign up for Albertson’s offer also gets an autographed copy of the book of poetry “Moy Sand and Gravel,” by the Pulitzer Prize winning author Paul Muldoon of Princeton University. Kathleen loves “Daffodils” and you want “in” on the action. Does it matter if Albertson’s gets to know today what I want tomorrow?

Convergence of falling prices on PDAs, low cost wireless/wired access and some “intelligent” software is the infrastructure a retailer may need to capture the “pull” demand directly from some customers, as illustrated in the near real-time predictive model. Can this data from customers reduce your waste of perishables by 10% or adapt forecasting to reduce your purchasing capital by 1%? Real-time POS data from RFID tagged (ePC encoded) objects and the data flow from customers’ pre-shopping lists may be combined for accurate forecasting and planning, particularly in procurement of perishables with short half-lives. In case of the latter, a final purchase order is sent only 36-24 hours prior to expected store delivery from producers (farmers, poultry, dairy). You can model the metrics in this scenario and claim that there may not be sufficient ROI to justify investment in this “pull” signal. How do you model the behavior of customers, say, in an area where more than 50% of the adults are internet users?

In 1959, GE recruited the reputable consulting firm of Arthur D. Little Inc. in Boston to conduct a study to determine whether there was a market for portable TV sets that GE could now build using solid state transistors. Several months later in 1959, after spending a staggering amount of money (millions) in focus groups and discussions, Arthur D. Little Inc. sent their analysis to GE suggesting that they do not believe there is any market for such TV sets. GE management pushed aside the project proposed by its engineers. Just before Christmas in 1959, Sony introduced a small B&W television in the US market. Sony sold more than 4 million television sets within months (Tellis and Golder, 1996).

5.1 ULTRAWIDEBAND: THE NEXT GENERATION RFID?

Instead of the customer's pre-shopping list in the retail scenario, what if that list was for spare parts at the Warner Robbins US Air Force Base (Agents case study) or US Army Aviation and Missile Command in Huntsville, Alabama? Can MRO (maintenance, repair and overhaul) improve its efficiency if the mechanics had visibility of the inventories of approved spare parts? In these and several other scenarios, it is likely that the benefits of using active ultrawideband tags will exceed low cost RFID tag usage. Only a brief overview of UWB is provided below since there is a mountain of original work in this area, especially from Dr. Gerry Ross and Dr. Robert Fontana (www.aetherwire.com/CDROM/Welcome.html).

The origin of ultra wideband technology stems from work in time-domain electromagnetics that began in 1962. At the Sperry Research Center, then part of the Sperry Rand Corporation, Dr. Gerry Ross, the father of baseband technology, applied these techniques to various applications in radar and communications. The experimental phases of these studies were aided by the development of the sampling oscilloscope by Dr. Bernard Oliver of the Hewlett-Packard Corporation (1962). In April 1973, Sperry Research Center was awarded the first UWB communications patent, due to Dr. Gerry Ross. Through the late 1980's, this technology was alternately referred to as baseband, carrier-free or impulse. The term "ultra wideband" was first applied by the US Department of Defense in 1989. By 1989, Sperry Research Center had been awarded over 50 patents including UWB applications such as communications, radar, collision avoidance, positioning systems, liquid level sensing and altimetry.

One recent application of UWB communications technology is the development of highly mobile, multi-node, *ad hoc* wireless communications networks for the US Department of Defense. The system is designed to be secure with low probability of intercept and detection. UWB ad hoc wireless

network supports encrypted voice/data (128 kbps) and high-speed video (1.544 mbps). A parallel effort, funded by the Office of Naval Research, under the Dual Use Science and Technology (DUST) program is developing a state-of-the-art, mobile *ad hoc* network (MANET) based upon Internet Protocol (IP) suite to provide a connectionless, multihop, packet switching solution for survivable communications in a high link failure environment. The thrust of DUST is toward commercialization of UWB technology for applications to high-speed (>20 mbps) wireless applications for the home office. The Hummingbird collision avoidance UWB sensor (originated from a US Marine Corps project) was created for an electronic license plate commissioned by the US National Academy of Science (Transportation Research Board). The UWB Electronic License Plate provides a dual function capability for both automobile collision avoidance and (RF) tagging for vehicle to roadside communications.

Therefore, UWB usage in tagging is a proven technology. A comparative analysis of RFID versus UWB shows that UHF RFID has a spatial capacity of 1 kbpsm² (grouper.ieee.org/groups/802). Spatial capacity of UWB is 1000 kbpsm² or 1000-fold more than RFID. Spatial capacity focuses not only on bit rates for data transfer but on bit rates available in confined spaces (retail stores) defined by short transmission ranges. Measured in bits per second per square meter, spatial capacity is a gauge of "data intensity" that is analogous to the way lumens per square meter determine illumination intensity. Growing demand for greater wireless data capacity and crowding of regulated radio frequency may increasingly favor usage of spectrum that will offer appreciable bit rates that will function despite noise, multi-path interference and corruption when concentrated in smaller physical areas (grocery stores and warehouses). Spatial capacity limits may clog (like cholesterol in arteriosclerosis) "interrogation" systems when and if item level tags are a reality and readers in smart shelves continually emit electromagnetic signals to solicit tag data from objects. Part of this reasoning is evident in independent efforts by Hitachi and Sony who are exploring Bluetooth options with spatial capacity of 30 kbpsm² and others in asset management (Rockwell Automation) are exploring 802.11a compliant 5GHz with spatial capacity of 55 kbpsm² (spare parts). Unfortunately, 802.11a is non-compliant with 802.11b but 802.11g is compliant with both (.11a and b).

In the past couple decades, several companies have engaged in commercializing UWB. As implied by its name, UWB spans several gigahertz of spectrum at low power levels below the noise floor of existing signaling environment. Conventional narrow band technology relies on a base "carrier" wave modulated to embody a coded bit stream. Carrier waves are modified to incorporate digital data through amplitude, frequency or phase shift key modulation. These mechanisms are, therefore, susceptible to

interference and the coded bit stream (for example, electronic product code or ePC) may be decoded/intercepted. UWB wireless technology uses no underlying carrier wave (hence secure military use) but modulates individual pulses either as a bipolar modulation or amplitude modulation or pulse-position modulation, where it sends identical pulses but alters the transmission timing. UWB offers narrower pulse time (300 picoseconds) and covers a broader bandwidth extending up to several gigahertz. Because UWB operates in picosecond bursts, power requirement is as low as 200 mW (compare 802.11b at 500 mW or 802.11a at 2000 mW). High data rate (0.1 to 1.0 gbps^2) for UWB compares poorly with 802.11b (0.01 gbps^2) or 802.11g (0.05 gbps^2). Thus, UWB is used for wireless transmission of data, video as well as networked games, toys and appliances. There are robotic vacuum cleaners (from iRobots) and lawn mowers that may clean the living room or manicure the garden without touching the sofa or grazing the rose bush. Universal appeal for UWB is enhanced by its capability to accommodate several standards (ePC, GTAG). Without spectrum restrictions specific to country or region, UWB may become a global wireless medium.

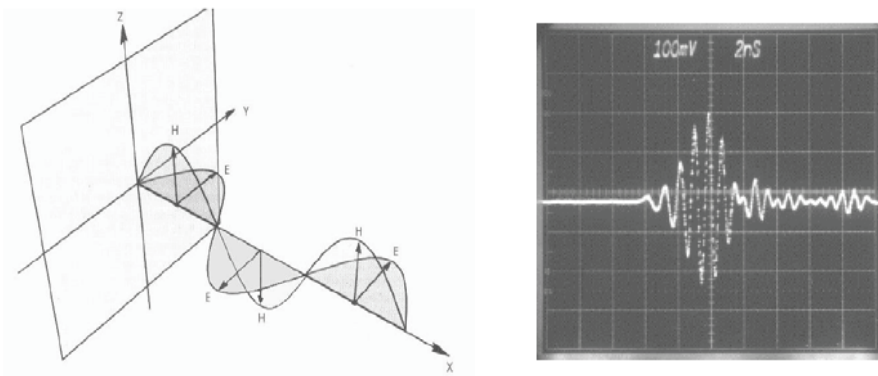


Figure 1-16. 860-930MHz RFID (left) and "Pulse" Transmission of UWB (right)

After the events of 11 September 2001, UWB transmitters (like RFID readers) were mounted on robots for search missions at the World Trade Center. UWB is not hindered by metal or layers of concrete. On 14 February 2002, the FCC gave qualified approval to use UWB (www.fcc.gov/e-file/ecfs.html) in the range >960 MHz, 3.1-10.6 GHz and 22-29 GHz. Active UWB tags cost \$1-\$10 while the transmitters may be cheaper than RFID readers because they do not need many analog components to fix, send and receive on specific frequencies. However, software defined radio (SDR) based readers may soon arrive. UWB is not without its critics. Dispute stems

from claims that UWB transmissions could interfere with spectrum used by GPS, cell phones and air traffic control. FCC is investigating, but plans to open up more spectrum for UWB commercial applications. Without the burden of fees for spectrum usage, the commercial floodgates for UWB usage may be unstoppable. Telecommunication giants who rushed to buy spectrum seduced by the future of 3G services are fighting to keep UWB off the news after investing billions in auctions to buy spectrum. Perhaps worse affected are the GSM sponsors in EU and USA. UWB is a tool for data acquisition (healthcare, hazardous chemicals) and thus a contributor to the future of adaptive value networks. An added value is its dual ability to provide data about objects when tagged to objects and form a wireless network to upload the data (over distances of 30-300 meters through metal and/or concrete) to the data infrastructure in much the same way that WiFi (802.11b) wireless networks may be used to upload RFID data in warehouses, stores or hospitals. Figure 1-17 shows plot of data rate and range capabilities of UWB.

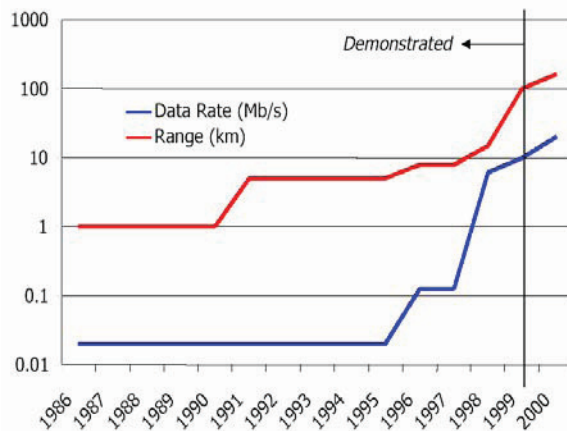


Figure 1-17. Data Rate and Range Capabilities of UWB
www.multispectral.com/pdf/APPsVGs.pdf

6. SENSOR NETWORKS

Wireless sensor networks may be the first example of pervasive computing. Its applications extend from sensing blood pressure in arteries and transmitting them to a patient monitoring device to suggesting trends of warehouse shelf occupancy to a plethora of uses in the security industry.

Sensors do not transmit identification data or ePC. Sensor data models cannot be used in the same manner as data models from UWB or RFID. Sensors are self-powered and form wireless *ad hoc* networks that upload through specific nodes which may be connected to data stores or the internet (Figure 1-18). However, each sensor has certain analytical abilities and due to in-network processing, the sensor network transmits analyses of the data rather than the raw bits of data to provide “answers” rather than “numbers” to the system. Embedded sensors are most likely to influence various forms of supply chain-related functions. For example, sensors attached to spindles in drilling machines may continually upload the status of the spindle such that it is serviced or replaced within a reasonable time to avoid breakdown of the machine and systemic downtime. Metrics like meantime between failure (MTBF) and other parameters may be helpful to determine when the service may be scheduled. Sensor data may require different thinking in terms of “adaptive flow” databases where the data (or analyses from sensor nodes) stream through the database where the query is stored. For example, embedded light emitting sensor network in a secure room sends positive light emission data on which the query (is anybody entering the room) need not act. Only when an obstruction causes a break in the *ad hoc* network or occludes the light signal from a sensor or group of sensors, then the query comes into effect. Service supply chains (such as heating, cooling companies) may benefit from sensor-based information to pre-dispatch technicians to stem problems before they reach break-points or require emergency attention. The key is to try to understand how to integrate sensor data to benefit supply chains functions. With the flood of nanosensors soon to arrive, the involvement of Agents may be absolutely imperative to harvest the benefits by extracting intelligence from such data.

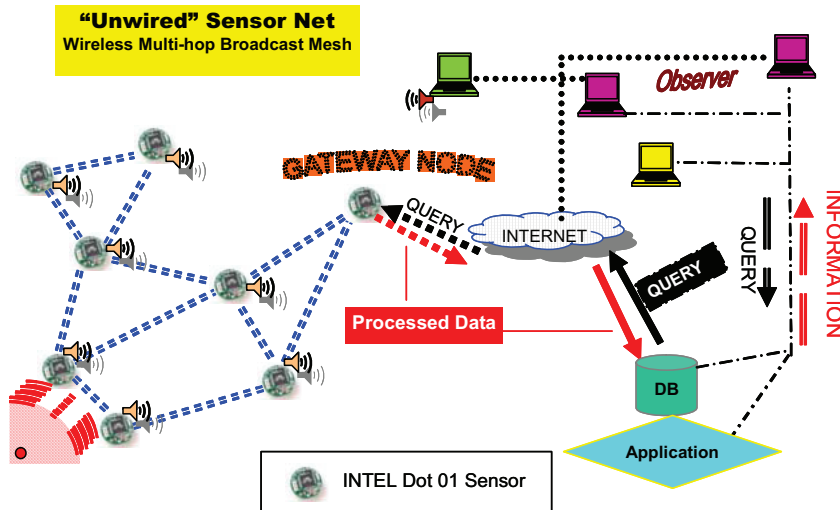


Figure 1-18. Unwired Sensor Net

7. THE SEMANTIC WEB (IS SPREADING)

The average user will never see this web but the buzz about the Semantic Web is as intense as the internet itself. Semantic metadata will let you do things with meaning. The massive amounts of data that we are likely to experience will be useless unless meaningful correlations and connections help us drive innovations, the profitable ones. But just because it is hidden from view does not mean that you can bypass the evolution of the Semantic Web, although it is intended for computers to improve searches, viewing data, interacting with services and sharing information. Taken together, it can offer process transparency across language and geographic boundaries to connect partners in a value network even if individual partners define or perform certain functions differently from others.

Tim Berners-Lee of MIT, the creator of the world wide web as we know it today (while at CERN, Geneva), had described the Semantic Web concepts perhaps as early as 1995 and certainly more clearly by 1998. Since that time, Tim Berners-Lee's vision has matured and significant progress has taken place in research communities around the world to demonstrate that semantic web can solve a variety of today's business problems. Semantics is a collection of Resource Description Framework (RDF) data (or any other semantic language) which describes the meaning of data through links to ontologies, which act as global decentralized vocabularies. In philosophy,

ontology is a theory about the nature of existence (of what types of things exist). Ontology as a discipline studies such theories. Artificial intelligence and semantic web researchers have co-opted the term to indicate a document or file that formally defines the relations among terms. Computers, empowered with this metadata, will be far more “meaningful” in their understanding of the data without human intervention provided data is in machine readable format.

Michael Dertouzos of MIT and James Hendler of the University of Maryland have authored books and articles which are excellent resources to understanding the concepts of semantic web (Dertouzos 2002). Human language thrives when using the same term to mean somewhat different things, but automation does not. The authors provide this example: Imagine that I hire a clown messenger to deliver balloons to my customers on their birthdays. Unfortunately, the service transfers the addresses from my database to its database, not knowing that the “addresses” in mine are where bills are sent and that many of them are post office boxes. My hired clowns end up entertaining a number of postal workers, not necessarily a bad thing, but certainly not the intention. An address that is a mailing address can be distinguished from one that is a street address and both can be distinguished from an address that is a speech, with the tools from the Semantic Web.

This is not the end of the story, because two databases may use different identifiers for what is, in fact, the same concept, such as *zip code*. A program that wants to compare or combine information across the two databases has to know that these two terms are being used to mean the same thing. Ideally, the program needs to discover such common meanings for whatever databases it encounters. For example, an *address* may be defined as a type of *location* and *city codes* may be defined to apply only to *locations*. Classes, subclasses and relations among entities are a very powerful tool for web use. We can express a large number of relations among entities by assigning properties to classes and allowing subclasses to inherit such properties. If *city codes* must be of type *city* and cities generally have web sites, we can discuss the web site associated with a *city code* even if no database links a city code directly to a web site.

Inference rules in ontologies supply further power. Ontology may express the rule “if a city code is associated with a state code, and an address uses that city code, then that address has the associated state code.” A program could then readily deduce, for instance, that a Cornell University address, being in Ithaca, must be in New York State, which is in the US and therefore should be formatted to US standards. The computer doesn't truly “understand” any of this information, but it can now manipulate the terms much more effectively in ways that are useful and meaningful to the human user.

The real power of the Semantic Web will be realized when Agents collect web content from diverse sources (stock quotes from Bloomberg), process the information (in relation to your business) and exchange the results with other programs or data (demographic data from the US Census Bureau). The effectiveness of such Agents will increase exponentially as more machine-readable web content and automated information services (such as, real time-data) become available. The Semantic Web promotes the synergy between Agents that were not expressly designed to work together but can now transfer data among themselves if data comes with semantics (which levels the playing field in terms of the meaning of data, such as, your purchase order is the supplier's sales order).

With ontology pages on the Web, solutions to terminology (and other) problems begin to emerge. The meaning of terms or XML codes used on a web page can be defined by pointers from the page to ontology. Of course, the same problems as before now arise if you point to an ontology that defines *addresses* as containing a *zip code* and one that uses *postal code*. This kind of confusion can be resolved if ontologies (or other web services) provide equivalence relations: one or both of our ontologies may contain the information that a zip code is equivalent to a postal code.

The scheme for sending in the clowns to entertain customers is partially solved when the two databases point to different definitions of *address*. The program, using distinct URIs (universal resource indicators) for different concepts of address, will not confuse them and in fact will need to discover that the concepts are related at all. The program could then use a service that takes a list of *postal addresses* (defined in the first ontology) and converts it into a list of physical *addresses* (the second ontology) by recognizing and removing post office boxes and other unsuitable addresses. The structure and semantics provided by ontologies makes it easier to provide such a service and can make its use completely transparent.

Ontologies can enhance the functioning of the web in many ways. They can be used in a simple fashion to improve the accuracy of web searches. Advanced applications will use ontologies to relate the information on a page to the associated knowledge structures and inference rules. An example of a page marked up for such use is www.cs.umd.edu/~hendler. If you send your Web browser to that page, you will see the normal web page entitled "Dr. James A. Hendler." As a human, you can readily find the link to a short biographical note and read there that James Hendler received his PhD from Brown University. A computer program trying to find such information, however, would have to be very complex to guess that this information might be in a biography and to understand the English.

For computers, the page is linked to an ontology page that defines information about computer science departments. For instance, professors

work at universities and they generally have doctorates. Further markup on the page (not displayed by the typical web browser) uses the ontology's concepts to specify that James Hendler received his PhD from the entity described at the URI <http://www.brown.edu> (the web page for Brown University in Rhode Island). Computers can also find that James Hendler is a member of a particular research project, has a particular e-mail address. All that information is readily processed by a computer and may be used to answer queries (where did Dr. Hendler receive his degree?) that currently would require a human to sift through the content turned up by a search engine.

In addition, this markup makes it much easier to develop programs that can tackle complicated questions whose answers do not reside on a single Web page. Suppose you wish to find the Miss Cook you met at a trade conference last year. You do not remember her first name, but you remember that she worked for one of your clients and that her son was a student at your alma mater. An intelligent search program can sift through all the pages of people whose name is "Cook" (sidestepping all the pages relating to cooks, cooking, the Cook Islands and so forth), find the ones that mention working for a company that's on your list of clients and follow links to Web pages of their children to track down if any are in school at the right place.

An important facet of (Agent) functioning will be exchange of "proofs" written in the Semantic Web's unifying language using rules and information such as those specified by ontologies. For example, suppose Miss Cook's contact information was located by an online service which places her in Johannesburg. Naturally, you want to check this, so your computer asks the service for a proof of its answer, which it promptly provides by translating its internal reasoning into the Semantic Web's unifying language. An inference engine in your computer readily verifies that this Miss Cook indeed matches the one you were seeking and it can show you the relevant Web pages if you still have doubts. Although they are still far from plumbing the depths of the Semantic Web's potential, some programs can already exchange proofs in this way, using the preliminary versions of the unifying language. Figure 1-20 shows Tim Berners-Lee's Semantic Web layers.

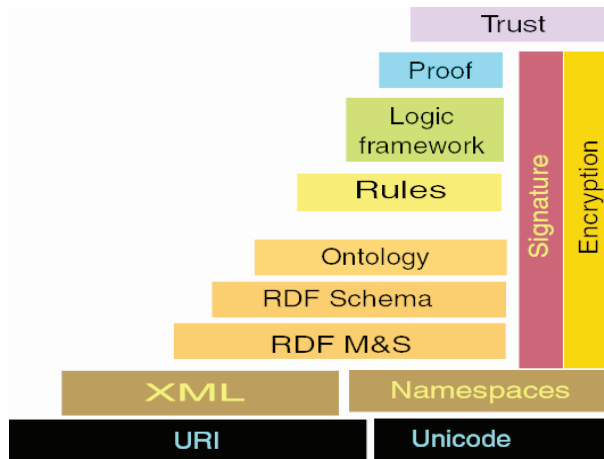


Figure 1-20. Semantic Web layers

(<http://www.csail.mit.edu/research/abstracts/abstracts03/web/02berners-lee.pdf>)

Many automated web services already exist commercially without semantics and their claims may be doubtful. Even if these services had Agents, at present Agents have no way to locate a service that will perform a specific function. This process, called service discovery, can happen only when there is a common language to describe a service in a way that lets other Agents "understand" both the function offered and how to take advantage of it. Services and Agents can advertise their function by, for example, depositing such descriptions in directories analogous to the Yellow Pages. Some low-level service-discovery schemes are currently available, such as Microsoft's Universal Plug and Play, which focuses on connecting different types of devices. Sun Microsystems's Jini aims to connect services. These initiatives, however, attack the problem at a structural or syntactic level and rely heavily on standardization of a predetermined set of functionality descriptions. Standardization can only go so far because we cannot anticipate all possible future needs.

The Semantic Web, in contrast, is more flexible. The consumer and producer Agents can reach a shared understanding by exchanging ontologies, which provide the vocabulary needed for discussion. Agents can even "bootstrap" (learn) new reasoning capabilities when they discover new ontologies. Semantics also makes it easier to take advantage of a service that only partially matches a request. A typical process will involve the creation of a "value chain" in which sub-assemblies of information are passed from one Agent to another, each one "adding value" to construct the final product requested by the end user. To create complicated value chains automatically on demand, Agents will increasingly exploit more and more artificial

intelligence technologies in addition to the Semantic Web. But the Semantic Web will provide the foundations and the framework to make such technologies more feasible.

8. CONCLUSION

Scientists use models to represent the basic nature of the universe. Businesses use models to optimize profits, products and services. Models may even predict future action. But, as ubiquitous as models are, they are, for the most part, isolated from one another. In other words, a model from one domain, such as weather forecasting, does not interact with another, such as purchasing or customer behavior. Can we harness the power of multiple individual data models into larger aggregates? What if we could make predictions based on not a few parameters in an equation based model but billions of diverse facts and functions that Agent based models might be able to accommodate? The latter may result in an unprecedented increase in productivity through the optimal use of resources, ability to adapt and prepare for change according to prediction. We may dramatically reduce the cost of goods and services through the elimination of inefficiencies.

To build these models, individually and then test them in combinations may be a worthy endeavor for generations of engineering and business students, supported by businesses. However, the business community may wish to embrace the key elements (tools and technologies) mentioned in this paper and seek ways to bring about the convergence, repeatedly mentioned throughout this article. Principles from Game Theory empowered by real-time data from automatic id technologies may enhance your profit optimization. Reducing information asymmetry with partners in your value chain through secure Agents-based systems may exponentially eliminate inefficiencies. Deriving more meaning from data through the Semantic Web will allow you to enhance inter-operability between diverse environments of the partners in a value network. Convergence will determine, in part, the pace of your ability to adapt.

Translating convergence to create a merger between bits and atoms is an evolution and is underway. The ability to use it in your business processes to innovate or invent is only limited by your imagination. You cannot visualize the future if your imagination is out of focus.

The payoff from information technology is in making transactions and processes more effective and efficient, it's not about creating a new economy or creating new models of industry. It is about taking a tool, powerful tool, and saying, "How can I make my supply chain more effective and efficient?" (Lou Gerstner, CEO, IBM, The New York Times, 10 March 2002).

ACKNOWLEDGEMENTS

For discussions, information and material in this article, the author wishes to gratefully acknowledge the contributors and help from:

Benson Adams, US Army
David Brock, MIT
Gerard Cachon, University of Pennsylvania
Nicole DeHoratius, University of Chicago
H. van Dyke Parunak, Altarum
Charles Fine, MIT
Gerry Frizelle, University of Cambridge
Neil Gershenfeld, MIT
Henry Lieberman, MIT
Grace Lin, IBM
Serguei Netessine, University of Pennsylvania
Ozalp Ozer, Stanford University
Greg Parlier, University of Alabama
Ananth Raman, Harvard Business School
Sanjay Sarma, MIT
David Simchi-Levi, MIT
Katia Sycara, Carnegie-Mellon University
Artificial Intelligence Laboratory, MIT

Support for the MIT Forum for Supply Chain Innovation provided by:

General Electric
General Motors
Intel Corporation
Michelin Corporation
MIT School of Engineering
MIT Sloan School of Management
SAP

Timogen Systems Inc
US Department of Defense
Xerox Corporation

The physicist Leo Szilard once announced to his friend Hans Bethe that he was thinking of keeping a diary: “I don’t intend to publish. I am merely going to record the facts for the information of God.” “Don’t you think God knows the facts?” Bethe asked. “Yes,” said Szilard. “He knows the facts, but He does not know *this version of the facts.*”

Hans Christian von Baeyer in *Taming the Atom*

APPENDIX

CLUES FOR BUSINESS PROCESS RELATED INNOVATION TO USHER IN ADAPTIVE SCM:

This article deals with the ideas and concepts that may converge for the future of adaptive value networks. Often the key question is where to get started. We have made the point that process is the key and technology is a catalyst. Here are some clues with respect to processes that may offer room for innovation (Simchi-Levi et al, 2002).

Table 1-3. What’s Good for Your Business: Optimize or adapt?

	Optimize?	Adapt?
	Global Optimization	Managing Uncertainty
Distribution to Customer Assignment		
Distribution Logistics Strategies		
Distribution Network Configuration		
Production-Distribution Schedule		
Inventory Control by SKU and Nodes		
Vendor Managed Inventory		
Supply Contracts		
Outsourcing & Procurement		
Strategic Partnerships		
Product Design and Differentiation		
Plant-Product Assignment		
Customer Value/Profitability		
Decision Support Systems		
Information Technology		

Table 1-4. SCM Models and Parameters

SCM : Model Simple, Think Complex	Paradigm or Parameters
Deterministic analytical models	Variables are known and specified
Stochastic analytical models	At least one variable is unknown and follows a probability distribution
Economic models	Game Theory models of buyer-supplier
Cost-based simulation CBS for material	Order quantities, response times, cost data
CBS of production control	Lot size, lead time, material response time
CBS of finished goods stockpile	EOQ, demand data, production lead times
CBS of distribution	Ordering policies, transportation time requirements, demand & cost data, fill rate

Model sources of **uncertainty** (with certainty theory, Bayesian updating, fuzzy sets):

- Customer demand (Bullwhip Effect or “Hog-Cycle” Effect);
- Supply deliveries;
- External markets.

Quick Wins from Logistics Network Configuration:

- Storage at manufacturing plants (raw material, WIP, finished goods);

- Pick, load, ship to warehouse or DC;
- Unload and store at warehouse or DC;
- Pick, load and ship for delivery to next node (customer);

Savings may be possible from analytical optimization of (Table 1-5):

Table 1-5. Process and Impact of Real Time Data

Process	Impact of Real-Time Data	Value from RFID
Dock receiving capabilities		
Storage capabilities		
Receiving methodologies		
Order-generation capabilities		
Delivery time constraints		
Pricing and Promotions		
Merchandising requirements		

Data Collection based on model:

- Group products and/or product families (demand per product per customer);
- Group accounts by customer value and/or geography (zone) plus delivery frequency;
- Product shipment mapped by source warehouse vs. customer/zone;
- Demand by SKU per product (family) per zone;
- Production capacity (annual) at each plant;
- SKU storage capacity in warehouses (BOM for delayed differentiation products);
- Transportation mode, rates (TL/LTL by SKU) and cost (product/mile) between nodes;
- Service level (observed vs. expected vs. promised vs. industry best);
- Inventory carrying cost for safety stock to reach service level;
- Delivery time by customer/zone (map locations vs. transportation distances);
- Order processing cost (labor) and fixed operating cost (by nodes);
- Return and warranties (service cost);
- Wastage and shrinkage (costs).

Estimate/quantify time lag between processes (consider total system benefit):

- point of origin of data/information and data upload/update/accessibility;
- systems visibility of data from any single point of contact;
- data/information usage in systems (disruption management delay);
- information application/use to improve (adapt) decision support system (DSS).

One Outcome:

Industry “clockspeed” vs. “lag” may suggest process innovations for real-time adaptive SCM.

Quick Wins from Inventory Management (Raw Material, WIP, Finished Product)

The source of system-wide savings forecast can be based on near-actual customer demand or “pull” strategies, such as buy-back or revenue-sharing contracts. Inventory carrying cost is

about 20-40% of (turnover) value/year. Most (software) planners use Economic Lot Size Model (1915) to calculate economic order quantity (EOQ) that minimizes the cost function:

$$Q^* = \sqrt{\{2KD/h\}}$$

Parameters of this model may still be valid, but assumptions in this formula are likely targets for (real time data catalyzed) improvements toward “adaptive” supply chain management. Model assumptions (Table 1-6):

Table 1-6. Assumptions

Assumptions: subject to change if process modified/benefits from→	Real Time Data (RFID)
Demand is constant at a rate of D items per day	
Order quantities fixed at Q items per order (safety stock)	
Fixed cost K is incurred each time warehouse places an order	
Inventory carrying/holding cost (h) accrues per unit per day	
Lead time is zero	
Initial inventory is zero (shift inventory cost to supplier)	
Cycle Count Frequency (labour)	
Infinite planning horizon (periodic review)	

If one can factor in the “improvements” from real-time data that may help reduce variability (lead time heterogeneity, demand fluctuations) then, this formulation may still remain an effective model to indicate when orders should be received at warehouses (precisely when the inventory level drops to zero). Implementing ZIOP (zero inventory ordering property) involves precision real-time data synchronization across value chain partners that may make it possible to delay orders until inventory is zero (for whom?). In a centralized system, practice of ZIOP may approach near-reality but in a decentralized system concepts like CPFR along with real-time data sharing may be required as a precursor to practice of ZIOP.

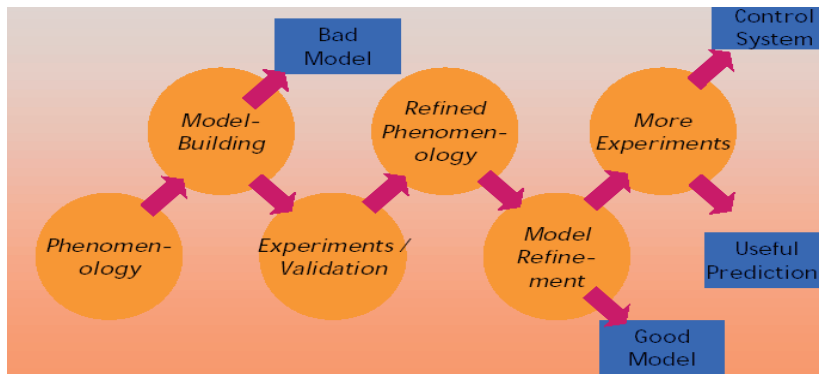


Figure 1-21. Steps in Model Building

Traditional SCOR Model based on “Push” System: Is it still relevant for your need?
(Table 1-7)

Table 1-7. Perspectives, Metrics and Measures

Perspectives	Metrics	Measure	Real-Time Data
Supply Chain Reliability	On-time delivery	Percentage	
	Order fulfillment lead time	Days	
	Fill Rate	Percentage	
	Perfect order fulfillment	Percentage	
Flexibility & Responsiveness	Supply chain response time	Days	
	Upside production flexibility	Days	
Expenses	SCM cost	Percentage	
	Warranty as % of revenue	Percentage	
	Value added per employee	USD/EUR	
Asset / Utilization	Total inventory days of supply	Days	
	Cash-to-cash cycle time	Days	
	Net asset turns	Turns	

(One solution fits all?) SCM Software: Can it help with strategic effects?

Top Line Revenue Growth:

- Reduced time from concept to production;
- Minimize engineering change orders after production release;
- Increased rate of innovation;
- Better on-time delivery (fewer canceled orders; fewer late penalties);
- Higher quality (fewer returns).

Reduced Requirements for Working Capital

- Raw material, WIP and finished goods inventory;
- Inventory obsolescence;

Higher Return on Fixed Assets

Higher Margins

- Lower shipping cost;
- Lower manufacturing costs;
- Lower wastage;
- Improved product mix;
- Reduced inventory carrying cost.

Above measures/metrics may be driven by the following applications:

- Collaborative Product Design;
- Collaborative Planning and Forecasting;
- Optimized Manufacturing Planning;
- Inventory Planning and Optimization;
- Synchronized Planning;
- Detailed Scheduling;
- Accurate Order Promising;
- Optimized Transportation Routing.

Strategic “quick wins” categories likely to benefit from real-time information/data (RFID):

- Reduced requirements for working capital;
- Higher margins;

NOTES

1. Information Asymmetry is a concept borrowed from economics. In 1776, in *The Wealth of Nations*, Adam Smith put forward the idea that markets by themselves lead to efficient outcomes. The mathematical proof specifying the conditions under which it was true, was provided in 1954 by Gerard Debreu (Nobel Prize 1983) of the University of California at Berkeley and Kenneth Arrow (Nobel Prize 1972) of Stanford University (Arrow, K. and G. Debreu (Existence of an equilibrium for a competitive economy. *Econometrica* 3 265–290). However, the latter result showing that when information is imperfect (information asymmetry) or markets are incomplete, competitive equilibrium is not efficient is due to B. Greenwald and J. Stiglitz in 1986 (*Globalization and Its Discontents* by Joseph E. Stiglitz).
2. Value Networks refers to concepts by Clayton Christensen (Harvard Business School) which builds on the concepts of Giovanni Dosi and Richard Rosenbloom (*The Innovator’s Dilemma*, 1997, Harvard Business School Press). We may often use supply chain management and value networks interchangeably.
3. It is beyond the scope of this chapter to delve into even a moderate level of discussion of Operations Research and Game Theory. Our intent is to offer some simple descriptions and indications about the possibilities of Game Theory applications in SCM. Game Theory applications, per se, are unlikely to make SCM more adaptive but these models can help the current processes by providing deeper insights. It is not uncommon to find businesses that are severely under-optimized in their current SCM practices. In such cases, it is speculative whether real-time information or efforts to be adaptive will meet with success. Optimization, including game theoretic tools, may be necessary to “tune the engine” before adaptive SCM can offer value.
4. Prisoner’s Dilemma was authored by A. W. Tucker of Princeton University [PhD advisor of John Nash]. Al Tucker was on leave at Stanford in the Spring of 1950 and, because of the shortage of offices, he was housed in the Psychology Department. One day a psychologist knocked on his door and asked what he was doing. Tucker replied: “I’m working on game theory,” and the psychologist asked if he would give a seminar on his work. For that seminar, Al Tucker authored the Prisoner’s Dilemma.
(www.nobel.se/economics/laureates/1994/nash-lecture.pdf)

REFERENCES

1. Albeniz, V. and Simchi-Levi, D. Competition in the Supply Option Market. Working paper, MIT, 2003
2. Anupindi, R. Bassok Y. and Zemel. E. A General Framework for the Study of Decentralized Distribution Systems. *Manufacturing and Service Operations Management* 2001; 3: 349-368
3. Aumann, R., Acceptable points in general cooperative n-person games. Volume IV, *Contributions to the Theory of Games*. Princeton University Press, 1959.
4. Cachon, G. P. and Netessine, S., "Game Theory in Supply Chain Analysis." to appear In *Supply Chain Analysis in the eBusiness Era*, Simchi-Levi, D., Wu D., and Shen, Z., to be published by Kluwer Academic Publisher, 2003.
5. Christensen, C., *The Innovators Dilemma: When New Technologies Cause Great Firms to Fail*, Chapter 8, 168-169, 2000
6. Cohen, M, Ho, T. Ren J., Terwiesch, C., Measuring imputed cost in the semiconductor equipment supply chain, Working Papers, Operations and Information Management Department, the Wharton School, University of Pennsylvania, 2003
7. DeHoratius, N.(2003), First Measure, Then Manage, *Capital Ideas*, 4: 1: summer, 2002. Retrieved October 2003 from:
<http://gsbwww.uchicago.edu/news/capideas/summer02/measuremanage.html>
8. Dertouzos, M., *The Unfinished Revolution*, Harper Collins, 2002.
9. Gell-Mann, M., *The Quark and The Jaguar*, by W. H. Freeman and Company, New York, 1994.
10. Heinrich, C. and Betts, B., *Adapt or Die: Transforming Your Supply Chain into an Adaptive Business Network*. John Wiley and Sons, 2003
11. Forrester, J., *Industrial Dynamics*, MIT Press, 1961.
12. Joshi, Y. V. Information visibility and its effect on supply chain dynamics MS.c. Thesis, MIT, 2000.
13. Kuhn, H. W. "Extensive games and the problem of information". In *Contributions to the Theory of Games II*, Kuhn, H.W. and Tucker, A. W. ed, Princeton: Princeton University Press, pp. 193-216, 1953.
14. Lee, H., Padmanabhan, P., and Whang, S. The bullwhip effect in supply chains. *Sloan Management Review* 1997; 38: 93-102
15. Nash, J. F., *Equilibrium points in N-Person Games*, Proceedings of NAS, 1950.
16. Negroponte, N., Less Is More: Interface Agents as Digital Butlers, *Wired Columns*, Issue 2.06 June 1994, Retrieved October 2003 from:
<http://web.media.mit.edu/~nicholas/Wired/WIRED2-06.html>, WIRED Ventures Ltd, 1994.
17. Neumann, J. V., and Morgenstern, O., *Theory of Games and Economic Behavior*, Princeton: Princeton University Press, 1947.
18. Norman Poire, Retrieved October 2003 from :
http://www.smalltimes.com/document_display.cfm?document_id=2141
19. Parunak, H., "Go to the Ant": Engineering Principles from Natural Multi-Agent Systems, *Annals of Operations Research*, 1997;75: 69-101.
20. Parunak, H., Savit, R., Riolo, R. Agent-Based Modeling versus Equation-Based Modeling in the Proceedings of Multi-agent systems and Agent-based Simulation, 1998
21. Sarma, S., Brock. D., The Internet of Things, White paper, Auto-ID center. MIT, 1998.
22. Scanlon, L., Behind Bars, *Technology Review*, April 2003, Retrieved April 2003 from:
<http://ww.technologyreview.com>

23. Shehory, O., Sycara, K., Sukthankar, G. Agent aided aircraft maintenance, Proceedings of Autonomous Agents '99, pp. 306-312, Seattle, Washington, May 1999
24. Shubik, M. Some Experimental Non Zero Sum Games with Lack of Information about the Rules. *Management Science* 1962; 8: January: 215-234.
25. Shubik, M. Incentives, Decentralized Control, the Assignment of Joint Costs and Internal Pricing. *Management Science* 1962; 8: April: 325-343.
26. Simchi-Levi, D., Kaminsky, P., Simchi-Levi, E., *Designing and Managing the Supply Chain*, 2nd edition, 2002
27. Serman, J.D., Modeling managerial behavior: Misperceptions of feedback in a dynamic decision making experiment. *Management Science* 1989;35: 321-339
28. Tellis GJ, Golder PN. First to Market First to Fail? Real Causes of Enduring Market Leadership. *Sloan Management Review* 1996; 37(2): 65-75.
29. Vickrey, W. Counterspeculation and Competitive Sealed Tenders. *Journal of Finance*. 1961;16(1): 8-37.

Other Web Sites Referenced

<http://www.wrmea.com/archives/sept-oct02/0209044-2.html>

<http://www.bea.doc.gov>

<http://www.cia.gov>

<http://william-king.www.drexel.edu/top/eco/game/ game.html>

<http://ww.legal-database.com>

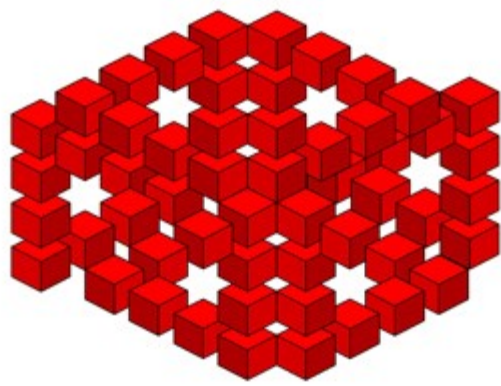
<http://ww.aetherwire.com/CDROM/Welcome.html>

<http://grouper.ieee.org/groups/802>

<http://www.multispectral.com/pdf/APPsVGs.pdf>

<http://ww.technologyreview.com>

<http://www.csail.mit.edu/research/abstracts/abstracts03/web/02berners-lee.pdf>



ADAPTER, OPTIMISER, PRÉVOIR

La convergence des concepts, des outils, des technologies et des normes peut-elle accélérer l'innovation ?

Dr Shoumen DATTA

Chercheur, Département Ingénierie des Systèmes, Forum pour l'Innovation dans la chaîne logistique
Directeur général de l'Ecole d'Ingénierie, Massachusetts Institute of Technology

Les outils et procédés permettant de réduire les insuffisances de la chaîne logistique sont très précieux. La capacité à s'adapter peut en effet ne pas dépendre de la seule technologie mais d'une perpétuelle aptitude à l'innovation des processus dans la gestion de la Supply Chain. Pour cela, les dirigeants doivent être capables d'imaginer l'utilisation combinée de différents concepts, outils et technologies pour réduire les insuffisances, les incertitudes, et l'asymétrie de l'information dans le réseau de valeur. Cet article propose de combiner différentes idées dans un esprit d'approche « solutions » visant à améliorer les décisions.

Les nouvelles technologies pour le Management Logistique Global (SCM) et la production flexible impliquent que les entreprises soient capables de percevoir très tôt les déséquilibres dans les stocks – virtuellement en temps réel – et puissent, en réaction à des signes d'accumulation non désirée, arrêter très vite la fabrication incriminée.

Alan Greenspan - Témoignage devant le Comité Sénatorial américain « *Banking, Housing and Urban Affairs* » (13 février 2001)

Cet article conceptuel vise à stimuler un large panel de décideurs qui voudraient pouvoir prendre de meilleures décisions en s'appuyant sur une connaissance plus approfondie tirée tant de l'innovation du processus que de l'analyse « au bon moment » de données en temps réel. Ce n'est pas la panacée pour s'affranchir des mauvaises étapes d'une prise de décision ; cela ne peut fonctionner qu'avec l'appui nécessaire, sinon approprié, des « facilitateurs » dont nous parlerons plus loin. Dans les systèmes décisionnels tels que, par exemple,

le Supply Chain Management (SCM) ou la disponibilité militaire, la gestion de l'incertitude est essentielle.

Nous proposons une convergence raisonnable des concepts, des outils, des technologies et des normes existants ; utilisés conjointement, ils peuvent améliorer l'adaptabilité des systèmes de décision pour lutter contre l'incertitude dans des applications aussi diverses que l'optimisation des profits ou le temps de réaction dans la disponibilité hospitalière ou militaire. Ces améliorations doivent viser à réduire le « bruit » et favoriser l'adaptabilité. Cette proposition est illustrée par la Figure 1.

En ce qui concerne les systèmes de décision, nous prendrons souvent le Supply Chain Management comme exemple et nous discuterons de la façon dont les pratiques actuelles de la chaîne logistique pourraient s'améliorer si les praticiens (les décideurs) adoptaient et utilisaient *réellement* un nouveau schéma de pensée, de nouveaux outils analytiques, de

Avertissement

Cet article est vraiment très simplifié, incomplet et plein de digressions. L'auteur endosse la pleine responsabilité des éventuelles erreurs et incohérences, et il présente ses excuses au cas où la lecture en serait peu convaincante. Il espère que ce brassage d'idées (simple exploration) suscitera de nouvelles réflexions.

Outre les collaborateurs cités en fin d'article, l'auteur s'est permis d'utiliser plusieurs sources d'information pour « nouer les fils » et montrer comment des disciplines a priori éloignées peuvent, lorsqu'elles sont fusionnées, offrir de nouvelles directions de recherche. Enfin, la liste des références est tout à fait incomplète.

Il est évident que la recherche initiale n'est pas due à l'auteur. En revanche, les opinions et commentaires exprimés ici sont bien les siens, et ne représentent en aucun cas la position du MIT en tant qu'institution ou celle des collaborateurs ou de leurs organismes d'appartenance.

Pour les spécialistes, il est possible que cet article n'amène rien de neuf. Mais c'est la synthèse, la convergence des idées telle que le suggère l'auteur qui peut précipiter la transformation de certains systèmes décisionnels dans le sens de l'adaptabilité ou peut-être, avec le temps, de la prédiction.

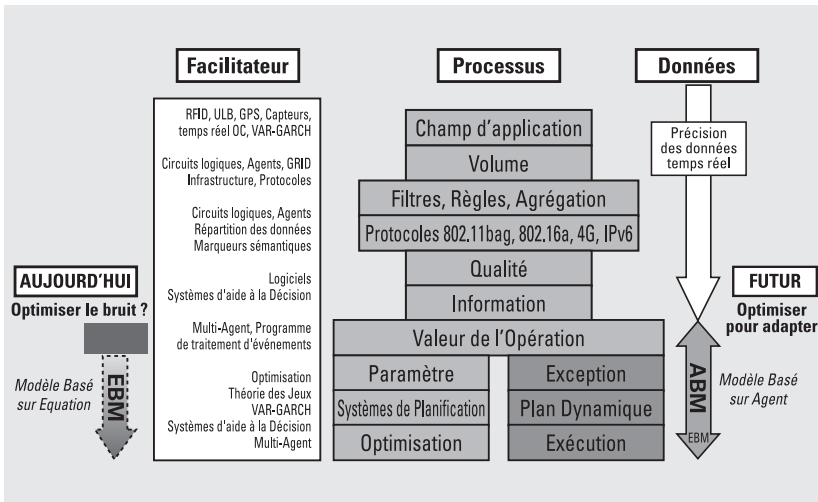
Toute suggestion peut être adressée par courriel à l'adresse suivante : shoumen@mit.edu

Titre original

Adapting Decisions, Optimizing facts and Predicting Figures:

Can Confluence of Concepts, Tools, Technologies and Standards Catalyze Innovations

Figure 1 : Proposition pour passer de l'optimisation du « bruit » à une meilleure adaptabilité à l'avenir.



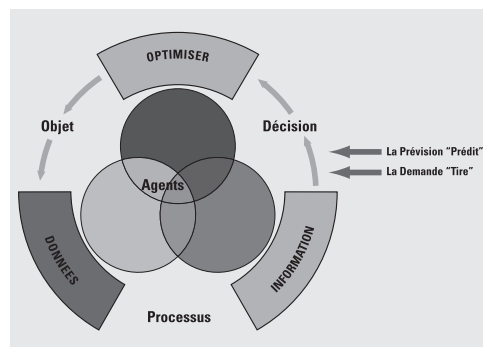
Quand Napoléon affirmait (si tant est qu'il le fit réellement) : « ceux qui ont besoin de se forger une représentation mentale de chaque chose sont incapables au commandement », il faut comprendre cela comme la dénonciation du défaut originel. En effet, s'il aborde une bataille avec devant lui un tableau décrivant comment tel ou tel combat s'est déroulé dans telle ou telle circonstance, le chef militaire réalisera dès les premiers contacts que quelque chose a mal tourné. Son Figure est détruit ; et il ne lui reste plus rien, sauf peut-être une autre représentation personnelle, qui elle-même ne lui servira pas longtemps. Il est possible d'autre part, quand sa première prévision s'avère erronée, qu'il soit assailli par une telle masse d'images différentes que, là-aussi, il ne sache plus quelles adaptations pratiques faire. En fait, trop de références au passé peut être presque aussi gênant que pas de référence du tout. Pour répondre de manière appropriée aux exigences d'un environnement en constante évolution, nous devons non seulement sélectionner et extraire des éléments de leur cadre général, mais aussi savoir quelles en sont les parties qui peuvent circuler et muter sans modifier leur sens et leurs fonctions générales.

F.C. Bartlett

I - Ou « appareil Internet ».
Note du Traducteur.

nouvelles technologies et les normes émergentes pour réduire l'incertitude. **L'emploi** de données temps réel est déterminant pour l'industrie (commerce de détail, santé) et la défense. Pourtant, ces quelques dernières années (1999-2003), on a constaté un intérêt disproportionné pour les outils d'acquisition de données type Technologies d'Identification Automatique (AIT), dont un exemple particulièrement marquant est l'identification par fréquence radio (RFID). A notre avis, le bon point de départ d'une réflexion sur la réduction de l'incertitude du système, c'est de voir **comment** les données temps réel peuvent influencer sur le processus (opérationnel). L'emploi des AIT pour identifier des objets avec le RFID est intéressant quand ces données (systémiques, locales) deviennent utiles « **au bon moment** » eu égard au processus opérationnel. Mais il faut aussi que ces processus fournissent des **informations décisionnelles**, c'est à dire destinées à élaborer les

Figure 2 : La connectivité des données temps réel et du processus (analytique temps réel) offre de meilleures informations pour les prises de décision.



décisions rapidement, à s'adapter si nécessaire, et à réagir ou se mettre en situation de réagir. Cette connectivité, qui découle de la proposition esquissée par le Figure n°1, est illustrée par le Figure n°2.

Les données temps réel au « bon moment » (**données right-time**) peuvent modifier les processus opérationnels actuels et stimuler l'innovation. Cependant, il n'est pas suffisant de fournir des données temps réel aux « systèmes Legacy » ou aux ERP. Pour améliorer l'adaptabilité, les systèmes décisionnels doivent pouvoir accéder à l'information « **right-time** », elle-même fondée sur des données temps réel (analytique temps réel) provenant de différentes sources (marqueurs RFID, capteurs, GPS, codes à barres). Le débat sur le format (code électronique/EPC ou codification identifiant universel/UID) reste encore ouvert, mais cela ne devrait pas bloquer la réflexion, condition préalable pour que l'innovation des processus fasse bon usage des « données right-time. »

Il est possible que les architectures agnostiques de format (logiciels) détiennent la clé pour connecter les données temps réel à d'autres logiciels ou ERP. Mais il nous semble peu probable que les progiciels ERP puissent traiter ou analyser des flux de données temps réel de l'ordre du Gigabit. Certains avaient suggéré (et nous leur emboîtons le pas) de s'intéresser à l'utilisation d'un logiciel basé sur agent (ABM) **combiné** à un logiciel traditionnel basé sur équation (EBM) afin d'extraire l'information du flot croissant de données temps réel. La connectivité de ces données est tout aussi importante que le partage de l'information **entre entités** pour améliorer le processus de prise de décision. Et à son tour, ce partage de données ou d'information permet d'améliorer la performance de l'ensemble du réseau de valeur.

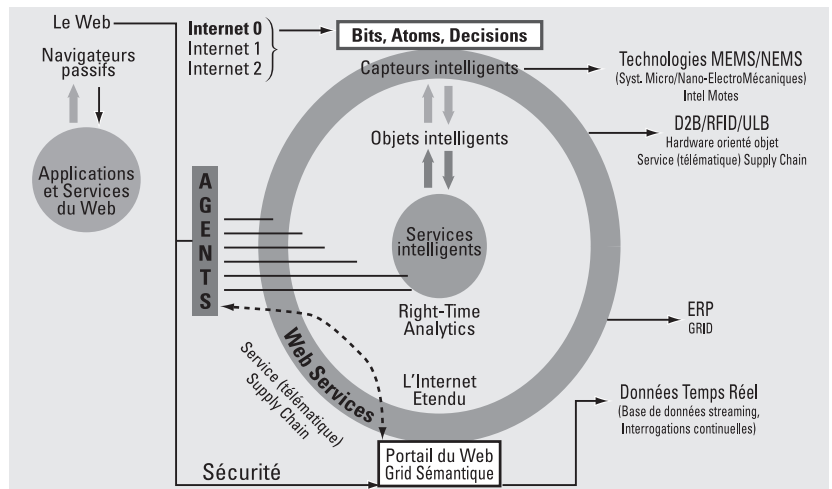
L'interaction entre entités exige une infrastructure sécurisée et une plate-forme diffuse totalement ouverte à la collaboration. Nous proposons une telle plate-forme (ubiquiste, agnostique avec transpondeur et appartenant à l'infrastructure civile) dans laquelle les interrogateurs de données sont des systèmes de radio logicielle (SDR-SWR). L'accès et le contrôle du partage des données sont régulés et authentifiés via la couche Application logicielle (transmise par l'Internet) de la même manière que pour une Internet « **appliance** » avec régulation à distance (ex : allumer le four micro-onde tout en rentrant chez soi en voiture).

Dans les 5, ou plus vraisemblablement les 25 à 50 prochaines années, quand nous pourrons passer d'un statut opérationnel auto-adaptif à un statut *prédictif*, il nous faudra d'autres concepts et outils, probablement encore inconnus aujourd'hui. Cependant, en contribution à la phase prédictive des opérations, nous proposons une idée issue de l'économétrie des séries de temps. Tout simplement, il s'agit d'étudier la possibilité d'utiliser des données temps réel « brutes » (sans regroupement ni tri) pour mieux comprendre les changements et y réagir, quasiment en temps réel. Ceci peut aider à réduire encore plus les risques et l'incertitude, et peut-être même à atténuer l'effet Coup de Fouet (Bullwhip). De tels outils analytiques économétriques sont utilisés dans le domaine de la finance (volatilité des prix de la bourse). Si l'on peut modifier les outils économétriques (tels que le GARCH - Hétéroscédasticité conditionnelle autorégressive généralisée) pour les utiliser avec des données ODD (données dépendant d'objets) temps réel, cela non seulement nous aidera à prédire les paramètres clés de la chaîne logistique (prévision de demande, prix) basés sur les entrées (données temps réel) mais, en plus, pourra nous fournir une mesure du *risque* associé à la prédiction. Et pouvoir quantifier le risque dans la chaîne logistique est tout particulièrement intéressant.

En résumé, nous allons essayer dans cet article de combiner différentes idées dans un esprit d'approche « solutions » dont le but est de réduire l'incertitude et d'améliorer les décisions. Nous enchaînerons les notions, allant de la Théorie des Jeux à la simulation, via les Technologies d'Identification Automatique (AIT), l'Econométrie des séries de temps, le Grid Computing, les Agents et le Web Sémantique. Il est fort possible que des gouvernements, des sociétés, des firmes de consultants et des universitaires ayant une connaissance approfondie dans un ou plusieurs de ces domaines passent les quelques prochaines décennies à tenter de synthétiser un ou des modèles ou un *modus operandi* efficace pour combiner ces idées avec d'autres concepts, outils, technologies et normes émergents qui, utilisés conjointement, pourraient permettre de mieux saisir les incertitudes, les analyser, les réduire et y répondre (Figure n°4). Comprendre la convergence facilitera l'étude du paradigme entre adaptabilité et efficacité. Le cadre de gestion (tableau de bord des outils) pour diagnostiquer et déterminer l'équilibre dynamique (spécifique à l'industrie) peut optimiser le

Infrastructure Ubiquiste de l'Internet 0 : Contrôle On/OFF des données Temps Réel

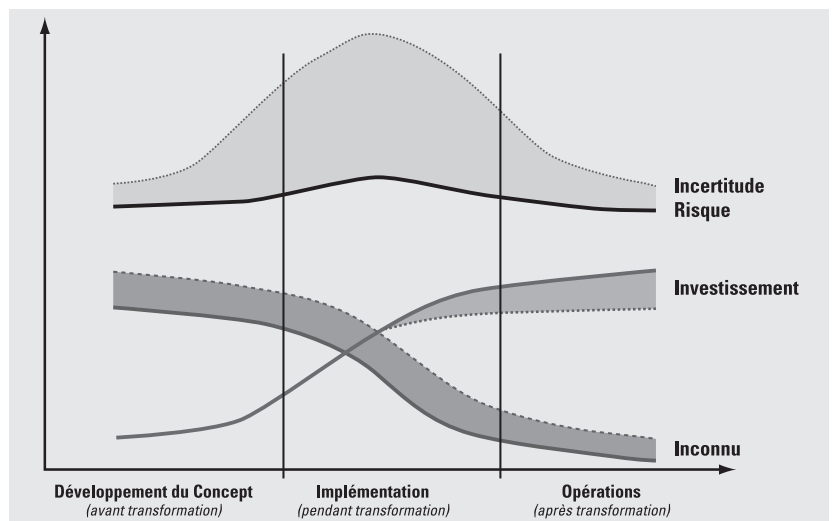
Figure 3 : Pour l'émergence de systèmes décisionnels adaptatifs, il est nécessaire de mettre en communication bits, atomes et décisions.



Depuis un bureau à Shinzen en Chine, vous vous connectez à un lecteur SDR situé dans un entrepôt aux Etats-Unis de manière à vérifier si vos produits sont arrivés en temps voulu. Ce fut le cas. Vous allez aussi apprendre que votre distributeur à Santiago du Chili et votre détaillant à Espoo en Finlande ont eux aussi vérifié où en était la livraison quelques instants avant vous.

Réduire le risque et l'incertitude : Séparer cause et effet

Figure 4 : Investir dans la convergence des idées pour réduire le risque et l'incertitude : un pas vers l'Equilibre de Gibbs.



« push-pull » entre adaptabilité et efficacité dans la recherche de l'*Equilibre Dynamique de Gibbs*.

« Au musée de la Science à Barcelone, j'ai vu une exposition qui illustrait parfaitement le chaos. Une version non linéaire d'un pendule était montée de telle manière qu'un visiteur pouvait saisir le poids et le faire se balancer comme il voulait, à la vitesse qu'il voulait. On observait alors le déplacement du balancier tout en l'enregistrant avec un crayon sur une

feuille de papier. Puis on demandait au visiteur de reprendre la lentille et de reproduire exactement le même mouvement (position et vitesse). Quel que fût le soin qu'il y mettait, le résultat obtenu était très différent de ce qu'il était la première fois.

Je demandais au directeur du musée ce que faisaient les deux hommes debout dans un coin, qui nous observaient. Il me répondit : « Oh, ce sont deux Hollandais qui attendent d'embarquer le « Chaos » ». Apparemment, cette exposition devait être démontée et transférée à Amsterdam. Depuis, je me suis toujours demandé si les services de ces deux Hollandais n'allaient pas être recherchés un peu partout dans le monde par des organisations qui voudraient se débarrasser de leur « chaos [1]. »

Pour l'industrie, la quête du Graal, c'est de débarrasser la chaîne logistique du « chaos » pour mieux l'adapter aux fluctuations de la demande. La gestion de l'incertitude est obérée par le degré croissant d'asymétrie de l'information^a entre les partenaires de la « chaîne » logistique ou du réseau de valeur^b - designers, fournisseurs, distributeurs, détaillants, consommateurs, dont les objectifs sont différents et souvent opposés, ce qui risque de parsemer d'embûches le chemin des réseaux d'affaires adaptatifs de l'avenir [2].

Un des objectifs commerciaux des fournisseurs est d'obtenir des fabricants qu'ils s'engagent sur des achats fermes de grands volumes (mais avec flexibilité de livraison). C'est donc en contradiction avec l'objectif du producteur pour lequel une réaction rapide à une fluctuation de la demande conduit à un excédent des stocks de matières premières. Le fabricant doit produire en masse (pour profiter des économies d'échelle), mais les flux de production doivent s'adapter aux variations de la demande même si l'utilisation des ressources avait été planifiée sur la base de prévi-

Ampex lança le premier magnétoscope en 1956. Chaque unité valait 50 000 USD et les seuls concurrents, RCA et Toshiba, étaient loin derrière. Sony, JVC et Matsushita étaient de simples observateurs. Masaru Ibuka, co-fondateur de Sony et Yuma Shiraishi, JVC, demandèrent à leurs ingénieurs respectifs de produire des appareils à 500 USD, soit à peine 1% du prix d'Ampex. Dans les années 1980, les ventes de magnétoscopes sont passées, chez Sony, de 17 millions à 2 milliards, chez JVC, de 2 millions à 2 milliards, chez Matsushita de 6 millions à 3 milliards de dollars US et pour Ampex [3], de 296 millions à 480 millions de USD.
S'adapter ou Disparaître !

sions. En fait, le producteur peut avoir besoin de plus ou moins de matières premières et rechercher la flexibilité en jouant sur les quantités achetées, ce qui va à l'encontre de l'objectif du fournisseur. Le désir du fabricant de produire en grand nombre se heurte à son tour à celui des centres de stockage et de distribution qui cherchent à réduire les volumes stockés, leur coût augmentant les frais de transport pour l'ensemble des acteurs.

Pendant l'année 2000 et pour les USA seuls, les coûts relatifs à la chaîne logistique dépassèrent le trillion de USD (10% du PIB), c'est-à-dire à peu près le PIB russe et plus que le PIB du Canada ou même le PIB combiné des 22 pays membres de la Ligue Arabe (dont les riches nations pétrolières), lui-même étant inférieur à celui de l'Espagne. Une simple économie de 10% des coûts de la chaîne logistique aux USA équivaldrait pratiquement au PIB de l'Irlande[4].

En conséquence, les outils et procédés permettant de réduire les insuffisances de la chaîne logistique sont très précieux[5]. La capacité à s'adapter peut en effet ne pas dépendre de la seule technologie mais d'une perpétuelle aptitude à l'innovation des processus dans la gestion de la SCM. Pour cela, les dirigeants doivent être capables d'imaginer l'utilisation combinée de différents concepts, outils et technologies pour réduire 1/ les insuffisances, 2/ les incertitudes, et 3/ l'asymétrie de l'information dans le réseau de valeur.

Le but recherché, c'est de passer d'un management logistique global basé sur l'offre (« push ») à un réseau auto-adaptatif basé sur la demande (« pull »). Un des moteurs de cette transformation, c'est l'utilisation potentielle de données et d'informations temps réel comme déclencheur d'étapes de décision autonomes susceptibles d'effectuer simultanément re-planification et exécution. D'après différentes études, en 2003 les entreprises ont généré un flux de données par seconde supérieur à un téraoctet (sans compter les données rassemblées par les AIT). Doit-on considérer cela comme de l'information ? En l'état, c'est peu probable ! L'aptitude à extraire des renseignements à partir de données de manière à gérer l'information peut être le facteur de différenciation entre les entreprises qui sauront exploiter les données (telles que l'identification automatique ou les capteurs) et celles qui ne le sauront pas.

Les données stockées dans les ERP peuvent pâtir de problèmes qui réduisent la valeur de

a - L'asymétrie de l'information est un concept emprunté aux économistes et utilisé de façon assez informelle ici pour bien souligner le manque de visibilité de l'information (données) entre organisations. En 1776, dans *The Wealth of Nations*, Adam Smith avançait l'idée que les marchés en eux-mêmes donnaient des résultats efficaces. La preuve mathématique spécifiant les conditions dans lesquelles ceci était vrai fut apportée en 1954 par Gérard Debreu (Prix Nobel 1983) et Kenneth Arrow (Prix Nobel 1972) dans leur ouvrage *Existence of an equilibrium for a competitive economy*, *Econometrica*. En 1986, B. Greenwald et J. Stiglitz amenèrent la preuve que quand l'information est insuffisamment distribuée (asymétrie de l'information) ou les marchés imparfaits, l'équilibre compétitif est inefficace (*Globalization and Its Discontents*, de Joseph Stiglitz).

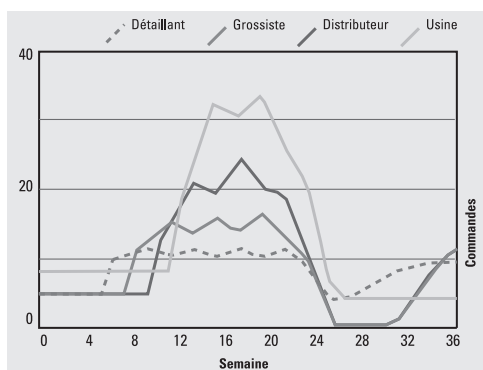
b - Les réseaux de valeur renvoient aux concepts avancés par Clayton Christensen dans son ouvrage *The Innovator's Dilemma* paru aux éditions Harvard Business School en 1997. Il se base sur les concepts de Giovanni Dosi et Richard Rosenbloom. Nous utiliserons indifféremment les expressions « management de la chaîne logistique - SCM » ou « réseaux de valeur ».

leur information. De même, les systèmes ERP peuvent compromettre l'efficacité des données dynamiques si les systèmes statiques sont incapables de répondre en temps quasi réel. Aussi, quand les planificateurs utilisent ce type de données ERP ou de sources d'information dans leurs prévisions ou optimisations, on peut s'interroger sur la validité du résultat. En effet, l'optimisation du processus ou la prévision elle-même peuvent avoir été fondées sur des « bruits » plutôt que sur des données dynamiques solides (cf. Figure n°1). La piètre qualité des données et l'asymétrie de l'information entre les différents partenaires de la chaîne logistique sont enfin sources d'erreurs (d'optimisation, de prévision), et celles-ci s'accumulent aux différents niveaux de la chaîne logistique, ce qui se traduit par l'Effet Coup de Fouet/Bullwhip⁶⁻⁹, comme le montre la Figure n°5. La Figure n°6 présente l'Effet Bullwhip basé sur des données réelles provenant de l'industrie des semi-conducteurs.

Vers des réseaux auto-adaptifs ?

Les outils et technologies servant à lisser l'Effet Bullwhip peuvent aussi être utilisés pour inciter les chaînes logistiques à devenir auto-adaptives. Cela suppose que les organisations encouragent l'innovation des processus d'affaires visant à améliorer l'interaction entre entités (échanges d'information intra et inter-entreprises) et qu'elles recherchent aussi la disparition des silos de données. En réalité cependant, « culture » organisationnelle et gestion du changement sont nécessaires pour stimuler de nouveaux modes de pensées concernant la convergence des concepts, des outils, des technologies et des normes. Alors, quelques groupes pourront imaginer la manière de connecter des objets (atomes) chargés de données (bits) à des processus ou à l'analytique temps réel pour en extraire

Figure 5 : L'Effet Coup de Fouet/Bullwhip [10]



l'information temps réel destinée à des décisions auto-adaptives qui pourront, à leur tour, optimiser la nature (design, répartition) ou les caractéristiques (prix, risque) d'objets dans une chaîne télématique.

Tableau 1 : Eléments de la convergence de concepts, d'outils, de technologies et de normes proposée.

Outils et Concepts	Sources de Données
Recherche Opérationnelle	Technologies d'Identification Automatique (RFID, ULB, GPS, RTLS ²)
Théorie des Jeux	Technologies d'identification (GPRS, Voix, Manuelle, Code à barres 2 ^e génération, Code à barres)
Agents (Intelligence Artificielle Distribuée)	Protocoles sans fil (802.11, 802.16)
Outils économétriques (ODD-VAR-GARCH)	Réseaux capteurs (technologie Zigbee - 802.15.4)
Web Sémantique	Systèmes de Radio Logicielle (swr).
Grid Computing	

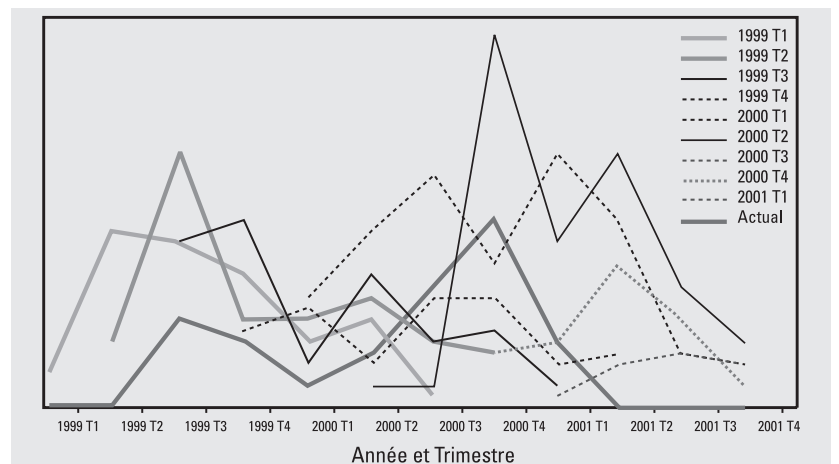
Recherche Opérationnelle et Théorie des Jeux.

La locomotive de l'optimisation (les algorithmes), c'est la recherche opérationnelle. C'est un domaine de prospection intense et d'innombrables sources d'information sont disponibles^c. La Théorie des Jeux n'était pas un nom d'usage courant jusqu'en 1994, date à laquelle les travaux de John Nash, et le film dont il fut l'objet, incitèrent les journaux économiques généralistes à en découvrir progressivement les vertus. Pendant des siècles, les économistes ont travaillé sur différents modèles de jeux théoriques, mais on considère que les pères de la Théorie des Jeux moderne [12]

2 - RTLS : Real-Time Location System = Système de localisation temps réel = RTLS. N.d.T

c - Cet article n'a pas pour but de rentrer dans le débat Recherche Opérationnelle et Théorie des Jeux. Nous souhaitons seulement fournir quelques descriptions et indications simples sur les possibilités des applications de la Théorie des Jeux dans la SCM. Ces applications, en elles-mêmes, ne rendent pas la SCM plus réactive, mais les modèles proposés peuvent offrir des vues plus profondes. La plupart des entreprises sont largement sous-optimisées. Et dans ce cas, savoir si l'information temps réel peut être une valeur ajoutée est strictement spéculatif. Aussi l'optimisation, incluant les outils théoriques des jeux, peut-elle être nécessaire pour « régler la machine » avant que l'information temps réel ne puisse aider à adapter la SCM aux événements. Pour un excellent débat sur l'utilisation de la Théorie des Jeux dans le SCM, voir : 1/ Competition in the Supply Option Market, Etudes de V. Albeniz et D. Simchi-Levi, MIT 2003, et 2/ Game Theory in Supply Chain Analysis, de G. Cachon et S. Netessine paru dans « Supply Chain Analysis in the eBusiness Era » sous la direction de D. Simchi-Levi, D. Wu et Z. Shen et publié par Kluwer Academic Press .

Figure 6 : L'Effet Coup de Fouet dans la chaîne logistique de l'équipement semi-conducteur montre les prévisions de demande par rapport à l'achat réel d'équipement [11]



sont John von Neumann et Oskar Morgenstern (1944). Cette théorie a connu depuis lors de fantastiques développements, dont le concept de l'équilibre, les jeux avec une information incomplète, les jeux coopératifs et les enchères [13-18, 25].

La Théorie des Jeux nous aide à modéliser, analyser et comprendre le comportement des nombreuses parties prenantes qui interagissent dans le processus de prise de décision. En tant que telle, cette théorie s'occupe des problèmes d'optimisation interactive. C'est, en particulier, un outil d'analyse de situations dans lesquelles les parties s'efforcent de maximiser leurs propres bénéfices (espérés) en même temps qu'elles choisissent leur stratégie. Au final, les dividendes de chaque partie dépendent du profil des stratégies choisies par l'ensemble des parties. La plupart des situations économiques peuvent être modélisées par un « jeu » car, dans toute interaction impliquant deux parties ou plus, le bénéfice de chacune dépend des actions de l'autre. Donc le thème essentiel dans la Théorie des Jeux est **Interactions**. Dans le monde des affaires, chaque décideur est un acteur qui prend une décision ou choisit une stratégie qui sera influencée par le concurrent. Et on suppose que les hommes d'affaires font des choix rationnels pour optimiser leurs bénéfices.

Pourquoi les entreprises se comportent-elles ainsi ? Dans cette situation, et dans quelques autres, elles sont confrontées à ce qui, dans la Théorie des Jeux, est connu sous le nom de « Dilemme du Prisonnier », la réponse rationnelle n'étant pas forcément la plus sensée^d.

Le Dilemme du Prisonnier

Alice et Bob sont arrêtés près du lieu d'un cambriolage. Ils sont interrogés séparément. Chaque suspect peut soit avouer, avec l'espoir d'une peine plus légère, soit refuser de parler (ne pas avouer). La police n'a pas d'informations suffisantes pour les inculper, à moins que l'un d'eux n'avoue. Chacun doit donc choisir entre avouer et incriminer l'autre ou se taire, sans savoir ce que l'autre va faire. Si aucun

Un fabricant de puces casse les prix de ses processeurs d'ordinateurs de bureau et portables plusieurs jours après un mouvement similaire d'un rival. « Nous allons faire tout ce qu'il faudra pour rester compétitifs sur les prix », dit un représentant. La politique agressive de réduction des prix de la compagnie signifie que la compagnie ne veut pas abandonner ses gains sur ce marché, même au prix de pertes en final. (CNet, 30 mai 2002)

n'avoue, tous les deux encourent alors une peine d'un an de prison pour port d'armes prohibé. Si les deux avouent et s'accusent mutuellement, ils écoperont de dix ans de prison. Mais, si l'un des voleurs avoue et accuse l'autre et que l'autre n'avoue pas, alors celui qui a coopéré avec la police ressortira libre tandis que l'autre sera condamné à la peine maximale, 20 ans de prison. Dans ce cas « l'espace stratégique » est simple : avouer ou ne pas avouer, et chacun choisit une des deux stratégies. Les dividendes (pénalités) sont les peines infligées.

Tableau 2 : Le Dilemme du Prisonnier : Alice (colonne) opposée à Bob (ligne).

		Alice	Alice
		avoue	n'avoue pas
Bob	avoue	10 - 10	0 - 20
Bob	n'avoue pas	20 - 0	1 - 1

Dans ce tableau, les nombres représentent les peines encourues par les prisonniers suivant les combinaisons de stratégies choisies. celui de gauche est pour la personne située dans les lignes (Bob), celui de droite pour celle figurant dans les colonnes (Alice). Ainsi, la lecture de la première colonne donne, de haut en bas : si tous les deux avouent, chacun est condamné à 10 ans, mais si Alice est la seule à avouer, Bob est alors condamné à 20 ans et Alice est libre.

En conséquence, quelles sont les stratégies « rationnelles » dans ce jeu si tous deux veulent avoir la peine la plus légère ? Alice va faire le raisonnement suivant : « De deux choses l'une : ou Bob avoue, ou il se tait. S'il avoue, je prends 20 ans (si moi, je n'avoue pas) et 10 ans si j'avoue (si je coopère) ; dans ce cas, il est préférable que j'avoue. D'un autre côté, si ni Bob ni moi n'avouons, j'écopé d'une année ; mais là, si j'avoue, je ressorts libre. Dans les deux cas, il s'avère préférable que j'avoue. Donc, je vais avouer. » Mais Bob peut, et vraisemblablement va, suivre le même cheminement intellectuel.

Les deux individus raisonnent de façon **rationnelle**, avouent et prennent chacun 10 ans. Or s'ils avaient agi de façon irrationnelle et n'avaient pas avoué, ils n'auraient écopé chacun que d'une année seulement [19].

Le Dilemme du Prisonnier est un exemple simple de jeu statique non-coopératif dans lequel les joueurs choisissent en même temps leur propre stratégie, et doivent s'y tenir. L'élément principal de ces jeux, c'est l'existence et la spécificité de l'équilibre de Nash (NE). NE est le point où aucun joueur n'a inté-

^d - A.W. Tucker, de Princeton University (il était conseiller de John Nash pour son doctorat), est l'auteur du Dilemme du Prisonnier. Au printemps 1950, il était à Stanford University et son bureau, à cause d'un manque de place, se trouvait au Département de Psychologie. Un jour, un psychologue frappa à sa porte et s'enquit de ce qu'il était en train de faire. Tucker répondit : « Je travaille sur la théorie des jeux. » Le psychologue lui demanda s'il pourrait faire une conférence sur son travail. Et il l'intitula « Le Dilemme du Prisonnier. » (www.nobel.se/economics/laureates/1994/nash-lecture.pdf).

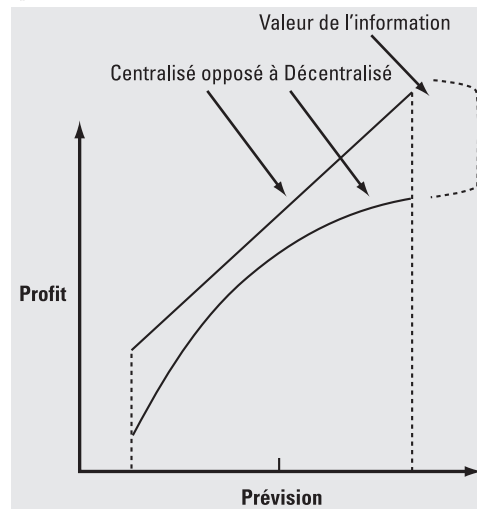
rêt à changer sa stratégie puisque chacun a choisi celle qui maximalise ses propres bénéfices compte tenu des stratégies des autres joueurs.

Un concept clé qui n'a pas été mis en exergue dans le Dilemme du Prisonnier, c'est la répétition des interactions. Or dans le monde des affaires, les joueurs savent qu'ils sont dans le « jeu » pour longtemps. Ils peuvent donc choisir de coopérer, surtout s'ils estiment que cette démarche a des chances de faciliter la coopération, voire la collaboration de demain. C'est par des actions répétées que les compagnies se bâtissent une réputation, qui influence les actions des autres. Par exemple, Intel Corp. utilise son programme de notation « fournisseurs », qui évalue, pour chacun d'entre eux, les coûts, la disponibilité, le service, la rapidité de réaction et la qualité des prestations. Il maintient ainsi ses principaux fournisseurs dans une course permanente à l'excellence. « Nous récompensons les fournisseurs qui ont les meilleures notes en faisant plus d'affaires avec eux », dit Keith Erickson, Directeur des Achats. Et comme incitation supplémentaire, Intel Corp. englobe de temps en temps ses meilleurs fournisseurs dans ses publicités. La compagnie laisse même les plus performants se prévaloir de leurs relations avec Intel Corp dans leur propre publicité.

Dans la réalité, chaque partie de la chaîne logistique agit de façon tout à fait égoïste. Et donc la somme des choix individuels n'aboutit pas à un résultat optimal pour l'ensemble de la chaîne. Le bénéfice d'une chaîne « décentralisée » composée de multiples compagnies gérées indépendamment est en général inférieur au total des bénéfices de la version centralisée de la même chaîne, version dans laquelle les interactions entre partenaires (fournisseurs, fabricants, détaillants) sont gérées par un seul décideur (moins d'inconnues) de façon à optimiser les bénéfices au profit de l'ensemble. Le partage de l'information dans cette dernière configuration réduit les évidentes insuffisances de la version décentralisée, qui sont dues à la « double marginalisation » découlant d'un processus de décision égocentrique. Donc, le bénéfice optimum est plus important dans une chaîne centralisée où l'information est partagée.

Une stratégie de réduction des carences dans une chaîne décentralisée est « l'intégration verticale » : une entreprise possède chaque élément de sa chaîne logistique. Ford Motor Company en fut un bon exemple. De nos

Figure 7 : Valeur du partage de l'information – Accroissement du gain pour l'ensemble de la chaîne logistique (performance)



jours, les demandes et préférences des consommateurs changent rapidement. Les compagnies qui se concentrent sur leur métier de base sont généralement plus réactives pour rester en tête de la compétition. En conséquence, on constate une tendance à « l'intégration virtuelle » dans laquelle les chaînes logistiques sont constituées de compagnies gérées indépendamment mais étroitement associées. Des stratégies fondées sur le partage de l'information comme celle de la gestion partagée des approvisionnements (VMI – Vendor Managed Inventory) sont utilisées par quelques firmes (Dell, P&G, Wal Mart).

En dépit de progrès dans le partage de l'information, il est rare que les chaînes logistiques actuelles disposent d'une connaissance totale des acteurs et des décisions ou des résultats. Il est courant qu'une firme ait une meilleure prévision de la demande qu'une autre ou qu'elle ait une meilleure information sur ses propres coûts et procédures de fonctionnement. Si une entreprise sait qu'une autre est susceptible d'avoir une meilleure information, elle peut choisir des modes d'action intégrant cette donnée. La Théorie des Jeux donne des outils pour étudier des cas avec une asymétrie de l'information d'une complexité analytique croissante. Pour illustrer ceci, nous allons nous intéresser à un type particulier de jeu, le Jeu de Signaux [20].

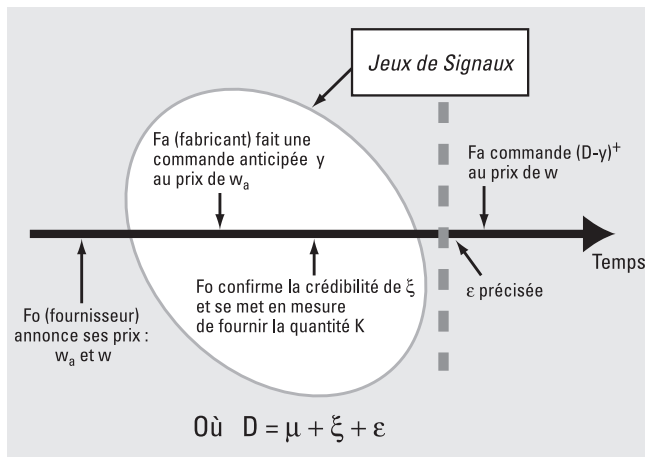
Jeu de Signaux

Dans sa forme la plus simple, le Jeu de Signaux se joue à deux. Un joueur a de meilleures infor-

mations que l'autre, et celui qui est le mieux informé bouge le premier. Par exemple, un fournisseur doit se mettre en situation de fournir un composant clé de la production d'un fabricant. Celui-ci a une meilleure prévision de la demande que le fournisseur. Dans un monde idéal, il pourrait partager son information avec son fournisseur pour que celui-ci se dote de la capacité appropriée. Mais il a aussi intérêt à ce que son fournisseur dispose d'un volume de composants plus important au cas où la demande serait plus forte que prévue. Il a donc intérêt à gonfler ses prévisions. Ce sera alors le fournisseur, s'il se fie au fabricant, qui supportera le coût de l'augmentation de ces volumes. Le fabricant espère donc que le fournisseur va le croire et augmenter ses réserves. Heureusement, ce dernier connaît le « jeu » du producteur. Quel geste (signal) venant du fabricant pourrait-il bien inciter le fournisseur à considérer comme crédibles les prévisions du fabricant ?

Dans cet exemple, la demande D est en fait la somme de trois prévisions. La prévision du marché (μ) est faite par des analystes. Le fabricant, à partir de ses sources ou de son expérience, établit ses propres prévisions ξ (ξ) qui, dans un système décentralisé, ne sont pas portées à la connaissance du fournisseur (asymétrie de l'information). Cependant, celui-ci, par son expérience, s'est constitué une grille de classement des fabricants fondée sur leurs antécédents et leur crédibilité. Ainsi, le fournisseur confirme la confiance qu'il accorde au « type » d'information prévisionnelle du fabricant et peut choisir une valeur de ξ censée être représentée par une distribution normale. Ceci introduit une variable aléatoire (stochastique). L'incertitude du marché est représentée par ϵ dont ni le fabricant ni le fournisseur ne peuvent contrôler la valeur. C'est donc une

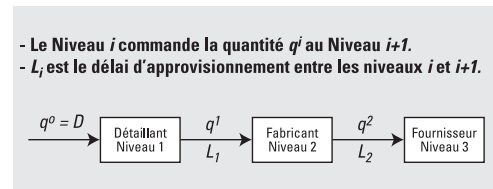
Figure 8 : Le Jeu de Signaux.



autre variable aléatoire (terme d'erreur), *censée* appartenir elle aussi à une distribution normale.

Ces hypothèses, qui ne sont pas rigoureusement quantifiées et que l'on suppose appartenir à une fonction donnée par une distribution normale, introduisent une variabilité. De telles erreurs s'accumulent au fil de chacune des étapes des chaînes logistiques (voir Figure n°9), contribuant ainsi à l'apparition de l'Effet Bullwhip. Nous énoncerons plus loin une proposition pour étudier comment on pourrait réduire ces écarts en se servant de données temps réel avec des outils analytiques combinant méthodes statistiques et dernières avancées dans l'économétrie des séries de temps [21].

Figure 9 : Les données temps réel peuvent-elles influencer sur la chaîne logistique traditionnelle au « bon moment » ?



Le jeu de signaux tel que décrit ci-dessus démarre par l'annonce des prix par le fournisseur : un prix ordinaire (w) et un prix pour achat anticipé (w_a). Le fabricant établit sa prévision de commande et, s'appuyant sur la fiabilité qu'il accorde à ses prévisions, il réagit à la proposition de prix global du fournisseur en émettant une commande anticipée (y) au prix convenu de w_a . Le volume de y envoie un « signal » au fournisseur, qui s'en sert pour confirmer la crédibilité qu'il doit accorder à la prévision « D » du fabricant. Fort de cela, le fournisseur peut donc déterminer ce que doit être sa capacité de fourniture (K) de manière à optimiser ses profits (risque inventaire). Au fur et à mesure, l'incertitude du marché se précise et le fabricant met à jour ses prévisions en utilisant cette valeur (ϵ). Il commande alors à son fournisseur le volume $D-y$, à un prix plus élevé (w). Bien que l'optimisation fondée sur des signaux puisse accroître les profits du fabricant et du fournisseur, elle demeure cependant sujette aux erreurs commises dans la valeur attribuée aux variables ξ et ϵ .

Le Jeu de Signaux permet de penser qu'un bon moyen de réduire les incertitudes serait de mieux préciser la valeur des variables ξ et ϵ . On dispose déjà d'un large éventail d'outils de recherche et d'optimisation pour s'attaquer à ces valeurs ou à la façon d'obtenir des valeurs

sûres. Cependant, la persistance d'amples variations dans les chaînes logistiques montre que les outils existants pour lutter contre l'incertitude ne sont pas forcément adaptés. C'est, en partie, l'une des raisons pour lesquelles **nous proposons l'emploi de données temps-réel pour réduire les erreurs, notamment pour les valeurs des variables ξ et ε .**

Odd-var-garch : Un outil analytique pour mieux utiliser les données temps-réel.

Les outils actuels de prévision peuvent être obérés par :

- des données de piètre qualité,
- des données agrégées,
- une visibilité réduite pour les décideurs,
- des modèles de flux de données médiocres,
- une architecture informatique incomplète.

La précision d'une prévision tient en partie à l'adaptation des modèles mathématiques aux processus des entreprises. Pour autant, même avec de meilleurs outils statistiques, le décrochage entre fonctionnement et stocks sera cause d'inadéquation. Seule la **convergence des données, des processus et des décisions permettra** d'obtenir une réelle visibilité.

Nous avons à notre portée une excellente occasion d'étudier les outils statistiques avec des flots à ultra haut-débit de multi-gigabits de données précises.

Un modèle proposé est le **Odd-var-garch³** (Données Liées à l'Objet – AutoRégression Vectorielle – Hétéroscédasticité AutoRégressive Conditionnelle Généralisée). Ce n'est que maintenant qu'arrive à maturité ce secteur de recherche qui vise à combiner des modèles séparés dans le but d'envisager la possibilité d'étudier les séries de temps dans les systèmes de supply chain.

Les modèles de séries de temps peuvent établir un rapport entre les valeurs « actuelles » d'une variable critique et ses valeurs passées (précédentes), et les **valeurs** des perturbations actuelles ou passées ou des termes d'erreur aléatoires. En ce qui nous concerne, pour étudier cette modélisation, examinons les prévisions de demande du marché D :

$$D = \mu + \xi + \varepsilon$$

sachant que :

En 1959, GE confia à la firme de consultants Arthur D. Little Inc. de Boston une étude pour déterminer s'il y avait ou non un marché pour des téléviseurs portables que GE était maintenant en mesure de construire en utilisant des transistors solides. Au bout de plusieurs mois, toujours en 1959, et après avoir dépensé des sommes vertigineuses (des millions de dollars) en groupes d'études ad hoc et en discussions, Arthur D. Little Inc. transmitt ses conclusions à GE : il n'y avait pas de marché pour de tels téléviseurs. La direction de GE écarta donc ce projet proposé par ses ingénieurs... Juste avant Noël 1959, Sony introduisait sur le marché américain un petit téléviseur B&W et en vendit plus de 4 millions en quelques mois [3].

« A l'opposé, des centaines de nouveaux MBAs intègrent chaque année des groupes aussi prestigieux que McKinsey et Cie, et presque autant en partent. Mais la firme réussit, année après année, à obtenir des résultats remarquables parce que ses compétences intrinsèques sont enracinées dans ses méthodes et ses valeurs plutôt que dans ses ressources (vision). J'estime cependant que cette force de McKinsey est en même temps sa faiblesse. Les processus rigoureusement analytiques et basés sur des données qui l'aident à dégager des profits pour ses clients sur les marchés actuels, relativement stables, le rendent beaucoup moins compétent sur les marchés des technologies [22]. »

μ = Prévision des marchés,
 ξ = Information des fabricants, et
 ε = Incertitude des marchés.

Pour déterminer μ , on peut exprimer le Modèle de Régression Linéaire Classique (CLRM) couramment utilisé comme une équation linéaire :

$$Y_t = \beta_0 + \beta_1 X_t + \varepsilon_t \quad (0)$$

dans laquelle :

Y = variable dépendante utile pour être modélisée à fins de prévision,
t = période de temps,
 β = coefficients à évaluer,
X = variable explicative, et
 ε = terme d'erreur aléatoire (stochastique).

Cette technique simple peut modéliser de multiples variables explicatives puisque la variation en Y dépend de paramètres multiples. Cependant, le CLRM **suppose** que ε est caractérisé par une **distribution normale** avec une moyenne = 0 et une variance = σ^2 pour toutes les périodes de temps (t) :

$$\varepsilon_t \sim N(0, \sigma^2)$$

Le but du CLRM est d'évaluer les paramètres (β_0, β_1) du modèle en fonction de l'échantillon des observations faites sur Y et X. Ce procédé statistique introduit deux sources d'erreur. En effet :

- 1/ prendre des données *échantillon* à partir d'observations entraîne nécessairement des erreurs d'échantillonnage, et

³ - Object Data Dependent – Vector AutoRegression – Generalized AutoRegressive Conditional

2/ étant données les multiples combinaisons de (β_0, β_1) que l'on peut évaluer, le but du CLRM est de choisir le couple (β_0, β_1) qui minimise la somme des restes au carré :

$$\sum_{t=1}^n e_t^2$$

dans laquelle : e_t est le terme d'erreur aléatoire pour les données « échantillon », ε_t est le terme d'erreur aléatoire des données « population », prise comme un tout.

Cette technique (le principe des moindres carrés ordinaires - OLS⁴) minimise les erreurs de prévision en sélectionnant la paire (β_0, β_1) la plus pertinente.

Le CLRM combiné aux données temps réel (RFID) représente une avancée. Cette (combinaison) idée est tirée des modèles arch et garch. **Odd-var-garch** a besoin de grands volumes de données et donne des prévisions avec une bien plus grande précision que ne le pourrait n'importe lequel des composants particuliers pris séparément.

Odd-var-garch requiert des progressions de type séquentiel pour combiner le CLRM avec les techniques de séries de temps. Une équation CLRM élémentaire est (1) :

$$Y_t = \beta_0 + \beta_1 X_{1t} + \beta_2 X_{2t} + \dots + \beta_k X_{kt} + \varepsilon_t$$

Et, parce que la **dépendance du processus** est capitale pour la réussite, la fourniture de données d'identification automatique temps réel à de vieux modèles de processus ne peut produire que des avantages mineurs.

Une tâche pour l'innovation du processus est d'étudier comment les « X » changent avec le temps réel. Dans la prochaine étape du développement de Odd-var-garch, les valeurs des « X » sont prévues, d'après les données historiques, pour obtenir une **prévision incondi-**
tionnelle de « Y ». Un modèle uni-variant est adapté à « X », dans lequel on utilise les valeurs passées (précédentes) de « X » pour prévoir « X ».

$$\begin{aligned} X_{1t} &= \alpha_{01} + \alpha_{11} X_{1t-1} + \alpha_{12} X_{1t-2} + \dots \\ &\quad + \alpha_{1N_{X1t}} X_{1t-N_{X1t}} + u_{X_{1t}} \dots \\ \dots X_{kt} &= \alpha_{0k} + \alpha_{1k} X_{kt-1} + \alpha_{12} X_{kt-2} + \dots \\ &\quad + \alpha_{1N_{Xkt}} X_{kt-N_{Xkt}} + u_{X_{kt}} \dots \end{aligned} \quad (2)$$

4 - OLS = Ordinary Least Squares.

5 - Automatic Identification Technology

6 - Stock Keeping Unit = unité de stockage

(3) :

$$Y_t = \beta_0 + \sum_{i=1}^{N_{X1}} \alpha_{1i} X_{1t-i} + \dots + \sum_{i=1}^{N_{Xkt}} \alpha_{ki} X_{kt-i} + \varepsilon_t$$

$$Y_t = \beta_0 + \sum_{K=1}^K \sum_{i=1}^{N_{Xkt}} \alpha_{ki} X_{kt-i} + \varepsilon_t \quad (4)$$

sachant que :

X_{1t} = variable X_1 au temps t ,

X_{kt} = variable X_k au temps t ,

X_{1t-1} = valeur de X_1 au temps $t-1$ (valeur précédente),

N = période jusqu'à laquelle les valeurs précédentes de X_{1t} peuvent être utilisées dans l'équation, et

U = terme d'erreur aléatoire.

Dans l'équation 2, α_{11} et α_{12} sont coefficients de X_{1t-1} et X_{1t-2} et sont appelés coefficients de pondération décalés. Suivant le nombre de « X » dans l'équation 1, on aura un nombre K d'équations qu'il faudra évaluer pour prévoir les « X » (X_1, \dots, X_K) qui seront alors utilisés pour obtenir une prévision incondi-
tionnelle de « Y ». Ainsi, nous pouvons évaluer tous les paramètres (α, β) simultanément en re-écrivant l'équation CLRM élémentaire (équation 3 ou 4). L'équation 5, qui prend en compte l'impact sur Y des valeurs passées de Y lui-même, est de préférence (5) :

$$Y_t = \beta_0 + \sum_{j=1}^{N_Y} \varphi_j U_{t-j} + \sum_{k=1}^K \sum_{i=1}^{N_{Xkt}} \alpha_{ki} X_{kt-i} + \varepsilon_t$$

sachant que $N \sim$ nombre de valeurs précédentes pour chacun des « X » dans le modèle.

En passant aux prévisions incondi-
tionnelles de « Y », on accroît énormément le nombre de paramètres à évaluer, ce qui nécessite un important **volume** de données précises (AIT⁵).

Il se peut que les entreprises plus petites se plaignent qu'il leur est impossible d'évaluer 6000 paramètres ou plus pour chaque sku⁶. Pourtant, cela deviendra faisable en recueillant, via le grid, la puissance de traitement non utilisée dans de nombreux domaines.

On peut élargir l'équation 5 de manière à englober le principe d'application de la co-intégration dans les systèmes décisionnels. La plupart des planificateurs pratiquent l'analyse de régression en la **supposant** fixe, produisant ainsi « des régressions fausses ». L'idée de variables multi-co-intégrées a été développée par l'introduction du concept de degré d'intégration d'une variable. Si une

variable peut être rendue plus ou moins fixe en la différenciant d fois, on dit qu'elle est intégrée de l'ordre d , ou $\sim I(d)$. Des variables aléatoires faiblement fixes sont par conséquent $I(0)$. Beaucoup de variables (macro-économiques) peuvent être considérées comme des variables $I(1)$. Si $Z_t \sim I(1)$, alors $\Delta Z_t \sim I(0)$.

Considérant le CLRM : $Y_t = \beta_0 + \beta_1 X_t + \varepsilon_t$

supposons que $Y_t \sim I(1)$ et en même temps $X_t \sim I(1)$. Alors, puisque les variables $I(1)$ dominent les variables $I(0)$ dans une combinaison linéaire, généralement $Y_t - \beta_1 X_t \sim I(1)$. Cependant, si le terme d'erreur aléatoire $\varepsilon_t \sim I(0)$, alors $Y_t - \beta_1 X_t \sim I(0)$. Dans une combinaison où le coefficient β_1 est unique, les variables Y_t et X_t sont dites *co-intégrées*. La somme cumulative des écarts de la relation co-intégrante $Y_t - \beta_1 X_t = 0$ est alors nécessairement une variable $I(1)$. Si cette nouvelle variable W_t est co-intégrée avec les variables co-intégrées d'origine (Y_t ou X_t), alors on dit que Y_t et X_t sont *multi-co-intégrés*.

Les insuffisances du CLRM découlent du fait que la valeur attendue du terme d'erreur prévu, $\hat{\varepsilon}_t$, lorsqu'elle est mise au carré, est supposée être la même en tout point, en tout temps et quelle que soit l'observation (données transversales).

Il y a souvent une présomption d'*homoscédasticité* quant aux données transversales. Quand cette supposition n'est pas respectée, on parle alors d'*hétéroscédasticité*.

Le CLRM ignore le comportement hétéroscédastique du terme d'erreur ε_t et il produit des prévisions qui peuvent donner un faux sentiment de précision parce que la volatilité de la prévision est liée à la volatilité du terme d'erreur ε_t . Pour modéliser cette variance non-constante (hétéroscédasticité), on utilisait la technique du Déplacement Moyen AutoRégressif (AR-MA).

AR est une technique qui permet de ramener une variable à ses propres valeurs précédentes : Y_t à $Y_{t-1}, Y_{t-2}, \dots, Y_{t-p}$

MA exprime les observations présentes d'une variable en fonction des valeurs actuelles et précédentes du terme d'erreur aléatoire $\varepsilon_t, \varepsilon_{t-1}, \dots, \varepsilon_{t-q}$, q étant l'ordre du processus moyen de déplacement MA (q). En combinant AR (p) et MA (q), on obtient ARMA (p, q), p et q représentant l'ordre précédent de AR et MA.

On utilisait cette technique ARMA pour modéliser la volatilité variant dans le temps, ce qui a conduit au modèle d'Hétéroscédasticité Conditionnelle Auto-Régressive appelé ARCH. ARCH nous permet de prévoir la volatilité du terme d'erreur aléatoire ; il nous offre ainsi une mesure de Valeur à Risque. La variance du terme d'erreur aléatoire (ε_t) dans l'équation 5 peut être développée en fonction des valeurs actuelles et précédentes ($\varepsilon_t, \varepsilon_{t-1}, \varepsilon_{t-2}, \dots, \varepsilon_{t-q}$) comme suit :

$$\sigma_t^2 = \theta_0 + \theta_1 \varepsilon_{t-1}^2 + \theta_2 \varepsilon_{t-2}^2 + \dots + \theta_q \varepsilon_{t-q}^2$$

dans laquelle σ_t^2 est la variante de ε_t [$\text{var}(\varepsilon_t)$].

Cette représentation MA (q) de σ_t^2 fut plus tard étendue à une représentation ARMA de σ_t^2 bande 1, que l'on appelle modèle « Hétéroscédasticité Conditionnelle Auto-Régressive Généralisée » ou GARCH. GARCH évolua par régression d'une variable (σ_t^2) sur ses propres valeurs précédentes (passées) $\sigma_{t-1}^2, \sigma_{t-2}^2, \dots, \sigma_{t-p}^2$.

$$Y_t = \beta_0 + \sum_{j=1}^{N_y} \varphi_j Y_{t-j} + \sum_{k=1}^k \sum_{i=1}^{N_{XKT}} \alpha_{ki} X_{kt-i} + \varepsilon_t$$

$$\sigma_t^2 = \theta_0 + \theta_1 \varepsilon_{t-1}^2 + \theta_2 \varepsilon_{t-2}^2 + \dots + \theta_q \varepsilon_{t-q}^2$$

La variance du terme d'erreur aléatoire dépend non seulement des valeurs précédentes de ε ($t-1, t-2, \dots, t-q$) mais aussi des valeurs précédentes de la variance $\sigma^2(t-1, t-2, \dots, t-p)$.

$$Y_t = \beta_0 + \sum_{j=1}^{N_y} \varphi_j Y_{t-j} + \sum_{k=1}^k \sum_{i=1}^{N_{XKT}} \alpha_{ki} X_{kt-i} + \varepsilon_t$$

$$\sigma_t^2 = \theta_0 + \sum_{i=1}^q \theta_i \varepsilon_{t-i}^2 + \sum_{j=1}^p \tau_j \sigma_{t-j}^2 \quad (6)$$

GARCH et Prévision.

La technique odd-var-garch saisit aussi la dynamique entre entités dans le réseau de valeur. La dynamique transversale réelle captée par les modèles VAR relie chaque variable aux valeurs passées de toutes les autres variables dans le modèle.

Pour modéliser une dynamique multi-variante de $n = 2$ en utilisant VAR(p), supposons que $p = 1$ (décalé de 1 période). L'équation 6 peut être étendue au type odd-var-garch pour modéliser deux entités et considérer seulement une période de décalage ($n=2, p=1$) comme figuré dans l'équation 7.

$$Y_{1t} = \beta_0 + \sum_{K=1}^K \sum_{i=1}^{N_{XKT}} \alpha_{ki} X_{kt-i} + \varphi_{11} Y_{1t-1} + \varphi_{12} Y_{2t-1} + \varepsilon_{1t}$$

$$Y_{2t} = \beta_0 + \sum_{k=1}^K \sum_{i=1}^{N_{K,T}} \alpha_{ki} X_{kt-i} + \varphi_{21} Y_{1t-1} + \varphi_{22} Y_{2t-1} + \varepsilon_{2t}$$

$$\sigma_{1t}^2 = \theta_0 + \sum_{i=1}^q \theta_i \varepsilon_{1t-i}^2 + \sum_{j=1}^p \tau_j \varepsilon_{1t-j}^2$$

$$\sigma_{2t}^2 = \theta_0 + \sum_{i=1}^q \theta_i \varepsilon_{2t-i}^2 + \sum_{j=1}^p \tau_j \varepsilon_{2t-j}^2$$

Dans le modèle var-garch, les interactions entre domaines de décision sont prises en compte en évaluant le coefficient φ_{ij} qui se rapporte aux changements en Y_i compte-tenu de Y_j .

L'impact du changement dans le terme d'erreur sur la variable fiable est appelé Fonction de Réponse d'Impulsion.

Appliqué à un grand volume de données précises fournies par l'AIT grâce au grid computing (sémantique), Odd-var-garch pourrait très bien devenir un outil pour des organisations recherchant une grande précision dans les prévisions de demande et dans les prédictions de chiffres en combinant les modèles basés sur équation (EBM) et les modèles basés sur agents (ABM).

Le GRID

Le modèle de simulation peut être optimisé par l'analyse basée sur données, qui en améliore ainsi la précision. De plus, les modèles basés sur équation (EBM) peuvent imposer d'évaluer des milliers de paramètres comme des objets uniques. En conséquence, l'avenir des analyses de données d'affaires peut avoir des besoins informatiques radicalement différents.

L'analytique de la supply chain exige des applications créatives, un partage des ressources à grande échelle et une informatisation à haut-débit qui puisse fonctionner dans un environnement dual EBM et ABM. Le Grid computing⁷ annonce un monde dans lequel les ressources partagées seront intégrées dans des « organisations virtuelles » (vo) réalisées via des portails Web (sémantiques) et des applications très largement distribuées.

Le Grid computing a fait un pas de plus vers le monde commercial lorsque le Projet Globus a sorti de nouveaux outils logiciels qui fusionnent grid et Web services, lesquels reviennent alors sous l'appellation : **Web Services Grid sémantique**.

Le grid en tant qu'instrument de **partage de ressources** est confronté à des défis d'accès exceptionnels. En général, les échanges B2B sont inhibés par des préoccupations de sécurité. Pourtant, il existe bien des protocoles, des services, des inter-faces de programmation (API – Application-Programming Interfaces) et des kits de développement de logiciels (SDK - Software Development Kits) qui garantissent la **sécurité** du **partage de ressources**. On étudie même l'emploi d'Agents comme gardes de sécurité.

Les Organisations Virtuelles peuvent varier dans leur but, leur étendue, leur taille, leur durée, leur structure et leur sociologie. Pourtant, elles ont toutes le même besoin de :

- [1] Relations de partage souples,
- [2] partage de ressources variées, et
- [3] Modes d'utilisation variés.

Les technologies de calcul⁸ distribué ne peuvent actuellement accepter que des accès hautement centralisés et donc limités – trop rigides pour les VO dynamiques. C'est donc là que les technologies grid peuvent apporter de la valeur ajoutée, dont des :

- [1] Solutions de Sécurité,
- [2] Protocoles de gestion des ressources,
- [3] Protocoles et services de recherche d'information, et
- [4] Services de gestion des données.

La concentration des technologies grid sur le partage transversal plutôt que sur la connectivité intra-organisationnelle **complète** plutôt qu'elle ne concurrence les technologies de calcul distribué existantes.

L'architecture grid doit indiquer comment les composants fondamentaux du système interagissent les uns avec les autres. L'interopérabilité dans un environnement en réseau découle de protocoles communs. De là, l'architecture grid est d'abord et avant tout une architecture de protocole. Et il était nécessaire que l'architecture constituant les services **Grid middleware** acceptât un ensemble commun d'applications dans un environnement de réseau distribué.

Les mécanismes doivent faciliter les relations de partage qui peuvent être mises en place entre des **parties arbitraires**, à travers différents environnements de programmation. Parce que les VO sont le complément des institutions existantes, les mécanismes de partage grid ne peuvent pas imposer de changements substantiels aux règlements locaux et doivent permettre aux institutions

7 - Technologie de mutualisation des ressources en réseau. N.d.T

8 - ou Computing distribué.

individuelles de garder le contrôle ultime sur leurs propres ressources.

La Figure 11 illustre les différentes couches de l'architecture grid établie sur un modèle « de sablier » dont « l'étranglement » définit un petit ensemble d'abstractions et de protocoles centraux sur lesquels de nombreux comportements différents de haut niveau (en haut) et de nombreuses technologies sous-jacentes (en bas) peuvent être mis en correspondance.

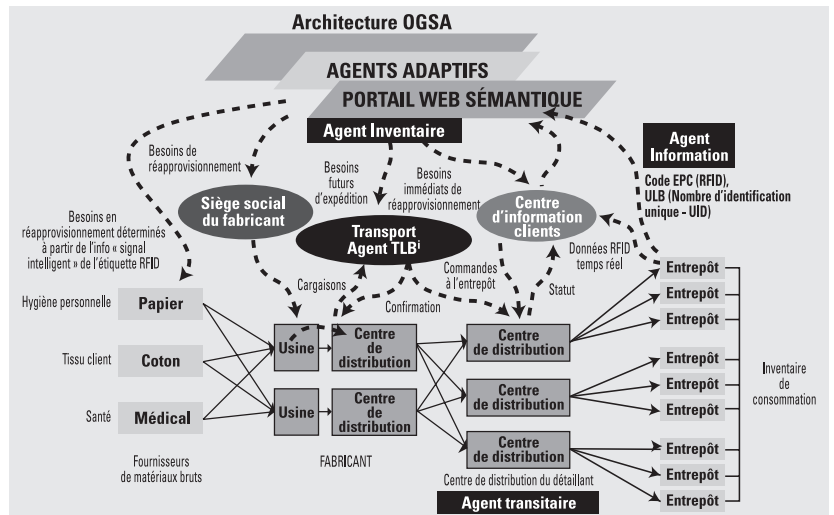
- Le « grid Fabric » est l'interface pour le contrôle « local ».
- La couche « Interface Fabric » fournit les ressources pour lesquelles l'accès partagé est géré par les protocoles grid.
- La couche « Connectivité » définit les protocoles centraux de communication et d'authentification requis pour les transactions de réseau spécifique grid.
- La couche « Ressource » s'ajoute à la couche Connectivité pour définir les protocoles régissant la gestion de la sécurité, le contrôle, la comptabilité et le *paiement des opérations de partage* faites sur les ressources individuelles.
- La couche « Collection » est donc globale par nature et peut mettre en œuvre une grande variété de comportements de partage sans imposer de nouvelles exigences sur les ressources.
- La couche finale du grid englobe les Applications « utilisateur » qui fonctionnent au sein d'une VO. Ces applications sont élaborées par échange de messages de protocoles avec le service ad hoc de manière à réaliser les actions souhaitées.

Prise dans sa globalité, cette architecture ouverte offre une multitude de combinaisons souples. Mais le grid computing concerne le partage contrôlé. Et actuellement, il y a un débat pour savoir si oui ou non le logiciel grid devrait définir les services du système de fonctionnement (OS – operating system) à installer sur *chaque* système participant.

Une grande partie de ce qui doit être réalisé par l'architecture grid ouverte est appelée « *grid middleware* ». On attend un grid computing haute performance pour qu'il soit possible d'effectuer des simulations à partir de plusieurs organisations différentes, ce qui permettrait d'entreprendre une simulation de l'ensemble du système.

La technologie et l'architecture constituent les « *Grid Middleware services* » nécessaires au soutien d'un ensemble complet d'applications dans un environnement de réseau distri-

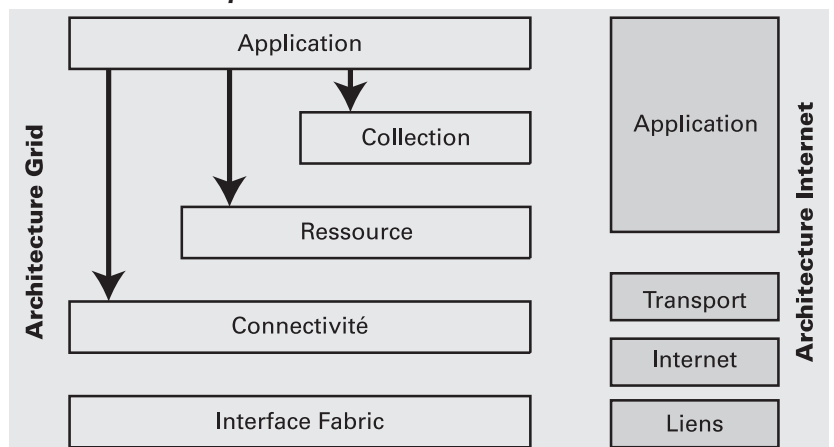
Figure 10 : Réseau de valeur auto-adaptif ?



bué tel qu'une « supply chain » ou un réseau de valeur.

Pourquoi l'interopérabilité est-elle une préoccupation fondamentale ? Imaginez les conséquences pour votre supply chain si vous deviez abandonner un fournisseur aux normes RosettaNet et vous approvisionner chez un fabricant de Shinzen (en Chine) qui n'a jamais entendu parler de RosettaNet ni de sa norme PIP's ! Le Grid doit faciliter les relations de partage qui peuvent être mises en place entre des *parties arbitraires* de manière à intégrer de nouveaux participants de façon dynamique et rapide, au-delà des différences de plate-formes, de langages, de localisations géographiques et d'environnements de programmation. Les mécanismes ne servent pas à grand chose s'ils ne sont pas définis et développés pour être interopérables quelles que soient les frontières organisationnelles, les politiques opérationnelles et les types de ressources.

Figure 11 : L'architecture Grid en relation avec l'architecture Internet. Parce que l'architecture Internet va du réseau à l'application, il y a une mise en correspondance du Grid avec les couches Internet.



En conséquence, les protocoles sont également cruciaux pour l'interopérabilité. Le Web a révolutionné le partage de l'information en fournissant une syntaxe (http, html) et un protocole universels pour les échanges d'information. De son côté, le Grid exige des protocoles et syntaxes standards pour le partage de ressources générales. Les protocoles Grid, par définition, préciseront à la fois la façon dont les éléments du système distribué interagissent les uns avec les autres (pour parvenir à un fonctionnement déterminé), et la structure de l'information échangée pendant cette interaction. Dans les versions futures, les ontologies pourraient jouer un rôle de plus en plus important dans la « compréhension » de l'information échangée via l'utilisation du langage sémantique (Web Ontology Language - WOL). L'accent mis sur les interactions externes plutôt qu'internes (software, caractéristiques des ressources) a des avantages pratiques importants pour le SCM, système dans lequel la fédération un peu distendue des partenaires tend à être floue.

De là, les mécanismes utilisés pour découvrir les ressources, établir l'identité, déterminer l'autorisation et lancer le partage doivent être suffisamment souples pour être établis et changés rapidement. Du fait que les organisations virtuelles (VO), type réseau de valeur, complètent plutôt qu'elles ne remplacent les institutions existantes, le partage de mécanismes ne peut pas imposer de changements substantiels aux politiques locales et il doit permettre à chaque établissement de garder le contrôle ultime sur ses propres ressources. Et comme les protocoles régissent l'interaction entre composants (mais pas leur mise en œuvre), le contrôle local est bien préservé. Le partenaire commercial de Shinzen, en conséquence, peut ne pas avoir à transformer son système b2b ou s'abonner à RosettaNet pour s'engager avec vous dans une relation d'affaires en tant que nouveau membre de la chaîne de valeur.

Pour que les outils de découverte soient utiles, les Web services exigeront une grille ontologique et l'intégration avec le grid, de manière à évoluer en services du grid Sémantique. Enfin, pour parvenir à une fonctionnalité complexe, il pourrait être nécessaire d'avoir une convergence des ABM à l'intérieur des services du grid sémantique.

Agents

Nous allons étudier ce que sont les Agents et quelle est leur importance dans les systèmes

décisionnels. Le concept d'Agents a germé au sein du MIT et s'est développé à partir de l'étude du fonctionnement de l'esprit humain et de l'intelligence [38]. Les origines des Agents sont donc inspirées de la biologie et inscrites dans le mouvement de l'Intelligence Artificielle (AI), mouvement qui s'imposa autour des années 1950. Quelques uns des tout premiers concepts d'Agents servirent à créer des « difference engines », l'unité logique peut-être la plus ancienne du réseau neuronal d'aujourd'hui (software). L'aspect « intelligence » des Agents est un paradoxe conceptuel. Par lui-même un Agent n'est pas intelligent ; en revanche, les « Agences » le sont. On insuffle aux Agents, qui fonctionnent collectivement comme un « essaim », une dynamique supérieure et des capacités adaptives basées sur l'apprentissage, ce dont les algorithmes statiques basés sur équation manquent.

Leur autonomie permet aux Agents d'exécuter des opérations en réponse à des changements sans qu'il y ait besoin d'une intervention humaine permanente. De plus, les Agents qui partagent un même environnement avec d'autres Agents (Agences) dans un Système Multi-Agents⁹ sont capables de mobilité entre les différents environnements.

Un logiciel ebm est incapable de s'adapter aux événements non-linéaires en intégrant de multiples sources d'information. Les Agences « Intelligentes » pourraient donc devenir un outil essentiel pour servir d'interface avec des sources multiples de données de manière à en extraire une information en temps réel.

Les Agents utiles doivent être alignés sur ces concepts :

- correspondre à des « choses » dans le domaine en question plutôt qu'à des fonctions abstraites,
- être petit en masse, en temps (capable d'oublier) et en étendue,
- respecter une grande diversité,
- inclure un mécanisme dispersif,
- avoir des moyens de saisir et de partager ce qu'ils apprennent sur leur environnement,
- planifier et exécuter de manière concurrente plutôt que séquentielle, et
- les Systèmes Multi-Agents (MAS) devraient être décentralisés.

Agents vs Equations

L'unité élémentaire des modèles basés sur équation (EBM) relie des données observa-

9 - MAS = Multi-Agent System.

bles dont les valeurs sont affectées par les actions d'individus multiples, alors que le fonctionnement d'un Agent n'influe pas directement sur la représentation de ces comportements individuels ; ce qui maintient donc des frontières entre individus. Cette différence donne aux modèles basés sur Agent (ABM) un avantage en terme de sécurité des applications commerciales :

- Dans un ABM, chaque entreprise a son propre groupe d'Agents. Il n'est pas nécessaire que les comportements internes de l'Agent soient visibles au reste du système. De cette façon, les firmes peuvent conserver l'information relative à leur fonctionnement interne.
- Une supply chain multi-sections complexe peut être découplée au niveau de l'Agent, permettant une modification des Agents individuels pour refléter une optimisation locale. Puisque ces agents font partie d'une Agence supérieure, la chaîne logistique complexe reflètera alors une optimisation globale – la migration d'un modèle de simulation vers un modèle de contrôle adaptatif est simple et directe.

Les Agents sont aussi pourvus d'un mécanisme *d'oubli*. Les outils de prévision types basés sur ebm utilisent comme alternative une moyenne pondérée des données historiques.

Les ebm ignorent aussi le fait que la planification et l'exécution ne sont pas concurrentes. Les Agents, qui cherchent à éviter le mode de fonctionnement « *planification puis exécution* », évaluent de manière probabiliste l'impact du travail sur son utilisation en fonction du temps, d'après l'information en provenance du client sur des durées acceptables.

On demande aussi que les systèmes puissent calculer plusieurs paramètres et les pondérer. En conséquence, les Agents présents dans l'architecture du système doivent être en lien logique avec les différents systèmes distribués.

Le Système Multi-Agents (MAS) nous offre la possibilité de répondre avec la finesse qui requiert de nombreuses connexions à la mémoire en succession rapide.

Agents en maintenance

Même quand une opération n'a que peu de variables critiques de mission, l'emploi d'Agents est crucial. Par exemple, telles opérations de maintenance sur un aéronef donné révèlent que l'incapacité à réparer les appa-

reils ou les moteurs était due à un manque de pièces de rechange. La modélisation basée sur Agent des processus de maintenance permettrait d'intégrer la demande en provenance des multiples postes, en anticipant sur les défaillances de pièces par la gestion des métriques comme le MTBF (Mean Time Between Failure - Temps moyen écoulé entre deux pannes).

Agents dans la Fabrication

L'industrie aéronautique commerciale fabrique peu de produits et vend à un ensemble de clients différents de celui du commerce de détail. Quelques pièces (modulaires) et composants servent à plusieurs modèles différents (variantes). Ce secteur, comme celui de l'industrie automobile, tire un bénéfice significatif de la vente subséquente de pièces de rechange et de services. En conséquence, les compagnies ont accès à une masse importante de données d'utilisation.

Prenons un exemple : la panne un peu trop rapide de deux pompes hydrauliques aux deux bouts du monde incite un Agent à étudier cette récurrence. Elles venaient toutes deux du même lot de fabrication. L'Agent pousse alors les techniciens de la maintenance à réaliser une analyse de vibration particulière, qui met en évidence un défaut dans l'ensemble du lot. Si l'Agent avait disposé, dans ce réseau de valeur, des données d'analyses de vibration faites par le fabricant, il aurait décelé cette tendance avant même qu'une seule pompe ne tombe en panne. Une analyse comparative implique l'accès à un traitement de données massives en un temps raisonnable. Les Agents pourraient accomplir de telles tâches rapidement et prédire, donc prévenir, une catastrophe potentielle.

Or, les réseaux de valeur avec points d'accès intégrés aux données distribuées via le Grid peuvent rendre disponible l'information nécessaire pour qu'un Agent puisse déceler une prédisposition à partir des données fabricant, lot, date d'installation et heures d'utilisation.

Dans un autre scénario, prenons un système Agent qui opère dans le domaine exclusif de l'analyse des retours. Cet Agent remarque que le taux de retour des produits d'un fabricant a dépassé un certain niveau ces dernières semaines. Pourquoi ? Ce produit a une valeur relativement élevée, il pèse plus de 08 kilos et la plupart ont été envoyés à 800 kilomètres ou plus. L'alerte lancée par l'Agent arrive au

manager qui inspecte par hasard un conditionnement. Bingo ! Ce packaging est différent de celui des produits qui ont un taux de retour moins élevé. Un coup de téléphone confirme que le fabricant a changé tout dernièrement de fournisseur d'emballage.

Figure 12 : La supply chain de l'industrie aéronautique commerciale : collecte de l'information.

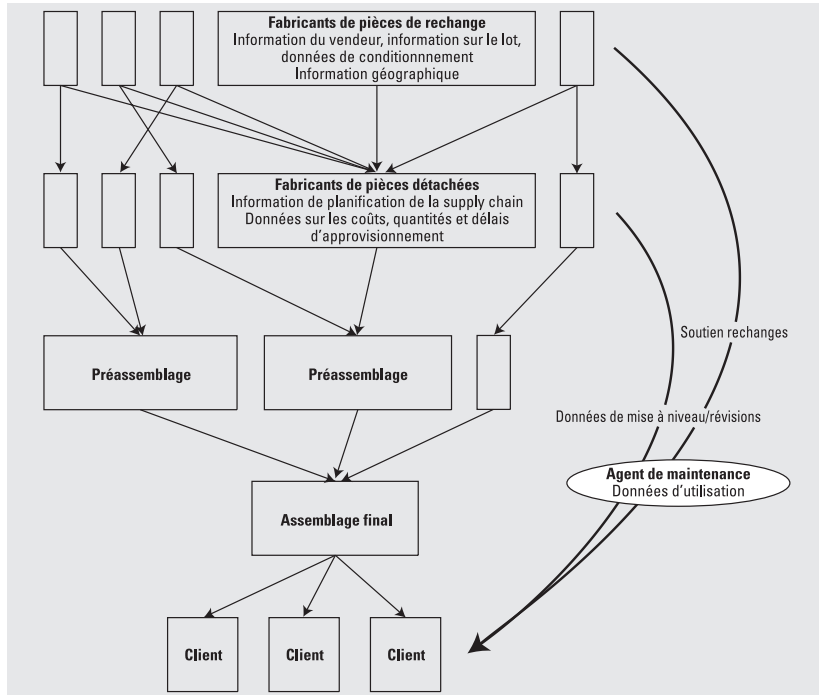
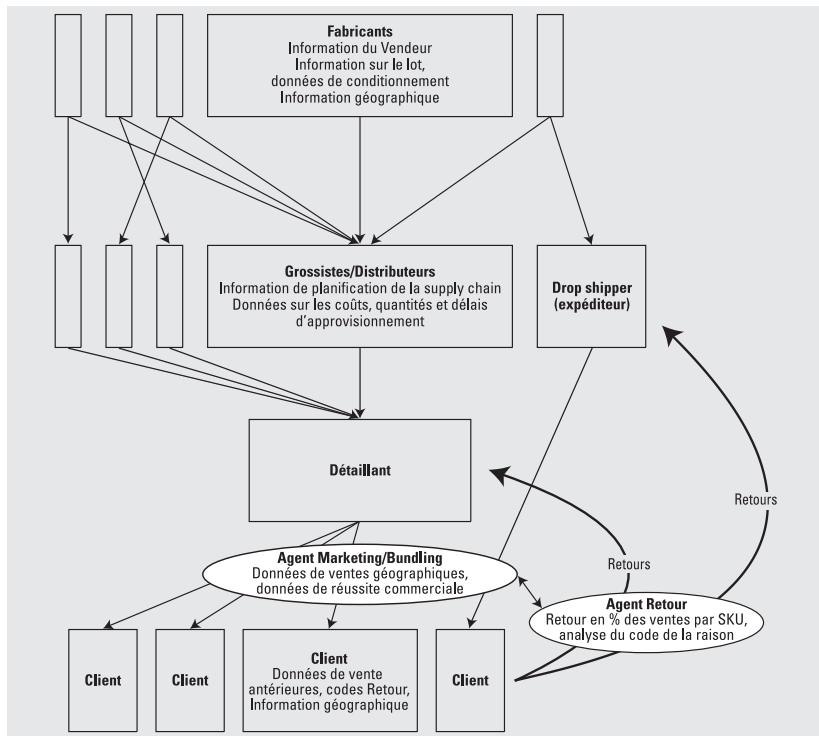


Figure 13 : Les Agents dans le commerce de détail



(ce schéma montre où l'on peut intégrer les Agents « retours » et « bundling »).

Les Agents peuvent aussi être utiles dans le domaine de la vente. Ainsi, Dell permet à ses clients de configurer eux-mêmes leurs ordinateurs. L'allotissement (ou bundling) est une technique de marketing ; on associe deux produits que l'on vend à un prix unique inférieur au montant normal de la vente séparée des deux produits. Ce système procure des recettes et bénéfices plus importants que si chaque élément était vendu séparément. Dell emmagasine des exaoctets d'information sur les habitudes d'achat des clients. Un Agent « analytique » est capable de repérer une tendance du type : 40% des clients qui achètent un supplément de mémoire prennent aussi un processeur grande vitesse. Un Agent « marketing » peut « parler » à l'Agent « prix » pour offrir des ristournes si la mémoire est achetée avec le processeur. Comme la tendance des choix pour les combinaisons (mémoire contre vitesse de processeur) évolue en fonction du profil démographique ou géographique, les données fournies par les Agents analytiques peuvent être utilisées par les agents « marketing » et « prix » pour offrir de nouvelles options de bundling (fixation dynamique du prix). Ce qui peut augmenter la demande pour la mémoire et accroître recettes et bénéfices. Il est possible aussi de cibler les clients potentiels pour commercialiser l'option de discount groupée.

En proposant trois options ou plus, sans parler des accessoires type appareils photos, MP3 ou imprimantes, le nombre de combinaisons possibles de produits augmente. Pour les Agents, analyser des montagnes de données, déceler les possibilités (multiples) de bundling et s'adapter aux fluctuations de la demande quasiment en temps réel est très simple. Ils le font beaucoup plus vite (des milliards de fois plus vite) que ne pourrait le faire un être humain ou un logiciel basé sur équations. La technique du bundling permet d'améliorer les ventes d'un stock de produits peu demandé ou en fin de vie (EOL- End-of-Life) avant d'introduire de nouvelles versions ou de nouveaux produits.

Technologies d'identification automatique (AIT).

Les AIT offrent aux outils le pouvoir d'acquérir des données sur l'objet. Les Codes Produits Electroniques (EPC) introduisent la standardisation d'un format pour données minimales sur les étiquettes RFID (étiquettes ULB) qui servent de référencement à des objets physi-

ques, dont l'avalanche des données pourrait être stockée sur Internet.

RFID : les questions de protection de la confidentialité.

Les avocats de la protection de la confidentialité sont anti-RFID parce qu'ils ne comprennent pas que le RFID, en tant que technologie, ne peut pas envahir la vie privée. Que les données consommateur soient liées ou non aux données inventaire est seulement une **décision de processus**.

ULB

Plusieurs scénarii semblent indiquer que les bénéfices tirés de l'utilisation d'étiquettes ULB dépasseraient le coût d'utilisation d'étiquettes RFID passives à faible coût. Le métal ou le béton n'arrêtent pas l'ULB, et ce système est sûr. La capacité spatiale de l'ULB est 1000 fois supérieure à celle de l'UHF. Elle offre d'appréciables taux de débit qui fonctionnent malgré des interférences multi-voies. Dépourvue de restrictions de spectre pays, l'ULB peut devenir une norme mondiale pour des communications courte portée.

Les réseaux de capteurs

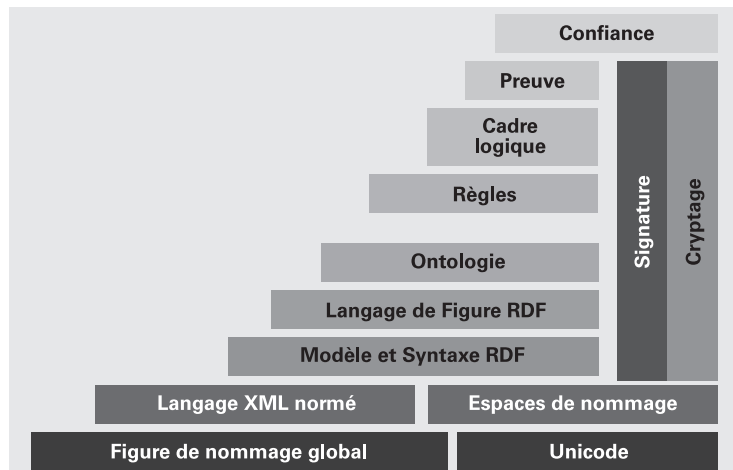
Les réseaux de capteurs sans fil sont un bon exemple de grille informatique diffuse. Ils sont autonomes et forment des réseaux sans fil qui se chargent de données à travers des nœuds spécifiques qui peuvent être connectés aux stocks de données. Du fait de certains pouvoirs analytiques, le réseau de capteurs transmet des analyses de données plutôt que des données brutes de manière à fournir des réponses.

Le web sémantique

Le Web sémantique est un recueil de données en langage rdf (Cadre de Description de Ressources) qui décrit la signification des données à travers les liens aux ontologies¹⁰, qui agissent comme des glossaires décentralisés. Le Web sémantique peut offrir la transparence du processus au-delà des frontières du langage et de la géographie, même si les partenaires individuels accomplissent certaines fonctions d'une manière différente des autres.

Les agents seront capables de collecter le contenu du Web à partir de différentes sources, de traiter l'information et d'échanger les résultats avec d'autres programmes ou données, rendant ainsi plus facile le développement de programmes qui peuvent s'attaquer à des questions compliquées dont les réponses

Figure 14 : Les couches du Web sémantique



ne se trouvent pas sur une seule et unique page du Web.

Les ontologies peuvent aussi être utilisées d'une manière toute simple pour améliorer la précision des recherches sur le Web, par exemple par l'utilisation des règles de déduction.

Une importante facette du fonctionnement (de l'Agent) sera l'échange de « preuves » écrites en langage unificateur du Web sémantique. Quelques programmes peuvent déjà échanger des preuves de cette manière, en utilisant des versions préliminaires. La Figure 14 montre les couches du Web sémantique de Tim Berners-Lee.

Le web sémantique adaptatif dans le domaine de la santé ?

Le partage de la connaissance dans le Web Sémantique via la conception d'Agents peut trouver un emploi dans le domaine de la santé :

L'utilisation de micro-antennes permet d'examiner l'expression des gènes, mais elle produit en même temps une masse ahurissante de données. Pour identifier un état de maladie, on doit identifier la position d'un gène sur la carte du génome humain. Une **combinaison** de l'information qui nous dit quels sont les gènes actifs et où l'on peut trouver ce gène actif sur le chromosome est un gain extraordinaire pour la bonne intelligence du meilleur mode d'administration du traitement.

Pour réaliser les connexions logiques à partir de ce vaste amas de données, nous avons besoin d'Agents dans le Web Sémantique.

¹⁰ - Ontologie = Spécification formelle de la représentation des concepts, objets et entités et de leurs relations. N.d.T.

Collaborateurs

Benson Adams,
Commandement du Matériel
de l'Armée de Terre

Mohua Barari,
Professeur d'Economie,
Université du Missouri
du Sud-Ouest

Bob Bettes,
Président Fondateur,
Applications Mainstreet

Mark Dinning,
Groupe de Stratégie
de la Chaîne Logistique,
Dell Corporation

Tom Gibbs,
Directeur, Intel Corporation

Hui Li, étudiant de 3^e cycle,
Département du Génie
Aéronautique
et d'Astrophysique, MIT

Mike Li, Chercheur,
Département du Génie Civil
et Environnemental, MIT

Yichen Lin,
professeur de Management
et de Technologie de
l'Information, Université de
Technologie de Taiwan Sud,
Taiwan

Greg Parlier,
Bureau du développement
Economique,
Université d'Alabama

Micah Samuels,
Directeur général
des Opérations, Amazon.com

Santtu Toivonen,
étudiant de 3^e cycle,
Technologie de l'Information
VTI, Finlande

Conclusion

Les entreprises utilisent des modèles pour optimiser les profits ou même prévoir l'action future. Mais ces modèles ont beau être omniprésents, un modèle tiré d'un domaine particulier n'interagit pas avec un autre. Pouvons-nous exploiter la puissance de modèles à données multiples ? Nous pourrions faire des prédictions basées non plus sur quelques paramètres comme dans un modèle basé sur équation (EBM), mais bien sur des milliards de faits et de fonctions différents que les modèles basés sur Agent (ABM) permettraient de contenir.

Les décideurs peuvent souhaiter profiter des éléments clés (outils et technologies) mentionnés dans ce document et rechercher des moyens de réaliser la convergence. Les progrès dans cette direction peuvent être mesurés par le degré de fusionnement significatif entre bits et atomes en fonction du processus.

Bibliographie

[1] Gell-Mann, M., « *The Quark and The Jaguar* », éditions W.H. Freeman and Company, New York 1994.

[2] Heinrich, C. et Bettes, B. « *Adapt or Die : Transforming your Supply Chain Into an Adaptive Business Network* », éditions John Wiley and Sons, 2003.

[3] Tellis, G.J. and Golder, P.N., « First to Market First to Fail? Real Causes of Enduring Market Leadership », *Sloan Management Review*, n°37 (2), 1996, pages 65-75.

[4] www.wrmea.com/archives/sept-oct02/0209044-2.html, et www.bea.doc.gov

[5] Shimchi-Levi, D., Kaminsky, P. et Shimchi-Levi, E., « *Designing and managing the Supply Chain* », 2nd ed, 2002

[6] Forrester, J., « *Industrial Dynamics* », MIT Press, 1961

[7] Sterman, J.D., « Modeling managerial Behavior : Misperceptions of feedback in a dynamic decision making experiment », *Management Science* (1989) ;

[8] Lee, H., Padmanabhan, P. et Whang, S., « The Bullwhip Effect in Supply Chains »,

Sloan Management Review n°38, 1997, pages 93-102

[9] Brame, J. et Simchi-Levi, D., « *The Logic of Logistics* », Springer 1997.

[10] Joshi, Y.V., « Information visibility and its effect on supply chain dynamics », MS Thesis, MIT, 2000.

[11] Cohen, M., Ho, T., Ren, J. et Terwiesch, C., « Measuring imputed cost in the semiconductor equipment supply chain. » Working papers ; Wharton School, 2003.

[12] Neumann, J.V. et Morgenstern, O., « *Theory of Games and economic Behavior* » ; Princeton University Press, 1947.

[13] Nash, J.F., « *Equilibrium points in N-Person Games* » ; PNAS, 1950

[14] : H.W. Kuhn : « *Extensive games and the problem of information* » dans « *Contributions to the Theory of Games* » (sous la direction de Kuhn et A.W. Tucker) aux éditions Princeton University Press 1953.

[15] Aumann, R., « *Acceptable points in general cooperative n-person games* ». Contributions to the Theory of Games (IV), Princeton University Press, 1959.

[16] Shubik, M., « Some Experimental Non Zero Sum Games with Lack of Information about the Rules ». *Management Science* n°8 (1962), pages 215-234.

[17] Shubik, M., « Incentives, Decentralized Control, the Assignment of joint Costs and Internal Pricing » ; *Management Science* n°8 (1962) pages 325-343

[18] Vickrey, W., « Counterspeculation and Competitive Sealed Tenders » ; *Journal of Finance* n°16 (1961) pages 8-37.

[19] <http://william-king.www.drexel.edu/top/eco/game/game.html>

[20] Ozer Ozalp, Stanford University, Communication personnelle.

[21] Enders, W., « *Applied Econometric Time Series*. » Wiley, 2^e édition, 2003.

[22] Christensen, C., « *The Innovators Dilemma* », 2000 ; pages 168-169.

[23] Datta, S. et al www.wkap.nl/prod/b/1-4020-7812-9?a=1

APPENDIX IV

Shoumen Datta

HAPHAZARD REALITY – IOT IS A METAPHOR

THIS PAGE IS LEFT BLANK

IoT Trends

This is not an original article. This is a collection of the status of various tools and technologies in the IoT domain to enhance understanding of the ecosystem. Edited by Shoumen Datta, MIT.

ABSTRACT

Internet of Things (IoT) is a design metaphor for the connected world. IoT implies connectivity between real/physical and virtual/logical states, hence, it may overlap with certain categories of cyberphysical systems (CPS). The focus of this paper is to identify the state of the art in IoT enabling tools and technologies, based on journal articles. The concepts and issues related to IoT are classified in various domains and sub-domains, since IoT, *per se*, is neither a tool nor a technology, but a convergence of functions. Results reveal that the IoT field is dominated by technology and software services domains (first), followed by communication domains (second) and trust management (19%, 14% and 13% respectively). Noteworthy sub-domains are related to wireless sensor networks (WSN), cloud computing, machine to machine (M2M) communications and cybersecurity.

Keywords: Internet of Things, Trends, Statistical analysis, Classification, Research domains, CPS

1. Introduction

The concept of IoT may be described, partially, as a pervasive network of systems to monitor and control physical world objects by collecting, processing, and analyzing sensor data. These systems may contain sensors, radio frequency identification (RFID) devices, global positioning systems (GPS), actuators, connected via gateways to local area networks (LAN) which can interact with other networks and impact anything, anywhere in the world [1].

This paper shall attempt to discuss most of the common elements under the IoT umbrella. Machine to machine (M2M) communication is the industrial version of IoT which facilitated exchange of information, among independent machines (devices), without any human in the loop [2]. Physical and virtual things have identities, hence, may be connected together through interfaces [1]. Routing protocols and standards enable decentralized self-discovery, variant configuration and variable infrastructure [3]. Communication protocols and technologies are key for the IoT paradigm [4]. Internet Engineering Task Force (IETF) has put forward an IoT protocol stack [5]. To be useful, Media Access Control (MAC) sublayer of wireless networks and routing protocols must be scalable and interoperable [6] to support billions of connected things.

Traditional internet architecture may be modified to adapt to IoT challenges [7]. Different types of architecture have been proposed by standardization bodies, academia and industry. A device layer and a network layer are common to all, but a “standard” IoT architecture is still not at hand. Layered and modular architecture is essential for industrial IoT [8] for scalability.

Sensors and mobile devices, generally, sense and monitor environments. Acquired data may be application-specific and tends to be correlated [9], hence, may be aggregated. Logical data fusion may reduce the volume of transmitted messages. The latter may reduce bandwidth need and energy consumption, with a consequent improvement in network performance. Key to data transmission are optimal flow of information, and communication topology, which efficiently routes the data to processing nodes [10].

Energy efficiency of IoT nodes are crucial for uninterrupted data harvesting. Low-power communication technologies are emerging to address this problem [1]. Energy-aware devices, which can harvest energy from environmental sources [12], are preferred for energy management.

Data generated from “personal” devices creates the need for security and privacy. In the context of data sharing and data mining, trust, is key. In addition, confidence, belief, reliability, integrity, and other features [11] may influence the user’s decision to allow or disallow access to the data. Therefore, trust management and information cybersecurity may be crucial for IoT.

Software as a service is one vehicle for dissemination of the value of data, for example, in logistics, smart homes, e-health, intelligent transportation systems (ITS), manufacturing and environmental monitoring [13-15]. Hence, middleware is central for IoT applications [16].

In Section 2 we will summarize the classification approach. Section 3 presents a cross-sectional analysis of different fields related to IoT. Section 4 contains concluding comments.

2. Classification Approach

Articles (Table 1) were analyzed and classified into domains and sub-domains. The nine domains are (Figure 1) architecture, communication, trust management, technology, resource management, energy management, software services, data stream, and infrastructure/hardware).

Table 1: Using ‘Internet of Things’ & ‘IoT’ as keywords, we found 339 papers from four journals. (We = groups of students in various countries, for this mentoring project on internet of things).

	2015	2016
IEEE	136	41
Elsevier	30	77
Springer	38	13
ACM	0	4

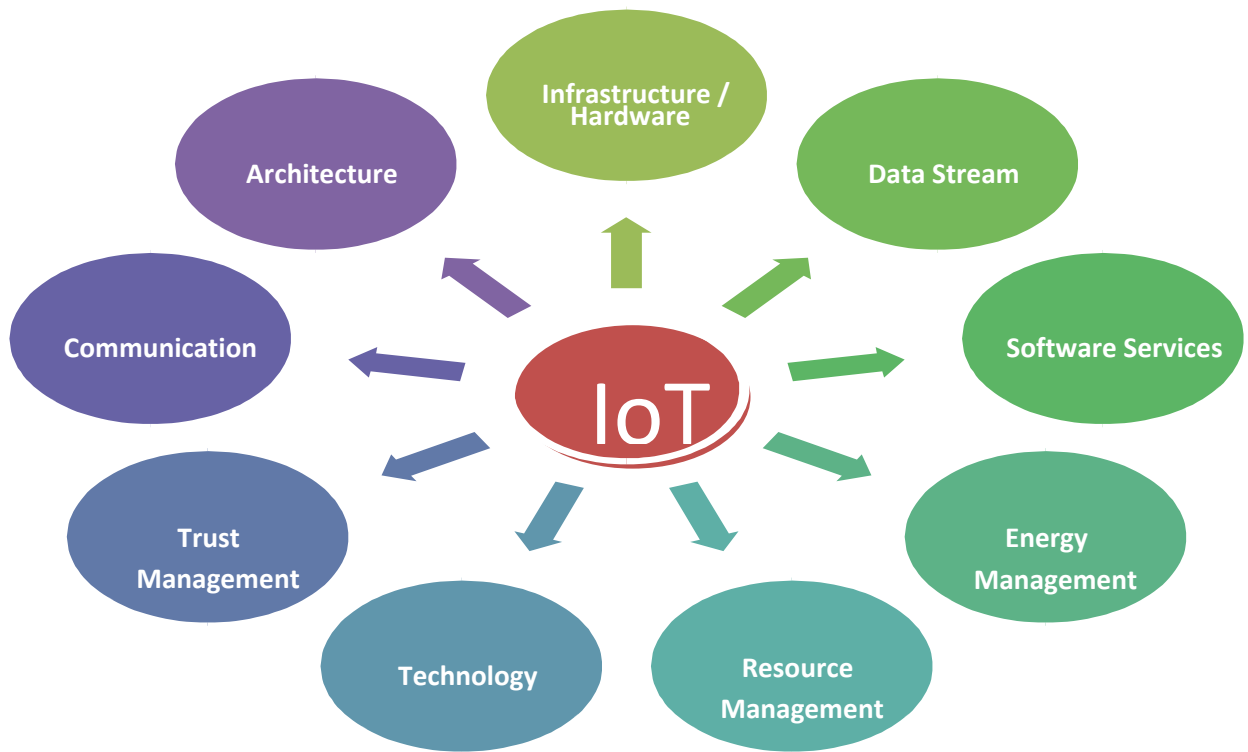


Figure 1: IoT Domains

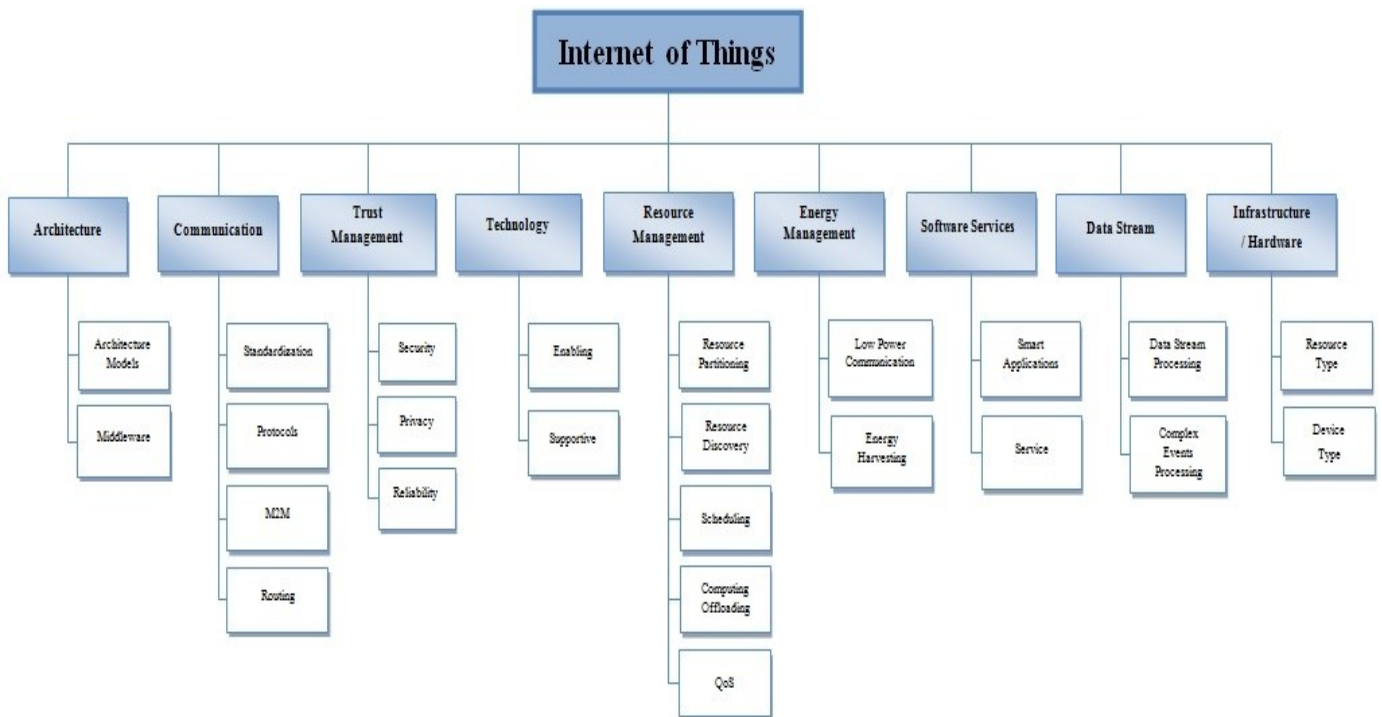


Fig. 2. IoT sub-domains

2.1. Architecture

Connectivity is central to IoT and architecture must support bridges between the cyber and the physical world. Most articles present new layers of middleware and integration layers for heterogeneous processes.

2.1.1. Architecture Models

Extensibility, scalability, and interoperability between heterogeneous devices are considered. Architecture should adapt to mobility, discover decentralized devices and connect, securely. Proposed architecture may be in 3 layers [17-19], 4 layers [20-21], or 5 layers [7].

International Telecommunication Union (ITU) has suggested a four layer design (Device, Network, Service Support & Application Support, and Application Layers). It has security and management capabilities, associated with all four layers [22].

Architectural Reference Model (ARM) for IoT-A is a hierarchical model [23]. It consists of 9 functionality groups (FG), with 7 longitudinal FGs, and 2 transversal FGs [20, 24].

Cisco architecture has three layers. PHY/MAC functionality is similar to device layer in ITU and IoT-A models. Network functionality is specific to communicate between things and application layer in order to monitor applications [21].

In Service-Oriented Architecture (SOA) [25], services are executed by things located in heterogeneous networks. SOA architecture contains four layers: [1] sensing layer, by which smart systems or sensors are able to exchange sensor data among different devices; [2] network layer connects things together and makes it possible to share information; [3] service layer, offers middleware based integration of applications; [4] interface layer, facilitates interoperability between heterogeneous objects, data exchange, communication and events processing.

Web Oriented Architecture (WOA) is a version of SOA architecture which aggregates users and systems by using a web of globally linked hypermedia, based on the web architecture. This type of architecture is focused on the generality of interfaces (APIs). WOA may be a combination of SOA, WWW, and REST features [26-27].

In methods based on web APIs and REST, all required resources change from network bandwidth to the computing capability and storage capacity, and data conversion (based on request/response method) are triggered during service call [28]. It is suggested [29] that devices, sensors, humans, and existing services are described by web API symbol and API description languages. Similarly in [30] a service layer of broker named FOKUS has been presented which shows a collection of APIs to activate a shared access to OpenMTC core.

2.1.2. Middleware

Heterogeneous devices in an IoT context (infrastructure level) require middleware for applications to integrate heterogeneous processes and communications. Middleware is located in the “middle” between the application layer and the infrastructure. It may support management of services, resources, data, events, security, stability and other requirements [16].

Middleware may be divided into several categories:

- event-based
- service-oriented
- VM-based
- agent-based
- tuple-spaces
- database-oriented
- application-specific

In some instances, middleware may be a hybrid (combine two, or more, approaches). For intelligent logistics field [31], integration of various heterogeneous devices is essential to build higher level of services. Smart logistics uses SOA and, in addition, must “find” proper composed services for each commercial process. The latter is accomplished by a series of agents (task agent, resource agent). Hence, this middleware is a combination of SOA and agent-based architecture.

Event-based (publish/subscribe) middleware [32] in crowd sensing systems, consists of cloud broker and mobile broker. Sensors collect and publish environmental data. It is transmitted through mobile broker (or directly) to the cloud. Results of cloud analytics are fed to mobile or edge devices (subscribers).

Table 2. Classification of Architecture Domain Papers

IoT Domain	Sub-domain	Research Field	References
Architecture	Architecture Models	ITU	[22]
		ARM (IoT-A)	[20], [23],[24]
		Cisco	[21]
		SoA	[25]
		WoA	[26], [27]
		API - Based	[28], [29], [30]
	Middleware	Event-based	[32]
		SOA-based	[33]
		Agent- and SOA-based	[31]

2.2. Communication

Standardization, protocols, machine to machine (M2M) communications and routing are key topics since a broad spectrum of heterogeneous entities must connect, appropriately and reliably, to create functional IoT networks, which offer value.

2.2.1. Standardization

If pervasive and global standards for IoT were introduced and applied [34], it may enhance interoperability between different components, services providers, and users [35]. Spectrum use, regulations about radio frequency, interoperability, authentication, identification, permission and protocols, are a part of the myriad of challenges for standardization [25].

2.2.2. Communication Protocols

IoT networks include mobile networks (3G, 4G, CDMA and etc.), wide area networks (WLANs), wireless sensors networks (WSN), and mobile *ad hoc* networks (MANET) [36]. Switching and integration between technologies, such as WiFi, Bluetooth, 802.15.4, Z-Wave, ZigBee, Advanced LTE (Advanced Long-Term Evolution), Radio Frequency Identification (RFID), Near Field Communication (NFC) and Ultra-Wide Bandwidth (UWB), is a part of the functional requirement [7]. Emerging providers (Thread, Neul, Sigfox) must be able to connect, too.

IoT uses at least three categories of protocols: (1) General purpose IP (Internet Protocol) and SNMP (Simple Network Management Protocol), used for management, monitoring, configuration of network devices and creating communication links, (2) Light protocols, like CoAP (Constrained Application Protocol), which are developed to satisfy the needs of devices with small hardware and limited resources, and (3) Specific protocols for device manufacturers which may require application programming interfaces (APIs) to connect. More details are in [37].

2.2.3. M2M Communication

Mobile M2M exists in various smart systems [38]. M2M communication focuses on efficiency, low cost, high security and safety [23]. Common models of message exchanges are referred to as Publish/Subscribe, and Request/Response. Publish/Subscribe is popular with MQTT (Message Queue Telemetry Transport). HTTP/REST (Hypertext Transfer Protocol / Representational State Transfer) and CoAP support Request/Response model [35], [39].

Adaptability to dynamic changes of network nodes and scalability of MAC protocols are essential for M2M. Wireless protocols for the physical layer in M2M may be divided into three main groups: Contention-Free MAC Protocols, Contention-Based MAC Protocols, and Hybrid MAC Protocols [2]. Disadvantages of contention-based protocols in M2M communications are: Lack of scalability, low throughput, high power consumption, overhead of control packets, channel eavesdropping, and delay in real-time applications. The contention-free protocols have better efficiency in higher loads, but are not suitable for M2M networks that require high flexibility and scalability. Hybrid model combines the advantages for low and high loads [2]. Papers [2] and [40] focus on message management by Real-Time Systems (RTS), and [41] deals with changing packets size and management of energy consumption. Papers [42] and [43] deal with the improvement of Quality of Service (QoS) parameters by scheduling. Scalability of nodes are discussed in [44].

2.2.4. Routing

Routing protocols are key for IoT networks to connect heterogeneous entities [3]. Different scenarios include smart homes, low power and lossy networks (LLNs), building automation, and in future, autonomous transportation [45-47]. Examples of routing protocols for IoT are [1]:

- IPv6 over low power wireless personal area networks (6LoWPAN) – IPv6 adaptation layer to enable LLNs.
- Routing protocol for low power and lossy networks (RPL) is a reference standard for IoT applications using LLNs compatible with IPv6.
- IPv6 over time slotted channel hopping (IEEE 802.15. 4e; 6TiSCH) can be used with wireless mesh networks (IEEE 802.15.4e; TiSCH). Routing protocol specifies packets, security, link management and neighbor discovery.

Increasing number of wireless devices makes it imperative to guarantee the efficiency of end-to-end networks, using creative tools [6], for example, the important effect of MAC parameters on the performance of IEEE 802.15.4 networks [48]. A Markov chain model has been used to design a distributed adaptive algorithm [49] and automatic selection of MAC protocol [50].

In order to prevent traffic congestion at the network center, Content-Centric Routing (CCR) was introduced [10]. CCR stores and shares data, based on the content. Thus, CCR can increase network lifetime, decrease network delay and improve reliability of communications significantly.

Security for IoT networks [1] is a work in progress [51-52]. RPL and 6LoWPAN lack proper security implementation. To compensate, different techniques, such as, key management, encryption, and trust management, are applied [1]. A routing protocol for Emergency Response IoT based on Global Information Decision (ERGID) has been presented [53].

Table 3. Classification of Communication Domain Papers

IoT Domain	Sub-domain	Research Field	References
Communication	Standardization	Standardization Technology	[25], [34], [35]
		Protocols	IoT Protocols – Case Study
	M2M	IoT Protocols	[37]
		MAC Layer Protocols	[2]
		M2M Communication	[23]
		Mobile M2M Computation for Cloud	[38]
		QoS Parameters for Design	[42], [43]
		Energy	[2], [40], [41]
		Scalability	[44]
	Routing	Secure Routing	[1]
		Content Centric Routing	[10]
		RPL	[45], [46], [47]
		Protocol for emergency response	[53]

2.3. Trust Management

Several topics, such as, confidentiality, integrity, availability, privacy, dependability, reliability, safety and security, are considered a part of the scope of trust management [11]. However, three sub-areas (security, privacy-preservation and reliability) are most common.

2.3.1. Security

Two main [54] categories:

I. Authentication and Confidentiality

Authentication Key Agreement Protocol (AKA Protocol) [55-57] enables remote authentication of smart cards, through one sensor. In the same phase of authentication, key agreement process was performed for agreement of two ends (sensor and user) on one shared session key. A group-based AKA protocol [58] may increase security in M2M communications using LTE networks. In this protocol, Authentication and Key agreement was implemented in a distributed manner such that the solution will update a group of security policies for nodes.

II. Access Control

Heterogeneous signcryption was developed [59] to perform digital signature and public key cryptography operations in one logical step. This work was based on studying access control (of internet users) while querying WSN. Signcryption reduces energy requirement in WSN.

Token-based encryption mechanisms [60] may be used to control access to guest devices and network applications. The MQTT [61] protocol claims to guarantee the process of data source authentication and authorization.

2.3.2. Privacy

Preservation of privacy must enable control of personal data, to determine what information, when, and how, it may be communicated with others [62]. In RFID systems, shared master keys [63] compromises privacy. To address this problem, the use of safe memories of PUF (Physical Unclonable Functions) may improve privacy [64]. Using this type of storage is to include required strategies against the enemy attempts in channel which is done to access the master key.

In an application designed for smart parking [62], privacy preservation was increased by two criteria: [1] application operated independent of platform and operating system and [2] avoided private and personal information exchanging (like work and home address). In the application, ECC (Elliptic Curve Cryptography) was used for public key cryptography. Other studies [65] have explored privacy preservation risks in the design of automated smart homes.

2.3.3. Reliability

Reliability is a measure of the probability that data packets are received successfully by the receiver [66]. Hence, the design of metrics for reliability must transition from a deterministic to a probabilistic process [67]. To optimize reliability, industrial WSN [66] uses HTP (hybrid transmission protocol), which consists of SW-ARQ (Stop-and-Wait Automatic Repeat reQuest) with high reliability and high delay around sink node, and NCRT (Network Coding Routing) scheme, with low delay and high energy consumption, far from sink node. Thus, HTP, maximizes reliability, reduces network delay, and increases network lifetime.

To further bolster reliability for mission-critical operations, a fault tolerance method [68] has been suggested, in which there are redundant radio modules for each node. The latter may be useful in M2M communication networks to upgrade reliability [69].

Table 4. Classification of Trust Management Domain Papers

IoT Domain	Sub-domain	Sub Area Concepts	Research Field	References
Trust Management	Security	Authentication	AKA PROTOCOL	[55], [56], [57]
			Group-Based (Distributed) AKA Protocol for M2M in LTE networks	[58]
		Access Control	Identity-based Access control for heterogeneous IoT	[59]
			Temporary & conditional access control	[60]
			Guarantee Access MQTT	[61]
	Privacy	-	Privacy-Preservation for RFID	[63]
			Privacy-Preservation for smart applications	[62]
			Privacy-Preservation for automation smart home	[65]
	Reliability	-	Reliability in industrial WSN	[66]
			Reliability in wireless network fault tolerant method	[68]
Reliability for M2M communication in cell network			[69]	

2.4. Technology

The various technologies under the IoT umbrella may be divided into two main categories: enabling and supportive technologies. RFID, WSN and devices represent enabling technologies. To support data acquired from these enabling technologies, the supporting technologies are essential, for example, cloud computing, edge analytics, etc.

2.4.1. Enabling Technologies

I. RFID

Any network of things must identify the things in the network [14], preferably with an unique identification. RFID may assist in identification [64] and in combination with WSN may be a part of the IoT environment [28]. However, privacy is a concern since RFID tag data may be accessible by most readers, hence the need for additional tools or protocols to improve data security [70].

II. Wireless Sensor Networks (WSN)

Vast networks of sensor nodes capable of acquiring information from the environment, and transmitting the data, with limited processing capability and limited energy. WSN are deployed due to low costs, scalability, trust, accuracy, flexibility, and simplicity [71]. The variety of nodes [72], QoS [73], security [74], and scalability [71] are challenges influencing performance.

2.4.2. Supporting Technologies

I. Cloud Computing

To support [75] IoT networks, cloud platforms [15] may be beneficial:

- Cloud-based Middleware for IoT

Implemented for mobile crowd sensing [32], the capabilities for the middleware include: selected acquisition of sensor data, aggregation, filtration and transmitting pre-processed data for analytics, and feedback (delivery, notification) to devices (mobile), in real-time.

- Cloud-based Architecture for IoT

One challenge in developing smart applications is integration of sensors and devices, automatically, in order to provide actionable data in a user-friendly service format to application layers [76, 77]. Sensor data from diverse sources are acquired by the lower layers in this cloud architecture. Data may be pre-processed prior to transmission to higher layers of the same cloud, or to different clouds, where analytics (applications) are performed.

- Cloud-based Platform for IoT

Cloud technology has the potential to assist in the design of platforms, for example, e-health platform [78]. Cloud-based platforms for smart wheelchairs may help disabled people [79].

- Cloud-based Framework for IoT

A hybrid framework, Calvin [80], claims to apply “new methods” to facilitate development and software management.

II. Information-Centric Networking (ICN)

ICN addresses scalability [81], uses in-network storage (effective cache) and multiparty communication for replication [82]. ICN directs network architecture evolution from IP-based to content-based [83] in a way that assigns to each content a unique and persistent name, which can be directly used by the router [84]. Various architectures under the ICN category, are as follows:

- Data-Oriented Network Architecture
- Content-Centric Networking (CCN)
- Publish-Subscribe Internet Routing Paradigm (PSIRP)
- Network of Information (NetInfo)

CCN, proposed in 2007, and NDN (Named Data Networking), presented in 2010 [85], were aimed to facilitate CCR, content centric routing [10], an approach for routing data based on their content [86]. By eliminating redundant data transmission through data aggregation, energy consumption, traffic and delay are reduced in the network.

III. Software Defined Network (SDN)

Growth of networks [87] and their heterogeneity [88] has increased complexity. SDN aims to improve efficiency by separating control operations from data exchange in routers [89]. In addition, the control segment offers programming capability [90]. SDN framework for IoT [91], scalability [92], and sensing [93], is discussed.

IV. Fog Computing

When latency is time critical, data and computational resources must be proximal to the edge (the device). This is implied by fog (and “mist” computing, that is nearer than the “cloud”). It may be more responsive in dynamic environments and the “local” edge may help with context awareness. Access to the fog [94] and security [95] are challenges to be addressed and optimized.

Table 5. Classification of Technology Domain Papers

Sub-domain	Sub Area Concepts	Research Field	References (Papers)
Enabling Technologies	WSN	Security services	[74]
		Efficient Management & Optimization	[72], [73], [96]
	RFID	RFID System Privacy	[70], [64]
		Automatic RFID Monitoring System	[97], [98]
Supportive Technologies	Cloud	Cloud-Based Middleware	[32]
		Cloud-Based Architecture	[76]
		Cloud-Based Platform	[78], [79]
		Cloud-Based Framework	[80]
	SDN	Framework	[91], [92]
		Sensing	[93]
	ICN	Content-centric	[10], [99]
		Name-centric	[84], [100]
Fog	Framework	[94], [95]	

2.5. Resource Management

For distributed systems, the choice and availability of resources will affect the quality of service (QoS). Efficient resource management must address stability, fault tolerance, scalability, energy efficiency, QoS, and Service-Level Agreement (SLA) significantly [28]. Resource management for IoT environments includes:

- Resource Partitioning
- Resource/Service Discovery
- Scheduling
- Computation offloading (code offloading - transfer specific tasks to external platforms)

2.5.1. Resource Partitioning

Partitioning is necessary in IoT environments to optimize the resources in order to reach a high utilization ratio. This idea is widely applied to cloud computing through virtualization techniques and suitable infrastructures [28]. Hypervisor is responsible for the interaction management between the host and the guest of virtual machines, therefore, it needs significant amount of memory and computational capacity. However, most devices in an IoT context may have limited memory and/or processing power. To address these challenges, the concept of “containers” was introduced. It refers to virtualization technologies [101] and adapts to resource constrained devices, for example, embedded systems for real-time applications.

2.5.2. Resource/Service Discovery

Identifying and locating the device, followed by discovery of the desired service [28], are two critical elements, yet they lack standards in the IoT environment. The challenge is more complicated due to mobility and delay in IoT environments [102]. In fog computing [103], available resources, such as, network bandwidth, computational power and storage capacity are converted into time resources, to facilitate resource sharing. Semantic Web of Things (SWoT) is an idea where resources and their metadata are defined by standard ontology languages like RDF (Resource Description Framework) and OWL (Ontology Web Language). It is of limited use, for example, collection and interpretation of data from SSN, Semantic Sensor Networks [104].

2.5.3. Scheduling

OpenIoT scheduler offers a wide scope. Optimization for cloud/IoT data management is usually applied as a tool to optimize the energy efficiency of networks [105]. Scheduler must maintain information in order to optimize the network based on aggregated operations [106]. Additionally, data processing and management must be implemented to optimize the processing time or to reduce required time to access sensor networks [107-108]. Caching techniques are also used by scheduling methods to decrease traffic and to increase data accessibility [109-110]. By clustering things/sensors into IoT subgroups [111], a message scheduling algorithm is used to improve energy efficiency in IoT systems.

2.5.4. Computation Offloading

Advantages of computation offloading include efficient power management, fewer storage, and higher performance of applications. Code offloading techniques generally use static code analyzers and dynamic code parsers, if there are network fluctuations and high latency [112]. In this context, use of virtual machines increases scalability and elasticity [113-114]. In another approach, computation offloading using a mobile cloud [115] IoT platform, utilizes a game theoretic strategy for traffic control, to maximize performance and improve QoS [116].

2.5.5. Quality of Service

In a 3 layered architecture, QoS metrics are necessary for application, network and infrastructure [117]. In the application layer, a lightweight method [118] simplifies management, increases reliability [119], decreases delay [120-122] and improves throughput [123].

Table 6. Classification of Resource Management Domain Papers

IoT Domain	Sub-domain	Research Field	References (Papers)
Resource Management	Resource Partitioning	Centralized Virtualization Techniques	[101]
	Service/Resource Discovery	Adaptive resource discovery in mobile cloud computing	[102]
		Service-oriented heterogeneous resource sharing in mobile cloud	[103]
		Resource discovery in the SWOT	[104]
	Scheduling	Optimization Techniques (Query Aggregation & Processing)	[105], [106], [107], [108]
		Caching Techniques	[109], [110]
		Message Scheduling Algorithm	[111]
	Computation Offloading	Computation/Code Offloading	[112], [113], [114]
		Mobile Cloud IoT systems	[115]
		Data offloading for traffic congestion problems	[116]
	Quality of Service	Lightweight Management	[118]
		Reliability	[119]
		Delay	[119], [120], [121], [122]
		Throughput	[123]
		Accuracy (for location)	[124]
Query Optimization		[96]	
QoS Parameters		[117]	

2.6. Energy Management

Vast numbers of energy constrained devices makes energy management a critical issue in IoT environments. Common approaches include low power technologies using radio frequency (RF) and improving battery efficiency through energy harvesting [125] to extend battery life.

2.6.1. Low Power Communication

Current standards for low power technologies include [125, 126]:

- IEEE 802.15.4 is a standard for low data rate, low power networks. IEEE 802.15.4 defines the physical (PHY) and Medium Access Control (MAC) layers and forms the basis for upper layer networking specifications including Thread, 6LoWPAN, ZigBee and Wireless HART.
- Bluetooth low energy (Bluetooth LE) is 15X more efficient compared to Bluetooth.
- Ultra-Wide Band (UWB) transmits over broad frequency range (frequency agnostic)
- ISO 18000-7 DASH7 is a low power standard with low complexity and a radio protocol for sub 1GHz devices.
- RFID/NFC (near field communication) proposes different standards for contactless methods.

Replacing device battery is impractical or very expensive in many IoT scenarios. To achieve ultra-low power consumption, super-regenerative architectures are suitable and efficient for wake-up receivers [126]. For RF architectures, energy consumption decreases significantly if bandpass sampling may be achieved at a lower frequency than Nyquist ratio [127]. Combining RF with Bluetooth LE [128] and, in another case, low power radio receiver dedicated to lower GHz frequencies [129], are examples of other strategies in use, to achieve low energy/power usage.

2.6.2. Energy Harvesting

Acquiring pulses of small but usable electrical energy from the environment (temperature, sound, environment vibration, RF) may be converted to power micro-controllers, sensors, and the network interface [130]. One purpose of decreasing energy consumption in ICT is the expected reduction of GHG (greenhouse gases) from data centers and WSN [131].

Energy harvesting from kinetic motion uses energy allocation algorithms to optimize performance of IoT applications [132]. Energy scavenging from photovoltaic (PV) systems allow the Maximum Power Point Tracking (MPPT) in order to scavenge maximum amount of solar energy [133] for IoT environments.

Table 7. Classification of Energy Management Domain Papers

IoT Domain	Sub-domain	Research Field	References
Energy Management	Low power Communications	Related Technologies	[125], [126]
		Bandpass Quantizer	[126]
		Bandpass Sampling	[127]
		RF-solutions for IoT applications	[128]
		RF Direct Sampling	[129]
	Energy Harvesting	Electrostrictive polymers	[126], [130]
		Energy-efficient approaches for the Internet protocol stack	[131]
		Wireless Energy Harvesting	[12]
		Kinetic Energy Harvesting	[132]
		Storage-less and Converter-less Photovoltaic Energy Harvesting	[133]

2.7. Software Services

Software is the essential “glue” for any smart application and almost all IoT related services, APIs, operating systems and platforms for digital connectivity/interoperability.

2.7.1. Smart Applications

IoT “smart” applications may be divided into categories [134, 135], for example, smart environment, smart city, smart metering, smart water, security and emergencies, retail, logistics, industrial control, smart agriculture, smart animal farming, domestic and home automation, and e-health [134]. Others have defined layers for the M2M market, such as, service sectors, application groups, locations, and devices [136].

2.7.2. Service

IoT services can be classified into four classes [137, 138], as follows:

- Identity-related service: identification of things for any application that captures the digital proxy or digital twin of a physical thing and transfers it to a virtual or cyberphysical system
- Information aggregation services: data collection for processing and reporting to IoT app
- Collaborative-Aware Services: higher level function of connectivity and interaction between devices or ecosystem necessary to sense and respond or support decision systems to react
- Ubiquitous Services: provide services anytime, anywhere, to anyone (most challenging)

A few applications provide the first three types of services (smart healthcare and smart grid). Smart homes, smart buildings, intelligent transportation and industrial automation, are closer to collaborative-aware services.

Table 8. Classification of Software Services Domain Papers

IoT Domain	Sub-domain	Research Field	References
Software Services	Smart Applications	Generic Smart Applications	[28], [134]
		Discovering IoT application	[135]
		Marketing field	[136]
		Healthcare	[98], [139]
		Industrial applications	[140]
		Smart City	[141]
	Service	Service Classification	[7]
		Operating System	[142]
		Programming	[143], [144]

2.8. Data Stream

In IoT networks, objects, devices and things are continuously generating huge volume of heterogeneous multidimensional data [145]. The challenges may resemble that of “big data” and divided into four groups [146] for ease of analysis:

- data stream processing
- complex event processing
- storage models
- search techniques

In data stream processing, the goal is to find the most valuable techniques to perform analysis, aggregation, and mining, to extract valuable patterns or knowledge discovery. CEP or complex event processing is based on data stream processing (where a collection of events have occurred in an environment) where the goal is to filter, compose and transform the result to a high level event [146]. CEP is at a higher level in terms of operational complexity and abstraction.

The heterogeneity of data in data streams, calls for dynamic architectures and storage solutions which will enable higher efficiency for searches. The latter will be influenced by the nature of the data storage [146].

2.8.1. Data Stream Processing

Data stream processing may identify valuable patterns, enable compression to omit redundant data [146]. By mining user generated http requests, sequences and dependency of web requests may be used to optimize design of web applications and predict user preferences [147]. Similarly, association rule mining may enable discovery of usage patterns [148]. Aggregation of data using a distributed service-oriented architecture has been presented [149] for industrial IoT applications.

2.8.2. Complex Event Processing (CEP)

Data stream is viewed as a collection of events that have occurred in environment [146], for example, a smart city [122]. CEP is helpful in instances where RFID tags and sensors may generate very high volume data. Hence, automated and accurate methods are necessary, such as, machine learning algorithms, used as rule-based classifiers [150]. After performing data pre-processing, different solutions from rule-based classifiers are applied to detect complex events.

Table 9. Classification of Data Stream Domain Papers

IoT Domain	Sub-domain	Sub Area	Research Field	References (Papers)
Data Stream		General Data Stream Processing	Association rule mining	[148]
			Web usage mining	[147]
	Data Stream Processing	RFID Data Stream Processing	SOA Architecture for Aggregation	[149]
	Complex Event Processing (CEP)	Complex event processing	Distributed Parallel CEP	[122]
		Semantic Complex Event Processing	Rule-based Machine learning CEP	[150]

2.9. Infrastructure/Hardware

Layer which consists of devices, routers and gateways for IoT implementation.

2.9.1. Resource Type

Consists of two categories: resource constrained devices, and resource unconstrained devices, considered as low-end and high-end, respectively. The resource constraint includes memory, energy, and CPU capacity which affects software and applications design. For example, memory constraint affects OS design, energy constraint affects interactions with devices and its activity, as well as CPU constraint affects determining application type [151]. TCP/IP protocol support capability is also a criteria in classifying things [7].

Based on available memory, resource constrained devices are classified into three main classes according to IEEE. Class 0 consists of devices with very low resources that have memory less than 100 KB. Class 1 consists of devices with medium level of resources which have about 10 KB RAM, and 100 KB flash memory. Class 2 contains devices with more resources but less resources in comparison with unconstrained devices [151].

Energy constrained devices are classified into four classes. Class E9 consists of devices that have no energy constraint. Class E2 consists of energy constrained devices, non-rechargeable, and their batteries are irreplaceable. Class E1 has constrained energy for a specific period of time, and they are chargeable or replaceable. Class E0 contains of energy constrained devices for a specific task. Because of the energy constraint, optimal consumption strategies are very important [151].

CPU-constrained devices are classified into 5 levels. First: smart sensors with processing power between 50-100 DMIPS (Dhrystone MIPS (Million Instructions per Second)). 2nd: sensors with about 1000 DMIPS processing power which has sound data processing capability. The third level has processing capability of video and sound. The fourth one has multi-core processors and 3D graphic processors. Fifth level consists of multi-core processors which have specific design, high efficiency and structured to use resources efficiently [152].

2.9.2. Device Type

Device type category consists of hardware which is used in network topology implementation, sense, and data aggregation, or operations like routing, communication, and security. These devices can be categorized as follows:

- **Sensor (Processing Devices):** IoT environments are likely to contain different types of sensors, for example, temperature, humidity, and pressure sensors. Most sensors have constrained resources. Receiving information and transmitting them are the most important tasks for sensors.
- **Gateway (Communication Devices):** Generally at a higher power level than sensors. Gateways support different standards of communication to facilitate data transmission from a variety of sensors. Gateways are able to provide accessibility services by creating an abstraction layer. This model improves horizontal development of various technologies. Gateways are classified into smart and non-smart levels. Conventional tasks of non-smart gateways are protocol translation and things management. Whereas, smart gateways are resource unconstrained, and have programming capability (rule based). They can perform various types of in-network processing, and due to their powerful operating system (OS), they may also enable various levels of data processing. Smart gateways have different management facilities due to their programming capability [153].

Gateways are classified into two categories from the viewpoint of code accessibility: industrial hardware (closed source) that depends on specific frameworks, and open source hardware that can be developed by users. Another model is based on programming capability and providing an abstract level for things [143].

- **Storage Devices:** Data in IoT environments may be very heterogeneous, may be different than traditional internet data, and have time and location stamps. Due to movement of things or devices, location changes are dynamic and IoT data are multi-dimensional. Appropriate database model in IoT is very important because it can provide QoS parameters. Object-based storage devices (OSD) mechanism of data storage and processing provides necessary data maintenance and management in IoT environments by presenting a hierarchical model, more memory and higher processing power [154].
- **Security Devices:** Different software programs, various hardware devices and Intrusion Detection Systems (IDS) are used in addition to security protocols in TCP/IP protocol stack to preserve security in internet networks [155]. This policy has been titled as “defense in depth” [156]. It seems that applying similar policies to preserve security in IoT, which is a network of interconnected things, may be a logical, albeit partial, solution.

One of the most important security devices is Intrusion Detection Systems (IDSs). A distributed IDS, both on the network and the node level, was designed and implemented for IoT network [157]. The IDS is presented under an appropriate architecture for IPv6 networks in IoT that use RPL protocol as the routing protocol in 6LoWPAN networks. It is also suitable to be used in resource-constraint nodes considering energy consumption. A formal framework for IDS devices in IoT was designed for 6LoWPAN devices [158]. IDS claims to prevent attacks or stop them before they start [159].

Table 10. Classification of Infrastructure/Hardware Domain Papers

IoT Domain	Sub-domain	Sub Area Concepts	Research Field	References (Papers)
Infrastructure Hardware	Resource			[151]
	Device	Processing Devices		[151], [152]
		Communication Devices		[143], [153], [161]
		Storage Devices		[154]
		Security Devices	IDS for IoT	
	Firewall for IoT			[160]

3. Conclusion

Internet of things is a network paradigm and service infrastructure, which is evolving. We explored the current trend based on a selection of recent publications (2015, 2016). It appears that the majority of the articles deal with technology and software services (19% in each domain) while communication and trust management are pursued by 14% and 13% of the publications. Security, however, seems to be peppered in many publications, even if it is not the thrust of the article. Hence, security in IoT networks seems to be a critical consideration for IoT evolution.

References

- [1] D. Airehrour, J. Gutierrez and S. K. Ray, “Secure routing for internet of things: A survey”, *Journal of Network and Computer Applications*, vol. 66, pp. 198-213, 2016.
- [2] A. Rajandekar and B.Sikdar, “A Survey of MAC Layer Issues and Protocols for Machine-to-Machine Communications”, *IEEE Internet of Things Journal*, vol. 2, no. 2, pp. 175-186, 2015.
- [3] L. Steenbrink, “Routing in the Internet of Things”, Hamburg University of Applied Science, Faculty of Engineering and Computer Science, 2014, Germany, Available: www.inet.haw-hamburg.de/teaching/ss-2014/master.../aw1_lotte_steenbrink.pdf [accessed: 8/5/2016].
- [4] C. Perera, C. H. Liu and S. Jayawardena, “The Emerging Internet of Things Marketplace From an Industrial Perspective: A Survey”, *IEEE Transactions on Emerging Topics in Computing*, vol. 3, no. 4, pp. 585-598, 2015.
- [5] Z. Sheng, S. Yang, Y. Yu, A. Vasilakos, J. Mccann and K. Leung, “A survey on the IETF protocol suite for the internet of things: standards, challenges, and opportunities”, *Wireless Communications, IEEE*, vol. 20, no. 6, pp. 91-98, 2013.
- [6] P. Di Marco, G. Athanasiou, P.-V. Mekikis and C. Fischione, “MAC-aware routing metrics for the internet of things”, *Computer Communications*, vol. 74, pp. 77-86, 2016.
- [7] A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari and M. Ayyash, “Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications”, *IEEE Communications Surveys & Tutorials*, vol. 17, no. 4, pp. 2347-2376, 2015.
- [8] S. Bandyopadhyay, M. Sengupta, S. Maiti and S. Dutta, “Role of middleware for internet of things: A study”, *International Journal of Computer Science and Engineering Survey (IJCSSES)*, vol. 2, no.3, pp. 94-105, 2011.
- [9] E. Fasolo, M. Rossi, J. Widmer and M. Zorzi, “In-network aggregation techniques for wireless sensor networks: a survey”, *IEEE wireless communication*, vol. 14, no. 2, pp. 70–87, 2007.
- [10] Y. Jin, S. Gormus, P. Kulkarni and M. Sooriyabandara, “Content centric routing in IoT networks and its integration in RPL”, *Computer Communications*, vol. 89-90, pp. 87–104, 2016.
- [11] Z. Yan, P. Zhang and A. V. Vasilakos, “A survey on trust management for Internet of Things”, *Journal of Network and Computer Applications*, vol. 42, pp. 120-134, 2014.
- [12] P. Kamalinejad, Ch. Mahapatra, Z. Sheng, Sh. Mirabbasi, V. C. M. Leung, and Y. L. Guan, “Wireless Energy Harvesting for the Internet of Things”, *IEEE Communications Magazine*, vol. 53, no. 6, pp. 102-108, 2015.
- [13] E. Anzelmo, A. Bassi, D. Caprio, S. Dodson, R. V. Kranenburg and M. Ratto , Discussion Paper on the Internet of Things, In 1st Berlin Symposium on Internet and Society: Exploring the Digital Future, Berlin: Oct. 2011.
- [14] L. Atzori, A. Iera, G. Morabito, “The Internet of Things: A survey”, *Computer Networks*, vol. 54, no. 15, pp. 2787-2805, 2010.
- [15] J. Gubbi, R. Buyya R, S. Marusic, M. Palaniswami, “Internet of Things (IoT): a vision, architectural elements, and future directions”, *Future Generation Computer Systems*, vol. 29, no. 7, pp. 1645-1660, 2013.
- [16] M. A. Razzaque, M. Milojevic-Jevric, A. Palade, S. Clarke, “Middleware for Internet of Things: A Survey”, *IEEE Internet of Things Journal*, vol. 3, no. 1, pp.70-95 , 2016.

- [17] M. C. Domingo, “An overview of the Internet of Things for people with disabilities”, *Journal of Network and Computer Applications*, vol. 35, no. 2, pp. 584-596, 2012.
- [18] X. Jia, Q. Feng, T. Fan, and Q. Lei, “RFID technology and its applications in Internet of Things (IoT)”, In: *Proceedings of the IEEE 2nd International Conference on Consumer Electronics, Communications and Networks (CECNet)*, pp. 1282-1285, April. 2012.
- [19] C. H. Liu, B. Yang, and T. Liu, “Efficient naming, addressing and profile services in Internet-of-Things sensory environments”, *Ad Hoc Networks*, vol. 18, pp. 85-101, 2014.
- [20] M. Bauer, M. Boussard, N. Bui, F. Carrez, Ch. Jardak, J. D. Loof, C. Magerkurth, S. Meissner, A. Nettsträter, A. Olivereau, M. Thoma, J. W. Walewski, J. Stefa and A. Salinas, “Internet of Things – Architecture Deliverable D1.5, Final architectural reference model for the IoT v3.0”, *IoT-A Project Consortium*, 2013.
- [21] M. Boland, *IoE and IoT Getting “Everything” to Happen*, Cisco Systems, IoT Asia, Singapor, April. 2014.
- [22] Recommendation ITU-T Y.2060, “SERIES Y: Global Information Infrastructure, Internet Protocol Aspects and next-generation Networks, Overview of the Internet of things”, 2013, Available: <https://www.itu.int/rec/T-REC-Y.2060-201206-I/en> [accessed: 8/20/2016].
- [23] J. Holler, V. T. siatsis, C. Mulligan, S. Karnouskos, S. Avesand and D. Boyle, “From Machine-to-Machine to the Internet of Things : Introduction to a new Age of Intelligence”, AP Publisher : Academic Press is an imprint of Elsevier, 2014.
- [24] S. Distefano, G. Merlino, A. Puliafito, “A utility paradigm for IoT: The sensing Cloud”, *Pervasive and Mobile Computing*, vol. 20, pp. 127-144, 2015.
- [25] S. Li, L. D. Xu and S. Zhao, “The internet of things: a survey”, *Information Systems Frontiers*, vol. 17, no. 2, pp. 243-259, 2015.
- [26] (8/14/2016). WOA. Available: https://en.wikipedia.org/wiki/Web-oriented_architecture.
- [27] (8/16/2016). WOA. Available: <http://www.gartner.com/it-glossary/web-oriented-architecture-woa>.
- [28] R. Buyya and A. V. Dastjerdi, “Internet of Things, Principles and Paradigm”, 1st Edition, Elsevier Press, 2016.
- [29] X. Jianguo, X. Gang and Y. Mengmeng, “Monitoring system design and implementation based on the Internet of Things”, In: *Proceedings of the IEEE fourth international conference on digital manufacturing and automation (ICDMA)*, Qingdao, China, June. 2013.
- [30] R. Kanagasundaram, S. Majumdar, M. Zaman, P. Srivastava and N. Goel, “Exposing resources as Web services:a performance oriented approach”, In: *Proceedings of the IEEE international symposium on performance evaluation of computer and telecommunication systems (SPECTS)*, Genoa, Italy, July. 2012.
- [31] Y. Rong, B. Li and Y. HU, “An Experimental Study for Intelligent Logistics: A Middleware Approach”, *Chinese Journal of Electronics, IEEE*, vol. 25, no. 3, pp. 561-569, 2016.
- [32] A. Antoni, M. Marjanovi, K. Pripuzic and I. PodnarZarko, “A mobile crowd sensing ecosystem enabled by CUPUS-Cloud-based publish-subscribe middleware for the Internet of Things”, *Future Generation Computer Systems*, vol. 56, pp. 607-622, 2016.
- [33] S. M. Balakrishnan and A. K. Sangaiah, “MIFIM-Middleware solution for service centric anomaly in future internet models”, *Future Generation Computer Systems*, vol. 74, pp. 349-365, 2017.

- [34] H. Jiang, S. Zhao, Y. Zhang and Y. Chen, “The cooperative effect between technology standardization and industrial technology innovation based on Newtonian mechanics”, *Information Technology and Management*, vol. 13, no. 4, pp. 251- 262, 2012.
- [35] G. K. Teklemariam, J. Hoebeke, I. Moerman and P. Demeester, “Facilitating the creation of IoT applications through conditional observations in CoAP”, *EURASIP Journal on Wireless Communications and Networking*, 2013.
- [36] A. Castellani, N. Bui, P. Casari, M. Rossi, Z. Shelby and M. Zorzi, “Architecture and protocols for the internet of things: a case study”, in: *Eighth IEEE international conference on pervasive computing and communications workshops (PERCOM workshops)*, pp. 678- 683, 2010.
- [37] B. P. Rimal, E. Choi and I. Lumb, “A taxonomy and survey of cloud computing systems”, In: *Proceedings of the IEEE Fifth international joint conference on INC, IMS and IDC*, pp. 44-51, Aug. 2009.
- [38] Y. Mehmood, C. Görg, M. Muehleisen and A. Timm-Giel, “Mobile M2M communication architectures, upcoming challenges, applications, and future directions”, *EURASIP Journal on Wireless Communications and Networking*, 2015.
- [39] M. Kovatsch, M. Lanter and Z. Shelby, “Californium: scalable cloud services for the internet of things with CoAP”, In: *Proceedings of the fourth international conference on the Internet of Things (IoT 2014)*, 2014.
- [40] G. Wang, X. Zhong, S. Mei and J. Wang, “An adaptive medium access control mechanism for cellular based machine-to-machine (M2M) communication”, In: *Proceedings of the IEEE International Conference on Wireless Information Technology and Systems (ICWITS)*, 2010.
- [41] Y. Chen and W. Wang, “Machine-to-machine communication in LTE-A”, In: *Proceedings of the IEEE 72nd Vehicular Technology Conference - Fall (VTC 2010-Fall)*, Sept. 2010.
- [42] C. Y. Hsu, C. H. Yen and C. T. Chou, “An adaptive multichannel protocol for large-scale machine-to-machine (M2M) networks”, In: *Proceedings of the IEEE 9th International Wireless Communications and Mobile Computing Conference (IWCMC)*, pp. 1223-1228, Italy, July. 2013.
- [43] C. W. Park, D. Hwang and T. J. Lee, “Enhancement of IEEE 802.11ah MAC for M2M Communications”, *IEEE Communications Letters*, vol.18, no. 7, pp. 1151-1154 , 2014.
- [44] N. K. Pratas, H. Thomsen, C. Stefanovic and P. Popovski, “Code expanded random access for machine-type communications”, In: *Proceedings of the IEEE Globecom Workshops*, pp. 1681-1686, Dec. 2012.
- [45] J. Martocci, P. D. Mil, N. Riou and W. Vermeylen, “Building Automation Routing Requirements in Low-Power and Lossy Networks”, RFC 5867, Internet Engineering Task Force (IETF), June 2010, Available: <https://tools.ietf.org/pdf/rfc5867.pdf> [accessed: 8/25/2016].
- [46] A. Brandt, J. Buron and G. Porcu, “Home Automation Routing Requirements in Low Power and Lossy Networks”, RFC 5826, Internet Engineering Task Force (IETF), April. 2010, Available: <https://tools.ietf.org/pdf/draft-ietf-roll-home-routing-reqs-08.pdf> [accessed: 8/25/2016].
- [47] M. Dohler, T. Watteyne, T. Winter and D. Barthel, “Routing Requirements for Urban Low-Power and Lossy Networks”, RFC 5548, Internet Engineering Task Force (IETF), May. 2009, Available: <https://tools.ietf.org/pdf/rfc5548.pdf> [accessed: 8/30/2016].

- [48] J. Misić, S. Shafi and V. B. Misić, “Performance limitations of the MAC layer in 802.15.4 low rate WPAN”, *Computer Communications*, vol. 29, no. 13-14, pp. 2534–2541, 2006.
- [49] P. Park, P. D. Marco, C. Fischione and K. H. Johansson, “Modeling and Optimization of the IEEE 802.15.4 Protocol for Reliable and Timely Communications”, *IEEE Transactions on Parallel and Distributed Systems*, vol. 24, no. 3, pp. 550-564, 2013.
- [50] S. C. Ergen, P. D. Marco and C. Fischione, “MAC Protocol engine for sensor networks”, In: *Proceedings of the IEEE Global Communications Conference*, 2009.
- [51] S. Hakak, S. A. Latif, G. Gilkar and M. K. Alam, “Performance analysis of DYMO and DSR protocols under variation of DSSS rate”, In: *Proceedings of the IEEE International Conference on Informatics, Electronics & Vision (ICIEV)*, 2014.
- [52] J. Karlsson, L. S. Dooley and G. Pulkkis, “Routing security in mobile ad-hoc networks”, *Issues in Informing Science and Information Technology*, vol. 9, pp. 369-383, 2012.
- [53] T. Qiu, Y. Lv, F. Xia, N. Chen, J. Wan and A. Tolba, “ERGIT: An efficient routing protocol for emergency response Internet of Things”, *Journal of Network and Computer Applications*, vol. 72, pp. 104-112, 2016.
- [54] S. Sicari, A. Rizzardi, L.A. Grieco and A. Coen-Porisini, “Security, privacy and trust in Internet of Things: The road ahead”, *Computer Networks*. Vol 76, pp. 146-164, 2015.
- [55] M. Turkanovic, B. Brumen and M. Hölbl, “A novel user authentication and key agreement scheme for heterogeneous ad hoc wireless sensor networks, based on the Internet of Things notion”, *Ad Hoc Networks*, vol. 20, pp. 96-112, 2014.
- [56] M. S. Farash, M. Turkanović, S. Kumari and M. Hölbl, “An efficient user authentication and key agreement scheme for heterogeneous wireless sensor network tailored for the Internet of Things environment”, *Ad Hoc Networks*, vol. 36, pp. 152-176, 2015.
- [57] R. Amin, SK. H. Islam, G. P. Biswas, M. K. Khan, L. Leng and N. Kumar, “Design of anonymity preserving three-factor authenticated key exchange protocol for wireless sensor network”, *Computer Networks*, vol. 101, pp. 42-62, 2016.
- [58] J. Li, M. Wen, and T. Zhang, “Group-based authentication and key agreement with dynamic policy updating for MTC in LTE-A Networks”, *IEEE Internet of Things Journal*, vol. 3, no. 3, pp. 408-417, 2016.
- [59] F. Li, Y. Han and C. Jin, “Practical access control for sensor networks in the context of the Internet of Things”, *Computer Communications*, vol 89-90, pp. 154-164, 2016.
- [60] J. Lee, J. Woo Seo, H. Ko and H. Kim, “TARD: Temporary Access Rights Delegation for guest network devices”, *Journal of Computer and System Sciences*, vol. 86, pp. 59-69, 2017.
- [61] A. Rizzardi, S. Sicari, D. Miorandi and A. Coen-Porisini, “AUPS: An Open Source AUthenticated Publish/Subscribe system for the Internet of Things”, *Information Systems*, vol. 62, pp. 29-41, 2016.
- [62] I. Chatzigiannakis, A. Vitaletti and A. Pyrgelis, “A privacy-preserving smart parking system using an IoT elliptic curve based security platform”, *Computer Communications*, vol. 89-90, pp. 165-177, 2016.
- [63] G. Avoine, M. Bingol, X. Carpent and S. Yalcin, “Privacy-friendly authentication in RFID systems: on sublinear protocols based on symmetric-key cryptography”, *IEEE Transactions on Mobile Computing*, vol. 12, no. 10, pp. 2037–2049, 2013.
- [64] M. Akgün, M. Ufuk Çaglayan, “Providing destructive privacy and scalability in RFID systems using PUFs”, *Ad Hoc Networks*, vol. 32, pp. 32-42, 2015.

- [65] A. Jacobsson, M. Boldt and B. Carlsson, “A risk analysis of a smart home automation system”, *Future Generation Computer Systems*, vol. 56, pp. 719-733, 2016.
- [66] A. Liu, Q. Zhang, Z. Li, Y. J. Choi, J. Li and N. Komuro, “A green and reliable communication modeling for industrial internet of things”, *Computers and Electrical Engineering*, vol. 58, pp. 364-381, 2017.
- [67] M. Ahmad and S. Jose, “Designing for the Internet of Things: A Paradigm Shift in Reliability”, In: *Proceedings of the IEEE 65th Electronic Components and Technology Conference (ECTC)*, May. 2015.
- [68] J. H. Park, “All-terminal reliability analysis of wireless networks of redundant radio modules”, *IEEE Internet of Things Journal*, vol. 3, no. 2, pp. 219-230, 2016.
- [69] A. Nessa and M. Kadoch, “Joint Network Channel Fountain Schemes for Machine Type Communications over LTE-Advanced”, *IEEE Internet of Things Journal*, vol. 3, no. 3, pp. 418-427, 2016.
- [70] T. Dimitriou, “Key Evolving RFID Systems: Forward/Backward Privacy and Ownership Transfer of RFID tags”, *Ad Hoc Networks*, vol. 37, no. 2, pp. 195–208, 2016.
- [71] P. Rawat, K. D. Singh, H. Chaouchi and J. M. Bonnin, “Wireless sensor networks: a survey on recent developments and potential synergies”, *The Journal of Supercomputing*, vol. 68, no. 1, pp.1-48, 2014.
- [72] B. Lee and S-J. Kim, “Energy-efficient sensor device personalization scheme for the internet of things and wireless sensor networks”, *IEICE Transactions on Communications Journal*, vol. E98.B, no. 1, pp. 231-241, 2015.
- [73] Z. Sheng, C. Mahapatra, C. Zhu, and V. C. M. Leung, “Recent advances in industrial wireless sensor networks toward efficient management in IoT”, *IEEE Access Journal*, vol.3, pp. 622-637, 2015.
- [74] P. Porambage, A. Braeken and C. Schmitt, “Group key establishment for enabling secure multicast communication in wireless sensor networks deployed for IoT applications”, *IEEE Access Journal*, vol. 3, pp. 1503-1511, 2015.
- [75] M. Díaz, C. Martín and B. Rubio, “State-of-the-art, challenges, and open issues in the integration of Internet of Things and Cloud Computing”, *Journal of Network and Computer Applications*, vol. 67, pp. 99-117, 2016.
- [76] Y. Xu and S. Hela, “Scalable Cloud-Sensor Architecture for the Internet of Things”, *IEEE Internet of Things Journal*, vo. 13, no. 63 , pp 285 - 298, 2016.
- [77] C. Chen, R. Bose and A. Helal, “Atlas: An open model for automatic integration and tele-programming of smart objects”, In: *Proceedings of DIPS0’09*, Orlando, Florida, 2009.
- [78] S. Luo and B. Ren, “The Monitoring and Managing Application of Cloud Computing Based on Internet of Things”, *Computer Methods and Programs in Biomedicine*, Elsevier, vol. 130, no. C , pp.154-161, 2016.
- [79] A. Škraba, R. Stojanovic, A. Zupan, A. Koložvari and D. Kofjac, “Speech-controlled cloud-based wheelchair platform for disabled persons”, *Microprocessors and Microsystems*, vol. 39, no. 8, pp. 819-828, 2015.
- [80] P. Persson and O. Angelsmark, “Calvin – Merging Cloud and IoT”, *Procedia Computer Science*, vol. 52, pp. 210-217, 2015.
- [81] A. S. Tanenbaum, “Distributed operating systems”, first edition, Pearson, 1994.

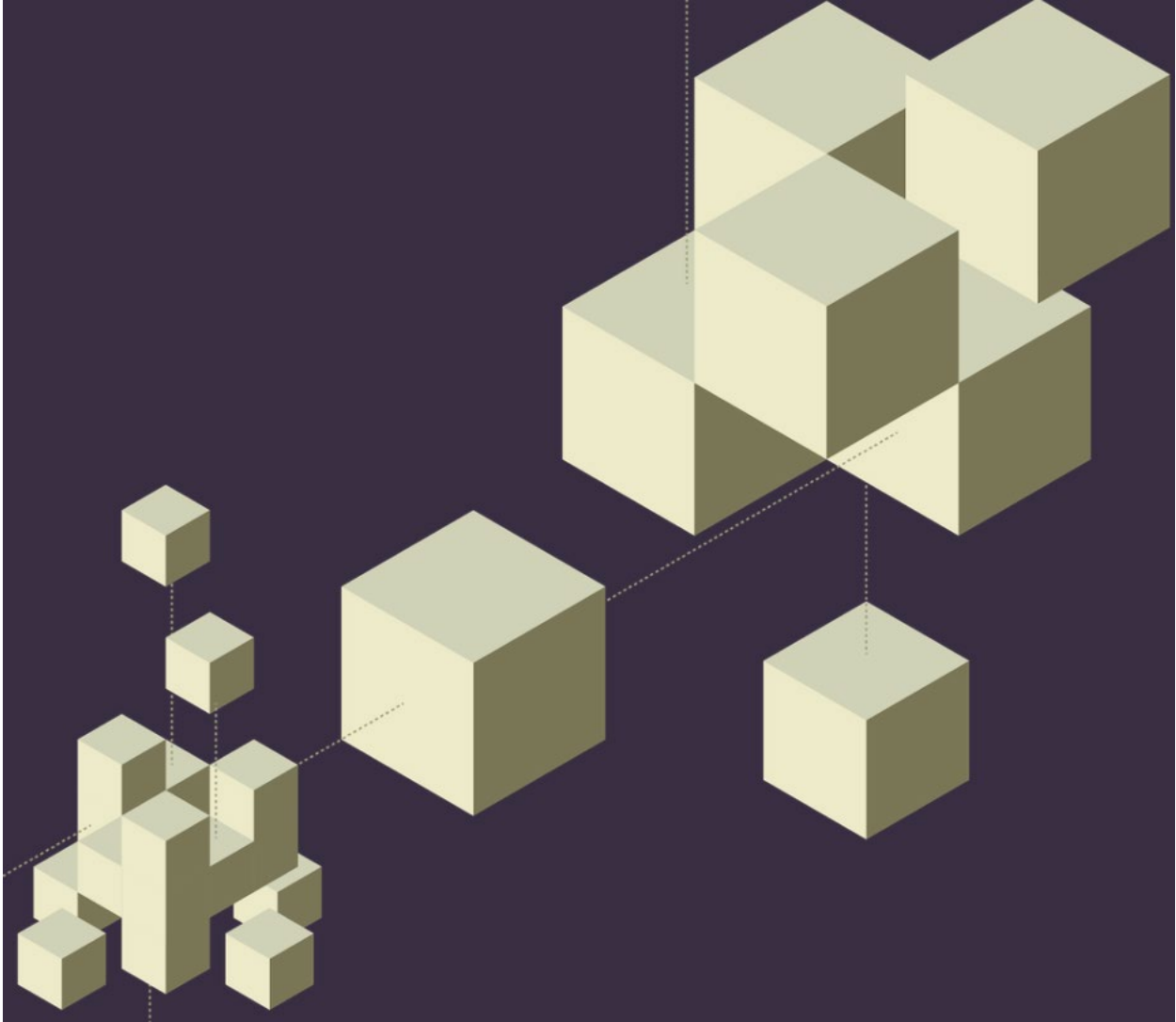
- [82] B. Ahlgren, C. Dannewitz, C. Imbrenda, D. Kutscher and B. Ohlman, “A survey of information-centric networking”, *IEEE Communications Magazine*, vol. 50, no. 7, pp. 26-36, 2012.
- [83] E. Baccelli, C. Mehlis, O. Hahm and T. C. Schmidt, “Information Centric Networking in the IoT: Experiments with NDN in the Wild”, In: *Proceedings of the 1st ACM Conference on Information-Centric Networking (ACM-ICN '14)*, pp. 77-86, 2014.
- [84] M. Amadeo, O. Briante, C. Campolo, A. Molinaro and G. Ruggerit, “Information-centric networking for M2M communications: Design and deployment”, *Computer Communications*, vol. 89-90, pp. 105–116, 2016.
- [85] G. Xylomenos, C. Ververidis, V. Siris, N. Fotiou, C. Tsilopoulos, X. Vasilakos, K. Katsaros and G. Polyzos, “A survey of informationcentric networking research”, *IEEE Communications Surveys & Tutorials*, vol. 16, no.2 ,pp. 1024-1049, 2014.
- [86] Y. Jin, P. Kulkarni, S. Gormus and M. Sooriyabandara, “Content centric and load balancing aware dynamic data aggregation in multi-hop wireless networks”, In: *Proceedings of the IEEE 8th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob)*, 2012.
- [87] H. Kim, T. Benson, A. Akella, and N. Feamster, “The evolution of network configuration: a tale of two campuses”, In: *Proceedings of the 2011 ACM SIGCOMM conference on Internet measurement conference*, pp. 499–514, Nov. 2011.
- [88] “What’s Behind Network Downtime?” White Paper, Juniper Networks, May. 2008, Available: <https://www.935.ibm.com/services/sg/gts/pdf/200249.pdf> [accessed: 9/1/2016].
- [89] W. Xia, Y. Wen, C. H. Foh, D. Niyato and H. Xie, “A Survey on Software-Defined Networking”, *IEEE Communications Surveys & Tutorials*, vol. 17, no. 1, pp. 27-51, 2015.
- [90] “Software-Defined Networking: The New Norm for Networks”, White Paper, Open Networking Foundation (ONF), Apr. 2012. Available: <https://www.opennetworking.org/images/stories/downloads/white-papers/wp-sdn-newnorm.pdf> [accessed: 9/8/2016].
- [91] Y. Jararweh, M. Al-Ayyoub, A. Darabseh and A. Rindos, “SDIoT: a software defined based internet of things framework”, *Journal of Ambient Intelligence and Humanized Computing*, vol. 1, no. 4, pp. 453-461, 2015.
- [92] A. Hakiri, P. Berthou and A. Gokhale, “Publish/subscribe-enabled software defined networking for efficient and scalable IoT communications”, *IEEE Communications Magazine*, vol. 53, no. 9, 2015.
- [93] J. Liu, Y. Li and M. Chen, “Software-defined internet of things for smart urban sensing”, *IEEE Communications Magazine*, vol. 53, no. 9, 2015.
- [94] M. Aazam and E. N. Huh, “Fog Computing and Smart Gateway Based Communication for Cloud of Things”, In: *Proceedings of the IEEE International Conference on Future Internet of Things and Cloud (FiCloud)*, 2014.
- [95] V. Sehgal, A. Patrick, A. Soni and L. Rajput, “Smart human security framework using internet of things, Cloud and fog computing”, *Advances in Intelligent Systems and Computing Journal*, vol. 321, pp. 251-263, 2015.
- [96] Z. Zhou, D. Zhao, X. Xu, C. Du and H. Sun, “Periodic Query Optimization Leveraging Popularity-Based Caching in Wireless Sensor Networks for Industrial IoT Applications”, *Mobile Networks and Applications Journal*, vol. 20, no. 2, pp. 124-136, 2015.

- [97] C. Zhai, Z. Zou, Q. Chen, L. Zheog and H. Tenhunen, “Delay-Aware and Reliability-Aware Contention-Free MF-TDMA Protocol for automated RFID monitoring in industrial IoT”, *Journal of Industrial Information Integration*, vol. 3 , pp. 8-19, 2016.
- [98] L. Catarinucci, D. de Donno, L. Mainetti, L. Palano, L. Patrono, M. L. Stefanizzi and L. Tarricone, “An IoT-Aware Architecture for Smart Healthcare Systems”, *IEEE Internet of Things Journal*, vol. 2, no. 6, pp. 515 - 526, 2015.
- [99] J. Suarez, J. Quevedo, I. Vidal, D. Corujo, J. Garcia-Reinoso and R. L. Aguiar, “A secure IoT management architecture based on Information-Centric Networking”, *Journal of Network and Computer Applications*, vol. 63 , pp. 190-204, 2016.
- [100] J. Quevedo, M. Antunes, D. Corujo, D. Gomes and R. Aguiar, “On the application of contextual IoT service discovery in Information Centric Networks”, *Computer Communications*, vol. 89-90 , pp.117 – 127, 2016.
- [101] Z. Gu, Q. Zhao. “A state-of-the-art survey on real-time issues in embedded systems virtualization”, *Journal of Software Engineering and Applications*, vol. 5, pp. 277-290, 2012.
- [102] W. Liu, T. Nishio, R. Shinkuma and T. Takahashi, “Adaptive resource discovery in mobile cloud computing”, *Computer Communications*, vol. 50, pp. 119-129, 2014.
- [103] T. Nishio, R. Shinkuma, T. Takahashi and N. B. Mandayam, “Service-oriented heterogeneous resource sharing for optimizing service latency in mobile cloud”, In: *Proceedings of the first international workshop on mobile cloud computing & networking*, ACM, pp. 19-26, July. 2013.
- [104] M. Ruta, F. Scioscia, A. Pinto, E. Di Sciascio, F. Gramegna, S. Ieva and G. Loseto, “Resource annotation, dissemination and discovery in the Semantic Web of Things: a CoAP-based framework”, In: *Proceedings of the IEEE international conference on Green computing and communications and IEEE Internet of Things and IEEE Cyber, Physical and Social Computing*, p. 527–534, Aug. 2013.
- [105] D. J. Abadi, S. Madden and W. Linder, “REED: robust, efficient filtering and event detection in sensor networks”, In: *Proceedings of the 31st international conference on Very large data base (VLDB)*, ACM, Norway, pp. 769-780, 2005.
- [106] Y. Yao and J. Gehrke, “The cougar approach to in-network query processing in sensor networks”, *ACM SIGMOD Record*, vol. 31, no. 3, pp. 9-18, 2002.
- [107] K. C. K. Lee, W. C. Lee, B. Zheng and J. Winter, “Processing multiple aggregation queries in geo-sensor networks”, In: *Proceedings of the eleventh international conference on database systems for advanced applications (DASFAA)*, pp. 20-34, April. 2006.
- [108] S. R. Madden, M. J. Franklin, J. M. Hellerstein and W. Hong, “Tinydb: an acquisitional query processing system for sensor networks”, *ACM Transactions on Database Systems (TODS)*, vol. 30, no. 1, pp. 122-173, 2005.
- [109] J. Li and S. Ji and J. Zhu, “Data caching based queries in multi sink sensor networks”, In: *IEEE proceedings of the fifth international conference on mobile ad-hoc and sensor networks*, Dec. 2009.
- [110] C. Y. Chow, H. V. Leong and A. T. S. Chan. “GroCoca: group-based peer-to-peer cooperative caching in mobile environment”, *IEEE Journal on Selected Areas in Communications*, vol. 25, no. 1, pp.179-191, 2007.
- [111] S. Abdullah and K. Yang, “An Energy Efficient Message Scheduling Algorithm Considering Node Failure in IoT Environment”, *Wireless Personal Communications*, vol. 79, no. 3, pp. 1815-1835, 2014.

- [112] B-G. Chun, S. Ihm, P. Maniatis, M. Naik and A. Patti, "Clonecloud: elastic execution between mobile device and cloud", In: Proceedings of the sixth conference on computer systems, pp. 301-314, 2011.
- [113] S. Kosta, A. Aucinas, P. Hui, R. Mortier and X. Zhang, "Thinkair: dynamic resource allocation and parallel execution in the cloud for mobile code offloading", In: 2012 proceedings IEEE INFOCOM, pp. 945-953, March. 2012.
- [114] M. S. Gordon, D. A. Jamshidi, S. Mahlke, Z. M. Mao and X. Chen, "COMET: code offload by migrating execution transparently", In: Proceedings of the 10th USENIX conference on Operating Systems Design and Implementation (OSDI), pp. 93-106, Oct. 2012.
- [115] S. Kim, "Nested game-based computation offloading scheme for Mobile Cloud IoT systems", EURASIP Journal on Wireless Communications and Networking, pp. 229-239, 2015.
- [116] Y. Park and S. Kim, "Game-based data offloading scheme for IoT system traffic congestion problems", EURASIP Journal on Wireless Communications and Networking, pp. 192-201, 2015.
- [117] L. Li, S. Li and S. Zhao, "QoS-Aware Scheduling of Services-Oriented Internet of Things", IEEE Transactions on Industrial Informatics, vol. 10, no. 2, May. 2014.
- [118] J. Pradilla, C. Palau and M. Esteve, "SOSLite: Lightweight Sensor Observation Service (SOS)", IEEE Latin America Transactions, vol. 13, no. 12, pp. 3758-3764, 2015.
- [119] R. Yerra, M. P. R. S. Kiran and R. Pachamuthu, "Reliability and delay analysis of slotted anycast multi-hop wireless networks targeting dense traffic IoT applications", IEEE Communications Letters Journal, vol. 19, no. 5, pp. 727-730, 2015.
- [120] S. Poslad, "A Semantic IoT Early Warning System for Natural Environment Crisis Management", IEEE Transactions on Emerging Topics in Computing, vol. 3, no. 2, pp. 246-257, 2015.
- [121] S. Fang, L. Xu, Y. Zhu, Y. Liu, Z. Liu, H. Pei, J. Yan and H. Zhang "An integrated information system for snowmelt flood early-warning based on internet of things", Information Systems Frontiers Journal, vol. 17, no. 2, pp. 321-335, 2015.
- [122] R. Mayer, B. Koldehofe and K. Rothermel, "Predictable Low-Latency Event Detection With Parallel Complex Event Processing", IEEE Internet of Things Journal, vol. 2, no. 4, pp. 274-286, 2015.
- [123] J. Kempf, J. Arkko, N. Beheshti and K. Yedavalli, "Thoughts on reliability in the Internet of Things", In: Proceedings of the Interconnecting Smart Objects with the Internet Workshop, March. 2011. Available: <https://www.iab.org/wp-content/IABuploads/2011/03/Kempf.pdf> [accessed: 9/5/2016].
- [124] P. Yang, "PRLS-INVES: A General Experimental Investigation Strategy for High Accuracy and Precision in Passive RFID Location Systems", IEEE Internet of Things Journal, vol. 2, no. 2, pp. 159-167, 2015.
- [125] O. Vermesan, P. Friees, "Internet of Things - From Research and Innovation to Market Deployment", River Publisher, 2014.
- [126] I. G. Smith, O. Vermesan, P. Friees and A. Furness, "The Internet of Things 2012 New Horizons", Halifax Publisher, UK, 2012.
- [127] L. Lolis, C. Bernir, M. Pelissier, D. Dallet and J.B. Begueret, "Bandpass Sampling RX System Design Issues and Architecture Comparison for Low Power RF Standards", In: Proceedings of IEEE International Symposium on Circuits and Systems (ISCAS), France, May. 2010.
- [128] Y. Hayashi, K. Yahagi, H. Sato, K. Sato and M. Muratani, "'Easy-to-use" RF-solutions for IoT applications", In: Proceedings of the IEEE International Symposium on Radio-Frequency Integration Technology (RFIT), pp. 13-15, 2015.

- [129] P. Bousseaud, E. Novakov and J. M. Fournier, “A direct RF signal sampling integrated receiver for IoT applications”, In: Proceedings of the IEEE International Conference on Advanced Technologies for Communications (ATC), pp. 237-242, Oct. 2015.
- [130] Y. Liu, K. L. Ren, H.F. Hofmann and Q. Zhang, “Investigation of electrostrictive polymers for energy harvesting”, IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, vol. 52, no. 12, pp. 2411-2417, 2005.
- [131] K. Cengiz and T. Dag. “A review on the recent energy-efficient approaches for the Internet protocol stack”, EURASIP Journal on Wireless Communications and Networking, pp. 108-129, 2015.
- [132] M. Gorlatova, J. Sarik, G. Grebla, M. Cong, I. Kymissis and G. Zussman, “Movers and Shakers: Kinetic Energy Harvesting for the Internet of Things”, IEEE Journal on Selected Areas in Communications, vol. 33, no. 8, pp. 1624-1639, 2015.
- [133] Y. Wang, Y. Liu, C. Wang, Z. Li, X. Sheng, H. G. Lee, N. Chang and H. Yang, “Storage-less and Converter-less Photovoltaic Energy Harvesting with Maximum Power Point Tracking for Internet of Things”, IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems, vol. 35, no.2 , pp. 173-186, 2016.
- [134] D. Gascon, A. Asin, “50 sensor applications for a smarterworld”. Available: http://www.libelium.com/resources/top_50_iot_sensor_applications_ranking/ [accessed: 9/7/2016].
- [135] S. Kim, Kim S. “A multi-criteria approach toward discovering killer IoT application in Korea”, Technological Forecasting & Social Change, vol. 102, pp.143–15, 2016.
- [136] M2M World of Connected Services (IoT), Available: <http://www.beechamresearch.com/article.aspx?id=4> [accessed: 9/11/2016].
- [137] X. Xiaojiang, W. Jianli and L. Mingdong, “Services and key technologies of the Internet of Things”, ZTE Communication, SPECIAL TOPIC: Evolution and Revolution of Internet Architecture, vol. 8, no. 2, pp. 26-29, 2010.
- [138] M. Gigli and S. Koo, “Internet of Things: Services and applications categorization”, Advances in Internet of Things (AIT), vol. 1, no. 2, pp. 27–31, 2011.
- [139] S. M. R. Islam, D. Kwak, M. H. Kabir, M. Hossain and K-S. Kwak, “The Internet of Things for Health Care: A Comprehensive Survey”, IEEE Access, Vol. 3, pp. 678-708, 2015.
- [140] X. Luo, J. Liua, D. Zhanga and X. Chang, “A large-scale web QoS prediction scheme for the Industrial Internet of Things based on a kernel machine learning algorithm”, Computer Networks, Vol. 101, pp. 81-89, 2016.
- [141] M. M. Rathore, A. Ahmad, A. Paul and S. Rho, “Urban planning and building smart cities based on the Internet of Things using Big Data analytics”, Computer Networks, Vol. 101, pp. 63-80, 2016.
- [142] P. Ruckebusch, E.D. Poorter, C. Fortuna and I. Moerman, “GITAR: Generic extension for Internet-of-Things ARchitectures enabling dynamic updates of network and application modules”, Ad Hoc Networks, vol. 36, no. 1, pp. 127-151 2016.
- [143] G. Barbon, M. Margolis, F. Palumbo, F. Raimondi and N. Weldin, “Taking Arduino to the Internet of Things: The ASIPprogramming model”, Computer Communications, Vol. 89-90, pp. 128-140, 2016.
- [144] S. Nastic, H-L. Truong and S. Dustdar, “SDG-Pro: a programming framework for software-defined IoT cloud gateways”, Journal of Internet Services and Applications, Vol. 6, pp. 21-37, 2015.

- [145] J. A. Silva, E. R. Faria, R. C. Barros, E. R. Hruschka, A. C. P. L. F. de Carvalho, and J. Gama, “Data stream clustering: A survey”, *ACM Computing Surveys*, Vol. 46, No. 1, 2013.
- [146] Y. Qin , Q. Z. Sheng, N. J. G. Falkner, S. Dustdar, H. Wang and A. V. Vasilakos, “When things matter: A survey on data-centric internet of things”, *Journal of Network and Computer Applications*, vol. 64, pp. 137-153, 2016.
- [147] J. Liu, C. Fang and N. Ansari, “Request Dependency Graph: A Model for Web Usage Mining in Large-scale Web of Things”, *IEEE Internet of Things Journal*, vol. 3, no. 4, pp. 598 - 608, 2016.
- [148] G. Poghosyan, I. Pefkianakis, P. Le Guyadec and V. Christophides, “Mining usage patterns in residential intranet of things”, *Procedia Computer Science*, vol. 83, pp. 988-993, 2016.
- [149] T. Zhu, S. Dhelim , Z. Zhou , S. Yang and H. Ning, “An architecture for aggregating information from distributed data nodes for industrial internet of things”, *Computers and Electrical Engineering*, vol. 58, pp. 337-349, 2017.
- [150] N. Mehdiyev, J. Krumeich, D. Enke, D. Werth and P. Loos, “Determination of Rule Patterns in Complex Event Processing Using Machine Learning Techniques”, *Procedia Computer Science*, vol. 61, pp. 395-401, 2015.
- [151] C. Bormann, M. Ersue and A. Keranen, “Terminology for constrained node networks,” RFC 7228 (Informational), Internet Engineering Task Force (IETF), May 2014, Available: <https://tools.ietf.org/pdf/rfc7228.pdf> [accessed:8/23/2016].
- [152] (9/15/2016). A Guide to Internet of Things (IoT) Processors, 2016. Available: <https://imgtec.com/blog/a-guide-to-iot-processors/>.
- [153] (9/18/2016). Using an IoT gateway to connect the “Things” to the cloud. Available: <http://internetofthingsagenda.techtarget.com/feature/Using-an-IoT-gateway-to-connect-the-Things-to-the-cloud>
- [154] Q. Xu, K. M. M. Aung, Y. Zhu and K. L. Yong, “Building a large-scale object-based active storage platform for data analytics in the internet of things”, *The Journal of Supercomputing*, vol. 72, no. 7, pp. 2796-2814, 2016.
- [155] Kizza and J. Migga, “Guide to Computer Network Security”, *Computer Communications and Networks*, 2015.
- [156] R. Margaret, defense in depth [Blog post], June. 2007, Available: <http://searchsecurity.techtarget.com/definition/defense-in-depth> [accessed:10/30/2016].
- [157] S. Raza, T. Voigt and L. Wallgren, “SVELTE: Real-time intrusion detection in the Internet of Things”, *Ad Hoc Networks*, vol. 11, no. 8, pp. 2661-2674, 2013.
- [158] G. Costamagna, P. Kasinathan, H. Khaleel, C. Pastrone and M. A. Spirito, “An IDS framework for internet of things empowered by 6LoWPAN”, In: *Proceedings of the ACM SIGSAC Conference on Computer and Communications Security*, pp. 1337-1340, Germany, Nov. 2013.
- [159] A. Grau, “The Internet Of Things Needs Firewalls Too”, 2013. Available: <http://electronicdesign.com/communications/internet-thingsneeds-firewalls-too> [accessed: 23/10/2016].
- [160] S. Kubler, K. Främling and A. Buda, “A standardized approach to deal with firewall and mobility policies in the IoT”, *Pervasive and Mobile Computing*, vol. 20, pp. 100-114, 2015.
- [161] (18/10/2016). Ponte - M2M Bridge Framework for REST developers. Available: <http://eclipse.org/proposals/technology.ponte/>.



COMMENTARY [A]

Shoumen Datta

HAPHAZARD REALITY – IOT IS A METAPHOR

THIS PAGE IS LEFT BLANK

Dynamic Socio-Economic Disequilibrium Catalyzed by Internet of Things

Dr Shoumen Palit Austin Datta

Senior Member, MIT Auto-ID Labs, Research Affiliate, Department of Mechanical Engineering,

Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, Massachusetts 02139, USA

Senior Scientist, MDPnP Lab, Department of Anesthesiology, Massachusetts General Hospital, Harvard Medical School,

Partners MGH Research, 65 Landsdowne Street, Cambridge, Massachusetts 02139, USA

shoumen@mit.edu • sdatta8@mg.harvard.edu

Previous English version “*Dynamic Socio-Economic Disequilibrium Catalyzed by the Internet of Things*” in *Journal of Innovation Management* (ISSN 2183-0606), vol. 3, n. 3, 2015; pages 4-9 • <http://hdl.handle.net/10216/80026>
<https://repositorio-aberto.up.pt/bitstream/10216/80026/2/104497.pdf>

The concept of the internet of things (IoT), and its variations [1], data of things (DoT), network of things (NoT) and the industrial internet of things (IIoT), may have started in earnest, circa 1988 with Mark Weiser of Xerox Palo Alto Research Center, who suggested that computers may “*weave themselves into the fabric of everyday life*” and influence the future of business (*Scientific American*, 1991). Weiser was referring to the discussion by Herbert Simon in his 1987 paper “*The Steam Engine and the Computer: What makes technology revolutionary*” where Herbert Simon frames his thoughts about the computer, “*you have to make friends with it, talk to it, let it talk to you.*”

Contrary to the media hype, neither the vision nor the implication of the Internet of Things (IoT) were the outcome of a marketing manager from P&G [2]. In the seminal paper (2000) *THE NETWORKED PHYSICAL WORLD* (MIT-AUTOID-WH-001) provided clues to the concept of the IoT [3] and the evolution of the industrial internet. Facts about IoT as well as the name “internet of things” [4] was discussed at a symposium at the MIT Sloan School.

Connecting physical world objects (made of atoms) with information (packaged as bits) may segue to another revolution, predicted by many, among them, Neil Gershenfeld. The current wave is referred to as the 3rd industrial revolution, in relation to the Information Age (2nd) and the First Industrial Revolution. In the EU, the trend is also referred to as Industrie 4.0 but these versions are also cyber-physical systems (CPS).

Revolutions are supposed to reshape the future. The current wave will not be an exception. It will generate friction, both social and economic. The clash of status quo with business *not as usual*. The collision between the imaginative vs those whose imagination is out of focus. The asphyxiation from old world ideas, versus, geographically-agnostic unbridled innovation, unleashing the wizardry of technology to leak into our *daily* lives.

Pundits, market observers and industries, are divided over the transformational capabilities of technologies, and the ubiquity of connectivity that IoT may necessitate. Social friction is erupting from erosion of privacy in its conventional format and the redefinition of privacy which challenges old world beliefs. There is justifiable concern about security, yet measurable reluctance to give up the benefits associated with either. Financial friction is evident both in industrial nations and emerging economies whenever unskilled labor is a part of the target. Labor, in general, abhors automation and robotics. It shrinks the demand for unskilled labor. The latter conjures a negative impression, even if the actual impact on social economy, as a whole, may be positive, over time.

These observations are centuries old. It will be repeated, again, albeit in different shades. According to economic historian Norman Poire, “the five centuries that span the years 1440 to 1939 were among the most dynamic in all of history. Many technological advances surfaced during that time, but three inventions stand above the rest as turning points in the direction of technology that led to decisive social change. The invention of the printing press by Johannes Gutenberg in 1440 spurred the arrival of the Information Revolution that spread the Renaissance throughout Europe. In 1609, Galileo Galilei’s telescope ushered in the Scientific Revolution and the Age of Reason. The Industrial Revolution and Marxism arrived shortly after James Watt unveiled his steam engine in 1769. In 1939, a fourth technological revolution began. In that year, John Atanasoff and his graduate student Clifford Berry, invented the electronic digital computer, and unwittingly, with it, the Second Information Revolution.” A little less than century later, we are on the cusp of yet another sea of change, which has the potential to evolve over at least a century. Perhaps, the fruits of progress, may sufficiently unfold or culminate around 2105-2120 [1].

The current (3rd) Industrial Revolution may spur the grand convergence of the industrial revolution with the information revolution, and may include many unknowns. Erik Brynjolfsson and Andrew McAfee at the MIT Sloan School of Management (Center for Digital Business) pontificates about the frictions that may surface from the 3rd revolution, namely, higher unemployment and rising inequality (*Race against the Machine* and *The Second Machine Age*). The incisive insight about inequality may be also found in the works of Joseph Stiglitz (*The Price of Inequality*) and Robert Reich (*Inequality for All*).

Brynjolfsson and McAfee revisit the discussion of higher unemployment which John Maynard Keynes described as “technological unemployment” in the 1930’s. Robert Frank revisits the same topic as technology-catalyzed “winner takes all” labor markets in 1990’s and in *The Darwin Economy*. Brynjolfsson and McAfee expect “our world will prosper on the digital frontier” but what about the *path* to the frontier? The road ahead is fraught with feuding nations, malnutrition, dysfunctional sanitation, inadequate education and poverty of energy. These factors are fueling acrimonious socio-economic frictions which are exacerbated by the pseudo-promise of a resplendent future due to IoT. The latter are perpetrated through glib marketing campaigns sponsored by smug corporations and consulting firms. These collusions are drowning the real benefits of connectivity and IoT.

The design and fruits of IoT may mature in proportion to our ability to interoperate between systems, and platforms, connecting objects and devices, from diverse ecosystems and environments, supporting different standards of operations, tools to acquire data, protocols, applications and analytics. It is impossible to expect the world to support any one common standard.

Hence, not standardization, *per se*, but the *interoperability between* major standards, is key to systemic adoption through **systems** integration of IoT related products and services, including the industrial internet. Industry-enabled open standards for APIs may connect with the global connectivity bus. SMEs may use common **platforms** to offer value-added services, bundled with analytical engines or niche applications. The general purpose [5] technical design, implicated by the IoT metaphor, may offer value only when *systemic* deployment of connectivity improves data acquisition and decision support.

Ultimately, the ability to make sense of the data, information arbitrage or extraction of “intelligence” from data will drive the value proposition of connectivity. In the process of transforming data into information, one must be careful about the tools of the analytical trade lest we should lose the knowledge in the process.

Long before information technology opened the gate to an information society, it was Thomas Stearns Eliot, who asked, “Where is the Life we have lost in living? Where is the wisdom we have lost in knowledge? Where is the knowledge we have lost in the information?” (*The Rock* in *Collected Poems 1909–1935*, Faber & Faber, London, 1951).

There aren't any simple and straight paths between information, knowledge and wisdom [6]. Whoever does not recognize this, will lose knowledge and wisdom, only to find a new, and a dangerous, form of stupidity. This form of stupidity has finally arrived and is now often referred to as "low hanging fruit" in the vernacular of modern day business [7].

The emphasis on low hanging fruits, short term return, prevalent in the business world, may impact the extent of acquisition of data. Inadequate investment may limit the tools necessary to accumulate critical mass of data. However, without sufficient data, the analytical tools may bumble around to unlock hidden patterns in the data. Patterns may be necessary in real time, if dynamic analytical engines (at the edge and core) may be a path to monetization of IoT. New sources of revenue may be created from micro-payments, based on pay-per-analytics model of information arbitrage. The latter may depend on intelligent predictive analytics to augment decision support for various levels of autonomic activities.

One lesson in data acquisition and analysis may be cryptic in the classical experiment in quantum mechanics, described as Young's double-slit experiment. A variation of the experiment was performed at Hitachi Central Research Labs by Dr Akira Tonomura (1942-2012) which revealed [8] the build-up of interference pattern from single electrons. But, it was not observed until sufficient electrons were allowed to pass through the slit. The lesson from this experiment for business is obvious – running pilots and experiments on small scale may not offer appropriate outcomes or provide wrong indications. One cannot construct an elephant using the mouse as a model. This work is insightful because it suggests large scale deployments may be the key to extracting the value and significance of the tools and technologies which, when combined and converged, may provide solutions.

Another lesson may be found in the history of general process technologies, in particular, the strategies which enabled the spread of electricity (*The Economic Future in Historical Perspective* edited by P. A. David and M. Thomas. British Academy Publication, 2006). Clayton Christensen's (*Innovators Dilemma*) over-use of the word 'disruptive' is a hype. He usurped the original concept of general process technologies introduced by Paul David and Gavin Wright. Christensen mis-used the word and using shoddy data analysis mis-led the business world through his consulting effort to suggest everything is disruptive.

We have observed for the past couple decades the lack of systemic integration of RFID. As a consequence, we may not have sufficiently profited from high volume data from RFID tags. As a result, we may have failed to deliver adequate transparency within supply chains and the savings from the value chain remains far below what was anticipated. The lessons from the abandoned RFID initiative at WalMart (*Is RFID dead?* Florian Michahelles [2010] Auto-ID Labs, ETH) is not a failure of the technology but inadequate use of data and data extraction tools, to utilize actionable information, in the *context* of business processes.

IoT by design may learn from the history of electrification, and RFID, in order to find better ways to progressively penetrate our daily reality through systemic use, integrated with connectivity and applications. IoT must evolve from things to internet of systems (IoS). Connectivity between the ecosystems of systems may create the next tsunami of profitability. It will generate clamor for security, privacy, trust and ethics, as well as, policy. IoT by design, connectivity, and communications with objects and processes, will morph the way we interact, and behave, in our personal and professional lives, in the systems era.

The pursuit of autonomy in healthcare, transportation and manufacturing will create new solutions, old headaches and germinate new business models. The prediction of cancer at least a decade before it affects you, is not an illusion. Autonomous vehicle that parks itself and freight trucks delivering cargo without humans in the loop is yesterday's news. The death of inventory and birth of distributed manufacturing on demand, at the edge, is the digital foundry of the future catalyzed by 3D printing of metals and non-metals. From heart valves to nano-satellites, from NASA-guided soil moisture active passive (SMAP) guidance for precision farming and graphene-purified arsenic-free desalinated drinking water, and everything euphoric in between (neurosynaptic web, neuromorphic chips), we have begun another 100-year journey, and may reach the summit during 2120.

According to Jeff Immelt, former CEO of GE, "in the future one expects an open, global fabric of highly intelligent machines that connect, communicate and cooperate with us. The Industrial Internet is not about a world run by robots, it is about combining the world's best technologies to solve our biggest challenges. It is about economically and environmentally sustainable, energy, it is about curing the incurable diseases, and preparing our infrastructure and cities for the next 100 years."

Economic friction is evident from the loss of middle-income repetitive tasks which may be largely and partially automated or can use online tools for completion. Bank tellers, store check-out clerks and even segments of K-16 teachers may be eliminated from the workforce in favor of ATMs, self-check-out kiosks and MOOCs. This is not only due to IoT, but the integration of computation with our daily lives, as predicted by Herbert Simon.

When, where, what and how, digital transformation will proceed will be determined by cost versus value. Even the veneer of altruism will be guided by transaction cost analysis and transaction cost economics (*The Nature of the Firm* by Ronald Coase, 1937) will be at the front and center of the discussion on the structure of infrastructure. Without the latter, connectivity will languish, without the ecosystem of networks, the value of haphazard connections will ruin the return on investment by increasing costs and decreasing value. Without sustained value and profitability, adoption and diffusion will remain a mirage.

IoT connectivity with a greater cross-section of objects and processes in addition to exposure to greater degree of monitoring (for example, in healthcare) will induce changes in behavior. Whether ubiquitous connectivity modifies rational versus irrational activity remains to be observed and analyzed (*Thinking Fast and Slow* by Daniel Kahneman). The outcome of such analyses must be taken into account when designing future products and services, for example, the wireless hospital of the future or MRI machines in hydrogen refueling stops or portable x-rays in medical huts in the Amazon. The utility may depend on the Gini coefficient, the socio-economic ethos (*Scarcity* by Sendhil Mullainathan) and its stage in socio-political development (*Development as Freedom* by Amartya Sen).

The prediction that connectivity will change behavior is rooted in the fundamental principles of particle physics. The observer effect, as it is called, refers to changes that the act of observation will have on a phenomenon being observed (not to be confused with the uncertainty principle proposed by Werner Heisenberg). The former may explain why one can sing in the shower but perhaps not in public.

It may be noted that combined behavior, especially, time-centricity of cyberphysical systems (hardware and software integrated with physical objects), may often change, if any one of the components are changed, even if the components are almost near-identical. The tryst with time may be difficult at times and time-spoofing is a global cyber-threat.

In addition to slow changes in behavior, economic re-equilibration will be sluggish because massive changes in our education system are necessary to optimize social consumption of the fruits of technology. No amount of technology or online courses will deter the spread of the rupture in our financial fabric unless we retrofit public education, re-install respect for academia, re-focus on rigor, re-invest in basic science research, restore the dignity due to educators and help to re-ignite the passion, latent in teachers.

The emerging supply chain of talent must include an abundance of girls who excel in mathematics, who can code and write cohesively, and may be multi-lingual with affinity for music. The trinity of math, music and multi-lingualism in the early years may be key for the pursuit of multi-disciplinarity of imagination, invention and innovation. It is essential that women pursue tertiary science, engineering, mathematics, economics and philosophy. We must not accept that 50% of the brain power is left out of the workforce, currently [9].

Educated women will help educate boys who are respectful and girls who are dignified. Integrity and dignity may lift humanity and induce innovation from distant crevices of the world, which will usher tectonic shifts in society and commerce. Mistakes will be made but failure is the new road to success, the new mantra for prosperity.

Distributed innovation demands an entrepreneurial approach and an assault on multiple levels, concurrently, rather than the mythical silver bullet solution (*Innovation: The Attacker's Advantage* by Richard Foster). The taxi cab industry vs uber, the hospitality industry vs airbnb and temp agencies vs oDesk/Elance/Upwork are examples [10].

Explosion of engineering tools has dramatically reduced the cycle time necessary to introduce innovation by vastly compressing the time from conception (development supply chain) to realization (fulfillment supply chain). The digital foundry made possible by 3D printing is one example. Industry giants must harness this explosion by giving away platforms in order to aggregate the intelligence that can run on open source platforms. The flow of micro-revenue from billions of “pings” on your product will be the differentiator. Value-added data-service will be related to intelligent analytics of data and delivery of actionable information to the point of use *before* data perishes. Real-time data, in a pay per use model of micro-payments will reduce the barrier to entry, in any market in the world, even when the per capita GDP may be struggling to reach \$2 per day.

The dynamics of perishability of data changes when the accumulation of time series data is far more critical for predictive analytics (for example, healthcare) rather than data with short half-life (for example, mean time between failure (MTBF) metric for spare parts). Data transport and data storage are important in this business but consumers may be willing to pay only for real-time analytics. Consumers may expect raw data to be free. Consumers in impoverished nations may only focus on essential supply chains for living.

However, all advantages are temporary. The financial wisdom from micro-revenue earnings from leasing the platform is one reason why Apple opened up its “bus” for anyone to hop on (create applications). Apps pour in from all over the world. The app creator is a part of the economic avalanche, allowing Apple, as the channel master, to aggregate micro-payments using crowd innovation. *Small data* from millions is the reason why Apple is laughing all the way to the bank with the world’s largest database of payments, to the tune of 99 cents at a time. PayPal’s success fueled Tesla, which may give away the car to sell swappable graphene based batteries, and on-board services using software defined networking (SDN). The automobile may be the mobile electricity grid of the future and the substitute for the smart *immobile* grid for off-grid distribution of power.

Free products with pay-per-use micro-revenue based services is a proven business strategy (printers vs ink, mobile phones vs services, water coolers vs bottled water) to amplify micro-earnings, which will last not only the life cycle of the product but the *life cycle of the user, the human*. Micro-payments can induce a paradigm shift by moving away from product lifecycle (1-10 years) to the user’s lifecycle (5-50 years). The micro-payment for service is paid by the (human) user as long as the person lives and uses the product. Even if the product lifecycle expires, the product can be replaced with a new version. The user continues to pay the micro-payment for the service, agnostic of the product version.

The diffusion of ubiquitous connectivity will accelerate the adoption of IoT by design, which is expected to give rise to new products and services. The consumption of such goods and improvements in efficiency may generate a magnitude of economic growth which is inducing CEOs to be euphoric. According to GE, Cisco and others, the IoT and the industrial internet (IIoT) may add about \$14 trillion to \$19 trillion to the global economy. One must not view this corporate marketing propaganda with blinders.

A concomitant explosion of consumerism is necessary for such numbers to materialize. The billions who are writing on the wall or posting photographs to buoy the software market cap of the social media bubble, are in an earnings group which cannot afford the talking car or the avatar to manage the morning bed-tea or robotic laparoscopy. The educated consumer is the best customer. The bubble of the twitter frenzied social media economy may be limited by the amount of “energy under the ROC curve” and the irrational exuberance may fuel the next global recession which may be around the corner. With 2008 as the last recession, we expect the next one around 2022 based on the 14 year “boom-bust cycle” according to economist Finn Kydland (Nobel Prize in Economics, 2004).

In the US, several initiatives throughout industry and academia are emerging to address the next generation of advances in IoT, industrial internet and exciting possibilities from research in cyber-physical systems (CPS). Several consortia were formed in 2014-2015 with backing from market-leading companies. The EU has funded a massive multi-year program called Horizon 2020 to the tune of more than \$100 billion to explore, at least in part, the potential growth of IoT and how to harvest the associated economic windfall.

But, it will be an egregious error on the part of the global leadership to be blinded by the economic projections and continue to polish the chrome without paying attention to tune the engine of education. Humanity needs dreamers [11] and education [12] is the salt (*Salt* by Mark Kurlansky) which drives inspiration, imagination, invention, innovation and implementation of ideas [13]. The education of a boy may change the fate of a man. The education of a girl may change the destiny of a nation.

1 Datta, S (2018) Connecting Atoms to Bits (Chapter 1) in Haphazard Reality – IoT is a Metaphor.

<https://dspace.mit.edu/handle/1721.1/111021>

2 Linda Bernardi, Sanjay Sarma and Kenneth Traub (2017) The Inversion Factor: How to Thrive in the IoT Economy. MIT Press, Cambridge, MA. <https://mitpress.mit.edu/books/inversion-factor>

3 <http://tinyurl.com/Industrial-Internet>

4 <http://tinyurl.com/MIT-IoT-1998>

5 Paul A. David and Gavin Wright (1999) General Purpose Technologies and Surges in Productivity: Historical Reflections on the Future of the ICT Revolution. http://ftp.unpad.ac.id/orari/library/library-ref-ind/ref-ind-1/application/poverty-reduction/ictd/Historical_Reflection_on_Future_ICT_Revolution.pdf

6 <https://hbr.org/2010/02/data-is-to-info-as-info-is-not>

7 <http://www.portlandpress.com/pp/books/online/wg85/085/0019/0850019.pdf>

8 <http://www.hitachi.com/rd/portal/research/em/doubleslit.html>

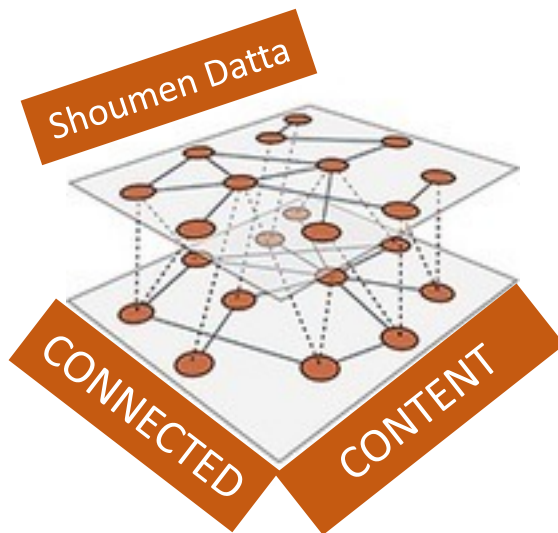
9 <http://bit.ly/GENDER-INEQUALITY>

10 <https://www.forbes.com/sites/elainepofeldt/2015/05/05/elance-odesk-becomes-upwork-today-odesk-brand-gets-phased-out/#6560a1ae51f5>

11 <http://bit.ly/HND-250>

12 <http://bit.ly/Book-by-S-Datta>

13 <http://bit.ly/MIT-IOT>



Dynamic socio-economic disequilibrium catalyzed by the Internet of Things

Dr Shoumen Palit Austin Datta

Research Affiliate, School of Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139 and Senior Vice President, Industrial Internet Consortium

shoumen@mit.edu

Letter from Academia

The technology based conceptualization of the internet of things (IoT) and the industrial internet may have started circa 1988 with the work of Mark Weiser of Xerox Palo Alto Research Center who suggested that computers may “weave themselves into the fabric of everyday life” and influence the future of business, as a consequence (*Scientific American*, 1991). The knowledge base Weiser was referring to is the discussion by Herbert Simon in his 1987 paper “*The Steam Engine and the Computer: What makes technology revolutionary*” where Herbert Simon frames his thoughts about the computer, “you have to make friends with it, talk to it, let it talk to you.”

Hence, contrary to the media hype, in progress, the vision of the Internet of Things (IoT) and its meaning did not germinate from a presentation (Ashton, 2009) at a retail product manufacturer. In 2000, the seminal paper entitled *THE NETWORKED PHYSICAL WORLD* (MIT-AUTOID-WH-001) gave birth to the concept of the IoT (Manyika et al., 2011; Sarma et al., 2000) and the evolution of the industrial internet. Facts about IoT as well as the name “internet of things” (The MIT Sloan CIO Symposium, 2013) was discussed at a recent symposium at the MIT Sloan School of Management.

Connecting physical world objects (made of atoms) with information (packaged as bits) may segue to another revolution, predicted by many, among them, Neil Gershenfeld. The current wave is often referred to as the third industrial revolution, in relation to the Information Age (second) and the first Industrial Revolution. In some quarters, the present trend is (also referred to as Industrie 4.0) the age of cyber-physical systems (CPS).

Revolutions are supposed to reshape things to come. The third wave will be no exception. It will generate friction, both social and economic. The clash of status quo with business not as usual. The collision between the imaginative versus those whose imagination is out of focus. The asphyxiation from old world ideas versus geographically-agnostic unbridled innovation unleashing the wizardry of technology to leak into our lives.

Pundits, market observers and industry players are divided over their belief regarding the transformational capabilities of technologies and the ubiquitous connectivity IoT necessitates. Social friction is erupting from erosion of privacy in its conventional format and the redefinition of privacy which challenges old world beliefs. There is justifiable concern about security yet there is measurable reluctance to give up the benefits associated with either. Financial friction is evident both in industrial nations

and emerging economies whenever unskilled labor is a part of the workforce. Labor, in general, abhors automation, which shrinks the demand for unskilled labor and creates a negative impact on the economy and society, as a whole.

But these are not new observations, in fact these are centuries old and will be repeated over and over, again, albeit in different shades. According to economic historian Norman Poire, “the five centuries that span the years 1440 to 1939 were among the most dynamic in all of history. Many technological advances surfaced during that time, but three inventions stand above the rest as turning points in the direction of technology that led to decisive social change. The invention of the printing press by Johannes Gutenberg in 1440 spurred the arrival of the Information Revolution that spread the Renaissance throughout Europe. In 1609, Galileo Galilei’s telescope ushered in the Scientific Revolution and the Age of Reason. The Industrial Revolution and Marxism arrived shortly after James Watt unveiled his steam engine in 1769. In 1939, a fourth technological revolution began. In that year, John Atanasoff and his graduate student Clifford Berry invented the electronic digital computer and unwittingly with it the Second Information Revolution.” A little less than century later, we are on the cusp of yet another sea of change.

The Third Industrial Revolution may spur the grand convergence of the industrial revolution with the information revolution and other existing unknowns.

Erik Brynjolfsson and Andrew McAfee at the MIT Sloan School of Management (Center for Digital Business) talks about the frictions that may surface from the third revolution, namely, higher unemployment and rising inequality (*Race against the Machine* and *The Second Machine Age*). The incisive insight about inequality may be also found in the works of Joseph Stiglitz (*The Price of Inequality*) and Robert Reich (*Inequality for All*).

Brynjolfsson and McAfee revisit the discussion of higher unemployment which John Maynard Keynes described as “technological unemployment” in the 1930’s. Robert Frank revisits the same topic as technology-catalyzed “winner takes all” labor markets in 1990’s and also in his book *The Darwin Economy*. Brynjolfsson and McAfee expect “our world will prosper on the digital frontier” but what about the path to the frontier? The road ahead is fraught with feuding nations, malnutrition, dysfunctional sanitation, inadequate education and poverty of energy. Taken together, these factors are already fueling glaring socio-economic frictions which may be exacerbated by the attributes necessary for the global diffusion of IoT (internet of things).

The fruits of IoT will depend on our ability to interoperate between systems, objects and devices in different environments supporting different standards of operations, protocols and applications. It is impossible to expect that the world will strive to support one common standard. Hence, not standardization *per se* but the *interoperability* between major standards will be the key to diffusion of the products and services of the IoT and the industrial internet which reaches into the domain of all things mechanical. Industry leaders must enable open standards for interfaces (APIs) where products from SMEs can plug into a common global bus to access the connectivity and add their value added services, analytical engines or enhance niche applications. The *systemic* deployment of open connectivity backbone is central to data acquisition and the spread of IoT.

Ultimately, the ability to extract intelligence from data will drive the value proposition of the connectivity. Transaction cost economics (*The Nature of the Firm* by Ronald Coase, 1937) of connectivity will determine the return on investment which will influence business adoption.

The emphasis on low hanging fruits, short term return, prevalent in the business world, may impact the extent of acquisition of data. Inadequate investment may limit

the tools necessary to accumulate critical mass of data. However, without sufficient data, the analytical tools may stumble to unlock hidden patterns in the data. The latter is necessary if real time dynamic analytical engines (at the edge and core) may be one path to monetization of IoT. New sources of revenue may be created from micro-payments based on pay-per-analytics model of information arbitrage which will use intelligent predictive analytics to augment decision support for semi-autonomous activities.

One lesson in data acquisition and analysis may be cryptic in the classical experiment in quantum mechanics described as Young's double-slit experiment. A variation of the experiment was performed at HCRL (Hitachi Central Research Labs) by Dr Akira Tonomura (1942-2012) which revealed (HITACHI, 2015) the build-up of interference pattern from single electrons but it was not observed until sufficient electrons were allowed to pass through the slit. The lesson from this experiment for business is obvious – running pilots and experiments on small scale may not offer appropriate outcomes or provide wrong indications because you cannot construct an elephant using the mouse as a model. This work is insightful because it suggests large scale deployments may be the key to extracting the value and significance of the tools and technologies which, when combined and converged, may provide solutions.

One lesson may be found in the history of general process technologies, in particular, the strategies which enabled the spread of electricity (*The Economic Future in Historical Perspective* edited by P. A. David and M. Thomas, Oxford University Press, 2003). Clayton Christensen's (*The Innovators Dilemma*) 'disruptive' is a hype based on the original concept of general process technologies (GPT) introduced during the era of electrification to indicate systemic integration versus "slap-on" *ad hoc* usage. Christensen mis-used the word and mis-led the business world using poor data analysis to suggest everything is disruptive.

We have observed for the past 15 years the lack of systemic integration of RFID. As a consequence, we have not sufficiently profited from the ability of RFID tags to acquire sufficient high volume data from a systems approach. As a result, we may have failed to deliver adequate transparency within supply chains and the savings from the value chain remains far below what was anticipated. The lessons from the abandoned RFID initiative at WalMart (*Is RFID dead?* Florian Michahelles [2010] Auto-ID Labs St. Gallen, ETH Zurich) is not a failure of the technology but an inadequate use of data tools in the *context* of the business process.

IoT (internet of things) may learn from the history of electrification and RFID in order to find better ways to progressively penetrate our daily reality through systems integration, connectivity and applications. IoT must evolve from things to internet of systems (IoS). Connectivity between the ecosystems of systems may create the next tsunami of profitability. In turn, it will generate even more clamor for security, privacy, trust and ethics related issues on our social policy agendas. IoT connectivity and communications with objects and processes will change the way we interact and behave in our personal and professional lives in the IoS era.

The pursuit of autonomy in healthcare, transportation and manufacturing will create new solutions, old headaches and germinate new business models. The prediction of cancer at least a decade before it affects you, is not an illusion. The autonomous vehicle that parks itself and a freight truck that delivers cargo without humans in the loop is yesterday's news. The death of inventory and birth of distributed manufacturing on demand (dMOD) at the edge (dMODE) is the embryonic Manufacturing 5.0 catalyzed by 3D printing. From heart valves to nano-satellites and from NASA-guided soil moisture active passive (SMAP) guidance for precision farming and graphene-purified arsenic-free desalinated drinking water and everything euphoric in between (neurosynaptic web and neuromorphic chips), we have already begun the next 100-year journey.

According to Jeff Immelt of GE, “in the future one expects an open, global fabric of highly intelligent machines that connect, communicate and cooperate with us. The Industrial Internet is not about a world run by robots, it is about combining the world’s best technologies to solve our biggest challenges. It is about economically and environmentally sustainable, energy, it is about curing the incurable diseases, and preparing our infrastructure and cities for the next 100 years.”

Economic friction is evident from the loss of middle-income repetitive tasks which may be largely automated or can use online tools for completion. Bank tellers, store check-out clerks and even K-16 teachers will be eliminated from the workforce in favor of ATMs, self-check-out kiosks and MOOCs. This is not only due to IoS but the integration of computation with our daily lives, as predicted by Herbert Simon and Mark Weiser.

IoS connectivity with a greater cross-section of objects and processes in addition to exposure to greater degree of monitoring (for example, in healthcare) will induce changes in behavior with increasing diffusion of the internet of things. Whether ubiquitous connectivity modifies rational versus irrational activity remains to be observed and analyzed (*Thinking Fast and Slow* by Daniel Kahneman). The outcome of such analyses must be taken into account when designing future products and services, for example, the wireless hospital of the future or MRI machines in hydrogen refueling stops or portable x-rays in medical huts in the Amazon. The utility of these advances may depend on the socio-economic ethos of the society (*Scarcity* by Sendhil Mullainathan) and its stage in socio-economic development (*Development as Freedom* by Amartya Sen).

The prediction that connectivity will change behavior is rooted in the fundamental principles of particle physics. The observer effect, as it is called, refers to changes that the act of observation will have on a phenomenon being observed (not to be confused with the uncertainty principle proposed by Werner Heisenberg). The former may explain why one can sing in the shower but not in public.

It may be noted that combined behavior, especially, time-centricity of cyberphysical systems (hardware and software integrated with physical objects) changes, if any one of the components are changed, even if the components are almost near-identical. The tryst with time may be difficult at times.

In addition to slow changes in behavior, economic re-equilibration will be sluggish because massive changes in our education system are necessary to optimize social consumption of the fruits of technology. No amount of technology or online courses will deter the spread of the rupture in our financial fabric unless we retrofit public education, re-install respect for academia, re-focus on rigor, rejuvenate all aspects of scientific research, restore the dignity due to a teacher and re-ignite the passion expected from a teacher.

The emerging supply chain of talent must include an abundance of girls who excel in math, who can code and write cohesively. It is essential that women pursue higher level of science, engineering, mathematics, economics and philosophy. How can we accept that about 50% of the brain power is left out of the workforce?

Educated women will help educate boys who are respectful and girls who are dignified. Taken together, they will accelerate the massively parallel innovation from distant crevices of the world. The latter is already ushering tectonic shifts even in the most traditional businesses. The analysis-paralysis approach of the behemoths may lead to their extinction if they continue to remain oblivious of the fact that failure is the new road to success, failure is the new key to success and failure is the mantra for those who wish to succeed.

Distributed innovation demands an entrepreneurial approach and an assault on multiple levels, concurrently, rather than the mythical silver bullet solution

(*Innovation: The Attacker's Advantage* by Richard Foster). The taxi cab industry vs uber, the hospitality industry vs airbnb and temp agencies vs oDesk are bright examples. Explosion of engineering tools has dramatically reduced the cycle time necessary to introduce innovation by vastly compressing the time from conception (development supply chain) to realization (fulfillment supply chain). Industry giants must harness this explosion by giving away platforms in order to aggregate the intelligence that can run on open source platforms. The flow of micro-revenue from billions of pings on your product will be the differentiator and that value-added data-service will be related to intelligent analytics of data and delivery of actionable information to the point of use *before* the data perishes.

However, the dynamics of perishability of data changes when the accumulation of time series data is far more critical for predictive analytics (for example, healthcare) rather than data with short half-life (for example, mean time between failure (MTBF) metric for spare parts). Data transport and data storage are important in this business but consumers may be willing to pay only for real-time analytics. Consumers expect raw data to be free.

However, all advantages are temporary. The financial wisdom from micro-revenue earnings from leasing the platform is one reason why Apple opened up its “bus” for anyone to hop on (create applications). Apps pour in from all over the world. The app creator is a part of the economic avalanche by allowing Apple, as the channel master, to aggregate micro-payments using open innovation. *Small data* from millions is the reason why Apple is laughing all the way to the bank with the world’s largest database of payments, to the tune of 99 cents at a time. PayPal’s success fueled Tesla which may give away the car to sell swappable graphene based batteries and on-board services using software defined networking (SDN). The automobile may be the mobile electricity grid of the future substituting for the smart immobile grid for off-grid distribution of power. Free products with pay-per-use micro-revenue based services is indeed a proven business strategy (printers vs ink, mobile phones vs services, water coolers vs bottled water) to amplify micro-earnings, which will enjoy a long life and substantiate the value of long tails.

The spread of IoT and IoS is expected to give rise to new (Datta, 2015b) products and services. The consumption of such goods and improvements in efficiency may generate a magnitude of economic growth which is inducing CEOs to be euphoric. According to GE, Cisco and others, the IoT and the industrial internet (IIoT) may add about \$14 trillion to \$19 trillion to the global economy, over the next decade. An explosion of consumerism is necessary for such numbers to materialize. The billions who are writing on the wall or posting photographs to buoy the software market cap of the social media bubble are in an earnings group which cannot afford the talking car or the avatar to manage the morning bed-tea or robotic laparoscopy. The educated consumer is the best customer. The bubble of the twitter frenzied social media economy may be limited by the amount of “energy under the curve” and the irrational exuberance may fuel the next global recession which may be just around the corner (2020-2022). With 2008 as the year of the last recession, we expect the next one around 2022 if the “boom-bust cycle” has a 14 year periodicity according to Finn Kydland (Nobel Prize in Economics, 2004).

In the US, several initiatives throughout industry and academia are emerging to address the next generation of advances in the IoT space, industrial internet, internet of systems (IoS) and the exciting possibilities from research in cyber-physical systems (CPS). Several consortia were formed in 2014-2015 with backing from market-leading companies. Several academic groups are leading the way with new inventions and innovation. The EU has funded a massive multi-year program called Horizon 2020 to the tune of more than \$100 billion to explore the growth of IoT and help harvest the associated economic windfall.

But, it will be an egregious error on the part of the global leadership to be blinded by the economic projections and continue to polish the chrome without paying attention to tune the engine of education. Is a smart city (Datta, 2015a) really smart without smart citizens?

Humanity needs dreamers (Datta, n.d.) and education (Datta, 2014) is the quintessential salt (*Salt* by Mark Kurlansky) which acts as the purveyor of inspiration, imagination, invention, innovation and drives implementation of ideas (Datta, 2015b). The education of a boy may change the fate of a man. The education of a girl may change the destiny of a nation.

References

- Ashton, K. (2009). In the real world, things matter more than ideas. *RFID Journal*. Accessed September 2015.
<http://www.rfidjournal.com/articles/pdf?4986>
- Datta, S. (2014). *Far Reaching Changes in the Near Future* [e-book]. Accessed September 2015.
<http://bit.ly/Book-by-S-Datta>
- Datta, S. (2014). *Internet of Systems (IoS) - Economic Re-equilibration Catalyzed by Internet of Things (IoT)*. Accessed September 2015.
<http://bit.ly/MIT-IOT>
- Datta, S. (2015a). *Smart Cities* [presentation]. Accessed September 2015. Retrieved from:
<http://bit.ly/SMART-CT>
- Datta, S. (2015b). *Presentation of Datta 2015* [presentation]. Accessed September 2015.
<http://bit.ly/RE-VIEW-IOT>
- Datta, S. (n.d.). *Humanity Needs Dreamers* [presentation]. Accessed September 2015.
<http://bit.ly/HND-250>
- HITACHI. (2015). Quantum Measurement. Accessed September 2015.
<http://www.hitachi.com/rd/portal/highlight/quantum/index.html#anc04>
- Manyika, J., Chui, M., Brown, B., Bughin, J., Dobbs, R., Roxburgh, C., & Hung Byers, A. (2011). Big data: The next frontier for innovation, competition, and productivity. *McKinsey Global Institute*. Accessed September 2015.
<http://tinyurl.com/Industrial-Internet>
- Sarma, S., Brock, DL., & Ashton, K. (2000). The Networked Physical World. *MIT AUTO-ID CENTER*. Accessed September 2015.
<http://tinyurl.com/Industrial-Internet>
- The MIT Sloan CIO Symposium. [MIT Sloan CIO Symposium Videos]. (2013, August, 29). *2010-09 The Internet of Things* [Video file]. Accessed September 2015.
<https://www.youtube.com/watch?v=44MLERLwxig>

L'Internet des Objets : catalyseur des tensions sociaux-économiques et de l'innovation technologique

Dynamic Socio-Economic Disequilibrium catalyzed by Internet of Things

Dr Shoumen Palit Austin Datta

Research Affiliate, School of Engineering, Massachusetts Institute of Technology, Cambridge, uSA

On peut dater de 1988, l'origine de la conceptualisation de l'Internet industriel des Objets (Internet of Things – IoT en anglais) grâce au travail de Mark Weiser du PARC de Xerox (Palo Alto Research Center Incorporated) qui, le premier, a émis l'idée que les ordinateurs « trament le tissu de la vie quotidienne », influençant dès lors l'avenir du secteur (cf. Scientific American, 1991). La base des connaissances dont parle Weiser renvoie au débat de Herbert Simon dans son papier de 1987 intitulé The Steam Engine and the Computer: What makes technology revolutionary. Celui-ci y donne sa vision de l'ordinateur : « rencontrez des amis par son intermédiaire, parlez-lui, laissez-le vous parler. »...

Mots clés : xxxxx

The technology based conceptualization of the internet of things (IoT) and the industrial internet may have started circa 1988 with the work of Mark Weiser of Xerox Palo Alto Research Center who suggested that computers may “weave themselves into the fabric of everyday life” and influence the future of business, as a consequence (Scientific American, 1991). The knowledge base Weiser was referring to is the discussion by Herbert Simon in his 1987 paper “The Steam Engine and the Computer: What makes technology revolutionary” where Herbert Simon frames his thoughts about the computer, “you have to make friends with it, talk to it, let it talk to you.” (...)

Keywords: xxxxx

Cet article est paru initialement dans la revue The Journal of Innovation Management (ISSN 2183-0606) Vol 3, No 3 (2015) qui nous a autorisé sa traduction.

This is the French translation from the original document in English published in the Journal of Innovation Management (ISSN 2183-0606) Vol 3, No 3 (2015); <http://www.open-jim.org> - HANDLE: <http://hdl.handle.net/10216/80026> - Open Access: <http://creativecommons.org/licenses/by/3.0>

Traduction Catherine Micolino

On peut dater de 1988, l'origine de la conceptualisation de l'Internet industriel des Objets (Internet of Things – IoT en anglais) grâce au travail de Mark Weiser du PARC de Xerox (*Palo Alto Research Center Incorporated*) qui, le premier, a émis l'idée que les ordinateurs « trament le tissu de la vie quotidienne », influençant dès lors l'avenir du secteur (cf. *Scientific American*, 1991). La base des connaissances dont parle Weiser renvoie au débat de Herbert Simon dans son papier de 1987 intitulé *The Steam Engine and the Computer: What makes technology revolutionary*. Celui-ci y donne sa vision de l'ordinateur : « rencontrez des amis par son intermédiaire, parlez-lui, laissez-le vous parler. »

Ainsi, contrairement aux idées véhiculées, la vision de l'Internet des Objets (IoT) et de sa signification même n'est pas le fruit¹ d'une quelconque présentation industrielle. En 2000, l'article fondateur *The networked physical world*² a donné naissance au concept d'IoT³ et à l'évolution de l'Internet industriel. Certains faits relatifs à l'IoT et l'expression même d'« Internet des Objets⁴ » ont donné lieu à des débats lors d'un colloque qui s'est tenu récemment à la *Sloan School of Management du MIT*.

La connexion des objets physiques (faits d'atomes) aux informations numériques (exprimées en bits) pourrait aboutir à une nouvelle révolution, ainsi que le prédisent certains experts dont Neil Gershenfeld. On parle souvent de troisième révolution industrielle, en allusion à l'ère – ou à la seconde ère – de l'information et à la première révolution industrielle. Certains préfèrent parler d'industrie 4.0 ou d'ère des systèmes cyber-physiques.

Les révolutions sont supposées refondre l'avenir. Cette troisième vague ne devrait pas faire exception. Elle devrait susciter des tensions sociales et économiques. La collision entre deux mondes : celui de l'imagination et de la créativité face à celui de la productivité. D'un côté, les idées conventionnelles ; de l'autre, une innovation effrénée qui apporte la technologie au cœur de nos vies.

Les experts, les observateurs du marché et les industriels sont divisés quant aux capacités de transformation prêtées aux technologies, mais aussi concernant la connectivité généralisée nécessaire à l'IoT. Certaines tensions d'ordre social apparaissent en raison de l'érosion de la sphère privée sous son acception traditionnelle et de l'émergence

d'une nouvelle définition remettant en cause d'anciennes convictions. On peut raisonnablement craindre qu'il soit porté atteinte à la sécurité, mais on note une certaine réticence à renoncer aux bénéfices associés. Des dissensions d'ordre financier émergent logiquement, tant dans les pays industrialisés que dans les pays émergents, dès lors qu'une part de la main-d'œuvre est non qualifiée. En général, l'automatisation tend à réduire les besoins en main-d'œuvre non qualifiée, avec un impact négatif sur l'économie et la société dans leur ensemble.

Ces observations ne sont pas nouvelles et l'on peut gager qu'elles se répéteront à l'avenir sous différentes nuances. D'après l'historien de l'économie Norman Poire, « *les cinq siècles couvrant les années de 1440 à 1939 furent parmi les plus dynamiques de l'histoire* ». De nombreuses avancées technologiques se firent jour sur cette période, mais trois inventions se démarquent et font figure de tournants car elles provoquèrent des bouleversements sociaux majeurs. L'invention de l'imprimerie par Johannes Gutenberg en 1440 a impulsé une véritable révolution de l'information, favorisant l'avènement de la Renaissance dans toute l'Europe. En 1609, le télescope de Galilée a ouvert la voie à la révolution scientifique et à l'âge de la Raison. La révolution industrielle et le marxisme suivent de peu l'invention de la machine à vapeur par James Watt (1769). 1939 marque les prémices de la quatrième révolution technologique. Cette année-là, John Atanasoff et Clifford Berry mettent au point le premier ordinateur numérique électronique qui aboutit incidemment à la deuxième révolution de l'information. Un peu moins d'un siècle plus tard, nous voilà au seuil d'un nouveau bouleversement.

La troisième révolution industrielle devrait être le prélude à la grande convergence de la révolution industrielle et de la révolution de l'information, avec un certain nombre d'inconnues.

Erik Brynjolfsson et Andrew McAfee de la *Sloan School of Management* du MIT (*Center for Digital Business*) prédisent d'éventuels troubles liés à la troisième révolution, avec notamment une augmentation du chômage et un accroissement des inégalités (*Race against the Machine and The Second Machine Age*). Cette vision perspicace concernant les inégalités est également présente dans les travaux de Joseph Stiglitz

1 - <http://bit.ly/Sound-Bite>

2 - http://cocoa.ethz.ch/downloads/2014/06/None_MIT-AUTOID-WH-001.pdf

3 - <http://tinyurl.com/Industrial-Internet>

4 - <http://tinyurl.com/MIT-IoT-1998>

(*The Price of Inequality*) et de Robert Reich (*Inequality for All*).

Brynjolfsson et McAfee ont réexaminé le sujet du chômage conjoncturel abordé par John M. Keynes, et qualifié dans les années 1930 de « chômage technologique ». Le phénomène est également abordé par Robert H. Frank qui décrit, dans les années 1990, un marché du travail et une société « des vainqueurs » (*winners-take-all*) impactés par le développement des technologies (*The Darwin Economy*).

Pour Brynjolfsson et McAfee, « notre monde va prospérer sur le front du numérique ». Certes, mais quelle voie emprunter ? De sérieux problèmes socio-économiques persistent : nations discordantes, malnutrition, hygiène publique inefficace, systèmes éducatifs défaillants, pauvreté énergétique. Additionnés, ces facteurs alimentent les tensions socio-économiques, que la diffusion de l'Internet des Objets (IoT) à l'échelle mondiale peut exacerber plus encore.

Les retombées de l'IoT vont dépendre de notre faculté à interagir au sein de systèmes, objets et dispositifs, dans des environnements variés, régis par divers modes de fonctionnement, protocoles et applications. Il est difficilement envisageable que notre monde s'aligne sur un seul et unique standard. Ainsi, ce n'est pas la standardisation en soi, mais l'*interopérabilité* entre les principales normes, qui sera la clé de la diffusion des produits et services de l'IoT, allant jusqu'à intégrer le domaine de la mécanique. Les grandes entreprises industrielles doivent autoriser des normes ouvertes pour les interfaces de programmation (*APIs = Application Programming Interfaces*) pour permettre aux produits de PME de rallier un protocole global commun, d'être connectés et d'accéder à des services à valeur ajoutée, voire de développer certaines applications de niche. Le déploiement systémique d'une connectivité ouverte est essentiel à la collecte des données et à la diffusion de l'IoT.

Enfin, la capacité à extraire des informations exploitables à partir de multiples données brutes impulse la valeur recherchée via la connectivité. L'économie des coûts de transaction (*The Nature of the Firm* de Ronald Coase, 1937) détermine le retour sur investissement de la connectivité, lequel influence à son tour l'adoption de cette dernière par les entreprises.

L'accent sur les résultats faciles et le court-termisme, très courant dans le monde des affaires, pourraient affecter l'importance des données collectées. Des investissements inappropriés pourraient limiter les outils nécessaires pour recueillir une masse critique de données. Toutefois, faute de données suffisantes à traiter, les outils d'analyse pourraient ne pas être en mesure de mettre au jour certaines tendances cachées. C'est pourtant indispensable pour que les outils dynamiques d'analyse en temps réel constituent une étape vers la monétisation de l'IoT. De nouvelles sources de revenus peuvent apparaître via des micro-paiements basés sur un modèle d'arbitrage informationnel de type *pay-per-analytics* qui permettrait de recourir à des analyses prévisionnelles intelligentes facilitant la prise de décisions pour les activités semi-autonomes.

Les déploiements de grande envergure sont la clé pour conférer de la valeur et de l'importance aux outils et technologies, lesquels apportent des solutions satisfaisantes lorsqu'ils sont employés de manière convergente et coordonnée.

Un autre enseignement tiré de l'histoire des GPT (*general process technologies*) concerne les stratégies de diffusion de l'électricité (*The economic future in historical perspective* de P.A. David et M. Thomas, 2003). L'expression « de rupture » (*disruptive*), employée largement par Clayton Christensen (*The Innovators Dilemma*), peut découler du concept de GPT (*general process technologies*), apparu à l'époque de l'électrification pour indiquer une intégration systémique par opposition à un usage ponctuel.

Au cours des 15 dernières années, on constate une faible intégration systémique des systèmes RFID. Dès lors, la capacité des balises RFID à recueillir des volumes suffisamment importants de données a été négligée. D'où certainement un manque de transparence au sein des *supply chain* d'une part, mais aussi des économies inférieures au niveau prévu pour la chaîne de valeur. L'abandon du projet de RFID par WalMart (*Is RFID dead?* Florian Michahelles, 2010) ne révèle pas l'échec de la technologie en question, mais souligne plutôt une utilisation inappropriée des outils de gestion des données dans le contexte des processus métiers.

Peut-être faudrait-il s'inspirer de l'histoire de l'électrification et de la RFID pour faire

en sorte que l'IoT prenne de plus en plus de place dans notre quotidien, via l'intégration des systèmes, la connectivité et les applications. On doit passer d'un IoT à un Internet des systèmes (*Internet of Systems* – IoS en anglais). La connectivité entre « écosystèmes de systèmes » déclenchera peut-être la prochaine manne de profits. En revanche, devrait apparaître également une revendication pour plus de sécurité, de protection de la vie privée, plus de confiance et de déontologie, thèmes liés à la politique sociale. La connectivité propre à l'IoT ainsi que la communication avec les objets et processus devraient affecter nos comportements et notre façon d'interagir dans les sphères personnelle et professionnelle, à l'ère de l'Internet des systèmes.

L'autonomisation en cours dans les domaines de la santé, des transports et de l'industrie va faire resurgir de vieux casse-têtes, tout en donnant lieu à de nouvelles solutions et à de nouveaux modèles d'affaires. Prévoir les risques d'un cancer dix ans au moins avant son apparition ne constitue plus une vue de l'esprit. Les véhicules autonomes capables de se garer automatiquement, les camions de transport délivrant les marchandises sans intervention humaine sont désormais une réalité. L'abandon des stocks au profit d'une fabrication répartie proche de la demande, préfigure la Fabrication 5.0, facilitée par le développement de l'impression 3D.

Les valves cardiaques, les nano-satellites, le satellite téléguidé SMAP (*Soil Moisture Active Passive*) de la NASA, le téléguidage pour l'agriculture de précision, l'eau dessalée et purifiée (sans graphène, ni arsenic), le web neuro-synaptique et les puces neuro-morphiques : autant d'exemples attestant que le futur est déjà là !

D'après Jeffrey R. Immelt, PDG de General Electric, « à l'avenir, on peut s'attendre à une économie planétaire ouverte de machines très intelligentes qui interagissent, communiquent et coopèrent avec nous. L'Internet industriel ne renvoie pas à un monde gouverné par des robots. Il s'agit plutôt d'associer les meilleures technologies mondiales pour relever nos plus grands défis. Il s'agit de promouvoir les sources d'énergie renouvelables, compétitives et respectueuses de l'environnement, de soigner les maladies incurables, mais aussi de préparer nos infrastructures et nos villes pour les cent prochaines années. »

Le développement accru de l'IoS et sa connectivité avec un échantillon plus important d'objets et de procédés, mais aussi la soumission à davantage de contrôle (dans le domaine de la santé, par exemple) entraîneront des changements de comportements. Reste à savoir si la connectivité généralisée affectera l'activité rationnelle / irrationnelle (cf. *Thinking Fast and Slow* de Daniel Kahneman). Il convient de tenir compte des résultats de ces études lors de la conception de nouveaux produits et services. À titre d'exemple, les hôpitaux du futur et l'utilisation de la technologie Wifi dans les soins médicaux, les appareils IRM aux points de ravitaillement en hydrogène, les appareils de radiographie mobiles dans les centres médicaux en Amazonie. L'utilité de ces avancées pourrait dépendre de l'éthos socioéconomique (cf. *Scarcity* de Sendhil Mullainathan) et du stade de développement socioéconomique en question (cf. *Development as Freedom* de Amartya Sen).

L'innovation distribuée exige une démarche entrepreneuriale et une offensive simultanée sur plusieurs fronts, plutôt qu'une prophétique solution miracle (*Innovation: The Attacker's Advantage* de Richard Foster). À titre d'exemples éclairants : l'industrie du taxi contre Uber, l'industrie hôtelière contre Airbnb, ou encore les agences de placement temporaire contre oDesk. Le récent foisonnement des outils d'ingénierie a considérablement réduit la durée du cycle nécessaire à l'introduction d'une innovation en compressant la durée entre conception et réalisation. Les géants de l'industrie doivent mettre à profit cette explosion en se donnant les moyens de regrouper les renseignements et informations utiles sur des plateformes ouvertes. Le flux de micro-revenus générés par les milliards de pings des produits fera la différence et le service de données à valeur ajoutée sera lié aux analyses de données intelligentes et à la transmission d'informations exploitables au point d'utilisation avant que ces données ne disparaissent. Le transfert et le stockage de données sont importants dans ce secteur, mais les consommateurs pourraient rechigner à payer, hormis pour les analyses en temps réel. En effet, tout le monde s'attend aujourd'hui à ce que les données soient gratuites.

Toutefois, les avantages ne sont que temporaires. Les micro-revenus générés par le *leasing* de sa plateforme ont incité Apple à ouvrir son « bus » et à permettre à tout un

chacun de créer ses propres applications, déclenchant un afflux d'applications en provenance du monde entier. Tout créateur d'applications participe de la manne économique, permettant à Apple, d'engranger des micro-payements (99 cents en moyenne) via sa plateforme d'innovation ouverte. C'est ainsi que la société engrange d'importants revenus grâce à la plus importante base de données sur les paiements au monde. Le succès du service de paiement PayPal a bénéficié au constructeur automobile Tesla qui pourrait mettre de côté son activité première pour commercialiser des batteries au graphène et des systèmes embarqués utilisant les technologies de réseau programmables SDN (*Software Defined Networking*). L'automobile pourrait devenir le réseau électrique mobile du futur, remplaçant le réseau statique classique pour une distribution hors réseau d'électricité. Les produits gratuits offrant des services facturés à l'usage (imprimantes / cartouches d'encre ; téléphones mobiles / applications ; fontaines d'eau fraîche / eau en bouteilles) constituent en fait une stratégie commerciale éprouvée destinée à accroître les micro-revenus sur le long terme.

Le développement de l'IoT et de l'IdS devrait favoriser l'apparition de nouveaux⁵ produits et services. La consommation de tels biens et les améliorations en matière d'efficacité devraient favoriser la croissance économique, ce qui ne peut que réjouir les dirigeants. D'après General Electric, Cisco et d'autres, l'IoT et l'Internet industriel des Objets (*IIoT* en anglais) devraient injecter de quatorze à dix-neuf mille milliards de dollars dans l'économie mondiale au cours de la décennie à venir. Une forte accélération du consumérisme est toutefois nécessaire pour parvenir à de tels chiffres. Les milliards d'individus qui publient des messages ou postent

des photographies sur les réseaux et maintiennent ainsi le marché des logiciels à flot tout en entretenant la bulle financière autour des médias sociaux font partie d'une certaine tranche de revenus et n'ont pas les moyens de se payer une voiture robot téléguidée, un robot ménager à tout faire ou une laparoscopie robotisée. Le consommateur aguerri constitue le meilleur client. La bulle financière qui s'est constituée autour des médias sociaux (engouement frénétique pour Twitter...) peut être atténuée par la quantité « d'énergie en dessous de la courbe ».

Aux États-Unis, diverses initiatives se font jour dans les milieux industriels et universitaires qui s'intéressent aux prochaines étapes des avancées touchant à l'IoT, l'IdS, l'Internet industriel, mais également aux possibilités prometteuses de la recherche en matière de systèmes cyber-physiques (SCP). Plusieurs consortiums se sont constitués courant 2014-2015, avec le soutien de sociétés leaders du marché. Des groupes de chercheurs universitaires ouvrent la voie via diverses inventions et innovations. L'UE a financé un vaste programme pluriannuel, baptisé Horizon 2020, à hauteur de quelque 100 milliards de dollars, dans le but d'analyser la croissance de l'IoT et de mieux profiter des avantages économiques ainsi générés.

En termes de leadership mondial, ce serait une grave erreur de se laisser éblouir par les projections économiques en faisant fi du moteur que constitue l'éducation. Les *smart cities* ou « villes intelligentes » peuvent-elles se passer de citoyens instruits ?

L'Humanité a besoin de rêveurs⁶ et l'éducation⁷ fournit un terreau propice à l'inspiration, à l'imagination, à l'inventivité, et à la mise en pratique des idées (cf. Salt by Mark Kurlansky).

5 - <http://bit.ly/TNT-346>

6 - <http://bit.ly/HND-250>

7 - <http://bit.ly/>
Book-by-S-Datta

Dr Shoumen Palit Austin Datta est

Dr Shoumen Palit Austin Datta is Senior Vice President, Industrial Internet Consortium and Senior Scientist, Massachusetts General Hospital, Harvard Medical School.

El desequilibrio socioeconómico consecuente de la industria de internet de las cosas¹

The consequent socioeconomic imbalance of the Internet industry of Things

Recibido: 31 de enero de 2016

Evaluado: 11 de abril de 2016

Aceptado: 5 de mayo de 2016

Shoumen Palit Austin Datta (Estados Unidos)

School of Engineering
Massachusetts Institute of Technology
shoumen@mit.edu

Victoria López López (España)

Universidad Complutense de Madrid
vlopez@fdi.ucm.es

Resumen

La evolución de la tecnología hacia internet de las cosas y la industria de internet está provocando cambios muy importantes en nuestra sociedad. Los cambios que se producen en las relaciones humanas así como el uso de los objetos físicos conducen a nuevas formas de comportamiento y por tanto de aprendizaje. La intimidad y la privacidad se convierten en un reto difícil de mantener y la seguridad se ve amenazada en todas sus vertientes. Sin renunciar a las ventajas del desarrollo tecnológico y a las nuevas fuentes de información en este artículo se plantea un desarrollo social responsable y consciente. Este artículo realiza una reflexión desde la evolución histórica de la tecnología industrial al desarrollo del internet de las cosas reconociendo los problemas a los que

Summary

The evolution of technology towards the Internet of Things and the Internet industry is causing major changes in our society. The changes that occur in human relationships and the use of physical objects lead to new ways of behavior and therefore of learning. The intimacy and privacy have become a difficult challenge to maintain and our security is threatened in all its aspects. Without giving up the advantages of technological development and new information sources, the present article tries to develop a responsible and conscious social development. This article makes a reflection from the historical evolution of industrial technology, to the development of the Internet of Things recognizing the problems that a new society faces and proposing as a best solution,

1 Este artículo está basado en la traducción y adaptación por parte de la doctora Victoria López del artículo titulado "Dynamic socio-economic disequilibrium catalyzed by the Internet of Things" publicado en inglés en la revista Journal of Innovation Management (ISSN 2183-0606), vol. 3, n.º 3, 2015; <http://www.open-jim.org> - HANDLE: <http://hdl.handle.net/10216/80026> - Open Access: <http://creativecommons.org/licenses/by/3.0>

se enfrenta la nueva sociedad y proponiendo como mejor solución la educación desde la igualdad y el respeto a los valores establecidos.

Palabras clave: internet de las cosas, desarrollo tecnológico, tecnología industrial, economía, desarrollo.

the education based on equality and respect for the established values.

Keywords: Internet of Things, technological development, industrial technology, economy, development.

Introducción

La conceptualización basada en la tecnología de internet de las cosas (IoT) y la industria de internet dio comienzo alrededor de 1988 con la obra de Mark Weiser del Centro de Investigación Xerox Palo Alto, quien sugirió que los computadores pueden “tejerse a sí mismos en el tejido de la vida diaria” e influir de forma determinante en el futuro de los negocios (Scientific American, 1991). Mark Weiser se refería al artículo seminal “El motor de vapor y el ordenador: ¿qué hace revolucionar la tecnología?”, donde Herbert Simon (1987) enmarca sus pensamientos sobre la tecnología del futuro: “tienes que hacer amistad con él, hablar con él, dejar de hablar tú”.

Por tanto, contrariamente a la exageración de los medios, la visión de internet de las cosas (IoT) y su significado no nacieron en una presentación (Ashton, 2009) de la venta de un producto. En 2000, un primer trabajo titulado “The networked physical world” dio a luz el concepto de *internet de las cosas* (Manyika et al., 2011; Sarma, Brock y Ashton, 2000) y la evolución de internet industrial. Tanto el concepto como el término *internet de las cosas* se discutieron en un simposio en la Escuela del MIT Sloan de Administración (The MIT Sloan CIO Symposium, 2013) donde Sarma acredita Ashton para el nombre de *internet of the things*.

La actual conexión de los objetos del mundo físico (átomos) y la información (bits) puede llevar a otra revolución, ya predicha por muchos, como Neil Gershenfeld. Esta corriente a menudo se denomina *tercera revolución industrial* en relación con la primera revolución industrial y la era de la información (segunda revolución).

En algunos sectores, la tendencia actual se denomina la edad de los sistemas

ciberfísicos (*cyber-physical system*), aunque también aparece el término industria 4.0 en referencia al mismo fenómeno.

Evolución de la sociedad en el entorno tecnológico

A lo largo de la historia, las revoluciones han surgido para remodelar el futuro y esta tercera revolución no será una excepción. Como cualquier otra revolución, generará controversia, tanto social como económica. Sin embargo, el choque del *statu quo* no será como hasta ahora. La sociedad ya está empezando a sufrir la colisión entre la imaginación y las ideas del viejo mundo que ahora se ven asfixiadas ante una innovación desenfrenada. La magia de la tecnología se filtra en nuestra vida cotidiana sin apenas control. Los expertos, observadores de los mercados y los actores de la industria, tienen opiniones divididas respecto de la capacidad de transformación de las tecnologías y la conectividad que necesita el internet de las cosas.

La sociedad está cambiando el formato convencional de intimidad y el concepto de *privacidad* se redefine y desafía los valores establecidos. La preocupación por la seguridad está muy justificada, pero todavía hay personas reticentes a renunciar a los beneficios individuales asociados a su pérdida. Los individuos claman por su seguridad y su privacidad, pero al mismo tiempo se despreocupan de estos valores cuando se les ofrece a cambio servicios gratuitos (*commodities*) como aplicaciones de mensajería, juegos o suscripciones a redes sociales.

En los países industrializados, es evidente la fricción financiera al surgir una fuerza de trabajo emergente de la que buena parte es trabajo no cualificado. Por otra

parte, la automatización de procesos reduce la demanda de mano de obra no cualificada, y crea un efecto negativo en la economía y en la sociedad en su conjunto. Sin embargo, la automatización no abolirá la necesidad de mano de obra en absoluto.

Estas observaciones no son nuevas. De hecho se repiten una y otra vez desde hace siglos, aunque en diferentes tonos. De acuerdo con el economista e historiador Norman Poiré, “los cinco siglos que abarcan los años 1440 hasta 1939 fueron los más dinámicos de toda la historia”. En dicho periodo, surgieron muchos avances tecnológicos pero algunos inventos destacan por encima del resto como puntos de inflexión en la dirección de la tecnología que llevaron a cabo un cambio social decisivo. La invención de la impresión por Johannes Gutenberg en 1440 estimuló la llegada de la revolución de la información que extendió el Renacimiento en Europa. En 1609, el telescopio de Galileo Galilei marcó el comienzo de la revolución científica y la edad de la razón. La revolución industrial y el marxismo llegaron poco después de que James Watt diera a conocer su máquina de vapor en 1769. En 1939, una cuarta revolución tecnológica dio comienzo. En ese año, el doctor John Atanasoff y su estudiante graduado Clifford Berry inventaron la computadora digital electrónica y sin querer con ello la segunda revolución de la información. Un poco menos de un siglo después estamos en la cúspide de un nuevo mar de cambios, donde nos preparamos con fervor para el próximo *tsunami*.

La tercera revolución industrial puede estimular la gran convergencia de los sectores de la revolución industrial con la revolución de la información y otras incógnitas existentes. En el Instituto Tecnológico de Manchester, Erik Brynjolfsson y Andrew McAfee de la Sloan School of

Management del MIT (Center for Digital Business) hablan de dos enfrentamientos que pueden surgir de la tercera revolución: el aumento del desempleo y el aumento de la desigualdad (*Race against the Machine* y *The second machine age*). La visión incisiva acerca de la desigualdad también se encuentra en las obras de Joseph Stiglitz (*El precio de la desigualdad*) y Robert Reich (*Desigualdad para todos*).

Brynjolfsson y McAfee revisitan la discusión de un mayor desempleo que John Maynard Keynes describe como “*desempleo tecnológico*” en el 1930. Robert Frank vuelve a debatir el mismo tema en los mercados laborales en 1990 y los problemas causados por la tecnología (*winner takes all*) en su libro *La economía Darwin*.

Brynjolfsson y McAfee predicen “nuestro mundo va a prosperar en la frontera digital”, pero ¿qué pasa con la ruta de acceso a la frontera? El camino por delante está lleno de naciones enfrentadas, desnutrición, sanidad disfuncional, educación y pobreza de la energía. Tomados en conjunto, estos factores ya están alimentando fricciones socioeconómicas evidentes que pueden ser exacerbadas por los atributos necesarios para la difusión global de IoT (internet de las cosas).

Los frutos de IoT dependerán de nuestra capacidad de interoperación entre sistemas, objetos y dispositivos en diferentes ambientes así como diferentes estándares de operaciones, protocolos y aplicaciones. No cabe esperar que el mundo se esfuerce por apoyar un estándar común en un primer momento. La opinión generalizada es que las normas son una buena idea, pero son difíciles de aplicar, puesto que nadie quiere usar normativas escritas por otros. Un sistema de normalización internacional en IoT desarrollado desde la Organización Internacional de Normalización (ISO

'International Organization for Standardization'), no parece viable a corto/medio plazo.

Por tanto, no la normalización en sí, sino la interoperabilidad entre los principales estándares puede ser la clave para la difusión de los productos y servicios de IoT y la internet industrial que alcanza en el dominio de todas las cosas mecánicas. Los líderes de la industria deben permitir estándares abiertos para interfaces (*application programming interface*), donde los productos de las pymes pueden conectarse a un sistema global común para acceder a la conectividad y poner sus servicios de valor añadido, motores de análisis o mejorar aplicaciones. El despliegue sistemático de datos abiertos (*open data*) y su conectividad es fundamental para la adquisición de datos y la difusión de IoT (López, 2014, 2015).

En última instancia, la capacidad inteligente a partir de la extracción de datos impulsará la propuesta de valor de la conectividad. La economía de los costes de transacción (naturaleza de la firma de Ronald Coase, 1937) determinará el retorno de la inversión que puede influenciar la adopción por negocios y empresas.

Los procedimientos tradicionales de retorno a corto plazo, y muy frecuentes en el mundo de los negocios, pueden retardar la adquisición de datos. Una inversión inadecuada puede limitar las herramientas necesarias para acumular una masa crítica de datos. Así, sin datos suficientes, las herramientas analíticas pueden fallar en el descubrimiento de patrones ocultos en los datos. Sin embargo, los procesos de descubrimiento de patrones son muy necesarios especialmente cuando los motores de análisis dinámicos en tiempo real son un camino a la monetización de IoT. En este aspecto, se pueden crear nuevas fuentes de ingresos a partir de micropagos basados en el modelo de pago por análisis de arbitraje

de la información (*pay-per-analytics model*), que utiliza análisis predictivo inteligente para mejorar el apoyo a la toma de decisiones semiautónoma.

Una lección de adquisición y análisis de datos puede extraerse del experimento clásico de la mecánica cuántica, que describe el experimento de la doble rendija de Young. Una variación de este experimento se realizó en el Hitachi Laboratorio Central de Investigación (HITACHI) en Kokubunji por el doctor Akira Tonomura (1942-2012). Este segundo experimento (HITACHI, 2015) reveló la existencia de un patrón de interferencia a partir de electrones individuales, pero no se observó hasta que se permitió el paso de un número de electrones suficientemente grande a través de la rendija. La lectura de este experimento para los negocios es obvia, porque la ejecución de experimentos a pequeña escala puede no ofrecer resultados adecuados e incluso podría proporcionar indicaciones equivocadas (puesto que no se puede construir un elefante tomando un ratón como modelo). En este sentido, este trabajo es intuitivo, porque sugiere despliegues a gran escala como clave para extraer el valor de los datos y la importancia de las herramientas y las tecnologías que, cuando se combinan y convergen, pueden aportar excelentes soluciones.

En la historia de los procesos tecnológicos, se pueden encontrar ejemplos como las estrategias que permitieron la difusión de la electricidad (*The economic future in historical perspective*, editado por P. A. David y M. Thomas, Oxford University Press, 2003). En el trabajo *The innovators dilemma*, de Clayton Christensen, el término *disruptive* es una exageración basada en el concepto original de las tecnologías de procesos generales (*general process technologies*) introducidas durante la era de la

electrificación para indicar integración sistémica frente al uso *ad hoc* del término *slap-on*. Christensen hizo un mal uso del término *disruptive* así como un erróneo análisis de datos que condujo a concluir que todo es perjudicial (Andrew King, MIT Sloan School of Management).

Cambios en la organización

Durante los últimos quince años se ha observado una falta de integración sistémica de etiquetas RFID (*radio frequency identification*) de identificación por radiofrecuencia, muy habituales en todo tipo de establecimientos para identificar los productos. A pesar de su uso muy extendido, la industria no se ha beneficiado suficientemente de la capacidad de las etiquetas RFID para adquirir grandes volúmenes de datos desde un enfoque de sistemas. Como resultado, es posible que hayamos fracasado para ofrecer una adecuada transparencia en las cadenas de suministro y el ahorro del valor de la cadena se mantiene muy por debajo de lo previsto. En WalMart (Is RFID dead? Florian Michahelles [2010] Auto-ID Labs St. Gallen, ETH Zurich), un trabajo sobre el abandono de la iniciativa de las tarjetas RFID, se sugiere que no es un fracaso de la tecnología, sino un uso inadecuado de la herramienta de datos en el contexto del proceso de negocio. Es un fracaso de cambio organizacional.

Internet de las cosas puede aprender de la historia de la electrificación y la tecnología por radiofrecuencia RFID, con el fin de encontrar mejores maneras de penetrar progresivamente nuestra realidad cotidiana a través de sistemas de integración, conectividad y aplicaciones. Internet de las cosas debe evolucionar a internet de los sistemas (IoS). La conectividad de sistemas en nuevos

ecosistemas puede generar el siguiente *tsunami* de rentabilidad. A su vez, aumentarán aún más los problemas de seguridad, privacidad, confianza y ética relacionados con nuestros programas de política social. La conectividad y las comunicaciones con los objetos y procesos cambiarán nuestra forma de interactuar y nuestro comportamiento tanto en la vida personal como en el entorno profesional en la era de la internet de los sistemas (IoS).

Nuevos modelos de negocio

La búsqueda de la autonomía en el cuidado de la salud, el transporte y la fabricación creará nuevas soluciones y germinará con nuevos modelos de negocio. La predicción de enfermedades como el cáncer con una década de anticipación no es una ilusión. Los vehículos con sistemas autónomos de estacionamiento, los camiones de carga y la distribución de paquetería sin interacción humana son ya noticias del pasado. La muerte del inventario y el nacimiento de la fabricación y distribución por demanda (dMODE) es el embrión de la Manufacturación 5.0 con el desarrollo de los sistemas de impresión 3D. Con el desarrollo de válvulas cardíacas, nanosatélites, la medición de la humedad del suelo por la NASA (SMAP) para la agricultura de precisión, la fabricación de agua potable desalinizada libre de arsénico y otros avances tecnológicos (*neurosynaptic web* y *neuromorphic chips*), podemos decir que ya ha comenzado el próximo viaje de cien años.

Según Jeff Immelt, CEO de General Electric,

En el futuro se espera un tejido abierto y global de máquinas altamente inteligentes que se conectan, se comunican y

colaboran con nosotros. La internet industrial no trata de un mundo dirigido por los robots, sino de combinar el mundo con mejores tecnologías para resolver nuestros mayores retos. Se trata de crear un mundo económicamente y ambientalmente sostenible, se trata de curar las enfermedades ahora incurables, y de preparar nuestras infraestructuras y ciudades durante los próximos 100 años.

La fricción económica es evidente tras la automatización de tareas repetitivas que hasta ahora han supuesto puestos de trabajo de ingresos medios: el personal de los bancos, el personal que atiende las ventanillas e incluso los profesores de cualquier grado en el sistema educativo (K-16 Teachers) están siendo sustituidos por cajeros automáticos, quioscos de autoservicio y los cursos abiertos masivos (MOOC). Esto no solo se debe a internet de los sistemas (IoS), sino también a la integración de la computación en nuestra vida cotidiana, según lo predicho por Herbert Simon en 1987 y popularizado por Mark Weiser en 1991.

Internet de los sistemas (IoT)

La conectividad de internet de los sistemas (IoS) con una sección transversal mayor de los objetos y procesos además de la exposición a mayor grado de supervisión (por ejemplo en cuidado de la salud) inducirá cambios en el comportamiento con el aumento de la difusión de internet de las cosas. La evolución de la actividad racional frente a la irracional debe ser observada y analizada (*Thinking fast and slow*, Daniel Kahneman). El resultado de estos análisis debe tenerse en cuenta al diseñar futuros

productos y servicios, por ejemplo, hospitales *wireless* del futuro o máquinas de resonancia magnética con repostaje automático de hidrógeno o máquinas de rayos X portátiles para ser usadas en las chozas en la Amazonia. La utilidad de estos avances puede depender de los valores socioeconómicos (*Scarcity*, Sendhil Mullainathan) y de la etapa de desarrollo del país o la región donde se aplica (*Development as freedom*, Amartya Sen).

La predicción de que la conectividad va a cambiar el comportamiento de las personas tiene sus raíces en el principio fundamental de la física de partículas. El “efecto del observador”, como se le llama, se refiere a los cambios que el acto de la observación produce cuando se observan fenómenos (y que no debe confundirse con el principio de incertidumbre propuesto por Werner Heisenberg). El primero puede explicar por qué cantamos en la ducha, pero no en público.

Cabe señalar que el comportamiento combinado de *hardware* y *software* integrados con objetos físicos cambiará si alguno de los componentes cambia, incluso si se sustituye por otro prácticamente idéntico. Además de los cambios en el comportamiento, el reequilibrio económico será lento, porque son necesarios cambios sustanciales en nuestro sistema de educación para optimizar el consumo social de los frutos de la tecnología. Ninguna cantidad de cursos de tecnología o cursos en línea evitará la propagación de la ruptura en nuestro tejido económico a menos que reformemos la educación pública y restauremos el respeto a las autoridades educativas, nos centremos en rejuvenecer todos los aspectos de la investigación científica, en restablecer la dignidad a los maestros y volver a encender la pasión que se espera de un profesor.

La cadena de suministro emergente de talento debe incluir la gran cantidad de niñas que sobresalen en matemáticas y que pueden programar y escribir coherentemente. Es esencial que las mujeres persigan el nivel más alto de la ciencia, la ingeniería, las matemáticas, la economía y la filosofía. ¿Cómo podemos aceptar que alrededor de 50 % de la energía del cerebro se quede fuera de la mano de obra especializada?

Las mujeres educadas ayudarán a educar niñas y niños respetuosos y dignos. El trabajo conjunto acelerará la innovación masiva en paralelo de las lejanas grietas del mundo en el que ya se está marcando el comienzo de movimientos tectónicos, incluso en las tareas más tradicionales. El enfoque de análisis-parálisis de los gigantes puede conducir a su extinción si siguen siendo ajenos al hecho de que el fracaso es el nuevo camino hacia el éxito, el fracaso es la nueva clave para el éxito y el fracaso como mantra para el éxito de la economía emergente.

La distribución de la innovación exige un enfoque empresarial y un salto a múltiples niveles en lugar de soluciones mágicas (*Innovation: The attacker's advantage*, Richard Foster). La industria del taxi frente a servicios como UBER (www.uber.com), la industria hotelera frente a aplicaciones como Airbnb (www.airbnb.com) y las agencias de trabajo temporal frente a oDesk (www.upwork.com) son buenos ejemplos. La explosión de herramientas de ingeniería ha reducido drásticamente el tiempo necesario para introducir el ciclo de innovación por lo que ha comprimido enormemente el tiempo desde la concepción (desarrollo de la cadena de suministro) a la realización (cumplimiento de la cadena de suministro). Los gigantes de la industria deben aprovechar esta explosión y facilitar la creación de plataformas de código abierto donde

concurran las ideas y el desarrollo inteligente de aplicaciones. El flujo de microingresos de miles de millones de clics en la web de un producto será el elemento diferenciador y el servicio de datos de valor añadido estará relacionado con análisis inteligente de datos y la entrega de información útil *antes* que los datos perezcan. La inteligencia de negocios es el factor clave en la economía resultante.

Sin embargo, el carácter precedero de los datos cambia cuando la acumulación de datos en el tiempo es mucho más crítica para un análisis predictivo (por ejemplo en medicina, en la evolución de algunas enfermedades) y no de datos con corta vida media (por ejemplo el tiempo medio entre fallos MTBF [*mean time between failures*] o la métrica de piezas en una turbina). El transporte y almacenamiento de datos son importantes, pero los consumidores pueden estar dispuestos a pagar solo por su análisis en tiempo real y los resultados de aplicar las técnicas inteligentes. Los consumidores esperan que los datos en bruto sean abiertos y libres (gratis).

Aun así, todas estas ventajas son temporales. La sabiduría financiera de microingresos de arrendamiento de las plataformas es una de las razones por las que Apple abrió su *bus* para que cualquiera puede subir sus aplicaciones. Las aplicaciones llegan de todas partes del mundo como una avalancha económica y le permite a Apple, como propietaria del canal, agregar micropagos mediante la innovación abierta. *Small data* de millones de fuentes es la razón por la que Apple sonríe con la base de datos más grande del mundo de pagos, con una suma de 99 centavos de dólar en cada pago. El éxito de PayPal se ve alimentado por firmas como Tesla, que es capaz de regalar el coche que fabrica para vender baterías intercambiables a base de grafeno y servicios a

bordo (utilizando *software* definido en red, *software defined networking*). El futuro del automóvil Apple podría usar la red eléctrica móvil en lugar de la red inmóvil inteligente para distribución de energía *off-grid*. Los productos gratuitos con servicios basados en pago por el uso (*pay per use*) son ya una estrategia de negocio madura (impresoras frente a compra de tinta, teléfonos móviles frente a servicios, cafeteras frente a cápsulas de café) para ampliar las microganancias y garantizar una larga vida a los productos. Rolls Royce venderá horas de uso (*thrust hours*) en lugar de motores de avión; Google venderá planes de ahorro de energía solar (*solar savings plans*) en lugar de alertas y Bosch no venderá sensores físicos sino la inteligencia de los sistemas de sensores.

Se espera que la propagación de IoT y IoS dé lugar a nuevos productos y servicios (Datta, 2015b). El consumo de estos bienes y las mejoras en la eficiencia puede generar una magnitud de crecimiento económico que está induciendo mucha euforia en los CEO (*chief executive officer*) de las empresas. Según General Electric, Cisco y otras compañías, IoT y la internet industrial (IIoT) pueden sumar entre US\$14 000 millones y US\$19 000 millones a la economía global en la próxima década. Para que estas cifras se materialicen, debe ocurrir una explosión en el consumo. Los cientos de millones de personas que están escribiendo en las redes o publicando fotografías para mantener a flote la burbuja de la capitalización del mercado de los medios sociales pertenecen a un grupo social con ingresos insuficientes para pagar coches que hablan o una laparoscopia robótica. El consumidor educado es el mejor cliente. La burbuja económica de Twitter como medio social puede estar limitada por la cantidad de “energía bajo la curva” y la exuberancia irracional puede alimentar la próxima recesión global que

podría estar a la vuelta de la esquina (2020-2022). Con 2008 como el año de la última recesión, se espera la próxima alrededor de 2022 si el “ciclo de auge y caída” todavía exhibe la periodicidad de catorce años, como explica Finn Kydland (Premio Nobel de Economía 2004).

Reflexiones finales

En los Estados Unidos están surgiendo varias iniciativas en la industria y el mundo académico para hacer frente a la próxima generación de avances en el espacio de IoT, IIoT, IoS y las interesantes posibilidades de investigación en sistemas ciberfísicos. En el periodo 2014-2015, se formaron varios consorcios de líderes del mercado. En investigación, varios grupos académicos están liderando el camino con nuevos inventos e innovación. También la Unión Europea ha financiado un programa de varios años denominado Horizonte 2020 por una suma de más de US\$100 000 millones para explorar el crecimiento de IoT y ayudar a la cosecha de la bonanza económica asociada.

Pero será un error atroz por parte de los líderes globales cegarse por las proyecciones económicas sin prestar atención a un ajuste necesario del motor de la educación. ¿Una *smartcity* puede ser realmente inteligente sin ciudadanos inteligentes (Datta, 2015a)? ¿Serán las *smartcity* también ciudades sostenibles (López, 2014, 2015; López et al., 2015)?

La humanidad necesita soñadores (Datta, 2009) y la educación (Datta, 2014, 2014b) es la quinta esencia (*Salt: A world history*, Mark Kurlansky) que actúa como el proveedor de inspiración, imaginación, invención, innovación y unidades de implementación de las ideas (Datta, 2015b). La educación de un niño puede cambiar el

destino de un hombre. La educación de una niña puede cambiar el destino de una nación.

Referencias

- Ashton, K. (2009). That 'internet of things' thing. *RFiD Journal*, 22(7), 97-114.
- Datta, S. (2014a). Far reaching changes in the near future. Recuperado de <http://bit.ly/Book-by-S-Datta>
- Datta, S. (2014b). Internet of Systems (IoS) - Economic Re-equilibration Catalyzed by Internet of Things (IoT). Recuperado de <http://dspace.mit.edu/handle/1721.1/86935>
- Datta, S. (2015a). Smart cities. Recuperado de <http://bit.ly/SMART-CT>
- Datta, S. (2015b). Presentation of Datta 2015. Recuperado de <http://bit.ly/RE-VIEW-IOT>
- Datta, S. (2013). Humanity Needs Dreamers. Recuperado de <http://bit.ly/HND-250>
- Foster, R. N. (1986). *Innovation: The attacker's advantage*. Nueva York: Summit.
- HITACHI (2015). Quantum measurement. Recuperado de <http://www.hitachi.com/rd/portal/highlight/quantum/index.html#anc04>
- Kahneman, D. Pensar rápido, pensar despacio, Ed. Farrar, Straus and Giroux, Nueva York, 2011.
- López, V. (2014). Big and open data: Challenges for Smartcity. Recuperado de <http://www.slideshare.net/vlopezlo/big-open-data-challenges-for-smartcity>.
- López, V. (2015). Open Data para Smartcity. Recuperado de https://www.youtube.com/watch?v=x9G_l-0rLIE
- Lopez, V., Miñana, G., Sínchez, O., González, B., Valverde, G. y Caro, R. (2015). *Big+Open Data: some applications for a Smartcity*. En Progress in Informatics and Computing (PIC), 2015 IEEE International Conference on (pp. 384-389). IEEE.
- Manyika, J., Chui, M., Brown, B., Bughin, J., Dobbs, R., Roxburgh, C., & Hung Byers, A. (2011). Big data: The next frontier for innovation, competition, and productivity. Recuperado de <http://tinyurl.com/industrial-internet>
- Sarma, S., Brock, D. L. y Ashton, K. (2000). The networked physical world. Recuperado de http://cocoa.ethz.ch/downloads/2014/06/None_MIT-AUTOID-WH-001.pdf
- Shah, A. K., Shafir, E. y Mullainathan, S. (2015). Scarcity frames value. *Psychological Science*, 7(1), 1-36.
- Stiglitz, J. E. (2012). *El precio de la desigualdad*. Madrid: Taurus.
- The MIT Sloan CIO Symposium (2010). 2010-09 The internet of Things. Recuperado de <https://www.youtube.com/watch?v=44MLERLwxig>
- <https://www.youtube.com/watch?v=44MLERLwxig>
- Weiser, M. (1991). The Computer for the 21st Century-Scientific American Special Issue on Communications. *Computers, and Networks*, 265(3).

Come l' IoT potrà cambiare la società e l'economia

di *Shoumen Palit Austin* La connessione degli oggetti alle informazioni apre la strada alla trasformazione digitale. Un cambiamento che porterà conseguenze rivoluzionarie per la società e per il business, e che non sarà indolore. Potrà essere guidato nel suo svolgimento positivo se l'educazione favorirà l'acquisizione della cultura necessaria

Ospitiamo su Industria Italiana un articolo del Dr. Shoumen Palit Austin Datta Senior Member, MIT Auto-ID Labs, Research Affiliate, Department of Mechanical Engineering, Senior Scientist, MDPnP Lab, Department of Anaesthesiology, Massachusetts General Hospital, Harvard Medical School. La traduzione dell'articolo intitolato "Dynamic socio-economic disequilibrium catalysed by the Internet of Things" già pubblicato nel Journal of Innovation Management vol. 3, n. 3, 2015 è stata elaborata dalla Dr. Marianna Marchesi Architetto e Ricercatore, Member of ISAAAC Association - Global Advisory Group e rivista dalla nostra redazione

Lettera dal mondo accademico

L'evoluzione della tecnologia basata sul concetto di Internet delle Cose (IoT, dall'inglese Internet of Things) e l'IoT industriale (IIoT) ha avuto inizio più o meno nel 1988 grazie al lavoro di Mark Weiser al Research Center di Xerox a Palo Alto. In questo lavoro l'autore avanzò l'ipotesi che i computer potessero intrecciarsi alla vita di ogni giorno e, conseguentemente, influenzare il futuro dell'imprenditoria (Scientific American, 1991). Le conoscenze a cui Weiser alludeva si riferivano alla discussione di Herbert Simon nel suo articolo del 1987 "The Steam Engine and the Computer: What makes technology revolutionary" [Il motore a vapore e il computer: cosa rende la tecnologia rivoluzionaria] nel quale Simon fotografa la sua riflessione sul computer in questo modo: "you have to make friends with it, talk to it, let it talk to you" [devi fare amicizia con esso, parlare ad esso, lasciare che esso parli a te].

Quindi, contrariamente a quanto sostenuto con una esagerata pubblicità dai media, l'idea dell'IoT e il suo significato non sono nati da una presentazione (Bernardi, Sarma and Traub, 2017) a un imprenditore di prodotti al dettaglio. È stato nel 2000, con l'articolo fondamentale intitolato "The Networked Physical World" (MIT-AUTOID-WH-001) che è stata data origine al concetto di IoT (Manyika et al., 2011; Sarma et al., 2000) e all'evoluzione dell'IoT. Le vicende

relative all'IoT - incluso il nome "internet of things" - sono state oggetto di discussione in un recente simposio presso la Sloan School of Management all'MIT (The MIT Sloan CIO Symposium, 2013).

Una nuova rivoluzione

La connessione degli oggetti fisici (composti di atomi) alle informazioni (confezionate in bit) potrebbe dare seguito a un'altra rivoluzione che in molti, tra cui Neil Gershenfeld, hanno predetto. L'attuale cambiamento viene spesso indicato come la terza rivoluzione industriale in relazione alla seconda, l'era dell'Informazione, e alla prima rivoluzione industriale. In alcuni settori, l'attuale tendenza (anche definita come Industria 4.0) è indicata come l'età dei sistemi ciber-fisici (CPS, dall'inglese cyber-physical system).

Si suppone che le rivoluzioni modifichino il futuro che ci aspetta e la terza rivoluzione non farà eccezione: genererà attriti sia sociali che economici. Un conflitto con l'attuale status quo che sarà fuori dall'ordinario. Determinerà uno scontro tra visionari e persone dotate di scarsa immaginazione, nonché tra vecchie idee asfittiche contrapposte all'innovazione prorompente e geograficamente delocalizzata, con il risultato che l'incantesimo tecnologico si riverserà nelle nostre vite.

Esperti, osservatori di mercato e figure di spicco del mondo industriale sono divisi nelle loro convinzioni relativamente alla capacità di trasformazione delle tecnologie e alla connettività diffusa di cui ha bisogno l'IoT. Sta emergendo con forza dirompente un attrito sociale dovuto al deterioramento della privacy per come viene intesa tradizionalmente e una sua ridefinizione che sfida le convinzioni vecchio stampo. C'è una preoccupazione giustificata che riguarda la sicurezza e, contemporaneamente, c'è riluttanza a rinunciare ai benefici ad essa associati. Un attrito di carattere finanziario si evidenzia sia nelle nazioni industrializzate sia nelle economie emergenti ogni qual volta manodopera non qualificata diventa parte della forza lavoro. La manodopera, in generale, aborre l'automazione, la quale restringe la domanda di lavoro non qualificato e crea un impatto negativo sull'economia e sulla società nel loro insieme.

Ma queste non sono osservazioni nuove, sono tendenze secolari che si ripeteranno ancora e ancora, anche se con differenti sfumature. Secondo lo storico economista Norman Poire, i cinque secoli compresi tra il 1440 e il 1939 furono i più dinamici di tutta la storia. Molti progressi tecnologici apparvero in quel periodo, ma tre invenzioni emersero rispetto al resto come punti di svolta nell'evoluzione della tecnologia, e condussero ad un decisivo mutamento sociale. L'invenzione della

macchina tipografica ad opera di Johannes Gutenberg nel 1440 spronò l'arrivo della Rivoluzione dell'Informazione che diffuse il Rinascimento attraverso l'Europa. Nel 1609 il telescopio di Galileo Galilei diede inizio alla Rivoluzione Scientifica e all'Epoca dell'Illuminismo. La Rivoluzione Industriale e il Marxismo arrivarono poco dopo l'invenzione della macchina a vapore da parte di James Watt nel 1769. Nel 1939 apparve una quarta innovazione tecnologica: in quell'anno John Atanasoff e il suo studente Clifford Berry inventarono il computer elettronico digitale e inconsapevolmente con esso avviarono la seconda Rivoluzione dell'Informazione. Poco meno di un secolo più tardi, siamo ancora alle soglie di un'altra fase di cambiamento. La terza rivoluzione industriale potrebbe incoraggiare decisamente la grande convergenza della rivoluzione industriale con la rivoluzione dell'informazione, con tutte le incognite esistenti.

Gli effetti sul mercato del lavoro

Erik Brynjolfsson e Andrew McAfee alla Sloan School of Management (Center for Digital Business) dell'MIT si interrogano sugli attriti che potrebbero manifestarsi in seguito alla terza rivoluzione: maggiore disoccupazione e una crescente disuguaglianza (*Race against the Machine* e *The Second Machine Age*). Una analisi incisiva relativamente alle disuguaglianze è presente anche nei lavori di Joseph Stiglitz (*The Price of Inequality*) e Robert Reich (*Inequality for All*). Brynjolfsson e McAfee ripercorrono la discussione sulla elevata disoccupazione che John Maynard Keynes aveva definito come “disoccupazione tecnologica” negli anni '30. Robert Frank negli anni '90 e anche nel suo libro *The Darwin Economy* rivisita lo stesso tema e lo individua come quello che, catalizzato dalla tecnologia, la fa da padrone sui mercati del lavoro.

Brynjolfsson e McAfee prevedono che il nostro mondo “prospererà sulla frontiera digitale”. Ma cosa si può dire riguardo il percorso per raggiungere questa frontiera digitale? La strada che si staglia di fronte a noi è piena di insidie, tra nazioni in lotta, malnutrizione, scarse condizioni igieniche, inadeguata istruzione e scarsità di energia. Considerati assieme, già di per sé questi fattori hanno la capacità di alimentare in maniera lampante attriti socio economici, che potrebbero essere ulteriormente esacerbati dalle caratteristiche ascritte alla diffusione globale dell'IoT.

L'impossibile definizione di un unico standard per l' IoT

I frutti che possono derivare dall'IoT dipenderanno dalla nostra abilità di scambiare e condividere informazioni tra sistemi, oggetti e apparecchi in differenti ambienti, che supportano diversi standard operativi, procedurali e

applicativi. Non è possibile coltivare l'aspettativa che il mondo cerchi a tutti i costi di supportare un unico comune standard. Quindi nessuna standardizzazione di per sé, ma lo scambio e la condivisione di informazioni tra i principali standard saranno la chiave per la diffusione dei prodotti e dei servizi dell'IoT e dell'IIoT, (Industrial IoT) che metteranno capo al dominio di tutte le cose meccaniche. Le aziende leader nel campo industriale devono abilitare standard aperti per le interfacce (APIs) attraverso le quali i prodotti delle piccole e medie imprese (SMEs) possono connettersi ad un bus, a un canale globale comune (un insieme di collegamenti fisici utilizzati in comune da più elementi per scambiare informazioni da elaborare) in modo da accedere al collegamento e includere i loro servizi a valore aggiunto i loro computer o valorizzare le loro applicazioni di nicchia. Lo sviluppo sistematico di una dorsale open di connessione è decisivo nell'acquisizione di dati e nella diffusione dell'IoT.

In definitiva sarà la capacità di estrarre informazioni dai dati a guidare la value proposition della connessione. I dati economici fondamentali relativi ai costi di compravendita nella connessione (*The Nature of the Firm* by Ronald Coase, 1937) determineranno il ROI, la resa del capitale investito, che influenzerà l'adozione del business da parte delle aziende.

L'enfasi sulla ricerca di risultati che siano immediatamente conseguibili e di un ritorno a breve termine, prevalenti nel mondo aziendale, può avere un impatto sulla misura dell'acquisizione dei dati. Investimenti inadeguati possono limitare gli strumenti necessari per accumulare una massa critica di dati. In ogni caso, senza un numero sufficiente di dati, gli strumenti di analisi potrebbero fallire nell'evidenziare dei modelli non evidenti. Un'azione di questo tipo risulta necessaria se i motori di analisi dinamica in tempo reale (all'edge e al core) rappresentano una delle strade per monetizzare l'IoT. Nuove fonti di fatturato potrebbero essere create da micro pagamenti basati su modelli "pay-per-analytics" di "information arbitrage", che utilizzeranno analisi intelligenti predittive per implementare il supporto decisionale nel caso di attività semi autonome.

Per l' Iot è necessario un dispiegamento su larga scala

Troviamo una lezione sulla acquisizione e l'analisi dei dati occultata nel classico esperimento di meccanica quantistica descritto come il cosiddetto esperimento della doppia fenditura di Young.

Una variazione dell'esperimento venne eseguita al HCRL (Hitachi Central Research Labs) dal Dr. Akira Tonomura (1942-2012). Si constatò lo sviluppo di modelli di interferenza derivanti da singoli elettroni, ma il fenomeno non si

manifestò se non quando un numero sufficiente di elettroni poté oltrepassare la fessura (HITACHI, 2015). La lezione che ne deriva per il mondo degli affari è ovvia: condurre test ed esperimenti a una piccola scala potrebbe non offrire adeguati risultati o potrebbe fornire indicazioni sbagliate perché non si può costruire un elefante utilizzando un topo come modello. Questo lavoro è rivelatorio, perché dimostra come il dispiegamento su larga scala può essere la chiave per estrarre valore significativo da strumenti e tecnologie che possano fornire soluzioni quando sono combinate e convergenti.

Un'altra lezione da tener presente può essere individuata nella storia delle tecnologie generali di processo, in particolare nelle strategie che resero possibile la diffusione dell'elettricità (*The Economic Future in Historical Perspective* edited by P. A. David and M. Thomas, Oxford University Press, 2003). Il termine 'disruptive' utilizzato da Clayton Christensen in "*The Innovators Dilemma*" è una iperbole basata sul concetto originale di tecnologie generali di processo (GPT, dall'inglese *general process technologies*) introdotto durante l'epoca dell'elettrificazione per indicare una integrazione sistemica, contrapposta a un uso ad hoc, di momento. Christensen usò impropriamente la parola e fuorviò il mondo delle aziende utilizzando un'analisi povera di dati per far pensare che ogni cosa è disruptive.

Negli ultimi 15 anni abbiamo osservato la mancanza di integrazione sistemica del RFID (dall'inglese Radio-Frequency Identification; in italiano identificazione a radiofrequenza). Di conseguenza, non abbiamo tratto sufficiente profitto dalla capacità dei tag RFID di acquisire un elevato volume di dati tramite un approccio di sistema. Come risultato, non siamo stati in grado di fornire adeguata trasparenza all'interno delle supply chains e i risparmi derivanti dalla catena di valore rimangono ben al di sotto delle attese. Le considerazioni che si possono trarre dall'abbandono dell'iniziativa RFID a WalMart (Florian Michahelles [2010] *Is RFID dead?* Auto-ID Labs St. Gallen, ETH Zurich), non riguardano il fallimento di una tecnologia, ma un utilizzo inadeguato dei data tools nel contesto del processo di svolgimento del business.

Dall' IoT (Internet of things) all' IoS (Internet of Systems)

L' IoT può imparare dalla storia dell'elettrificazione e da quella dell' RFID così da individuare i modi migliori per farsi progressivamente spazio nella nostra realtà quotidiana attraverso l'integrazione dei sistemi, la connessione, e gli applicativi. L' IoT deve evolversi dall'internet delle cose all'internet dei sistemi (IoS). Dalla connessione tra ecosistemi di sistemi può arrivare il prossimo tsunami di redditività. A sua volta questo genererà ancora più dibattito nelle

nostre agende di politica sociale relativamente a sicurezza, privacy, fiducia e aspetti relativi all'etica. La connettività IoT e la comunicazione con gli oggetti e i processi cambierà la maniera in cui interagiranno e ci comporteremo nelle nostre vite personali e professionali, nell'era dell'IoS.

Il perseguimento dell'autonomia nell'assistenza sanitaria, nel trasporto e nella produzione creerà nuove soluzioni e vecchi grattacapi, e genererà nuovi modelli di business. La possibilità di diagnosticare un tumore almeno un decennio prima che si manifesti non è un'illusione. Il veicolo autonomo che si parcheggia da solo e un carico merci che arriva a destinazione senza la presenza di umani nel processo è ormai storia vecchia. La morte delle giacenze di magazzino e la nascita delle produzioni distribuite su richiesta (dMOD) marginali (dMODE) rappresenta l'embrione della Manifattura 5.0, catalizzata dalle stampanti 3D. Con le valvole cardiache fino ai nano-satelliti, con l'assistenza attiva e passiva (SMAP) per l'umidità del suolo messa a punto dalla NASA ai fini dell'agricoltura di precisione, con l'acqua potabile desalinizzata priva di arsenico e depurata dal grafene e ogni cosa esaltante che sta nel mezzo (web neurosinaptico e chip neuromorfici), abbiamo appena cominciato il viaggio dei prossimi 100 anni.

Secondo Jeff Immelt di GE “nel futuro ci si aspetta una fabbrica globale e aperta di macchine altamente intelligenti che si connettono, comunicano e cooperano con noi. Quando si parla di Internet industriale non si parla di un mondo fatto girare dai robot, ma si parla di mettere insieme le migliori tecnologie del mondo per risolvere le nostre sfide più importanti. Vale a dire quelle che riguardano l'energia economicamente e ambientalmente sostenibile, la cura di malattie incurabili e la predisposizione delle nostre infrastrutture e città in vista dei nostri prossimi 100 anni.

La connettività diffusa cambierà i modelli di comportamento

L'attrito economico risulta con evidenza quando si considera la perdita delle mansioni ripetitive a reddito medio, che possono essere largamente automatizzate o che possono disporre di strumenti online per il loro svolgimento. Cassieri di banca, addetti alla cassa del negozio e anche insegnanti di scuola superiore saranno eliminati dalla forza lavoro a favore di sportelli bancomat, casse self-service e MOOC (Massive Open Online Courses; in italiano, corsi online aperti su larga scala). Questo non è solo dovuto all'IoS, (Internet Operating System) ma all'integrazione della modellistica computazionale nella nostra vita di tutti i giorni, come previsto da Herbert Simon e Mark Weiser.

La connessione dell'IoS con una più vasta interdipendenza di oggetti e processi unita all'esposizione ad un maggiore grado di monitoraggio (per esempio nella salute) indurranno cambiamenti nel comportamento con una crescente diffusione dell'IoT. Che poi la connessione ubiquitaria modifichi l'attività razionale contrapposta a quella irrazionale, è tutto da vedere e da essere analizzato (*Thinking Fast and Slow* di Daniel Kahneman). I risultati di queste analisi devono essere presi in considerazione nella progettazione di oggetti e servizi futuri, per esempio l'ospedale wireless o le macchine per la risonanza magnetica (RM) situate in stazioni di rifornimento d'idrogeno, o quelle portatili per i raggi X nei presidi medici di Amazon. L'utilità di queste proposte potrebbe dipendere dall'etica socio economica della società (*Scarcity* di Sendhil Mullainathan) e dal livello raggiunto nell'ambito dello sviluppo socio-economico (*Development as Freedom* di Amartya Sen).

La previsione che la connettività cambierà i modi del comportamento è radicata nei fondamentali principi della fisica delle particelle. Il cosiddetto "effetto dell'osservatore", si riferisce ai cambiamenti che l'azione dell'osservare avrà sul fenomeno osservato, da non confondere con il principio di indeterminazione proposto da Werner Heisenberg. Il primo potrebbe spiegare perché uno può cantare sotto la doccia e non in pubblico.

Si può osservare che il comportamento collegato, in particolare la centralità temporale nei sistemi ciber-fisici (hardware e software integrati con oggetti fisici), cambia se uno qualsiasi dei componenti viene modificato, anche se i componenti sono pressochè identici. Il rendez vous con il tempo può a volte risultare difficile.

La necessità di ammodernamento dell'istruzione pubblica

In aggiunta alla lentezza dei cambiamenti nel comportamento, pure il riequilibrio economico sarà lento, perchè sono necessari cambiamenti di massa del nostro sistema educativo per ottimizzare il consumo sociale dei frutti derivati dalla tecnologia. Nessun quantitativo di tecnologia o corsi online inibirà la diffusione della frattura nel nostro sistema finanziario, a meno che non venga ammodernata l'educazione pubblica, ripristinato il rispetto per l'università, ci si rifocalizzi sul rigore, vengano rinnovati tutti gli aspetti della ricerca scientifica, restaurata la dignità dovuta all'insegnante e riaccesa la passione che ci si attende dall'insegnante stesso.

La filiera emergente del talento deve includere con dovizia ragazze che siano eccellenti in matematica, e che possano programmare e scrivere in maniera

logica. È essenziale che le donne abbiano come obiettivo il raggiungimento di un elevato livello nelle scienze, in ingegneria, matematica economia e filosofia. Come possiamo accettare che il 50% circa del potere intellettuale sia escluso dalla forza lavoro?

Donne istruite contribuiranno all'educazione di ragazzi che siano rispettosi e ragazze che si possano distinguere. Tutto questo insieme accelererà la parallela innovazione di massa proveniente dai più distanti recessi del mondo e che sta preannunciando uno spostamento tettonico anche nei più tradizionali business. L'approccio analisi-paralisi dei colossi potrebbe portarli all'estinzione, qualora rimanessero noncuranti del fatto che l'insuccesso è la nuova strada del successo e l'insuccesso è il mantra per coloro che desiderano avere successo.

I nuovi modelli di business

L'innovazione distribuita richiede un approccio imprenditoriale e un'azione aggressiva che si svolge su livelli multipli simultanei piuttosto che la mitica soluzione semplice e diretta ad un problema complesso (*Innovation: The Attacker's Advantage* di Richard Foster). L'industria dei tassisti contro Uber, l'industria alberghiera contro Airbnb e le agenzie interinali contro Upwork sono un chiaro esempio. L'esplosione di strumenti ingegneristici ha drammaticamente ridotto il ciclo di tempo necessario per introdurre innovazioni comprimendo enormemente il tempo necessario dalla concezione (sviluppo della filiera) alla realizzazione (realizzazione della filiera). I giganti dell'industria devono imbrigliare questa esplosione liberandosi delle piattaforme in modo da aggregare intelligenza che può operare su piattaforme open source. Il flusso di micro-entrate che deriva da miliardi di ping (Packet internet grouper) sul tuo prodotto sarà quello che fa la differenza e quel data service a valore aggiunto sarà messo in relazione con l'analisi intelligente dei dati e il possesso di una informazione operativa fino al punto d'utilizzo, prima che il dato si deteriori.

Ad ogni modo, la dinamica di deperibilità dei dati cambia quando la raccolta della loro serie storica è molto più determinante per l'analisi predittiva (ad esempio l'assistenza sanitaria) piuttosto che per i dati di breve vita (per esempio, la misura del tempo medio di guasto (MTBF) per i pezzi di ricambio). Il trasporto e l'archiviazione dei dati sono importanti in questo business, ma i consumatori potrebbero voler pagare solo per il real-time analytics (l'istantaneo accesso e uso dei dati di analisi); i consumatori si aspettano che i dati grezzi siano gratis.

Ad ogni modo tutti i vantaggi sono temporanei. L'esperienza finanziaria di guadagni derivati da micro-entrate per il noleggio della piattaforma è una delle

ragione per cui Apple ha aperto il suo “bus” affinché chiunque potesse salirvi (creando applicativi). Le App vi si riversano in massa da ogni parte del mondo. Il creatore di app è parte della valanga economica che ha consentito ad Apple, in qualità di gestore del canale, di aggregare micropagamenti utilizzando l’open innovation. Questo meccanismo di aggregazione da milioni di *small data* ha consentito ad Apple di realizzare il più grande database di pagamenti al mondo per la modesta somma di 99 centesimi alla volta. Il successo di PayPal ha alimentato Tesla, la quale potrebbe svendere sottocosto l’auto in modo da piazzare batterie estraibili al graphene e servizi a bordo basati sul SDN (Software Defined Networking). L’automobile può diventare la rete elettrica mobile del futuro per la distribuzione off-grid dell’energia sostituendo le reti smart fisse. Dare la disponibilità libera di prodotti in cambio di micro-entrate derivate dal pagamento dei servizi in base all’effettivo utilizzo (pay per use) è una strategia di business collaudata (stampanti contro inchiostro, telefoni cellulari contro servizi, distributore di acqua fredda contro acqua imbottigliata) per accrescere quei micro-guadagni che godranno di una lunga vita e comproveranno il valore della “*long tail*”.

Il consumatore istruito è il miglior consumatore

È previsto che la diffusione dell’IoT e dell’IoS dia luogo a nuovi prodotti e servizi (Datta, 2015 b). Il consumo di questi beni e i miglioramenti in efficienza potrebbe generare una crescita economica talmente grande da indurre all’ euforia gli amministratori delegati. Secondo GE, Cisco e altri, l’IoT e l’IIoT potrebbero aggiungere circa da 14000 a 19000 miliardi di dollari all’economia globale nel corso del prossimo decennio. Per materializzare questi numeri è necessaria un’esplosione di consumerismo.

I milioni di persone che scrivono sui muri o che pubblicano fotografie per tenere a galla il tappo del mercato dei software della bolla dei social media, appartengono ad un gruppo i cui guadagni non permettono di comprarsi la macchina parlante o l’avatar per gestire il tè del mattino a letto o la laparoscopia robotica. Il consumatore istruito è il migliore consumatore. La bolla dell’economia dei social media del chiacchiericcio frenetico può essere limitata dalla quantità di “energia sottesa dalla curva” e l’irrazionale esuberanza potrebbe alimentare la prossima recessione globale, potenzialmente dietro l’angolo (2020-2022). Con l’ultimo anno di recessione nel 2008, attendiamo la prossima attorno al 2022, se è vero che il “ciclo di espansione e contrazione” ha una periodicità di 14 anni, stando a quanto dice Finn Kydland (Premio Nobel in Economia, 2004).

Negli Stati Uniti si stanno sviluppando numerose iniziative che riguardano l'industria e il mondo accademico per indirizzare la nuova generazione di innovazioni verso l'IoT spaziale, l'IoT industriale, l'IoS e le entusiasmanti possibilità derivate dalla ricerca nei sistemi ciberfisici (CPS). Numerosi consorzi sono stati creati nel 2014-2015 con il supporto dalle aziende leader nel mercato. Numerosi gruppi accademici fanno da battistrada con nuove invenzioni ed innovazioni. L'Unione Europea ha finanziato un massiccio programma pluriennale chiamato Horizon 2020 per un importo pari a più di 100 miliardi di dollari per esplorare la crescita dell'IoT e aiutare a raccogliere i frutti del guadagno economico inaspettato.

Ma sarà un flagrante errore da parte della leadership globale ignorare le previsioni economiche continuando a lucidare la cromatura senza prestare attenzione a calibrare il motore dell'educazione. Una città smart (Datta, 2015 a) è realmente smart senza cittadini smart?

L'umanità ha bisogno di sognatori (Datta, n.d.) e l'istruzione (Datta, 2014) è il sale per eccellenza (*Salt* di Mark Kurlansky), che agisce come fornitore di ispirazione, immaginazione, invenzione, innovazione guidando l'implementazione di idee (Datta, 2015 b). L'istruzione di un ragazzo potrebbe cambiare il destino di un uomo. L'istruzione di una ragazza potrebbe cambiare il destino di una nazione.

Bibliografia

Linda Bernardi, Sanjay Sarma and Kenneth Traub (2017) *The Inversion Factor: How to Thrive in the IoT Economy*. MIT Press, Cambridge, MA.
<https://mitpress.mit.edu/books/inversion-factor>

Datta, S. (2014). *Far Reaching Changes in the Near Future* [e-book]. Accessed September 2015. <https://dspace.mit.edu/handle/1721.1/111021>

Datta, S. (2014). *Internet of Systems (IoS) - Economic Re-equilibration Catalyzed by Internet of Things (IoT)*. Accessed September 2015. <http://bit.ly/MIT-IOT>

Datta, S. (2015 a). *Smart Cities* [presentation]. Accessed September 2015. Retrieved from: <http://bit.ly/SMART-CT>

Datta, S. (2015 b). Presentation of Datta 2015 [presentation]. Accessed September 2015. <https://dspace.mit.edu/handle/1721.1/111021>

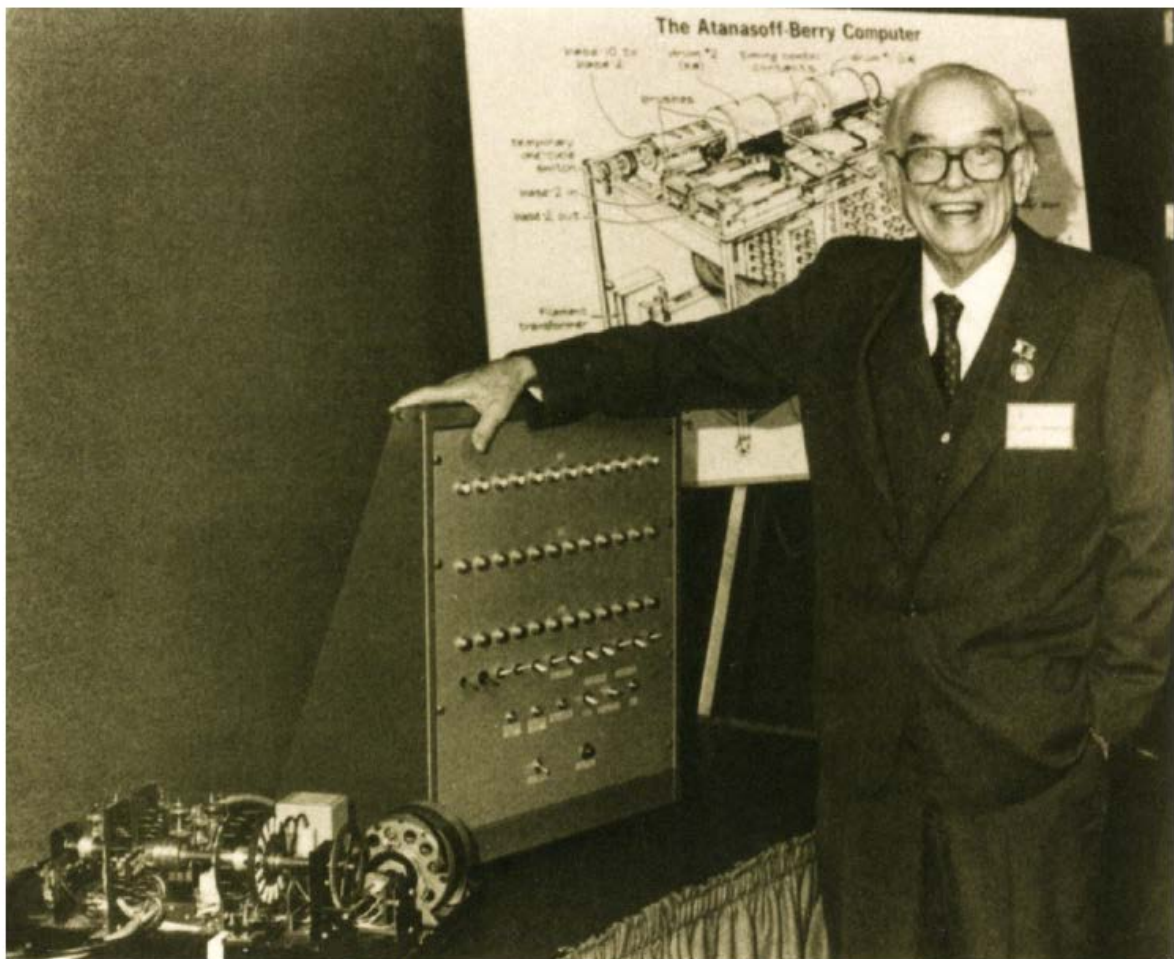
Datta, S. (n.d.). Humanity Needs Dreamers [presentation]. Accessed September 2015. <http://bit.ly/HND-250>

HITACHI. (2015). Quantum Measurement. Accessed September 2015. <http://www.hitachi.com/rd/portal/highlight/quantum/index.html#anc04>

Manyika, J., Chui, M., Brown, B., Bughin, J., Dobbs, R., Roxburgh, C., & Hung Byers, A. (2011). Big data: The next frontier for innovation, competition, and productivity. McKinsey Global Institute. Accessed September 2015. <http://tinyurl.com/Industrial-Internet>

Sarma, S., Brock, D.L., & Ashton, K. (2000). The Networked Physical World. MIT AUTO-ID CENTER. Accessed September 2015. http://cocoa.ethz.ch/downloads/2014/06/None_MIT-AUTOID-WH-001.pdf

The MIT Sloan CIO Symposium. [MIT Sloan CIO Symposium Videos]. (2013, August 29). 2010-09 The Internet of Things [Video file]. Accessed September 2015. <https://www.youtube.com/watch?v=44MLERLwxig>



JOHN ATANASSOFF E IL COMPUTER DIGITALE MESSO A PUNTO CON CLIFFORD BERRY

di Shoumen Palit Austin Datta ♦ L'Internet delle cose cambia la società e le aziende, e rende possibile digital transformation e creazione di valore. Un cambiamento che non è indolore e necessita di investimenti in cultura e formazione. Ecco come fare

Ospitiamo su Industria Italiana un articolo del Dr Shoumen Palit Austin Datta, Senior Member, MIT Auto-ID Labs, Research Affiliate, Department of Mechanical Engineering, Senior Scientist, MDPnP Lab, Department of Anaesthesiology, Massachusetts General Hospital, Harvard Medical School (vedi scheda a fondo pagina per la biografia completa e la bibliografia relativa all'articolo). La traduzione dell'articolo intitolato originariamente "Dynamic socio-economic disequilibrium catalysed by the Internet of Things" già pubblicato nel Journal of Innovation Management vol. 3, n. 3, 2015 è stata elaborata dalla Dr. Marianna Marchesi, Architetto e Ricercatore, Member of ISAAAC Association – Global Advisory Group.



L'AUTORE DELL' ARTICOLO, IL DR. SHOUMEN PALIT AUSTIN DATTA

L'evoluzione della tecnologia basata sul concetto di Internet delle Cose (IoT, dall'inglese Internet of Things) e l'IoT industriale (IIoT) ha avuto inizio più o meno nel 1988 grazie al lavoro di **Mark Weiser** al **Research Center di Xerox** a Palo Alto. In questo lavoro l'autore avanzò l'ipotesi che i computer potessero intrecciarsi alla vita di ogni giorno e, conseguentemente, influenzare il futuro dell'imprenditoria (Scientific American, 1991). Le conoscenze a cui Weiser alludeva si riferivano alla discussione di **Herbert Simon** nel suo articolo del 1987 "*The Steam Engine and the Computer: What makes technology revolutionary*" [Il motore a vapore e il computer: cosa rende la tecnologia rivoluzionaria] nel quale Simon fotografa la sua riflessione sul computer in questo modo: "*you have to make friends with it, talk to it, let it talk to you*" [devi fare amicizia con esso, parlare ad esso, lasciare che esso parli a

ISCRIVITI ALLA NOSTRA NEWSLETTER

sono nati da una presentazione (Bernardi, Sarma and Traub, 2017) a un imprenditore di prodotti al dettaglio. È stato nel 2000, con l'articolo fondamentale intitolato "The Networked Physical World" (MIT-AUTOID-WH-001) che è stata data origine al concetto di IoT (Manyika et al., 2011; Sarma et al., 2000) e all'evoluzione dell'IoT. Le vicende relative all'IoT – incluso il nome "internet of things" – sono state oggetto di discussione in un recente simposio presso la Sloan School of Management al MIT (The MIT Sloan CIO Symposium, 2013).

Una nuova rivoluzione

La connessione degli oggetti fisici (composti di atomi) alle informazioni (confezionate in bit) potrebbe dare seguito a un'altra rivoluzione che in molti, tra cui Neil Gershenfeld, hanno predetto. L'attuale cambiamento viene spesso indicato come la terza rivoluzione industriale in relazione alla seconda, l'era dell'Informazione, e alla prima rivoluzione industriale. In alcuni settori, l'attuale tendenza (anche definita come Industria 4.0) è indicata come l'età dei sistemi ciber-fisici (CPS, dall'inglese cyber-physical system).

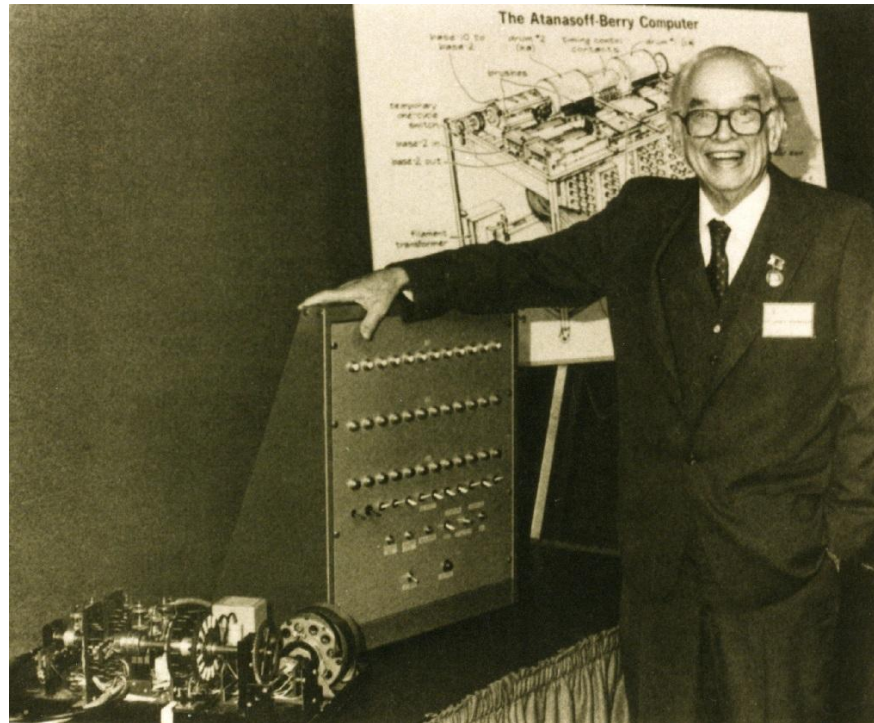
Si suppone che le rivoluzioni modifichino il futuro che ci aspetta e la terza rivoluzione non farà eccezione: genererà attriti sia sociali che economici. Un conflitto con l'attuale status quo che sarà fuori dall'ordinario. Determinerà uno scontro tra visionari e persone dotate di scarsa immaginazione, nonché tra vecchie idee asfittiche contrapposte all'innovazione prorompente e geograficamente delocalizzata, con il risultato che l'incantesimo tecnologico si riverserà nelle nostre vite.

Sta emergendo con forza dirompente un attrito sociale dovuto al deterioramento della privacy per come viene intesa tradizionalmente e una sua ridefinizione che sfida le convinzioni vecchio stampo. C'è una preoccupazione giustificata che riguarda la sicurezza e, contemporaneamente, c'è riluttanza a rinunciare ai benefici ad essa associati. Un attrito di carattere finanziario si evidenzia sia nelle nazioni industrializzate sia nelle economie emergenti ogni qual volta manodopera non qualificata diventa parte della forza lavoro. La manodopera, in generale, aborre l'automazione, la quale restringe la domanda di lavoro non qualificato e crea un impatto negativo sull'economia e sulla società nel loro insieme.

Ma queste non sono osservazioni nuove, sono tendenze secolari che si ripeteranno ancora e ancora, anche se con differenti sfumature. Secondo lo storico economista **Norman Poire**, i cinque secoli compresi tra il 1440 e il 1939 furono i più dinamici di tutta la storia. Molti progressi tecnologici apparvero in quel periodo, ma **tre** invenzioni emersero rispetto al resto come punti di svolta nell'evoluzione della tecnologia, e condussero ad un decisivo mutamento sociale. L'invenzione della macchina tipografica ad opera di **Johannes Gutenberg** nel 1440 spronò l'arrivo della Rivoluzione dell'Informazione che diffuse il Rinascimento attraverso l'Europa.

Nel 1609 il telescopio di **Galileo Galilei** diede inizio alla Rivoluzione Scientifica e all'Epoca dell'Illuminismo. La Rivoluzione Industriale e il Marxismo arrivarono poco dopo l'invenzione della macchina a vapore da parte di **James Watt** nel

dell'informazione. Poco meno di un secolo più tardi, siamo ancora alle soglie di un'altra fase di cambiamento. La terza rivoluzione industriale potrebbe incoraggiare decisamente la grande convergenza della rivoluzione industriale con la rivoluzione dell'informazione, con tutte le incognite esistenti.



JOHN ATANASOFF E IL COMPUTER DIGITALE MESSO A PUNTO CON CLIFFORD BERRY

Gli effetti sul mercato del lavoro

ISCRIVITI ALLA NOSTRA NEWSLETTER

Machine Age). Una analisi incisiva relativamente alle disuguaglianze è presente anche nei lavori di **Joseph Stiglitz** (*The Price of Inequality*) e **Robert Reich** (*Inequality for All*). Brynjolfsson e McAfee ripercorrono la discussione sulla elevata disoccupazione che **John Maynard Keynes** aveva definito come “disoccupazione tecnologica” negli anni `30. **Robert Frank** negli anni '90 e anche nel suo libro *The Darwin Economy* rivisita lo stesso tema e lo individua come quello che, catalizzato dalla tecnologia, la fa da padrone sui mercati del lavoro.

Brynjolfsson e McAfee prevedono che il nostro mondo “*prospererà sulla frontiera digitale*”. Ma cosa si può dire riguardo il percorso per raggiungere questa frontiera digitale? La strada che si staglia di fronte a noi è piena di insidie, tra nazioni in lotta, malnutrizione, scarse condizioni igieniche, inadeguata istruzione e scarsità di energia. Considerati assieme, già di per sé questi fattori hanno la capacità di alimentare in maniera lampante attriti socio economici, che potrebbero essere ulteriormente esacerbati dalle caratteristiche ascritte alla diffusione globale dell'IoT.

L'impossibile definizione di un unico standard globale per l' IoT

I frutti che possono derivare dall'IoT dipenderanno dalla nostra abilità di scambiare e condividere informazioni tra sistemi, oggetti e apparecchi in differenti ambienti, che supportano diversi standard operativi, procedurali e applicativi. Non è possibile coltivare l'aspettativa che il mondo cerchi a tutti i costi di supportare un unico comune standard. Quindi nessuna

meccaniche.

Le aziende leader nel campo industriale devono abilitare standard aperti per le interfacce (APIs) attraverso le quali i prodotti delle piccole e medie imprese (SMEs) possono connettersi ad un bus, a un canale globale comune (un insieme di collegamenti fisici utilizzati da più elementi per scambiare informazioni da elaborare) in modo da accedere al collegamento e includere i loro servizi a valore aggiunto i loro computer o valorizzare le loro applicazioni di nicchia. Lo sviluppo sistematico di una dorsale open di connessione è decisivo nell'acquisizione di dati e nella diffusione dell'IoT.

In definitiva sarà la capacità di estrarre informazioni dai dati a guidare la value proposition della connessione. I dati economici fondamentali relativi ai costi di compravendita nella connessione (*The Nature of the Firm* di **Ronald Coase**, 1937) determineranno il ROI, la resa del capitale investito, che influenzerà l'adozione del business da parte delle aziende.

L'enfasi sulla ricerca di risultati che siano immediatamente conseguibili e di un ritorno a breve termine, prevalenti nel mondo aziendale, può avere un impatto sulla misura dell'acquisizione dei dati. Investimenti inadeguati possono limitare gli strumenti necessari per accumulare una massa critica di dati. In ogni caso, senza un numero sufficiente di dati, gli strumenti di analisi potrebbero fallire nell'evidenziare dei modelli non evidenti. Un'azione di questo tipo risulta necessaria se i motori di analisi dinamica in tempo reale (all'edge e al core) rappresentano una delle strade per monetizzare l'IoT. Nuove fonti di fatturato potrebbero essere

risultati o potrebbe fornire indicazioni sbagliate perché... non si può costruire un elefante utilizzando un topo come modello. Questo lavoro è rivelatorio, perché dimostra come il dispiegamento su larga scala può essere la chiave per estrarre valore significativo da strumenti e tecnologie che possano fornire soluzioni quando sono combinate e convergenti.

Un' altra lezione da tener presente può essere individuata nella storia delle tecnologie generali di processo, in particolare nelle strategie che resero possibile la diffusione dell'elettricità (*The Economic Future in Historical Perspective* edited by **P. A. David and M. Thomas**, Oxford University Press, 2003). Il termine 'disruptive' utilizzato da **Clayton Christensen** in "*The Innovators Dilemma*" è una iperbole basata sul concetto originale di tecnologie generali di processo (**GPT**, dall'inglese general process technologies) introdotto durante l'epoca dell'elettrificazione per indicare una integrazione sistemica, contrapposta a un uso ad hoc, di momento. Christensen usò impropriamente la parola e fuorviò il mondo delle aziende utilizzando un'analisi povera di dati per far pensare che ogni cosa è disruptive.



UTILIZZAZIONE ETICHETTE RFID

Negli ultimi 15 anni abbiamo osservato la mancanza di integrazione sistemica del **RFID** (dall'inglese Radio-Frequency Identification; in italiano identificazione a radiofrequenza). Di conseguenza, non abbiamo tratto sufficiente profitto dalla capacità dei tag RFID di acquisire un elevato volume di dati tramite un approccio di sistema. Come risultato, non siamo stati in grado di fornire adeguata trasparenza all'interno delle supply chains e i risparmi derivanti dalla catena di valore rimangono ben al di sotto delle attese. Le considerazioni che si possono trarre dall'abbandono dell'iniziativa RFID a **WalMart** (**Florian Michahelles** [2010] *Is RFID dead?* Auto-ID Labs St. Gallen, ETH Zurich), non riguardano il fallimento di una tecnologia, ma un utilizzo inadeguato dei data tools nel

ISCRIVITI ALLA NOSTRA NEWSLETTER

progressivamente spazio nella nostra realtà quotidiana attraverso l'integrazione dei sistemi, la connessione, e gli applicativi. L'IoT deve evolversi dall'internet delle cose all'internet dei sistemi (IoS). Dalla connessione tra ecosistemi di sistemi può arrivare il prossimo tsunami di redditività. A sua volta questo genererà ancora più dibattito nelle nostre agende di politica sociale relativamente a sicurezza, privacy, fiducia e aspetti relativi all'etica. La connettività IoT e la comunicazione con gli oggetti e i processi cambierà la maniera in cui interagiranno e ci comporteremo nelle nostre vite personali e professionali, nell'era dell'IoS.

Il perseguimento dell'autonomia nell'assistenza sanitaria, nel trasporto e nella produzione creerà nuove soluzioni e vecchi grattacapi, e genererà nuovi modelli di business. La possibilità di diagnosticare un tumore almeno un decennio prima che si manifesti non è un'illusione. Il veicolo autonomo che si parcheggia da solo e un carico merci che arriva a destinazione senza la presenza di umani nel processo è ormai storia vecchia. La morte delle giacenze di magazzino e la nascita delle produzioni distribuite su richiesta (dMOD) marginali (dMODE) rappresenta l'embrione della Manifattura 5.0, catalizzata dalle stampanti 3D. Con le valvole cardiache fino ai nano-satelliti, con l'assistenza attiva e passiva (SMAP) per l'umidità del suolo messa a punto dalla NASA ai fini dell'agricoltura di precisione, con l'acqua potabile desalinizzata priva di arsenico e depurata dal grafene e ogni cosa esaltante che sta nel mezzo (web neurosinaptico e chip neuromorfici), abbiamo appena cominciato il viaggio dei prossimi 100 anni.



JEFF IMMELT, CHAIRMAN & CEO GE (PHOTO BY GAGE SKIDMORE)

Secondo **Jeff Immelt** di **GE** « nel futuro ci si aspetta una fabbrica globale e aperta di macchine altamente intelligenti che si connettono, comunicano e cooperano con noi. Quando si parla di Internet industriale non si parla di un mondo fatto girare dai robot, ma si parla di mettere insieme le migliori tecnologie del mondo per risolvere le nostre sfide più importanti. Vale a dire quelle che riguardano l'energia economicamente e ambientalmente sostenibile, la cura di malattie incurabili e la predisposizione delle nostre infrastrutture e città in vista dei nostri prossimi 100 anni.»

La connettività diffusa cambierà i modelli di comportamento

ISCRIVITI ALLA NOSTRA NEWSLETTER

☰ Menu

superiore saranno eliminati dalla forza lavoro a favore di sportelli bancomat, casse self-service e MOOC (Massive Open Online Courses; in italiano, corsi online aperti su larga scala). Questo non è solo dovuto all'IoS, (Internetwork Operating System) ma all'integrazione della modellistica computazionale nella nostra vita di tutti i giorni, come previsto da Herbert Simon e Mark Weiser.



GLI SPORTELLI BANCOMAT HANNO ELIMINATO PERSONALE DALLE BANCHE

ISCRIVITI ALLA NOSTRA NEWSLETTER

dell'IoT. Che poi la connessione ubiquitaria modifichi l'attività razionale contrapposta a quella irrazionale, è tutto da vedere e da essere analizzato (*Thinking Fast and Slow* di **Daniel Kahneman**). I risultati di queste analisi devono essere presi in considerazione nella progettazione di oggetti e servizi futuri, per esempio l'ospedale wireless o le macchine per la risonanza magnetica (RM) situate in stazioni di rifornimento d'idrogeno, o quelle portatili per i raggi X nei presidi medici di Amazon. L'utilità di queste proposte potrebbe dipendere dall'etica socio-economica della società (*Scarcity* di **Sendhil Mullainathan**) e dal livello raggiunto nell'ambito dello sviluppo socio-economico (*Development as Freedom* di **Amartya Sen**).

La previsione che la connettività cambierà i modi del comportamento è radicata nei fondamentali principi della fisica delle particelle. Il cosiddetto "effetto dell'osservatore", si riferisce ai cambiamenti che l'azione dell'osservare avrà sul fenomeno osservato, da non confondere con il principio di indeterminazione proposto da **Werner Heisenberg**. Il primo potrebbe spiegare perché uno può cantare sotto la doccia e non in pubblico. Si può osservare che il comportamento collegato, in particolare la centralità temporale nei sistemi ciber-fisici (hardware e software integrati con oggetti fisici), cambia se uno qualsiasi dei componenti viene modificato, anche se i componenti sono pressochè identici. Il rendez vous con il tempo può a volte risultare difficile.



PER DATTA È IMPORTANTE AUMENTARE L'INCLUSIONE DEL PERSONALE FEMMINILE NELLA FORZA LAVORO

La necessità di ammodernamento dell'istruzione pubblica

In aggiunta alla lentezza dei cambiamenti nel comportamento, pure il riequilibrio economico sarà lento, perchè sono necessari cambiamenti di massa del nostro sistema educativo per ottimizzare il consumo sociale dei frutti derivati dalla tecnologia. Nessun quantitativo di tecnologia o corsi online inibirà la diffusione della frattura nel nostro sistema finanziario, a meno che non venga ammodernata l'educazione pubblica, ripristinato il rispetto per l'università, ci si rifocalizzi sul rigore, vengano rinnovati tutti gli aspetti della ricerca scientifica, restaurata la dignità dovuta all'insegnante e riaccesa la passione che ci si attende dall'insegnante stesso. La filiera emergente del talento deve includere con dovizia ragazze che siano eccellenti in matematica. e che possano

ISCRIVITI ALLA NOSTRA NEWSLETTER

☰ Menu

ingegneria, matematica economia e filosofia. Come possiamo accettare che il 50% circa del potere intellettuale sia escluso dalla forza lavoro? Donne istruite contribuiranno all'educazione di ragazzi che siano rispettosi e ragazze che si possano distinguere. Tutto questo insieme accelererà la parallela innovazione di massa proveniente dai più distanti recessi del mondo e che sta preannunciando uno spostamento tettonico anche nei più tradizionali business. L'approccio analisi-paralisi dei colossi potrebbe portarli all'estinzione, qualora rimanessero noncuranti del fatto che l'insuccesso è la nuova strada del successo e l'insuccesso è il mantra per coloro che desiderano avere successo.



ISCRIVITI ALLA NOSTRA NEWSLETTER

L'innovazione distribuita richiede un approccio imprenditoriale e un'azione aggressiva che si svolge su livelli multipli simultanei piuttosto che la mitica soluzione semplice e diretta ad un problema complesso (*Innovation: The Attacker's Advantage* di **Richard Foster**). L'industria dei tassisti contro **Uber**, l'industria alberghiera contro **Airbnb** e le agenzie interinali contro **Upwork** sono un chiaro esempio. L'esplosione di strumenti ingegneristici ha drammaticamente ridotto il ciclo di tempo necessario per introdurre innovazioni comprimendo enormemente il tempo necessario dalla concezione (sviluppo della filiera) alla realizzazione (funzionamento della filiera). I giganti dell'industria devono imbrigliare questa esplosione liberandosi delle piattaforme in modo da aggregare intelligenza che può operare su piattaforme open source. Il flusso di micro-entrate che deriva da miliardi di ping (*Packet internet grouper*) sul tuo prodotto sarà quello che fa la differenza e quel data service a valore aggiunto sarà messo in relazione con l'analisi intelligente dei dati e il possesso di una informazione operativa fino al punto d'utilizzo, prima che il dato si deteriori.

Ad ogni modo, la dinamica di deperibilità dei dati cambia quando la raccolta della loro serie storica è molto più determinante per l'analisi predittiva (ad esempio l'assistenza sanitaria) piuttosto che per i dati di breve vita (per esempio, la misura del tempo medio di guasto (MTBF) per i pezzi di ricambio). Il trasporto e l'archiviazione dei dati sono importanti in questo business, ma i consumatori potrebbero voler pagare solo per il real-time analytics (l'istantaneo accesso e uso dei dati di analisi); i consumatori si aspettano che i dati grezzi siano gratis.

noleggio della piattaforma è una delle ragioni per cui **Apple** ha aperto il suo “bus” affinché chiunque potesse salirvi (creando applicativi). Le App vi si riversano in massa da ogni parte del mondo. Il creatore di app è parte della valanga economica che ha consentito ad Apple, in qualità di gestore del canale, di aggregare micropagamenti utilizzando l’open innovation. Questo meccanismo di aggregazione da milioni di small data ha consentito ad Apple di realizzare il più grande database di pagamenti al mondo per la modesta somma di 99 centesimi alla volta. Il successo di **PayPal** ha alimentato **Tesla**, la quale potrebbe svendere sottocosto l’auto in modo da piazzare batterie estraibili al graphene e servizi a bordo basati sul **SDN** (Software Defined Networking).

L’automobile può diventare la rete elettrica mobile del futuro per la distribuzione *off-grid* dell’energia sostituendo le reti smart fisse. Dare la disponibilità libera di prodotti in cambio di micro-entrate derivate dal pagamento dei servizi in base all’effettivo utilizzo (pay per use) è una strategia di business collaudata (stampanti contro inchiostro, telefoni cellulari contro servizi, distributore di acqua fredda contro acqua imbottigliata) per accrescere quei micro-guadagni che godranno di una lunga vita e comproveranno il valore della “long tail” .

Il consumatore istruito è il miglior consumatore

È previsto che la diffusione dell’IoT e dell’IoS dia luogo a nuovi prodotti e servizi (Datta, 2015 b). Il consumo di questi beni e i miglioramenti in efficienza potrebbe generare una crescita

consumerismo.

I **milioni** di persone che scrivono sui muri o che pubblicano fotografie per tenere a galla il tappo del mercato dei software della bolla dei social media, appartengono ad un gruppo i cui guadagni non permettono di comprarsi la macchina parlante o l'avatar per gestire il tè del mattino a letto, o la laparoscopia robotica. Il consumatore istruito è il migliore consumatore. La bolla dell'economia dei social media del chiacchiericcio frenetico può essere limitata dalla quantità di “energia sottesa dalla curva” e l'irrazionale esuberanza potrebbe alimentare la prossima recessione globale, potenzialmente dietro l'angolo (2020-2022). Con l'ultimo anno di recessione nel 2008, attendiamo la prossima attorno al 2022, se è vero che il “ciclo di espansione e contrazione” ha una periodicità di **14 anni**, stando a quanto dice **Finn Kydland** (Premio Nobel in Economia, 2004).



DATTA: UNA SMART CITY È REALMENE SMART SENZA CITTADINI SMART

Negli Stati Uniti si stanno sviluppando numerose iniziative che riguardano l'industria e il mondo accademico per indirizzare la nuova generazione di innovazioni verso l'IoT spaziale, l'IoT industriale, l'IoS e le entusiasmanti possibilità derivate dalla ricerca nei sistemi ciberfisici (CPS). Numerosi consorzi sono stati creati nel 2014-2015 con il supporto dalle aziende leader nel mercato. Numerosi gruppi accademici fanno da battistrada con nuove invenzioni ed innovazioni. L'Unione Europea ha finanziato un massiccio programma pluriennale chiamato Horizon 2020 per un importo pari a più di **100 miliardi** di dollari per esplorare la crescita dell'IoT e aiutare a raccogliere i frutti del guadagno economico inaspettato.

Ma sarà un flagrante errore da parte della leadership globale ignorare le previsioni economiche continuando a lucidare la cromatura senza prestare attenzione a calibrare il motore

ISCRIVITI ALLA NOSTRA NEWSLETTER

guidando l'implementazione di idee (Datta, 2015 b). L'istruzione di un ragazzo potrebbe cambiare il destino di un uomo. L'istruzione di una ragazza potrebbe cambiare il destino di una nazione.

Shoumen Palit Austin

Datta

Il Dr Shoumen Palit Austin Datta è Senior Member del MIT Auto-ID Labs, Research Affiliate at the Department of Mechanical Engineering, School of Engineering, MIT and Senior Scientist, MDPnP Lab, al Massachusetts General Hospital, Harvard Medical School . In precedenza è stato co-fondatore e Executive/ Research Director del MIT Forum for Supply Chain Innovation (2001-2010) e della MIT School of Engineering, e membro dell' Auto ID Center al MIT (1999-2003), del MIT Data Center (2004-2006) e del MIT Energy Initiative (2008-2009).

Come scienziato ricercatore per la Engineering Systems Division, MIT School of Engineering, ha analizzato nell'ambito dell' innovazione tecnologica RFID, IoT, supply chain, data analytics e la convergenza delle soluzioni in verticale. Ha insegnato Supply Chain,

Senior Vice President dell' Object Management Group (OMG). Il suo impegno con il MDPnP Program al Massachusetts General Hospital, Harvard Medical School riguarda la convergenza tra l'interoperabilità delle apparecchiature mediche con le attrezzature in via di sviluppo nell'ambito medicale, relativamente ai CPS e all' IoT.



ISCRIVITI ALLA NOSTRA NEWSLETTER

I suoi interessi spaziano dall' IoT/IIoT alla promozione della vision dell' internet of systems (IoS) che estende la connettività ubiquitaria, incluso l' industrial internet, per catalizzare la crescita economica globale . E' autore di diversi articoli riguardanti l'evoluzione dell' industrial internet (2003), isoftware intelligenti (2001), gli ambienti per l'analisi predittiva , la gestione e le operazioni generali relative alla supply chain , l'utilizzo dei sensori nelle piattaforme sanitarie, le energie rinnovabili e tutte le varie forme della trasformazione digitale dell'economia globale. Ha svolto il ruolo di advisor per associazioni e governi incluso il Dipartimento della difesa statunitense, le Nazioni Unite (UNDP), la World Customs Organization (WCO) e altri ancora.

E' stato Research Fellow in Medicina (Thyroid Lab, Neuro-Endocrine Lab, Molecular Oncology) al Massachusetts General Hospital and Instructor in Medicine all' Harvard Medical School. E' stato Research Associate al Whitehead Institute del MIT e membro del MIT Human Genome Project, così come Research Scientist all' University of California UCSF School of Medicine, San Francisco, California. Il Dr Datta si è impegnato nel settore pubblico per migliorare l'educazione e la tecnologia come Special Assistant per City & County of San Francisco, California; Science Education Partnership alla UCSF School of Medicine;

Bibliografia

- Linda Bernardi, Sanjay Sarma and Kenneth Traub (2017) The Inversion Factor: How to Thrive in the IoT Economy. MIT Press, Cambridge, MA.
<https://mitpress.mit.edu/books/inversion-factor>Datta, S. (2014). Far Reaching Changes in the Near Future [e-book]. Accessed September 2015.
<https://dspace.mit.edu/handle/1721.1/111021>
- Datta, S. (2014). Internet of Systems (IoS) – Economic Re-equilibration Catalyzed by Internet of Things (IoT). Accessed September 2015. <http://bit.ly/MIT-IOT>
- Datta, S. (2015 a). Smart Cities [presentation]. Accessed September 2015. Retrieved from: <http://bit.ly/SMART-CT>
- Datta, S. (2015 b). Presentation of Datta 2015 [presentation]. Accessed September 2015.
<https://dspace.mit.edu/handle/1721.1/111021>
- Datta, S. (n.d.). Humanity Needs Dreamers [presentation]. Accessed September 2015. <http://bit.ly/HND-250>
- HITACHI. (2015). Quantum Measurement. Accessed September 2015.
<http://www.hitachi.com/rd/portal/highlight/quantum/index.html#a>
- Manyika, J., Chui, M., Brown, B., Bughin, J., Dobbs, R., Roxburgh, C., & Hung Byers, A. (2011). Big data: The next frontier for innovation, competition, and productivity

2015. http://cocoa.ethz.ch/downloads/2014/06/None_MIT-AUTOID-WH-001.pdf

The MIT Sloan CIO Symposium. [MIT Sloan CIO Symposium Videos]. (2013, August 29). 2010-09 The Internet of Things [Video file]. Accessed September 2015. <https://www.youtube.com/watch?v=44MLERLwxig>

CONDIVIDI QUESTO ARTICOLO SUI SOCIAL NETWORK



TAGS:



ISCRIVITI ALLA NOSTRA NEWSLETTER

物联网催化下的动态社会经济失序

Dynamic Socio-Economic Disequilibrium Catalyzed by the Internet of Things

TRANSLATION: MR JIANCHAO WANG, KEDGE BUSINESS SCHOOL, TALENCE, BORDEAUX FRANCE

Dr Shoumen Palit Austin Datta

Senior Member, MIT Auto-ID Labs, Research Affiliate, Department of Mechanical Engineering,
Massachusetts Institute of Technology, 77 Massachusetts Ave, Cambridge, Massachusetts 02139
Senior Scientist, MDPnP Lab, Department of Anesthesiology, Massachusetts General Hospital,
Harvard Medical School, Partners MGH Research, 65 Landsdowne St, Cambridge, MA 02139, USA
shoumen@mit.edu ▪ sdatta8@mgh.harvard.edu

Previous English version "*Dynamic Socio-Economic Disequilibrium Catalyzed by the Internet of Things*" in *Journal of Innovation Management* (ISSN 2183-0606), vol. 3, n. 3, 2015; pages 4-9
<http://hdl.handle.net/10216/80026>

<https://repositorio-aberto.up.pt/bitstream/10216/80026/2/104497.pdf>

Also available as a book chapter in "IoT is a Metaphor" which can be downloaded from the
MIT Library using this URL <https://dspace.mit.edu/handle/1721.1/111021>

物联网催化下的动态社会经济失序

摘要

近年来物物相连的物联网兴起，在世界各国的产业界掀起风潮。但是物联网的兴起有其潜在的隐患，就是随着物物相连带来的商机，对于隐私权的侵害，以及印物联网兴起的工业4.0造成对劳动力的冲击。人类该如何面对这些隐患与冲击，便成为值得探究的议题。本文针对物联网的兴起，可能产生的商机，以及造成的社会经济不平衡进行探讨，并提出可能的应对之道，供业界与学界参考。

关键字：物联网，系统联网，工业4.0，社会经济失序，隐私，人力资源

TRANSLATION: MR JIANCHAO WANG, KEDGE BUSINESS SCHOOL, TALENCE, BORDEAUX FRANCE

Dynamic Socio-Economic Disequilibrium Catalyzed by the Internet of Things

ABSTRACT

The ideas about internet of things (IoT) and the industrial internet may have started in the 19th century. However, IoT has its defects: the erosion of privacy and potential for reduction of workforce, with the further development of IoT: Industrial Internet and Industry 4.0. How to face these challenges is important to discuss. This article discusses the development of IoT, the business of IoT, and possible socio-economic disequilibrium. We suggest possible solution to these challenges.

Keywords: Internet of Things; Internet of Systems; Industrial Internet; Industry 4.0; Socio-Economic Disequilibrium; Privacy; Human Resource

物联网 (Internet of Things, IoT) 以及变体[1]事物数据(Data of Things, DoT)、工业物联网 (Industrial Internet of Things, IIoT)的概念最早于大约 1988 年便被提起(Rifkin, 2014)。Herbert Simon 在其 1987 年发表的论文“蒸汽机与计算机”中提到将电脑运算技术应用到日常生活中,他认为“人类可以跟电脑结交朋友,并跟他进行互动”(Simon, 1987)。而根据 Xerox Palo Alto 研究中心 Dr. Mark Weiser 的文章 (Scientific American, 1991) 表示:“计算机应该逐渐与人类的生活密切结合在一起,并可以逐渐影响商业行为”。

事实上,物联网或是工业物联网这些名词不是来自于应该与其密切相关的零售制造商 [2],在麻省理工大学斯隆学院的一个研讨会上,一篇名为“网络物理世界”(MIT-AUTOID-WH-001)的论文提出了物联网的概念和工业网络发展的线索,关于物联网的本质以及它的名字“物联网”。[3]

连接由原子组成的实体物件与数据组成的虚拟世界,这就是大家认知上的再一次工业革命 (Ilic, Xie, Khan, & Moura, 2008) 相对于机械化带来的第一次工业革命以及信息化带来的第二次革命,大多数人认为这就是第三次工业革命 (Gershenfeld, 2008; Gershenfeld, & Vasseur, 2004)。而当红的工业 4.0 (Industrie 4.0) 也正是基于物联网上所兴起的网络物理系统 (Cyber-Physical System, CPS) 的一种扩大应用 (Ilic, Xie, Khan, & Moure, 2008; Smirnov, & Sandkuhl, 2015)。

革命应该重塑未来。目前的浪潮也不会例外。它会产生社会和经济的摩擦。现状与商业冲突并不会像往常一样。富有想象力的人与那些不太具备想象力的人之间将产生冲突。旧世界观点将与无拘束的创新碰撞,技术的魔力将渗透到我们的日常生活中。

专家、市场观察人士和行业人士对技术的转换能力、以及物联网可能需要的互联性都存在分歧。社会摩擦的爆发是由于传统格式的隐私侵蚀和对旧世界信仰的挑战。人们对安全的担忧是合理的,但也不愿意放弃与之相关的利益。无论在工业国家还是新兴经济体,只要非技术劳动力是体系的一部分,摩擦都是显而易见的。一般来说,劳动力将由自动化和机器人技术代替。它减少了对非技术劳动力的需求。这些劳动力会对此产生消极的想法,即使这项革命对整个社会经济会有实际影响。当然,随着时间的推移也可能变得积极。

这些观察已有数百年历史。它会再次重复,尽管处于不同的色调。根据经济史学家 Norman Poire 的说法,“1440 年至 1939 年间的五个世纪是历史上最具活力的时期之一。在那段时间里,许多技术进步浮出水面,但有三项发明高于其他技术,成为决定性社会变革的技术方向的转折点。Johannes Gutenberg 于 1440 年发明的印刷机促使了信息革命的到来,

使得文艺复兴在整个欧洲传播开来。1609年，伽利略的望远镜迎来了科学革命和理性时代。1769年瓦特发明蒸汽机后不久，工业革命和马克思主义就出现了。1939年，第四次技术革命开始了。在那一年，John Atanasoff和他的研究生 Clifford Berry发明了电子数字计算机，并在不知不觉中进行了第二次信息革命。不到一个世纪之后，我们正处于另一个变化之海的风口浪尖，它有可能在至少一个世纪内发展。或许，进展的成果可能会在2105-2120左右展开或达到高潮 (1)。

当前(第三次)工业革命可能会刺激工业革命与信息革命的大融合，可能还包括许多未知因素。麻省理工学院斯隆管理学院(Center for Digital Business)的 Erik Brynjolfsson 和 Andrew McAfee 就可能出现的第三次革命的摩擦——即失业率上升和不平等加剧(与机器人竞争和第二次机器时代)进行了讨论。在 Joseph Stiglitz (不平等的代价)和 Robert Reich (所有人的不平等)的作品中也可以看到关于不平等的深刻见解。

Brynjolfsson 和 McAfee 重新讨论了 John Maynard Keynes 在 20 世纪 30 年代所称的“技术失业”的高失业率问题。Robert Frank 在 20 世纪 90 年代的作品“达尔文经济”中重申了由技术催化的相同的话题：“赢家通吃”的劳动力市场。Brynjolfsson 和 McAfee 预测“我们的世界将在数字前沿繁荣起来”，但通向前方的道路究竟是怎样的呢？前方的道路充满了国家之间的争斗，营养不良，卫生系统紊乱，教育资源不足和能源的贫乏。这些因素助长了激烈的社会经济摩擦，而这种摩擦因物联网所带来所谓辉煌未来的缥缈承诺而加剧。而物联网是通过由沾满鲜血的企业和咨询公司运作的。这些共谋掩埋了连通性和物联网的真正好处。

物联网的设计和成果可能与我们在系统、平台、连接对象和设备互通的能力成比例(从不同的生态系统和环境、支持不同的操作标准、获取数据、协议、应用程序和分析的工具)。我们不可能指望世界支持任何一个共同的标准。

因此，通过物联网相关产品和服务(包括工业物联网)系统集成的关键不是标准化本身，而是主要标准之间的互通性。应用程序接口可以通过行业开放标准连接到全局连接总线(global connectivity bus)。中小型企业可以使用公共平台提供增值服务，与分析引擎或特殊应用捆绑。一般用途[5]技术设计，涉及到物联网的隐喻，只有在系统的联网部署改善数据获取和决策支持时才可能提供价值。

最终，理解数据，信息套利或从数据中提取“智能”的能力将推动连接的价值主张。在将数据转化为信息的过程中，必须注意分析行业的工具，以免我们在流程中丢失知识。

早在信息技术开启信息社会大门之前，Thomas Stearns Eliot 就曾问道：“我们生活中失去的生命在哪里？我们在知识中丢失的智慧在哪里？我们在信息中丢失的知识在哪里？”（The Rock in Collected Poems 1909–1935, Faber & Faber, London, 1951）。

信息，知识和智慧之间没有任何捷径[6]。谁不承认这一点，就会失去知识和智慧，只会发现一种新的，危险的愚蠢形式。这种愚蠢的形式终于到来了，现在通常被称为现代商业白话中的“低果先摘” [7]。

商业界普遍存在的低果先摘或是追求短期回报原则可能会影响数据获取的程度。投资不足可能会限制积累关键数据所需的工具。如果没有足够的数据库，分析工具可能会难以发现数据中隐藏的模式。如果动态分析引擎（在边缘和核心）可能成为实现物联网货币化的途径，这些隐藏的模式可能需要实时进行。基于信息套利的按分析付费模式，微支付可以创造新的收入来源。后者可能依靠智能预测分析来增加对各个层次自主活动的决策支持。

在自然界里，许多事实都是要数量足够大才会被发现。像是在量子力学的经典实验中，有一个关于数据采集和分析的例子，被称之为杨氏双缝实验。该实验是由 Akira Tonomura 博士(1946 -2012)在日立中央研究室进行，他发现到单个电子束的时候，根本不会有干扰现象的发生，直到足够的电子被允许通过狭缝时干扰现象才被观察到。这个实验给商业带来的教训是显而易见的——小规模试点和小规模的实验可能不会提供适当的结果或提供错误的迹象。人们不能用老鼠作为模型来构造大象。这项实验具有深刻的意义，因为它表明大规模部署可能是通过工具和技术获取价值与特征的关键，而这些工具和技术在结合或整合资源时或许能够提供解决方案。

在一般性流程技术（general process technologies）的演进中可以找到另一个教训。Clayton Christensen 在《创新者困境》中提出了颠覆性技术，从一般性流程技术的概念来推论并过宣扬“颠覆性”这个词来进行炒作。Clayton Christensen 认为所谓的颠覆才能创造成功，并认为良好的管理导致企业的失败，因为良好的管理往往抹杀了创新的可能。但他的概念来自于少量的资料，缺乏完整的数据分析，从而错误的使用了“颠覆”二字来误导商业界“只有颠覆才会成功”。

类似的例子在商界也看得出来。过去 15 年，RFID（Radio Frequency Identification）在缺乏系统性整合下，导致了应用上的受限。没有系统性的整合，我们无法获得足够数量的资料来说明 RFID 的应用情况，从而使我们无法充分的将 RFID 标签进行广泛应用。例如沃尔玛曾经错误估计了 RFID 的应用，大张旗鼓的要采用 RFID 作为其供应链整合上下游的工具，最后

却不得不放弃或是收紧对其的应用 (Is RFID dead? Florian Michahelles [2010] Auto-ID Labs, ETH)。但这并不是技术的问题,而是来自于对可能在供应链网络中的应用欠缺大量数据分析就贸然提出研究结论的下场。

目前物联网方兴未艾,或许人类可以从上述失败案例中吸取教训并加以改善,从而找到更好的方式来让这个将深入渗透进我们生活的机制得以完善的连结、整合以及应用。但物联网的下一步就是系统联网 (Internet of Systems, IoS) (Uckelmann, Harrison, & Michahelles, 2011)。如若物联网这一阶段没能处理好相关问题,那对于将不同生态系统整合之后的系统联网更可能造成进一步的灾难。在物联网上的信息安全、隐私、信任或是道德问题都会在系统联网上出现,甚至更加严重。因为物联网所形成的物体与物体之间的连接与通讯会彻底改变我们原先已经习惯的互动方式,并进一步影响人类在系统联网中的行为举止。

通用电气前首席执行官 Jeff Immelt 表示:“在未来,人们期待一种拥有能与我们联系、沟通和合作的高智能机器的,开放的、全球化的架构。”工业物联网不是一个由机器人主宰的世界,而是将世界上最好的技术结合起来,以解决我们面临的巨大挑战。例如经济、能源和环境的可持续发展,或是治疗绝症。并为我们未来 100 年的基础设施和城市的建设做好准备。

的确,物联网或者系统联网的诞生将会解决在医疗保健,运输业和制造业的现有问题,并萌发新的商业模式。透过大数据分析,在癌症发病十年之前就对其进行预测并不是幻想。自动泊车和无人驾驶也已经是昨天的消息。3D 打印搭配物联网将作为未来的数字铸造厂,即不在有库存,按个人需求制造并配送。美国国家航空航天局发展的的土壤湿度主动被动计划 (soil moisture active passive, SMAP) 将精准地进行农业指导,人类可以完全依照精密需求种植农作物或是生产出石墨烯纯化的无砷淡化饮用水。还有心脏瓣膜,纳米卫星,神经突触网,神经形态芯片等所有令人欣喜的事物,我们已经开始另一个 100 年的旅程,并可能在 2120 年达到巅峰。

然而伴随着物联网的发展,经济摩擦也将进一步扩大。经济摩擦来自于现阶段进行重复性工作的中等收入阶层的可替代性。这些重复性工作大部分是能够被自动化作业或是能够通过在线工具完成的。银行出纳员、商店收银员、甚至是大学老师都有可能被淘汰,取而代之的是自动取款机、自助结账机和大规模开放在线课堂 (Massive Open Online Courses, MOOCs)。事实上,正如 Herbert Simon 在 1987 年所预测的那样:这些问题不单纯只因为物联网,而是从整合我们的生活与电脑运算之后就开始产生的问题。

何时、何地、何处以及如何进行数字化转换将由成本与价值决定。即使是利他主义的表象，也将以交易成本分析和交易成本经济学为指导，讨论基础设施的结构（*The Nature of the Firm* by Ronald Coase, 1937）。如果没有后者，连通性将会衰退，没有网络的生态系统，随意连接的价值将通过增加成本和降低价值来破坏投资的回报。如果没有持续的价值和盈利能力，采用（*adoption*）和扩散（*diffusion*）将仍然是个海市蜃楼。

物联网的大量跨系统连接性除了使人类暴露在更大程度的监控下（例如在医疗保健领域），还会引发行为的改变。是否无处不在的连接性改变了理性与非理性的活动仍有待观察和分析（*Thinking Fast and Slow* by Daniel Kahneman）。这些分析的结果必须在设计未来的产品和服务时考虑到。比如未来的无线医院或是加氢站的核磁共振仪，又比如在亚马逊森林医疗棚里的便携式 X 光机。其效用可能取决于基尼系数、社会经济思潮（*Scarcity* by Sendhil Mullainathan）以及在社会政治发展中的阶段（*Development as Freedom* by Amartya Sen）。连通性会改变行为的预测根源于粒子物理学的基本原理：“观察者效应”。所谓观察者效应是指观察行为会对观察到的现象产生变化（不要与 Werner Heisenberg 提出的不确定性原理混淆）。如果被观察者知道自己被观察可能会改变原先对于刺激应有的反应，例如人们可以在淋浴中唱歌，但也许无法在公众瞩目的舞台上唱。

可以注意到，即使组件几乎完全相同，如果组件中的任何一个发生了变化，组合的行为，特别是网络物理系统（硬件和软件与物理对象相结合）的时间中心也会经常发生变化。随着时间的推移可能会很困难，时间欺骗（*time-spoofing*）是一种全球性的网络威胁。除了行为上的缓慢变化之外，经济的再平衡也将是缓慢的，因为我们的教育系统的巨大变化对于优化科技成果的社会消费是必要的。任何技术或在线课程都不能阻止我们的金融体系的破裂，除非我们改进公共教育，重新树立对学术界的尊重，重新关注严谨，重新投资基础科学研究，恢复教育工作者的尊严，帮助重新点燃教师的激情。

新兴的人才供应链必须包括大量擅长数学的女生，能够连贯编码和写作的女生，对音乐有亲和力亦或是会多种语言的女生。早期的数学，音乐和多语言三位一体可能是追求想象力，发明和创新的多学科的关键。女性追求高等科学，工程，数学，经济和哲学至关重要。目前来说，我们不能接受 50% 的脑力被排除在劳动力之外。[9]

受过良好教育的妇女将帮助教育那些有礼貌的男孩和有尊严的女孩。正直和尊严可以提升人性，并从世界的每一个角落引发创新，这将引发社会和商业的结构性的转变。错误是会犯的，但失败是通往成功的新道路，是通往成功的新口号。

分布式创新需要一种企业家的方式，同时也需要对多层次的攻击，而不是神话般的银弹解决方案（silver bullet）（Innovation: The Attacker's Advantage by Richard Foster）。出租车行业对优步(uber)、酒店业与爱彼迎（airbnb）、临时工机构对于oDesk/Elance/Upwork等都是例子[10]。

工程工具的井喷极大缩短了引入创新的周期，从概念(开发供应链)到实现(实现供应链)。通过3D打印实现的数字铸造厂就是一个例子。行业巨头们必须通过提供平台来控制这种爆炸式的增长，以聚合在开源平台上运行的智能。在你的产品上，来自数十亿的“pings”的微收入流将是微分器。增值数据服务将与数据的智能分析和可操作的信息交付到数据消失前的使用点相关。实时数据，在每一种小额支付的使用模式下，将减少进入世界任何市场的门槛，即使是在人均国内生产总值(GDP)可能难以达到每天2美元的情况下。

当时间序列数据的积累对于预测分析(例如，医疗保健)而不是短半衰期的数据(例如，对部件的故障间隔时间(MTBF))而言，数据变化的易变性是非常重要的。数据传输和数据存储在这项业务中很重要，但消费者可能只愿意为实时分析付费。消费者可能希望原始数据是免费的。贫困国家的消费者可能只关注生活必需品的供应链。

然而，所有好处都是暂时的。来自租赁平台的微型收入所带来的财务智慧是苹果公司开放其“公交车”的原因之一，以便任何人跳上（创建应用程序）。应用程序从世界各地涌入。应用程序创建者是经济雪崩的一部分，允许苹果作为渠道的主人，通过人群创新来聚合小额支付。来自超过一亿人小数据就是苹果为什么一直笑到成为世界上最大的支付数据库的原因，一次仅要99美分。贝宝的成功推动了特斯拉的发展，特斯拉可能会放弃销售可交换石墨烯电池的汽车，以及使用软件定义网络(SDN)的车载服务。汽车可能是未来的移动电网，替代了智能移动电网的电网外配电。

基于付费的微收入服务的免费产品是一种经过验证的商业策略(打印机 vs 墨水，移动电话 vs 服务，饮水机 vs 桶装水)，以放大微收益，这不会持续到产品的生命周期，甚至会持续到用户的生命周期。微支付可以通过从产品生命周期(1-10年)转移到用户的生命周期(5-50年)来引发范式转换（Paradigm shift）。服务的微支付是由用户支付的，只要用户活着并使用该产品。即使产品生命周期结束，产品也可以用新版本替换。用户将继续对服务进行微支付。

无处不在的连接性的扩散将加速物联网的设计，预计将产生新的产品和服务。这种商品的消费和效率的提高可能会产生一种经济增长的幅度，这将使CEO们欢欣鼓舞。根据通用电气、思科和其他公司的说法，物联网和工业物联网可能会为全球经济增加14万亿到19万

亿美元。我们不能用盲目的眼光来看待这种企业营销宣传。

消费主义的激增是实现这些数字的必要条件。数十亿人在墙上涂鸦或发布照片，以支撑社交媒体泡沫的软件市场上限。这些人都属于一个收入群体，他们无法负担得起能说话的汽车或智能管家来将早茶送到床头。受过教育的消费者是最好的顾客。twitter 狂热的社交媒体经济的泡沫可能受到“ROC 曲线下的能量”的限制，而非理性的繁荣可能会引发下一场全球经济衰退，而这场衰退可能即将到来。根据经济学家 Finn Kydland(2004 年诺贝尔经济学奖)的说法，2008 年是最后一次经济衰退，基于 14 年的“盛衰周期”，我们预计下一个将在 2022 年左右。

在美国，整个行业和学术界的一些举措正在出现，以探索物联网，工业物联网的下一代发展以及网络物理系统（CPS）研究带来的令人兴奋的可能性。2014-2015 年在一些巨头公司的支持下成立了几个财团。欧盟资助了一个名为“地平线 2020” (Horizon 2020)的大规模多年计划，该计划将耗资 1000 多亿美元，至少在一定程度上是为了探索物联网的潜在增长，以及如何收获相关的经济暴利。

但是，全球领导层被经济预测所蒙蔽双眼，却不注意调整教育引擎，那将是一个巨大的错误。人类需要梦想家[11]，教育是盐（Salt by Mark Kurlansky）[12]，它会激发灵感，想象力，创造力和对想法实施[13]。一个男孩的教育可能会改变一个男人的命运。一个女孩的教育可能会改变一个国家的命运。

参考文献

- 1 Datta, S (2018) Connecting Atoms to Bits (Chapter 1) in Haphazard Reality – IoT is a Metaphor. <https://dspace.mit.edu/handle/1721.1/111021>
- 2 Linda Bernardi, Sanjay Sarma and Kenneth Traub (2017) The Inversion Factor: How to Thrive in the IoT Economy. MIT Press, Cambridge, MA.
<https://mitpress.mit.edu/books/inversion-factor>
- 3 <http://tinyurl.com/Industrial-Internet>
- 4 <http://tinyurl.com/MIT-IoT-1998>
- 5 Paul A. David and Gavin Wright (1999) General Purpose Technologies and Surges in Productivity: Historical Reflections on the Future of the ICT Revolution.
[http://ftp.unpad.ac.id/orari/library/library-ref-ind/ref-ind-1/application/poverty-reduction/ictd/Historical Reflection on Future ICT Revolution.pdf](http://ftp.unpad.ac.id/orari/library/library-ref-ind/ref-ind-1/application/poverty-reduction/ictd/Historical%20Reflection%20on%20Future%20ICT%20Revolution.pdf)
- 6 <https://hbr.org/2010/02/data-is-to-info-as-info-is-not>
- 7 <http://www.portlandpress.com/pp/books/online/wg85/085/0019/0850019.pdf>
- 8 <http://www.hitachi.com/rd/portal/research/em/doubleslit.html>
- 9 <http://bit.ly/GENDER-INEQUALITY>
- 10 <https://www.forbes.com/sites/elainepofeldt/2015/05/05/elance-odesk-becomes-upwork-today-odesk-brand-gets-phased-out/#6560a1ae51f5>
- 11 <http://bit.ly/HND-250>
- 12 <http://bit.ly/Book-by-S-Datta>
- 13 <https://dspace.mit.edu/handle/1721.1/111021>

COMMENTARY [B]

Shoumen Datta

HAPHAZARD REALITY – IOT IS A METAPHOR

THIS PAGE IS LEFT BLANK



THE COMMENCEMENT ADDRESS

esse non videri

This “speech” was not delivered at any commencement, to the best of our knowledge. The first couple pages are modified from an inspiring manifesto by Sanjay Sarma. The remainder was authored by Shoumen Datta. The opinions in this article are personal views of the authors and do not represent the views of MIT or any other organizations.

Thank you Madam President, students, parents, faculty and friends – it is a great day for all of us to celebrate the achievements of the graduating class of 2014. Congratulations!

While preparing this address, I reminded myself that some people come in our lives and it is a blessing but others come in our lives as lessons. Today, I think, I shall serve as a lesson to some of my young friends in the audience. I propose to ask a few questions. It is not for the faint-hearted and business will not be as usual. I apologize if it offends a few. It may.

Today, especially today, as you graduate, is your 6th sense telling you that change is afoot? Are you afraid or excited that you do not have immunity from the risk of disruption?

Are you able to navigate through the explosion in engineering tools which is collapsing the time between conception and realization of an idea?

What an engineer took years to accomplish a decade ago, she might be able to accomplish it in a matter of a few weeks, today. Is that engineer among you and graduating today?

→ Need 20 plastic cases for a new Internet-controlled thermostat you just invented?

- Design it with a CAD package in the cloud and 3D-print it in your garage.

→ Need a complex circuit to control the system?

- Hire a designer in Pakistan for \$11 an hour. Delivery time: 5 days.

→ Need that prototyped?

- Send it off to your favorite PCB fab and have it expressed to you within a week.

→ Need customers?

- Pretail on Kickstarter

→ Need to make a million devices now that you've pre-sold a million units?

- Find a manufacturer on Alibaba or work with an emerging class of plug-in companies that can act as your virtual manufacturing arm.

→ Need a complex piece of web technology to run the above system?

- Prototype it using "Ruby on Rails" instead of writing miles of code in C or Java.

→ Need to have it up and running for your first million customers?

- Deploy it on the Amazon Cloud (AWS EC2).



What did I just describe?

I described an express version in the engineering and product development process cascading from each other in a chain-reaction.

- Did your curriculum, industry internships and peer pressure prepare you to imagine, undertake the challenges of innovation, manage technology explosion, expose you to entrepreneurship and the social business of science in society?
- Can you exude and embrace balanced impatience as a virtue?
- Did your education teach you to think?
- Did you question the *status quo*?

Conventional wisdom encourages patience, planning, deliberation, steadiness and a “look before you leap” attitude. All good virtues and all sadly outdated. The issue is not the thoughts themselves, but the fetishized weight we give them and the paralysis and risk-aversion they have come to represent. The competitive world values action over over-planning. It rewards impatience over stodgy patience. It values agility over static steadiness. It values deliberate aggression over passive deliberation. And here is the key: the new way of thinking is not about taking risks, but about controlling risks using quick, small actions and experiments followed by rapid and agile adaptation.

In this age of systems of ecosystems, the risk lies increasingly in not realizing that you are in a manic episode of the Hunger Games. This is about “ready” “shoot” “aim” – not ready, aim, shoot.

If you have only one bullet, it makes sense to follow the mantra: ready, aim (carefully) and then shoot. If you have many bullets, then, get ready, shoot first, then correct your aim and shoot again. And repeat. Or your opponents will shoot first and a bullet will likely hit you.

Innovation is transitioning from breach-loaded dueling pistols to machine guns in a sort of massively multiplayer parallel innovation.

I know you are rolling your eyes and thinking, hey, don't you know that the first instinct of institutions to disruptive thoughts or to innovative people is to expel them, prevent them from entering or locking them in a cage of red tape if one happens to enter through the cracks?



That is where the cultural chasm deepens. Unlike old school institutions, innovative companies are ruthless in breaking rules to get the job done. Entrepreneurs do not fear failure. Entrepreneurs have fought battles and lost and lived to fight again. Failure is the new road to success. Learning is expensive and painful, but death is the nail on the coffin (just ask Nokia).

In 1997, one of my friends helped a major city and a venerable academic institution to start an online tutoring program in mathematics over a fixed point to point Ethernet connection using the “new” medium of the Internet.

Fifteen years later, in the Winter of 2012, MIT launched MITx, a MOOC-esque effort to offer learning using digital tools to transform the way students learn on campus and the way students might be able to learn around the world. MITx was launched almost overnight. The time from its announcement in the end of December 2011, to the launch of the first massive online class (6.002x, Circuits and Systems) was just 3 months. More than 150,000 students registered for the class but don’t conclude that all 150,000 students took the class or completed the class. But I think a few did and we may have changed a few lives.

In the summer of 2012, MIT and Harvard launched edX, an independent not-for-profit entity to offer free courses to the world. They each invested \$30M into edX. Today, edX has over 2 million enrollees and courses from 30 universities offered to students in 195 countries. EdX is the only not-for-profit in this space (Coursera, Udacity and NovoEd are MOOCs-for-profit). EdX is the only one whose platform code has been open-sourced to enable massively parallel innovation. Anant Agarwal, an MIT professor who happens to be an entrepreneur, spearheaded edX. In short, MIT embraced innovation, it jumped on the engineering express, it leveraged an intrapreneur, it protected the idea from institutional antibodies and grafted on to itself the Office of Digital Learning at MIT (directed by another brilliant intrapreneur Sanjay Sarma of MIT) and placed it in the Office of the Provost at MIT. Leadership from the top, directly from the Provost and President of MIT, in order to create a new world order.

I see a hand waving in the audience, “Yes, do you have a question for me?”

“Yes, I do. My name is Aziz Boxwala. I am the Vice President for Human Resources in this University. How many applicants did you have when you advertised for the position of CEO of edX and Director of Digital Learning at MIT?”



“We often do not advertise for leadership positions that require vision and institutional knowledge.”

“How amazing! There was no process, charter, by-laws and committee approvals. You just did it by fiat?”

“Yes, Mr Aziz Boxwala. Things are not “as is” and we have moved beyond the box. Charters and by-laws are relics found in the old countries.”

Let me return to the students. The task that lies ahead of you, students, requires that you must break rules and must climb out of boxes in order to innovate toward a better *karma*.

That is your task, students, to unchain the shackles of solipsistic bliss and proactively help to create a new world order. The new order of things is not about the internet of things or polishing the chrome, it is about tuning the economic engines using a trinity of platforms which are inextricably linked and must be pursued using the same mantra of massively parallel innovation. They are as follows -

[1] education of girls and women in math, science, engineering, economics and philosophy

[2] access to energy for all nations at a cost which is feasible, at a level of sustainability which is balanced with respect to the dynamic socio-economic context and at a quality of service which acts as an egalitarian purveyor of civilization

[3] catalyze affordable healthcare and endow it with the dignity of human rights.

For the remainder of my time, I will drive toward my conclusion, which will significantly digress from the “speech” and the rhetoric. I will present a tangible grand challenge that I continue to dream about and I wish to pursue, if the opportunity presents itself. May be you can help or if you are fired up, you can pursue it. It is neither a proprietary idea nor a recipe for a secret sauce. It is a confluence of ideas including platforms [1] & [2] outlined, earlier.

My idea is about the global business of carbon neutral energy manufacturing and distributed cooperative ownership of the energy enterprise by women, who know math.

Before you tune off from me and turn on your Pandora, please allow me to explain the out of the box thinking. Let us start in this state, locally, but it is applicable, globally, where ever the sun shines. Yes, this specific example is about renewable solar energy but there is more.



In California, by 2020, we have a mandate to generate about a third of the state-wide consumption of energy from carbon-neutral or renewable sources. This energy can be produced by private corporations, such as the recently completed Ivanpah project. The utility companies are mandated to buy the renewable energy from these sources.

Efficiency of solar panels and photo-voltaics are driving down the cost from a high of around 80 cents per kilowatt-hour (kWh) to less than a tenth of that price. Government guaranteed loans combined with 9 to 1 leveraging of private capital and free government land available in the US southwest may bring the cost down to about 6 cents per kWh or about twice the cost of coal generated electricity. We may save a few more cents with Nest-like devices or standard wireless sensor networks (WSN) to monitor, reduce waste and optimize usage.

The gigantic nature of energy may be gleaned from the fact that a three reactor nuclear power plant produces about 3 GW. Compare that to the US annual peak demand for 786 GW and another 117 GW to meet the NERC target reserve supply. The Ivanpah Solar Power Plant took six years to construct at a cost of about \$1.6 billion to tax payers and another \$168 million from BrightSource Energy Company and Google. It was inaugurated on February 13, 2014 by US Secretary of Energy Ernie Moniz. This solar plant will generate 392 MW (0.392 GW) of electricity. The total amount of solar installations in the US generate just above 2 GW while the US peak demand is creeping toward 1000 GW or 1 TW.

Solar energy is time dependent and electricity is perishable. The solar peak does not match the demand peak. Hence, the importance of storage to make the energy supply agnostic of insolation and add mobility to energy in order to divorce the distribution from the grid infrastructure. Transporting energy to serve geographies with local micro-grids or an absence of electricity grids (major parts of the world) is of paramount importance for developing nations.

The era of lithium nano-phosphate batteries may be reaching its zenith but graphene based storage systems may offer hope with nearly 50% more capacity and charge density. Ask Anne (Sastry) or Samir (Mayekar) or Bob (Robert F Curl) or Harry (Kroto) to explain.

The convergence of insolation-dependent production with high density storage is a far better solution that is implementable. The abundance of high insolation areas in the US, Africa, India, Brazil, Indonesia and China makes this combined solution a sustainable approach to reduce dependency on fossil fuels and greenhouse gas (GHG) emissions.



Building and operating solar farms require no new invention or imagination. Distributing the energy through conventional schemes (grid) and new storage (nano-tech or graphene based batteries) offers room for [1] technology innovation, [2] financial innovation in the use of price as a supply-demand control parameter and [3] social innovation to deliver mobile energy units (truck load of energy containers) to areas devoid of grid or any other source of electricity. The latter immediately enables the operation of cell towers and explodes the potential penetration of mobile telephony, smart phones and the connectivity to the internet of things or the industrial internet of intelligent machines or smart objects.

What stands between this simple idea and reality is the relative availability of investment to create and operate solar farms. OECD nations are less likely to struggle for investors but the emerging economies may remain immersed in the vicious cycle of cost versus profits or the length of time necessary for the return on investment based on the cost per unit which the local market can bear. It is the same argument that asphyxiated the bio-butanol effort which can help 80% of the world even if photo-butanol production remained sub-optimal.

This economic segregation is in no way less perverse than the “legal” social segregation in the US in the first half of the 20th Century. I have to digress to present you with the context.

In the fall of 1944, Soledad Vidaurri took her children and those of her brother, Gonzalo Méndez, to enroll at the 17th Street School in Westminster, California, a part of the Garden Grove School District. Although they were cousins and shared a Mexican heritage, the Méndez and Vidaurri children looked quite different: Sylvia, Gonzalo Jr. and Geronimo Méndez had dark skin, hair and eyes, while Alice and Virginia Vidaurri had fair complexions and features. An administrator looked the five children. Alice and Virginia could stay, he said. But, their dark-skinned cousins would have to register at the Hoover School, the town's "Mexican school" located a few blocks away.

In *Méndez v. Westminster*, James L. Kent, the superintendent of the Garden Grove School District, took the stand and under oath, Kent said he believed people of Mexican descent were intellectually, culturally and morally inferior to Euro-Americans. Even if a Latino child had the same academic qualifications as a white child, Kent stated, he would never allow the Latino child to enroll in an Anglo school. U.S. District Court Judge Paul J. McCormick was also appalled by Kent's blatant bigotry. On February 18, 1946, he ruled in favor of the plaintiffs.

The Orange County school boards filed an appeal.



By now, *Méndez v. Westminster* was drawing national attention. Civil rights lawyers in other states were watching the proceedings closely. For half a century, they had been trying to strike down the "separate but equal" doctrine of *Plessy v. Ferguson*. Among those following the suit was a young African American attorney, Thurgood Marshall. Marshall and two of his colleagues from the NAACP submitted an *amicus curiae* brief in this case.

On April 14, 1947, the Ninth Circuit Court of Appeals in San Francisco upheld the lower court decision regarding *Méndez v. Westminster*. The court stopped short, however, of condemning the "separate but equal" doctrine of *Plessy v. Ferguson*.

Seven years later, the NAACP did find a successful test case to reverse *Plessy v. Ferguson*. Thurgood Marshall argued the landmark *Brown v. Board of Education of Topeka* before the U.S. Supreme Court, presenting the same social science and human rights theories he outlined in his *amicus curiae* brief for *Méndez v. Westminster*. Former California Governor Earl Warren, then Chief Justice of the U.S. Supreme Court, wrote the historic opinion finally ending the legal segregation of students on the basis of race in American schools in 1954.

In 1954, by an unanimous vote (9-0) the U.S. Supreme Court declared "separate educational facilities are inherently unequal." However, sixty years later, US public education may be still separate, still unequal, but what is even more alarming is the fact that the ethos appears to be infectious. It has infected the renewable energy economy.

The rich and the powerful are using energy to drive a wedge between nations. Access to energy and development of non-fossil alternatives are at the heart of this quagmire. Sixty years from now, the energy economy will dictate if nations are "still separate, still unequal" because of the reluctance of seed investors to invest in alternative forms of energy with lower return on investments. Thus, the power of investment is depriving the emerging nations of energy and creating more "have-nots" if measured by purchasing power parity.

A few months ago in Brussels, seated in the basement of 5 rue Duquesnoy, I heard a fine gentleman from the famed Tata Sons talk about the mantra of social responsibility that Mr Jamshed Tata expounded before the West claimed social responsibility as a buzz word.

That morning, in Brussels, it dawned on me that the obvious idea of the solar energy farm, may be an instrument to improve mathematics education among girls and women. Math to a basic level, for example, a US high school standard of math comparable to students graduating from Stuyvesant High School. Delivering math through MOOCs should be easy.



To inspire and reward women who are able to grasp the fundamental principles of high school mathematics, can we offer them a percent ownership of the solar farm energy cooperative?

If you are an investor in the audience, you may want to walk out. I can't stop you. But, those of you who may have open minds, consider my suggestion before you begin to deride me.

If Mr Tata were to invest in creating the solar farm, I suggest that he retains 51% ownership of the enterprise and recovers his entire investment from the energy sales (which may take 10-20 years). After Mr Tata (or Mr Gates or Mr Khosla or Mr Slim) has recovered the initial investment plus interest, the "energy company" morphs to an "energy cooperative" which continues to provide 51% of the profit to the investors.

It is the remaining 49% which can ignite global productivity and usher in a new era of civilization if 49% of the company is owned by women who are proficient in high school mathematics. Hence, 49% of the profit from the energy cooperative will be distributed between millions of math-proficient women-owners. What if you owned 0.01% of Apple?

This plan lifts many boats. Natural resources belong to people and a right to share in the economy. Investors must obtain the ROI but is it so difficult to uphold ethical globalization?

You are the first group to hear of this plan, this radical idea, this dream, this fantasy. I acknowledge that energy is not a panacea to solve everything, but, I don't think it is absurd or impossible or financially untenable. Women will apply for their ownership in droves. If they are not qualified in math, we will offer temporary ownership with the expectation that in about three years, with a stipend and access to Khan Academy, they will qualify for the mathematics proficiency test. Imagine the impact of millions of math proficient women.

Once they pass the test and are owner-members of the energy cooperative, visualize the quantum leap in their self-esteem, knowledge and confidence not to mention the dramatic rate of socio-economic evolution which will change the tapestry of life in every domain.

Can you force a math proficient woman to accept domestic abuse?

Can you force a math proficient woman to become pregnant each year?

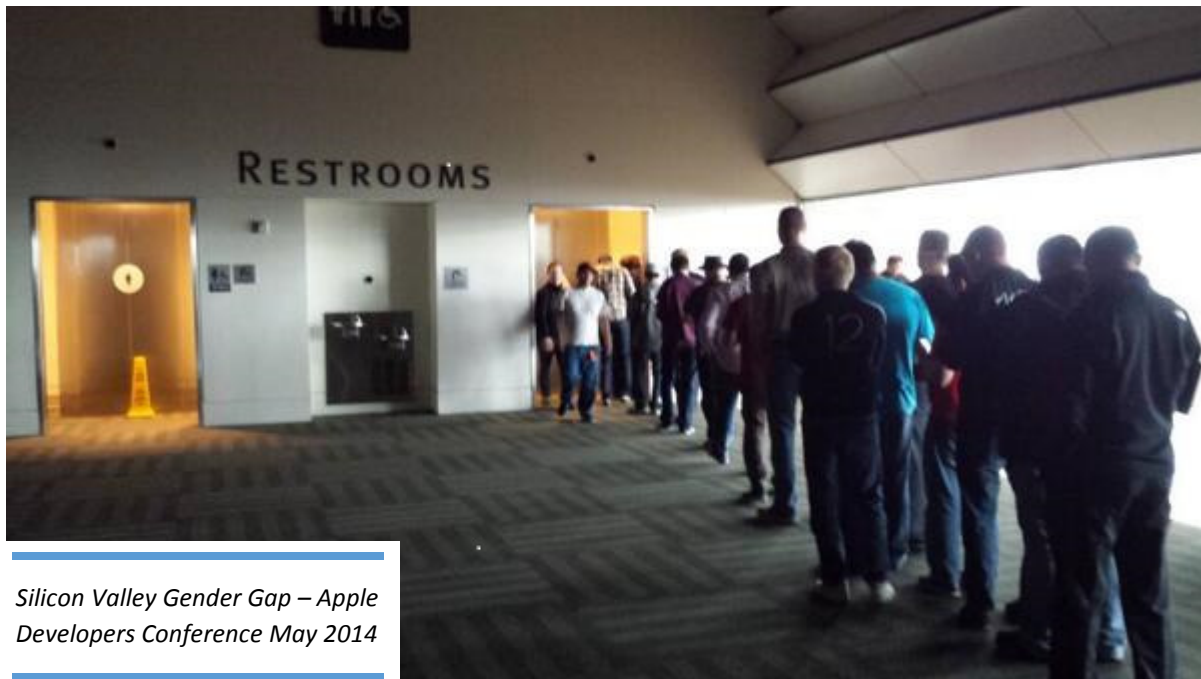
Can you force a math proficient woman to submit to female genital mutilation?

Can you force a math proficient woman to ignore math education for her own children?



The education of a boy can change the fate of a man. The education of a woman will change the destiny of a nation. Your task, students, is to change the world, one solar cooperative at a time. Your task, students, is to create a cottage industry for energy. Your task, students, is to change the fate of freedom and education.

It is time, students, for your tryst with destiny.



Silicon Valley Gender Gap – Apple Developers Conference May 2014

This is the true joy in life, the being used for a purpose you consider a mighty one, the being a force of nature rather than a feverish, selfish clod of ailments and grievances complaining that the world will not devote itself to making you happy. (GBS)

The best people possess a feeling for beauty, the courage to take risks, the discipline to tell the truth, the capacity for sacrifice. Ironically, their virtues make them vulnerable; they are often wounded, sometimes destroyed. (EH)





A blog by

Esse non Videri

THE COMMENCEMENT ADDRESS

This “speech” was not delivered at any commencement, to the best of my knowledge. Suggestions reflect the views of the author and do not represent the views of any other organizations. Any similarity to names, symbols and acronyms, are purely coincidental.

Our Connected Sense of the Future – The Journey Ahead

Welcome to the University of the Future Commencement ceremonies for 2018. I thank you for joining us today on this special day for our students at the University of the Future (UF). I am J. Fox Kenneth, President of UF. My friends call me JFK and most people from the South call me President Fox. Many years ago, when I was a faculty at Purdue University, the Dean of the School of Engineering, called me Ken, an abbreviated form of my last name. Ken has stuck with me in my professional world.

I am Ken. I am happy to be here with you at UF, today. Thank you for the privilege Madam Governor, students, parents, faculty and friends. It is a bright sunny day for all of us to celebrate the achievements of the graduating class of 2018. Congratulations!

While preparing this address, I reminded myself that the success we are celebrating here, today, is a reason for great joy, yet one may pause to reflect that success is ephemeral. The brevity of the feeling of success may not diminish our success, but it reinforces a fact, which we must have the courage to accept. Success is a rental. The rent is due every day.

Hence, you and I, and everybody else who may aspire to succeed in their chosen path, must prepare to pay the rent, every day. The chef who prepared a delicious lamb stew, yesterday, will not receive any praise, today, if she serves a soggy, runny and bland lasagna. The surgeon who performed a miracle, yesterday, separating conjoined twins, may be chastised tomorrow if the spina bifida surgery goes awry, today. Rent is due every day.

The job of the University, the mission of education and the role of academics, is to prepare you, in as many ways, directions and dimensions, as possible, to enable you to pay your rental dues, each day, every day, for the next 25,000 days or more, hopefully.

UF is committed to support you, and those who will pass through these doors, after you and after them. UF must prepare, every day, to garner the resources, to deliver the academic environment, to seed the network, which will allow our students and faculty and staff, to move forward the mission of UF, through caring, teaching, research and global entrepreneurship, to lift many boats.

Today, I will take this opportunity, to put forward our collective vision of the future. I wish to speak my mind and what we are thinking.

**Rosalyn Sussman Yalow & Norman Ernest Borlaug Memorial Commencement Address
by J. Fox Kenneth, President of the University of the Future (UF), on November 3, 2018**



I chose to share ideas with you because now you are adults, and I can request you to help me, to help UF, and through UF, to help make the world a better place, to serve our fellow citizens, and civilization, with dignity.

Conventional wisdom encourages patience, planning, deliberation, steadiness and a “look before you leap” attitude. All good virtues but perhaps, outdated, because of the paralysis and risk-aversion they have come to represent. The competitive world values action, over, over-planning. It rewards impatience over stodgy patience. It values agility over steadiness. It values deliberate aggression, without malice, over passive deliberation. The new way of thinking is not a revolution but a higher threshold of assuming the risks of leadership and, hopefully, controlling the risks using quick, small actions and experiments. Rapid and agile adaptation, while pursuing goals and targets, needs no additional emphasis.

Hence, we must act, we must transform our vision into reality, even if we fail, at first. Failure is an option, in order to prepare for grand success. The safety of using statistics to show incremental progress, has lost its place on the leadership agenda. We must lead and shoulder the risks of leadership. Failure, or the sense of failure, never goes unrewarded, if we have the vision to visualize, beyond where the eye can see, if we have the vision to consult and use corrective lenses, to re-view, if our imagination appears to be out of focus.

In this age of systems of ecosystems, the risk lies increasingly in not realizing that you are in a manic episode of the Hunger Games. Today it is about “shoot” then “aim” – it is no longer sufficient to stick to the old adage: ready, aim, shoot, repeat (if you are still alive).

The educational institution, as mammoth as UF, must keep pace with the speed and trajectory of global dynamics. Innovation is transitioning from breach-loaded dueling pistols to machine guns in a sort of massively multiplayer parallel innovation. UF must approach the world on multiple fronts, in order to prepare you better to pay the rent, on success, every day. UF entrepreneurs must not fear failure. UF entrepreneurs include all UF faculty, staff and students. UF entrepreneurs must unite behind our entrepreneurial spirit. Entrepreneurs must fight battles, wage wars, and lose, and live, to fight again. Failure is the new road to success. Stagnation is not an option.

If we wish to use the fruits of science, engineering, medicine, mathematics and the arts to lift society to a higher quality of life, for everybody, locally and globally, then we must acknowledge the immense difficulties we may face. There are no short cuts in science and life. Only those who may not dread its fatiguing climb, may reach its luminous summit.



I will share with you the history, and the future, shaped, literally, by a couple French visionaries. I will start with one now and end my speech narrating the “future” by another.

In 1830, Ferdinand de Lesseps, a French diplomat in Cairo, dreamed of linking Europe and Asia (Mediterranean and Red Seas) by digging a canal through 118 miles of arid land at a cost of 200 million French Francs (FFR). On November 17, 1869, the Suez Canal opened. Fewer than 500 ships passed through in 1870, far below the projected return on investment. Dividends failed to materialize and Egyptians, desperate for cash, sold the shares to Great Britain for 4 million Sterling (GBP). In 2002, 15,000 ships passed through the Suez Canal generating US\$2 billion in revenues for Egypt (*Parting the Desert: The Creation of the Suez Canal* by Zachary Karabell). In 2016 nearly 25,000 ships passed through the Suez Canal and generated nearly US\$5 billion for Egypt. In 2016, Suez Canal II was completed. Now, each day 100 ships can cross the Canal or 36,000 each year.

In 1513, the discovery of the isthmus at Panama by Vasco Núñez de Balboa triggered the idea of creating a trans-oceanic canal. Francisco Lopez de Gomara suggested (in his book, in 1552) Panama, Nicaragua, Darien and Tehuantepec as choices for a canal. Not for another 300 years, not until the 19th century, would the canal building actually commence, once again under the leadership of Ferdinand Marie Vicomte de Lesseps, the French diplomat, who orchestrated the creation of the first Suez Canal (1869).

Eleven years after the opening of the Suez Canal, in 1880, Ferdinand de Lesseps formed a company to replicate his feat in Panama. This travail was undone both by weather and tropical diseases (yellow fever, cholera, malaria) that killed 22,000 laborers. Ferdinand de Lesseps (1805 - 1894) could not complete the Panama Canal. He did not live to see the successful completion of the Panama Canal, in 1914, by the US Army Corps of Engineers.

In 1904, through the urging of US President Theodore Roosevelt, the US Army Corps of Engineers completed the Panama Canal. It would cost US\$352 million and 5,609 lives. In 1918, after 4 years in operation, less than 5 ships passed through the Panama Canal, daily. Today, more than 14,000 ships pass each year, generating US\$2 billion in revenue (*The Path Between the Seas: The Creation of the Panama Canal* by David McCullough).

In the 20th century, the 31 mile tunnel linking England to the Continent got started in 1987 fueled by GBP 5 billion from banks and 112,000 British investors. In its first 3 years since May 1994, The Chunnel saw fire and operating expenses around GBP 2 billion.

Rosalyn Sussman Yalow & Norman Ernest Borlaug Memorial Commencement Address
by J. Fox Kenneth, President of the University of the Future (UF), on November 3, 2018



In 1997, the investors suffered losses when the banks seized shares in exchange for restructuring the crushing debt. By 2001, the winds changed, failure turned into success (*The Chunnel: The Amazing Story of the Undersea Crossing of the English Channel* by Drew Fetherston). In 2016, The Chunnel transported more than 10 million passengers, nearly 2 million vehicles, generated more than 1 billion Euro in revenue. In 2016, net profit was 200 million Euro.

Big ideas offer big dividends, but may have stormy beginnings. Society will regress if leaders are blinded by short-term ROI, resist change, are risk averse and choose *status quo*. I wish to present to you a few ideas that UF may wish to think, reflect and perhaps, pursue.

In addition to supporting our ongoing efforts, collaborations, multi-disciplinary institutes and cross-pollinating centers of convergence, we will embark on strategic advancements in manufacturing, healthcare, energy and global goods.

In every endeavor, we will abide by our code of moral ethics, ethical globalization and entrepreneurship which is commensurate with reasonably shared profitability. I must mention “profitability” in this context because sustaining the educational mission, and research, is resource intensive. We cannot continue to depend on state and federal governments, because fiscal cycles continuously clash with our need for continuity. The support necessary for research to be productive, must take into consideration the long road ahead. I quote, Albert Szent-Györgyi von Nagyrápolt, a Hungarian biochemist, who was awarded the Nobel Prize in Physiology or Medicine, in 1937, and is credited with discovering vitamin C. He said “research is four things: brains with which to think, eyes with which to see, machines with which to measure and, fourth, money.”

Entrepreneurial innovation, out-of-the-box confluence of ideas and unusual paths to social businesses, must be captured by UF. Segments may be ploughed back into UF accelerators to boost even more imagination, invention and convergence of innovation. The thought of profitability, however ethical, is an anathema for academics and a paradox for non-profit, land-grant, sea-grant and space-grant nature of major US state universities.

As a top 10 university, we may not lack in capacity, in any dimension, in any metric, except for the number of Nobel Prize winners on faculty, when compared to private institutions with endowments of \$35 billion, Harvard, or \$22 billion, Stanford, or \$15 billion, MIT, to name a few of the prominent names.



Stanford inventions generated \$65 million in income in 2009. Stanford's total earnings from inventions were \$1 billion during the past 4 decades, with more than half coming from 2 inventions: the hypertext search and recombinant DNA technology.

UF is not inexperienced in this domain but we must be more proactive. We must look for the next Gatorade. The mixture of common everyday ingredients, which packed an uncommon profitability, is made of water, sugar, lemon juice, sodium, potassium, and phosphate. It has yielded the University of Florida, more than \$80 million, since 1973. The abstraction latent in this mixture – common yet unconventional convergence – is the paradigm which we must emulate, innovate and differentiate a non-formulaic approach.

Manufacturing, healthcare, energy and global goods, are a few of the domains in our connected view of the networked physical world. Appropriate integration, with digital trends, data analytics, operations and online education, will follow. I shall summarize the ideas in each of these domains.

I request that you try to abstract the systems approach, in each effort. The design metaphor – atoms to bits – was suggested by Herbert Simon at CMU in 1987, but the phrase was used by Hiroshi Ishii, at MIT in 1997. After a quarter century, perhaps, it is time to extend the concept and propose a new design metaphor – swappable atoms. I will mention the context of swappable atoms, near the end of my speech, today.

Manufacturing is no longer limited to your grandfather's steel mill in Pittsburgh. Today, manufacturing is a platform to aggregate creative ideas, new tools and applications. Students and faculty from different departments can use this platform to cross-pollinate. By creating corporate partnerships, we can collectively add value to the manufacturing industry, in many sub-verticals, for example, aerospace, automobiles, devices, prosthetics, sensors, energy and tools for the telecommunication and semiconductor industries.

Manufacturing has grown to become a catch-all term. As I lay out the suggestion, one or more areas of interest will rise to the surface. It may span from nanotech to mega machines. Let us fast forward to a term that is now a part of our daily vernacular, 3D printing. We propose the creation of the UF "Digital Foundry" as a complement to the 3,000 year old industry of casting (investment casting, sand casting). The UF Digital Foundry will break new grounds for integrated manufacturing, from CAD models to finished products. It will involve multiple arenas, including distributed cyber-physical production systems.



3D printers are now sold by Amazon and can be bought for the price of a dinner at Harry's. UF alum Erin Winick gained entrepreneurial attention by printing toys and beads for sale. We are not talking about the convenience store 3D printed mugs or plastic jewelry. We propose a robust materials science approach, working with scientists, engineers and corporations, involved in creating parts and tools for the aerospace, auto and biomedical industry. In addition to metal and ceramic 3D additive manufacturing, we hope to explore far and wide, including, embedded printed electronics, soft sensors, nano-bio-sensor-array integrated packaging, prosthetics and sol-gel printing (for example, skin for burn victims).

The barrier to 3D additive manufacturing for metals and alloys is due to the fact that a majority of the more than 5,500 alloys in use, today, cannot be additively manufactured, because the melting and solidification dynamics, during this process, lead to cracks in the material. Hence, very high value components for heavy industries, rely exclusively on investment casting to create these parts. The latter creates cycle times of months to years, starting from CAD drawings to a final cast, which must be validated and certified prior to production. The process could become prohibitively expensive due to iterative design changes, testing, metrology and concurrent 3D engineering reconfiguration. High cost and reduced agility, handicaps the ability of manufacturers to compete with low wage nations. We are losing high paying jobs and transferring knowledge base to other countries.

We propose that UF takes the steps necessary to retain additive manufacturers in this country, create a cluster for additive manufacturing and bring new jobs to grow the economy through the UF Digital Foundry initiative. Academic-industry-government collaboration can boost additive manufacturing 3D printing by reducing the cycle time and cost by half, or even three quarters, by facilitating rapid prototyping and manufacturing for final product assembly, testing and certification. 3D printers can create parts directly from CAD drawings transmitted to 3D printer without the need for co-location (distributed systems). It will speed up iterative design changes and variant configuration of components by allowing (crowd-sourced) designers, researchers and industrial experts, located in different corners of the world, to collaborate and 3D print various prototypes, in a matter of hours, obtain feedback, refine designs and identify design errors. Using machine learning, the 3D printed product can be self-checked to make sure that the 3D printer is delivering according to specifications. These processes may be repeated until component design and quality expectations are satisfied, in terms of the structure and function of the component. The final design version can be mass 3D printed or the design used for investment casting in order to mass produce by conventional methods, depending on the total cost of operation.



Digital Foundry at UF may enable the manufacturing industry to create the tools necessary for this process. In one vein, the convergence of nano-particulate chemistry with material science of alloys. Recently, software analysis of over 4,500 different alloys and nano-particle combinations, uncovered two aluminum alloys (7075, 6061), when coated with hydrogen-stabilized zirconium nanoparticles, and additively manufactured using SLS (selective laser sintering), showed no signs of cracking and demonstrated strengths comparable to conventional wrought materials.

Digital Foundry at UF can take orders from any part of the world, to create anything, if amenable to the platform. Conversely, the platform can serve as a medium or a clearing house, for design orders, to be channeled to 3D printers in remote parts of the world, closer to where the component may be used. It calls for a revision of cost structures with respect to logistics and transportation of materials, components and spare parts. The use of the Digital Foundry platform will allow experts from UF, and any other part of the world (crowd sourcing), to influence concurrent 3D re-engineering, to improve the design or recommend changes to the structure, which may optimize the function. These pay-per-services *modus operandi* may be used by millions of small and medium businesses, which may not have in-house experts, yet engaged in manufacturing, eg, China, India, and Brazil.

UF Digital Foundry is expected to become a node in the value chain and global supply chain of manufacturing for high value items, with metal alloys and ceramics, for the aerospace industry, hyperloop, vehicles, military-industrial complex and machine tools.

The academic contribution of the Digital Foundry to students at UF will be immense. Students graduating with engineering degrees will be skilled in the complete end-to-end scenario, from design to manufacturing, applicable to any product. The core competency of UF may not be in the actual product (it can be, we don't know) but UF will certainly lead the R&D and data analytics services platform. The value proposition of the UF Digital Foundry Collaborative will be rooted in its research credibility, unbiased analytical tools and trusted advisory services. We expect financial returns from these activities to fuel UF Accelerator Programs and feed forward to enhance faculty research, student projects and global dissemination, through online education, skills training and workforce development.

I hope that UF Digital Foundry, in about 5 years of its commencement, will grow to become involved in, and penetrate to capture, 0.1% of the global parts and components manufacturing market, in some form or the other, related to additive manufacturing (AM).



We wish to earn \$100 per aviation component or part. Commercial aviation industry manufactures about 3,000 aircrafts each year, with 300,000 parts per aircraft but 3D-AM printed metal parts may constitute only 1% of parts. Thus, total number of new 3D-AM parts manufactured per year is 9 million. If UF claims 0.1% of 9 million at \$100 per part, then Digital Foundry revenue from aviation related components may be \$0.9 million a year.

What I just explained to you is the conventional wisdom of product sales, applied to the radically unconventional Digital Foundry concept, in the midst of a tsunami of digital transformation. Incongruent. Isn't it?

Let us re-try the scenario and this time let us break the mold. Forget about products and one-time payments based on product sales. Let us try the service model where we seek payment for each event, for example, each successful flight by the aircraft. Rolls Royce no longer sells the aircraft engine (turbine) as a product but sells "thrust-hours" as a service to the buyer (airline manufacturer, such as Boeing). If the engine is not generating thrust, it is not working and the plane is not moving. Hence, each time the airline flies, thrust is key and Rolls Royce will charge for thrust-hours, which means, you pay-per-use.

The product concept of sales is likely to die a very slow death, at the hands of digital transformation. We are entering an era of ubiquitous service, where all products are simply the "Trojan Horse" to deliver the service. If you let the product in, you must pay for service.

Let us think different and adopt the service model for long term stream of micro-revenue. Let us change our mind set from products to services. From our example, let us still assume we will penetrate only 0.1% of the market. From a service point of view, there are about 100,000 flights per day. Hence, 0.1% market means only 100 of these flights may have UF DF 3D-AM printed parts on board. Instead of charging \$100 per part as a product, we will charge \$100 as the pay-per-flight fee, for each successful flight. For 100 flights per day, anywhere in the world, the revenue will be \$10,000 per day or \$3.65 million per year. By moving from product cost to services pricing, we increased our revenue from aviation market, alone, from \$0.9 million to \$3.65 million per year, every year. Think long term!

Sounds, good? Let me rain on this parade. The chasm, between grand ideas and successful monetization, is deep and wide. Orchestration of multiple domains, replete with their own dynamics, volatility and uncertainty, requires cohesive collaboration, to bring together diverse people, disciplines and cultures, to work together, towards a common goal.



The science and engineering research that must precede the 3D-AM printing is our core competency as a University. We need electrical engineering, computer science and chemical engineering to mesh and meld with material science, mechanical engineering and biomedical engineering. External collaboration is necessary to translate our technical expertise to an actual product. The latter is the outcome expected from creating the UF Digital Foundry initiative under the umbrella of manufacturing. We can create the part, test, evaluate and partner with certification agencies to validate the widget.

What must follow for successful monetization is the adoption of the product by aerospace industry. This is at the edge of our competency which we may not influence and domains we cannot control. Even if our product is sufficiently differentiated by quality, cost and value, how can we guarantee that it will be used in the manufacturing process? This is where alliances will be critical yet these alliances will not come into effect unless we have the product. The critics will ask if the adage “if you build they will come” may still hold true.

The one-time sale of goods (aircraft and spare parts) may not be our preferred path. For the manufacturing behemoths in the aerospace industry, our potential clients, agility is not a household word. Hence, the pay-per-use service model, each time the product is in use, is a different concept. Most service models are associated with standard maintenance contracts (MRO) and based on servicing the aircraft. Here, again, the pay per flight model is a business innovation which UF can standardize and catalyze its adoption in the aviation industry. The road block is actually an opportunity. The latter may be a prerequisite if we expect to claim a fraction (\$100) of the per flight revenue, if \$100 is a reasonable amount, after the manufacturer completes the transaction cost analysis and revenue sharing model.

The revenue will be paid by the user (airline) to the manufacturer. The aircraft manufacturer must honor revenue sharing. What is our visibility into this process? To answer this question, in the context of digital transformation, we must address another enormous arena of multi-disciplinary R&D potential, referred to as **Digital Twins**.

Digital Twins evolved from NASA experiments, to reproduce on earth, exactly what may be happening in a spacecraft, millions of miles away, in space. Visibility of physical processes are no longer limited to space explorations. The quest for low cost (TQM/TCO) operations, made it imperative that manufacturing must be globally distributed. Development of semi-autonomous mass manufacturing further eliminated humans in the loop to improve quality control.



Remote visibility of distributed manufacturing and remote operations, for example, oil rigs, ushered in the need for a digital replica of the physical machines and operation of plants. Thus evolved the Digital Proxies or Digital Duplicates or Digital Twins, to capture the operations and their status in near real-time, through 3D model visualization on a remote screen. Today that screen is an iPhone or an iPad. Behemoths like GE can now monitor its machines operating in Dalian, China from GE headquarters in Boston or GE GRC in Niskayuna, NY, in near real-time, 24/7/365.

Digital Twin driven remote monitoring, in near real-time, offers performance optimization of machines, reduction of waste, predictive maintenance to reduce downtime. The data from machines, “swarms” of machines on the shop floor, plants and massive operations (refineries, oil rigs, water filtration plants) are associated with traditional operations, for example, enterprise resource planning (ERP) solutions. The data from the Digital Twins, therefore, can vastly improve the digitalization and/or workflow automation of supply chain, product life cycle management, spare parts inventory, transportation and logistics planning.

Digital Twins are the data proxies of the entire operational world, any operation, anywhere, can be, theoretically, captured and displayed on any screen. We can peer inside coal mines, to cobalt mines, submarines and space stations, your dog in the veterinary clinic and your Mom in the hospital, just after her gall-bladder surgery. With the right platforms, with the appropriate interoperable software architecture, with seamless handover between telecommunication protocols and user-friendly graphic user interfaces, we can visualize on a smartphone, the temperature inside the turbine in a 787 flying over the North Pole or query the end-tidal carbon dioxide level and respiratory rate of your Mum recovering in the post-operative care unit.

Digital Twins represent the tip of the visible iceberg, which is an outcome of digital transformation, sweeping every industry, every domain, every facet of modern life. Hence, digital transformation, albeit amorphous and evolving, may be a key bullet point on our list of UF innovation initiatives. Digital Foundry is not an independent separate concept. The journey from CAD models to 3D printed end product requires digital transformation, too.

The world needs an army of experts in computer science and math. We need engineering experts from every field and specialty, we need integration of cyber-security by design with software innovation, we need convergence of hardware and software in distributed cyber-physical production systems, perhaps even on nano-satellites in space.



Digital Twins, in practice, may be the tool to track and trace the part produced by the UF Digital Foundry. Unless we can uniquely identify the part and its status (sitting on a shelf or in a plane at the gate or in a plane which is in flight), we cannot get paid because payment is based on pay-per-use. Therefore, we must know when the product is in service.

To access the inventory of the manufacturer and the “in use” status, which will be controlled by the airline and the FAA, we will need multiple levels of secure access through a cacophony of systems, which must be interoperable to catalyze transparency. The latter in turn, will enable us to acquire the track and trace data from each node of the operation. It may be complex as a process but technically it is possible, by combining automatic identification systems, such as, RFID or radio frequency identification, plus sensors to monitor the status and link the visibility of the data, in real time, from the physical object to the Digital Twin.

This digital by design metaphor has taken the world by storm and is referred to as the Internet of Things or IoT. Digital Twins, digital transformation and various parts of other forms of connectivity we will discuss, including healthcare and medical IoT, may be collectively a result of the IoT era. IoT is not a tool or technology. IoT is a concept, it is an idea with origins in embedded systems, ubiquitous computing and connectivity. Diffusion of the IoT concepts may have started early in the 20th century. The term IoT was coined by the MIT Auto ID Center in 1999 and their first paper “Networked Physical World” by Sanjay Sarma, David Brock and Kevin Ashton, is generally viewed as the birthplace of IoT. Various other descriptions have emerged and industrial internet of things (IIoT) has gained quite a bit of momentum since the founding of the Industrial Internet Consortium on 3/27/2014.

At UF, we are proceeding, albeit gingerly, on the IoT trajectory, through engineering domains, to build a comprehensive momentum. In this amorphous zone of IoT, as a design metaphor, a clear direction is the practice of connectivity, almost, without boundaries. This is no longer only embedded systems, software or electronics but the convergence of all these areas with many others, such as natural language processing, neural networks, remote sensing, biomedical engineering, medical devices, automobiles and anything where sensing and connectivity may add value. The grand explosion has ushered the crucial need to secure the connections, data transmission and information dissemination. Cybersecurity by design, hence, is a foundational layer. Hence, “pay per cybersecurity as a service” has the vast potential to become a must use service, if any form of telecommunication is involved.



IIoT or the industrial version of this explosion, cannot even take its first step without cybersecurity. Data breach, or intrusion in data communication, can be fatal.

In the design of IIoT, data from active components are coupled with objects (things). When this data, for example, sensor data, is fed to the relevant physical object (sensor icon in the digital version) and the processes, taken together and displayed in the digital version, is referred to as a Digital Twin, that is, a functional digital replica of the physical object complete with the status of the physical components (turbine in the aircraft, parts, the landing gear complex, water pumps, HVAC). But, it is not a static model or a simulation of the physical structure. The Digital Twin is a visualization platform for near real-time status of the functions that physical structure is expected to execute. If an aircraft is flying, then the Digital Twin will display, upon query, the actual temperature inside the turbine.

Imagine if this temperature data is compromised during the communication. Algorithms in the optimization function can change the rate and flow of the fuel, which could over-heat the turbine and cause the insulation to melt away. Reduced burn rate could decrease thrust and plane can lose control, in flight. The role of cybersecurity is critical. It is creating next generation of Cognitive Digital Twins and it includes cognitive firewalls.

The “live” Digital Twin concept is central to our current thinking and the tsunami of digital transformation we shall experience. The manufacturer or operator or engineering systems designer, wants raw data, in 5 seconds interval, of the *range* of temperatures inside the combustion chamber, while the aircraft is flying at 37,000 feet over Polynesian Islands. The temperature sensors, behind the ceramic tiles that layer the combustion chamber of the turbine, is sensing the temperature. The sensor operating system (tinyOS) may transfer the data to the sensor database system (tinyDB) which uploads the MEMS data, in real-time, to the private manufacturer-specific cloud hosted on an Accion nano-satellite, in the low earth orbit (LEO). Accion transmits the data from the nano-satellite to an AWS secure private cloud server in Reykjavik, Iceland, which auto-updates the laptop computer at UF, where we have installed the Digital Twin repository. When I point to the image representing the turbine and drill down to the parameter, temperature value, the temperature data is displayed on my iPhone screen. Behind the scenes, solvers using various algorithms and machine learning tools are computing the data to optimize function.

This Digital Twin is alive. I observe the fluctuation of the temperature range while staring at the iPhone screen for a few minutes.



Margaret Hamilton, in the mathematics department at UF, and our engineering systems expert Gwilym Jenkins, demonstrates how the temperature data is used in a machine learning (ML) algorithm. The solver also takes in to account the molecular composition of the fuel and real-time humidity data from the in-flight onboard hygrometer. The outcome of this complex calculation using ML, is a dynamic optimization protocol to adjust the fuel pump pressure, which influences the rate and flow of fuel through multiple fuel injectors, to deliver the fuel to the turbine combustion chamber. Swati Patel, a student working with the faculty team, explains the target is environmental conservation by reducing direct and indirect greenhouse gases (GHG). Temperature monitoring is an indicator of energy efficiency of the aircraft turbine engine, while in flight. The goal is to optimize efficiency – maximize the aircraft motion while reducing NOx emissions (indirect GHG) without increasing carbon dioxide emissions.

I have digressed, intentionally, to capture a few strands of the fabric of the world, evolving constantly. The UF Digital Foundry initiative is one layer among several cascading layers of the ecosystem.

We have to deal with the ecosystem. We cannot simply create a widget and leave it there, because the rest of the process is not our domain. We have to get into these domains, through collaborations, alliances and associations. The world needs answers, not numbers.

But, we must advance research to get to the “numbers” and, in parallel, educate the citizens of the future, at the University of the Future, to sense the big picture, to contribute the details and develop the ability to continuously oscillate between these worlds, when necessary, with ease and confidence, to generate answers, provide global solutions and lift the plight of humanity.

This is not an easy task. But we will pursue these goals and "do the other things, not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one which we intend to win."

To recap, UF Digital Foundry initiative, using back of the envelope arithmetic, offers the potential to increase our revenue, from the aviation market alone, from \$0.9 million to \$3.65 million per year, every year, if we can move from product costing to services pricing.



60 million commercial automobiles are produced each year, with about 30,000 parts, each. Assume 3D printed metal parts may constitute 1% of the whole. Thus, total number of new 3D-AM parts manufactured per year is 18 billion. If UF claims 0.1% penetration into 18 billion parts, at \$1 per part, UF Digital Foundry revenue from automobile parts may be \$18 million per year, in the traditional product approach.

In the pay-per-service model, we charge \$1 per mile, because consumers pay for service when they use the automobile. If the user, drives the vehicle, the user pays \$1 per mile. We understand that vehicles may be driven by people or may be semi-autonomous or autonomous and may have internal combustion engines (ICE) or electric vehicles (EV) or fuel cell vehicles (FCV). What may not change is the fact that they will travel. Assuming it is driven 12,000 miles per year per vehicle, 60 million vehicles, taken together, will travel 0.7 trillion miles per year. If we charge \$1 per mile then UF may earn \$0.7 trillion per year.

The product vs service approach enables us to promote ethical profitability and lowers the barrier to entry, into economic zones of billions. Instead of \$1 pay-per-mile service fee, let us charge \$0.01 or 1 cent (1 penny). If we charge 1 penny per mile then UF may earn \$7.2 billion per year, each year, every year, from UF Digital Foundry auto parts.

Hip and knee replacements may be made to exact specifications using MRI data feeding 3D-AM printers. Assume we wish to earn \$1 per replacement. If 1% of the *susceptible* global population required hip or knee replacements, that will be about 30 million people, worldwide. If UF claims 1% of 30 million joint replacements at \$1 per part then Digital Foundry revenue from 3D printed hip or knee joints is \$0.3 million per year.

Alternatively, we could use the “Miss Money penny” strategy and charge 1 penny-per-day for each joint as long as the recipient is using the replacement joint. Let us assume that an average post-replacement longevity is 10 years. The recipient pays one penny every day for 365 days per year for a total of \$3.65 per year. For UF, 1% of the 30 million market amounts to \$1 million per year in revenue, at a rate of one penny-per-day per replacement.

In 2013, 767 million people (10% of the global population) lived on less than \$1.90 a day. Our quest for one penny-per-day may be affordable for all individuals in the world. But, please don't rush to gush with unbridled optimism. That 10% of the world may not even have access to clean water. About 50% of the world population may not have access to formal healthcare and more than 1 billion are without any healthcare, whatsoever.



The reports from a few august organizations claiming that only 400 million people lack access to essential health services is an example that may belong to the 21st Century edition of the seminal book “How to Lie with Statistics” by Darrell Huff.

Healthcare is a complicated problem. It will be arrogant and audacious of us even to think that we can alleviate the ills which has infected healthcare. We are only scratching the surface of a very tiny area. The biotech / bio-prosthetics sector in UF may benefit from 3D-AM (printed devices/skin/teeth, dental implants, implanted or ingestible nano-sensors).

The examples from the UF Digital Foundry initiative stimulates the core mission of education and research. Micro-revenue will boost UF development, provide the school of management with new challenges to help manage labyrinth of operations, globally, to sustain social businesses. Coupling rigorous research programs with entrepreneurial innovation, global education and ethical profitability, calls for new models that may not have been conceived, yet. Exploring ways to reduce cost of transaction (transaction cost economics) may benefit from the ecosystem of digital transformation, data and analytics. The central role of software, systems, data and analytics, will need robust cybersecurity.

Data analytics and cybersecurity demands depth of knowledge in mathematics, computer science, statistics and how to use tools from artificial intelligence (the truth, not the hype). The “ammunition” necessary may include knowledge representation, symbolics, representational learning, machine learning, deep learning and other AI techniques.

To raise that army we must increase enrollment of women in STEM fields in UF. But we can't stop there. Convergence, cross-pollination and trans-disciplinary collaborations are quintessential to create solutions. Technologies, tools, papers and monographs are useful but the solutions approach require we dissolve silos of data, information and knowledge.

We need more women to pursue statistics, computer science, basic sciences, engineering, agriculture, medicine, public health, economics and econometrics. For all students, we need to emphasize depth but concomitantly an awareness for breadth. The academic expectation of students to learn more and more, about fewer and fewer things, is pivotal for depth and rigor. But, the new generation must also remain cognizant about the global need to connect and converge, more and more things, from wider and wider circles, in order to provide the end-to-end solutions, which improves quality of life and living.



This amorphous tapestry may not be a defined system but system of systems or even more pertinent, complex system of ecosystems. The principles and practice of connectivity, convergence and complex systems, are here to stay, and amplify.

The supply chain of talent, necessary for these transformation, are not unique to UF. We must tune the engine, if we hope to polish the chrome. UF outreach to middle schools and high schools, must be at the heart of the UF strategy to be a purveyor of civilization. UF outreach to teachers in the elementary and secondary education system, must rise far above the shoddy and second grade masquerading, as good enough. There is no room for good enough, if we aspire to educate, shape and transform the future. The UF promise to build, maintain and secure the Cathedral of Learning, cannot happen in a field of ignorance.

In summary, the manufacturing proposal of the future has been given a name, we refer to it as the “Digital Foundry” but if we elaborate, we may think of it as a decentralized cyber-physical production system for additive manufacturing using 3D printing tools. The scope of the UF Digital Foundry is not limited to materials science or computer engineering or embedded systems or MEMS or NEMS or cybersecurity but also relevant to medicine, business, and social sciences, as well as social re-engineering and social enterprises.

UF will need resources, collaborations, partnerships with companies, governments, VC’s. But, ultimately, success depends on the zeal of the faculty and talented students, to create not what has been created but create a resplendent sense of the future, using the Digital Foundry initiative as one tool, a catalyst, an enabler. It is a means to an end, but the end is not an end, literally, it is a metaphor for a new beginning, a continuum, in which we use science to help society, to lift many boats. It will be driven by you, the students, and you, the faculty, but only if you think differently, only if you are not afraid of failure.

Now, I shall turn to health and healthcare, as an equally important engagement, where UF is already a champion but there is always room to evolve. Health and healthcare are related but not synonymous, a distinction that I hope to illustrate, in a few minutes.

The evolution of technology has created an illusion of proximity. After the telegraph and the telephone, it was AOL’s Instant Messenger, or IM, and “you’ve got mail” which signaled the birth of a new era in communications for the public, at large. Today you cannot find a communications tool without an “instant” component, to advertise yourself. The selfie storm appears to be a category five hurricane.



Narcissism aside, we use this electronic space as a buffer, a justification to increase our emotional distance, perhaps for some, to protect the fragile nature of disequilibrium in our micro-space. Are we reducing our ability to engage in inter-personal interactions? It is a vicious social cycle which further fuels the nuclear ethos and helps to build walls. There is less and less “skin” in the game. It is more and more cyber, a declining preference for, even, ethical physical presence, a social discomfort for civilized touch. We are sporting colors of camouflage by embracing the aphorism that only words can touch places where touch doesn’t know how to enter. Hence, a veiled and calm, yet vociferous denial of all things personal, extending to personalized services.

Healthcare is under siege by these forces. Denial of personalization even wants to target the role of the primary care physician, citing reduction of cost of operation, as the benefit. In the October 17, 2017, issue, the august journal *Nature* chimed in to replace primary care using artificial intelligence. The stupidity of publishing may be excused by acknowledging *Nature’s* desire to exercise its First Amendment rights. In the article, the author’s lack of understanding of the role of primary care physician in health, healthcare and society, was paraded as the march of AI and cost-savings. The capitalistic pressure to focus on cost erodes the socio-economic concept of relative value. The short term gain far outweighs the long term vision. Socio-economic parameters of primary care are a small part of a complex network of factors which shape quality of life, not only morbidity and mortality.

The University of the Future initiative for health and healthcare shall take the long road. Improving global quality of life will serve as our target. It is a lofty target, a complex vision and a grand challenge. I urge you to reflect on this quote from Daniel Burnham, an architect. But, I want you to do more, in addition to the written words, I want you to reach out to the inaudible and the unwritten allegory and allusion these words may provoke or evoke. “Make no little plans; they have no magic to stir men's blood and probably will not be realized. Make big plans, aim high in hope and work, a noble diagram, once recorded will never die, but long after we are gone will be a living thing.”

This commencement speech is the “record” I wish to share with you. It may stir new ideas and make you see old things with new eyes. It doesn’t matter if ideas in this speech never sees the light of the day. What matters is that these ideas may ignite new thoughts or shed some light how to transform your vision into reality. This is not my plan for a “me” “me” “me” modus operandi.



I request you think big, dream bigger and ACT, where T stands for “things” and C stands for “changes” and A stands for “action.” Remember Action Changes Things (ACT).

The internet of things (IoT) will remain an utopian design metaphor unless we ACT to embed this design through the principles and practice of connectivity. Ubiquitous connectivity, ubiquitous computing and computing at the edge are ideas to connect atoms to bits. All things physical, all processes, all decisions, may eventually be a part of this networked physical world. The data from these plethora of sources, the bits, will be connected to the things, events, processes and decisions, and that, as a whole is the practice of atoms to bits. Do you think it can happen without ACT?

The pursuit of ACT must touch all facets of life. For healthcare, it is the lack of action, lack of common sense, lack of standards, lack of leadership, lack of our zeal to fight greed, which are a few of the reasons why nearly half a million people, may die in the US, each year, due to errors. These errors arise due to lack of interoperability and data sharing between medical devices and patient data, in medical records, which cannot talk to each other. This is a gross injustice. But is it a remediable injustice? You must decide and ACT.

Imagine, today, you use your ATM card in the Student Center to take out cash, before your trip to Mongolia. Upon arrival, using the same ATM card, you take out money from an ATM machine at Sükhbaatar Square, in Ulaanbaatar, Mongolia. You can take out money in Gainesville, FL and Ulaanbaatar, Mongolia, using your globally interoperable ATM card.

But, here is a less known fact. Your electronic health/medical records (EHR/EMR) cannot be used in a different hospital *across the street*. Assume your records are in the UF Shands system and you are unfortunate enough to be in an accident, when visiting your friend Josh, in Jacksonville. You are rushed to the emergency room at the Baptist Health Center, in Jacksonville, FL. The ER staff desperately needs your medical data. But, your medical records cannot be accessed by the Baptist ER or Trauma Center, even if you consciously permitted the staff at Baptist to access your EHR/EMR.

The medical records software and system used by these two hospital systems, are not compatible or accessible from another system, due to lack of interoperability between systems, which was deliberately configured by design, by the manufacturer of the software systems, the vendor who sold the EHR/EMR. The same applies to vast number of devices.



You may ask, if this is the biggest problem in healthcare? I recommend that you ask a better and more specific question. Framing the correct question is important. I suggest you ask, is this the biggest problem in US healthcare? My answer will be quite incomplete.

But, I would reply, no, it is not the biggest problem in US healthcare, it is the THIRD biggest problem.

You can easily imagine that problems in healthcare are immensely complex. I am neither going to dissect the problems nor suggest that UF feels obligated to address the framework of all these problems. I suggest we view our role, contribution and use of our brains, to address segments of this system. Remember, our goal is to improve quality of life.

The dedication of the students, faculty, and staff at UF can find ways to get the world congregate behind this worthy cause. I think UF can improve the quality of life, for at least few of the nearly half million people in the US, who may die due to medical errors. There are many problems with healthcare but as Mother Teresa of Calcutta, often remarked, "charity begins at home." Let us pledge to help decrease the number of deaths due to medical errors, in the US. Even if we can reduce the numbers by only 10%, we have saved 25,000 to 50,000 lives.

The published figures are somewhere between 250,000 and 440,000, deaths due to medical errors, per latest reports from the Institute of Medicine (IoM). According to the seminal study by Johns Hopkins University, published by the British Medical Journal, in 2016, if deaths due to medical errors per year, are taken at their lowest numbers, that is, 250,000, per year, then, deaths due to medical errors in the US are the THIRD leading cause of death after cancer (585,000) and heart disease (611,000).

Hence, my reply, earlier, it is not the biggest problem in US healthcare, it is the THIRD biggest problem.

My suggestions, plans and views may be incorrect. I wish to reiterate that this is not about me or the President of UF or institutional advancement. This is about the granularity of talent that is embedded in each one of you. This is about your eye on the target to help improve quality of life. This is your challenge to find ways and ACT to implement the tools in a manner that is safe, secure and sustainable. This is not going to be easy.



That is why I urge you to pursue this goal, because it is going to be hard, difficult and complex. You will meet insurmountable barriers that you must overcome, you will face political quagmire you must navigate with diplomacy, you will face the wrath of the medical-industrial complex, you will feel the burden of the world on your shoulders, yet you must rise to meet the challenge. When you think about the very hard road ahead, and whether you should make it your mission, or not, I recommend you reflect on the ethos, semantics and eschatological wisdom attributed to the words from Matthew 7:13 and 7:14.

My faith in the ability of UF students, faculty and staff to ACT, is rooted in the fact that death due to medical errors have solutions which can evolve from engineering, science and medicine. The attempt to alleviate this moral, ethical and inhuman disaster of death due to errors, may be held hostage only by our inaction, lack of intervention and failure of implementation. UF and its medical excellence in the US and affiliations we wish to create, globally, may strengthen UF's leadership to prevent this march of unreason.

Let us begin with relatively simple things which may be the lowest common denominator. Medical devices are data harvesting tools. When data from medical devices are acquired, curated and appropriately integrated for analysis, in context of the person or patient, it offers us information. Part of this information may add to the person's medical knowledge base (EHR/EMR), a part of this information may offer predictive analytics, to help in prevention, and yet another part of data analytics may trigger immediate action.

When you are in an automobile or aircraft, you don't even think why you should integrate the data from the fuel consumption meter, the transmission fluid chamber, tire pressure, brake fluid level, the residual battery charge, wind velocity, speed and motion. We take systems integration for granted, and of course, structural integration for function.

Health and healthcare, is the outcome of systems integration, and an integrated structure, optimized for function. We wouldn't be here, there would be no evolutionary development of organisms or *homo sapiens*, if biological systems lacked integration.

With the advances in medicine, there must be a concomitant advance in systems integration for medical devices, working outside the body, with the intent to help restore equilibrium, in some manner, inside the body. The medical devices outside the body cannot remain oblivious to the basic need for an integrated outcome, for the whole patient or the person, not only some for parts or organs.



The failure of such an integrated outcome, related to the external processes, is one reason for the nearly half million deaths, per year, due to preventable medical errors.

For example, a 49-year-old woman underwent an uneventful total abdominal hysterectomy (removal of uterus and cervix through an abdominal incision) and bilateral salpingo-oophorectomy (removal of both sets of fallopian tube and ovary). Post-surgical pain management was initiated with intravenous morphine sulfate, in small increments. She began receiving a continuous infusion of morphine via a patient controlled analgesia (PCA) pump. A few hours after leaving the PACU [post-anesthesia care unit] and arriving on the floor of the general ward, she was found pale with shallow breathing, a faint pulse and pinpoint pupils. The nursing staff called a “code” and the patient was resuscitated and transferred to the intensive care unit on a respirator [ventilator]. Based on family wishes, life support was withdrawn. The patient expired. A case review affirmed death due to PCA overdose, a medical systems error which lead to morphine overdose through PCA.

Medical devices connected to this patient did their job of collecting the data, but did not do their job of connecting the data. Making sense of data is fundamental to our sense of the future.

Morphine administered by the analgesic delivery pump delivers morphine and it can be pre-set or controlled by the patient (patient controlled analgesia or PCA). Morphine reduces respiratory rate (RR). RR may be monitored using an inductive or resistive belt. The plethysmogram produced by the pulse oximeter, a device to monitor oxygenation, however, does not act until oxygenation (pO_2) is affected. Generally, a heart rate monitor also displays respiration rate. But when RR is depressed, it reduces oxygen saturation in the blood ($\downarrow pO_2$) due to reduced diffusion in the alveoli (decreased RR leads to shallow breathing). Capnography, measures end tidal carbon dioxide ($etCO_2$), an indicator of carbon dioxide which was not exhaled (residual) due to shallow breathing, caused by the reduction in RR, triggered by morphine ($\uparrow etCO_2$). Analysis of plethysmogram by wavelet transforms would enable the determination of changes in respiratory rate (RR) at an earlier stage (predictive analytics). If corroborated with an increase in end tidal carbon dioxide ($(\uparrow etCO_2) / (\downarrow pO_2)$) due to shallow breathing, the *combination of data* from two different devices, may suggest that the negative effect of morphine, on reducing the respiratory rate of the patient, is a far higher risk, than the anticipated reward, from the administered dose of morphine, to reduce post-operative pain (increase patient comfort).



Convergence of the data from the heart rate monitor, respiratory rate, pulse oximeter and capnography, must be integrated, analyzed and the status synthesized, in real time, in the context of the patient. The data analytics output must determine the dose and duration of morphine administration (control of pump), when the patient requests more morphine through the PCA. The raw data, waveforms, analytics and decisions, must be communicated in real-time, to the nurse manager or attending physician's smartphone. Data integrity and security must validate situational alarms and "code red" signals.

This is not in place, today, in most instances. The data from these devices are not integrated and not synthesized to reflect the real-time physiological status of the person or patient. Today, the nurse manager, in the observation station of the ward, may glance at several monitors, for several patients, and may arrive at an *ad hoc* determination, of the actions to follow, the alarms to ignore, or the situations to escalate.

In our example, the 49-year old woman, continued to deliver/receive morphine through the patient controlled analgesia (PCA) device, to reduce her post-operative pain. The lack of integration of medical device data, the lack of information interoperability between devices and the lack of a platform to integrate the clinical environment, in order make sense of the data, in context of the patient, lead to her un-timely demise. This is the nature of the problem, a relatively simple problem, we can solve at UF, in order to reduce the morbidity and mortality due to lack of real-time data integration, data analytics and data-dependent decisions in healthcare. If there was an intervention, an auto shut-off should have been triggered for the morphine PCA pump, based on the integrated data and information. Then, the woman may be celebrating her 50th birthday, with us, here today.

On closer inspection, you can identify the domains that must come together to solve this problem: [a] biomedical engineering of devices, [b] embedded electronics [c] data delivery interfaces (application programming interfaces, API) from medical devices for raw waveform data, [d] wireless transmission of data in multi-user dense clinical environments which must address and resolve errors due to radio frequency signal collision, bandwidth consumption, jitter, bounded latency, and time guarantee [e] interoperable platform for integration of data, [f] analytical engines using basic workflow or machine learning (ML) to make sense of the data, [g] feedback systems and control automation for rate limiting nodes [h] visualization on 3rd party monitors [i] real-time mobile data connectivity to the medical staff [j] authorization, privacy and cybersecurity of data, analytics and information, [k] back-end synchronization with EHR/EMR [l] de-identified data for systems and census.



Did we just transform one of the problems in healthcare as a solution we may expect from medical IoT? Collect the bits about atoms and connect the data to gain information.

This is a simple design metaphor and if you thoughtfully apply this metaphor to any domain or any industry or vertical, you will find, in most cases, we shall return to the principles of systems engineering, the need to address system of systems. We must address the whole, not just a piece of the problem, in a complex systems approach we must address the ecosystem. Most initiatives shy away due to the sheer complexity and lack of resources.

There are many tactical, practical and pragmatic problems in health and healthcare where UF can provide leadership. I would like to appeal to each one of you to undertake this complex challenge, albeit in a modular fashion, where modules can be connected to synthesize the outcome, the whole outcome. I request you to make it our mission to help create the systems and ecosystems to develop, demonstrate, disseminate and implement the processes, tools, technologies and platforms, necessary to reduce death due to errors of integration.

This is the true convergence of minds with machines. This is the convergence of principles with practice. This is the convergence of research and its translation to serve society, to lift many boats, not just a few yachts. Can we ACT (Action Changes Things) to improve healthcare?

Health is a prime example of how we can turn our thoughts into action through sense and sensibility. Health is human health, health of animals, environmental health, plants and organisms. Our sense of the future must be an *informed* sense of the future. Our sense of the future, in practice, may turn into an euphoria for sensors to predict the state of the future. The latter has created the utopia where trillions of sensors permeate every fabric of life. Somewhere between utopia and euphoria lies the panorama that we must foresee, anticipate and cultivate. The journey doesn't have a roadmap. We will encounter hills and valleys, failures and successes, joys and sorrows, dismay and exhilaration.

But, what we may have for the journey, our tryst with destiny, is a compass. Data is the new compass. If we cannot sense, if we cannot acquire data, if we cannot make sense of data, if we cannot convert data to information, if we cannot extract knowledge from information, then, we may not be able to guide our future, our future decisions. Without data, our imagination will be out of focus, and we may not be able to visualize what lies ahead, we may not be able to see the future.

Rosalyn Sussman Yalow & Norman Ernest Borlaug Memorial Commencement Address
by J. Fox Kenneth, President of the University of the Future (UF), on November 3, 2018



A sense of the future, as seen through the eyes of sensor data, is one view of the transformation of paradoxes to paradigms. Agreed in 1997, the Stockholm Convention on Persistent Organic Pollutants (POP) was tasked to detect and eliminate POP. Today we can use low cost, pervasive deployment of sensors and other tools for remote monitoring of aerosols and the Finnish Meteorological Institute (Ilmatieteen Laitos) is leading the way to monitor the health of the planet.

We wish to sense everything, we wish to acquire data from [a] temperature sensors inside the aircraft engine sending real-time data to the digital twin of the turbine, [b] gas-detecting sensors on the ocean floor transmitting data about chemo-organotrophs and chemo-lithotrophs [c] sensors inside the stomach of cows alerting us about complex microbiome changes due to lactation, food intake and pesticides/herbicides in the pasture [d] sensor-guided micro-robots in the large intestine of humans removing benign polyps [e] surface enhanced Raman spectroscopy based nano-sensors measuring parts per billion of Arsenic in water in Bangladesh or Mercury contamination in artisan gold mines of Colombia [f] nano-wire nano-array sensors screening for TB, leprosy, Hanta, Ebola, Flu, Measles, Plague and other communicable diseases, at immigration check points, in airports of the world [g] embedded nano-sensors on flash drives connected to smartphones which measures blood glucose and transmits data to your nurse practitioner [h] graphene nano-ribbon hydrogen sensor in your fuel cell (FCV) automobile [i] nitrate/phosphate sensor for precision agriculture [j] *ad hoc* self-organizing mesh network of sensors dropped from low flying aircrafts to detect landmines in hostile territory [k] implanted sensor-controlled time dependent chemotherapy dose which can be remotely monitored [l] swarm of sensors with nano-copper catalysts converting carbon dioxide to alcohols for renewable energy. The list can go on and on. Sensors are going to be a part of the fabric, more or less, sooner or later.

Deploying trillions (10^{12}) of sensors may not be wishful thinking. One could imagine bigger numbers, such as, decillion (10^{33}) or centillion (10^{303}) of sensors. To keep it in perspective, note that we may have about 7 quintillion (10^{18}) of sand in the world. Let us assume that we will “sense” every grain of “sand” in the world and send this “sand” castle of data **directly** to the internet, to feed distributed analytical engines. For 7 quintillion grains of sand we need 7 quintillion (7×10^{18}) sensors. If each sensor must communicate with the internet, **directly**, then we need 7×10^{18} unique IP addresses (internet protocol). Can we handle that volume of direct data routing to the internet? If I had to answer this question before June 6, 2012, I would say perhaps. But, now I can tell you, yes, we have the ability to provide unique IP addresses for each of the 7×10^{18} sensors, under discussion.



The latter is possible because as of June 6, 2012, the world has moved from internet protocol version 4 (IPv4) to IPv6. One advantage of IPv6 is its larger address space. The length of an IPv6 address is 128 bits, compared with 32 bits in IPv4. Because every binary “bit” has 2 states, 0 and 1, the address space was limited to 2^{32} for IPv4. The address space for IPv6 has the potential to accommodate 2^{128} or about 3.4×10^{38} **unique** addresses.

Yes, we can sense every grain of sand in the world, if there is a good reason. Yes, we can take the space elevator to the Moon on a nanowire frame, if necessary, in the future.

The value of 3.4×10^{38} unique addresses is not in our theoretical discourse about attaching a sensor to every grain of sand in the world. The real value of this discussion is the granularity with which we can track and trace events, and how the ecosystem partners can monetize miniscule nano-fractions of micro-payments, from social business ventures.

To alleviate hunger, poverty and hopelessness, in the world, we must gently transform our efforts from dependence on governments, philanthropists and foundations to solutions which are low-cost, sustainable and socially structured business ventures peddling prosperity for all, not a few.

We are back to making money. Today, our penchant for progress must keep pace with the inaudible stampede to gather resources. For academic institutions, our money making ability is entirely in your hands, the outcome of your brains and your desire to share your fertile imagination with the institution, in terms of your output, contributions and patents. UF must seek financial resources from every angle, because every penny must be re-invested in you. UF wishes to better enable you and provide an environment which may trigger, catalyze and fertilize even more opportunities for cross-pollination, synthesis, convergence and random sparks to ignite your imagination, inventions and innovations.

IPv6 *per se* is a routing protocol co-invented by Bob Hinden. But, the conceptual implications of the 3.4×10^{38} unique addresses, which are a result of the hexadecimal format with sub-divided domains, may spark new thinking about formats and domain subdivisions which may be essential to identifying every instance, of every activity, for every transaction, for every person, related to every object, every process, every decision, and every bit, connected to groups of atoms (objects). In ancient times, a related concept was the hash table or hash map and use of hash function to compute indices. A related hype, is the use of blockchain. Today, blockchain is on steroids, for all and every purpose.



Nothing is a panacea. Hash tables are still very much in use. Multi-disciplinary research is necessary to figure out [a] how can we decompose a systemic solution to its granular parts (think beyond BOM explosion, bill of materials) [b] assign a monetary value for that part [c] pay the entity who developed/created/manufactured that part, if that part was consumed by users (the core monetization function necessary for the service model).

This *modus operandi* is essential for pay-per-use business models using micro-payments, micro-earnings and micro-revenues, as tools for economic growth, globally, for more than 6 billion people in the world, who are much less fortunate than most of us in US, UK, Europe and Japan.

This research and its potential integration in global business is crucial for many, including UF. I wish to advocate this mechanism as one of the tools for UF to use and claim one penny from each instance of work, which our research can contribute to the global economy.

Why do I keep returning to this one penny model? Because, we can achieve miracles if we are less greedy, if we let the rest of the world find and share resources to do what is good for them, if we are a partner for global progress rather than a scavenger. We must help ourselves but we must help others, too. Collective growth fosters opportunities, equity and trust. There is enough in the world for human need but never enough for human greed.

The “Money penny” strategy, applied to “trillions of sensors” idea (10^{12}), generates the potential to earn 1 cent every day from every sensor or US\$3.65 trillion per annum. If UF could transform the vision and find ways to insert itself in 100 million sensors (10^8) then UF may anticipate to earn 10^8 cents or US\$365 million per annum. If these ideas are only 10% successful, then, UF can earn US\$36.5 million per year.

Critics will be justified to question the sanity of UF producing 100 million sensors. I admit that it is well-nigh impossible for an academic institution to manufacture 100 million sensors. That’s not what we do. True. But, don’t forget institution-supported start-ups which can grow in a garage to become a gigantic enterprise. Think outside the garage.

Think how many different massive economies of scale use cases we may address. If 10% of India and China may buy a sensor to check for blood glucose, that is a market for 250 million sensors and the service associated with the lifecycle of data from that sensor.



If UF had a remote hold even in 10% of that market, we can “insert” UF as a service in the lifecycle of 25 million sensors. This application may generate about US\$91 million per year for UF at a rate of 1 cent per day per sensor. Critics will jump up to point out that why would anybody allow UF to capture 10% of a foreign market where we do not have any presence, experience, credibility, or relationships, whatsoever.

The critics will be correct. UF needs an international advancement strategy and create research relationships, before we engage in potential entrepreneurial enterprises. Let me remind you that our strategy is not to disrespect or deplete the people in these nations. Our strategy is to help improve quality of life, our strategy is to build long term relationships, our strategy is to co-opt the talent in these markets to improve the economy. Remember, success is a rental. The rent is due every day. For our role, we request 1 penny.

Our claim for 1 penny per sensor per day is an open source approach, to penetrate any market in the world, by lowering the barrier to entry, to its most basic denominator. The per capita income in Kenya is about US\$3,000 per year, India’s per capita income is twice that of Kenya and China is more than twice compared to India. At US\$3,000 per year, it is not impossible that a person may spend 10% on healthcare. Out of the US\$300 budget for a person in Kenya, can UF claim \$3.65 per year? I don’t know. Is it impossible?

What may appear to be impossible, may just take a bit longer. We have to think big, bold and out of the box. We have to invest to generate revenue. But, above all, we need the leadership to promote the vision, the economies of scale by seeking granularity, not greed. It is not about blockbusters which costs \$9,850 per month, for example, the cancer drug, Ibrance, produced and priced by Pfizer. It is about population-busters at 1 penny per day.

Creating population-buster sensors may not be difficult for UF but creating the ecosystem to take the sensors from the lab to the million level manufacturing, distribution, sales and return on investment, is complicated. This is why UF needs the relationships at every node in that ecosystem. The global ecosystem is not going to accept proprietary tools.

Monetization of open source models, patents and technology licensing, deserves attention. Data acquisition from devices, the data model and interfaces, are some of the essential “open” elements. Safety, security and privacy must be demonstrated in the open model. Authorized access to raw data must be kept open, and almost free for patients, hospitals, healthcare workers and anybody else who may be legally permitted to use.



The sensor is the hardware, one part of the package, where software managed services are central to the lifecycle value of the sensor (hardware). It may be paradoxical, in the past, to contemplate that one may buy an object but may not own all of it. The case with John Deere and the software used in the tractor to obtain data was the milestone. The farmer owned the equipment but not the data since the software in the tractor was only licensed for use, not a product for purchase. However unfair, this is the paradigm shift where we may buy less and less “things” and pay per service, when used. If you use your washing machine, LG will record the use and charge you for its use. You may never have to buy another washer or dryer. The paradox is now a paradigm.

In another twist to this model, open source healthcare platform vendors may not be able to legally restrict you from obtaining your data (raw data, just the numbers) but may impose a micro-payment for accessing the vendor’s platform to access your data. It is a model that the banks have been using since the inception of banking. The outcome of the banking model is right in your face – if you visit any US city and look for the nicest tallest structure or the most opulent building – it is a bank.

Health and healthcare services will incur a cost to develop, implement, maintain and secure the infrastructure to enable the transactions. It will be a quantum leap forward if the health and healthcare industry is able to obtain raw data from devices and use an open platform model as a tool for convergence. If it is your data, then, you should be able to access your health data, anytime, anywhere. But, perhaps, there will be pay-per-access nano-payment for service. For health purposes, the information from this data could prevent you from a heart attack or alert you to the possibility of glaucoma due to type II diabetes. For healthcare, the information from this data, integrated for your specific physiological status, can spell the difference between life and death.

The data-driven service is the key. The discussion is no longer about the sensor, the physical product, but the lifecycle of the sensor which is inextricably linked to its purpose to sense, acquire and transmit data. The sensor, as a physical object, group of atoms, is like music, silent, unless performed. Data as a service is the yardstick for performance. Hence, the service must accompany the sensor in order for it to deliver its value. This is the next level where UF must “insert” itself – the interdisciplinary domain of software as a service. For global operations, security, interoperability between systems, data models and formats must be amenable to “discovery” through standards and open source standardization. If you cannot “discover” the availability of a function, then you cannot connect. In software parlance, you can’t initiate a remote function call (RFC) without an API or routing protocol.



UF must accelerate its role in global standardization bodies. UF faculty are integral part of IEEE, ITU, TOGAF, DoDAF and other organizations. Do we need to do more in this space? Instead of creating millions of sensors as hardware, UF can contribute to create interfaces, architecture and semantic interoperability standards. These standards may become integrated not with millions but billions of sensors and the sensor data ecosystem which is critical to make sense of the data through data analytics. The diffusion of CORBA sponsored by the Object Management Group may serve both as an example and a lesson.

A person using a blood glucose sensor on a smartphone observes that the blood glucose level is 139 mg/dl and wishes to know what it means. This query may trigger a different application, which may require the services of an analytical engine to process the data and respond to the query. This analytical engine may be provided by the platform vendor or may be sourced from a third party vendor peddling apps on Apple/Google. This is the engine that can evolve out of UF brains. UF can insert an algorithm in this analytical tool via an app. The query may cost the customer 10 cents each time. If 1% of the world's population (7.5 billion people) asked one question, each month, then this one single app could generate \$90 million per year. The monetization model must distribute fractional micro-payments to the app creator, platform host, telecom provider and other service vendors. If the system required 30 different vendors to contribute for systems integration in order to answer that question, then each vendor may receive 1/30th of the \$90 million revenue or \$3 million per year (if revenue was shared equally among the partners). If UF had 1% share of the revenue, from this app, then UF earns \$0.9 million per year *per app*.

Dynamic pricing of queries may be based on the computational complexity of the question. Dynamic composability of micro-services, analytical tools, algorithm engines or portfolio of solvers, must be sourced, aggregated, activated and executed in sequence, in order to respond. The structural elements of this architecture must be modular, “drag and drop” blocks to be “discovered” if necessary, interoperable, agile, compatible, and perhaps capable of natural language processing and preferably deployed as Agent based software.

Platform analytics will evolve as a key tool for monetization for open platforms and internet of things including medical internet of things (MIoT). Security, privacy and data de-identification may play pivotal roles. The question of “intelligence” in analytics and how the platform will address *context* of input data will always remain a challenge. Reasoning (often erroneously and synonymously referred to as AI) must occur in a specific context for a specific goal(s). These are questions which must be rooted in research outcomes.



The hype around so-called medical or healthcare AI systems accepting list of symptoms as input and generating output (most likely diagnosis) ignores the basic tenets of medicine: hypothesis-directed gathering of information, complex task of interpreting sensory data (obtain uncertain indicators of symptoms) and the goal of curing the patient. The latter may involve the decision to treat less likely but potentially dangerous condition rather than dwell on the likely but harmless condition. Is that the role of AI in healthcare?

These various steps and processes are events and instances that are proceeding in near real-time through the fabric of connectivity. The plethora of hardware and software related components, cyberphysical systems and Digital Twin instances, must be stitched, synthesized and orchestrated in sequence, to deliver a seamless service output, for which the end customer will be eager and ready to pay. That payment, at the end of the tunnel, is the only incoming revenue. The customer will pay if the customer is satisfied.

The customer will not pay UF, if UF contributes one algorithm, inserted in one app, which is hosted by Amazon cloud (AWS), in the app store for UCSF School of Medicine, distributed either through Apple or Samsung Health. This is similar to General Motors advertising their North Star onboard service. It is an outsourced operation hosted by GM to connect emergency services for humans and automobiles. Other value added services from external parties (restaurants, movie theaters, shopping malls) used the platform to push their offers, discounts and updates, based on location, proximity or customer's preferences.

Trans-disciplinary research is necessary to create unique identification tools that specifies what is requested, what is delivered, who serves as the medium of delivery, who is receiving the delivery and how payment is handled. Each sequence must be identified. An entity (corporation, person, crowd-sourced, agency) will have created and contributed that sequence, as a part of the seamless symphony, delivered to the user. The creator, vendor or supplier will want a share of that revenue. That fraction is critical. It must be accounted in a manner that is trustworthy, credible and resistant to cyber-theft.

For example, consider a MEMS in an automobile. Let us assume that it is by design integrated as a system on a chip (SoC) with on-board tinyOS and tinyDB. In an alternative scenario, the MEMS could be just a MEMS device (devoid of any microprocessor). If UF created this MEMS, in principle, and it was licensed by Bosch, in principle, we, UF, must make money each time the customer uses the MEMS (classic pay-per-use service model). The end user is completely unknown to us. We have licensed the MEMS to Bosch Inc.



In order to earn the micro-revenue from the service through the MEMS, we can pursue the Digital Twins route. However, Bosch, may not allow us to access the Digital Twin. I am unclear how the “politics” will be resolved but let us follow the engineering steps.

We need to have a record of every ping on the MEMS, which must have a unique id. This UID linked relational system log must capture each time instance of activity involving the MEMS. Using traditional systems, each time there is a state change, it may be logged in a hash table (hash map). Using this hash function, the series of state changes may be recorded in an array of buckets or slots (think tinyDB on the MEMS SoC). If the raw data from the MEMS is transported, through a gateway to a node in the automobile, then a central CPU may host the hash table for UID linked to the MEMS (if the MEMS SoC had a CPU/IC, then we could be looking at an ASIC).

For micro-payment purposes, event granularity <UID + state change> tells us how many times the MEMS service was requested and delivered. If the transaction cost of the MEMS is billed as a pay-per-use service then this data is the key to the billing process. This data needs to be secured but using blockchain could be akin to killing a fly with a sledge hammer. The log must be secured and relevant only when the cost is challenged or if the security was breached with the intent to tamper with the log (increase or decrease events).

The output we need from this is just a simple number – the MEMS was used 45 times from 1104 hours (car ignition time stamp) through 1713hours (last time stamp).

This number (45) is the number of events for which the end-user or customer or OEM has to pay, for operations on a given day or 24 hour period or any other bucket. This number is transmitted to the bank or credit card registered to the automobile. Hereafter, it is fintech as usual, which transfers the charged amount (let us say 45 events at 1 cent per event for a total of 45 cents). Cybersecurity in this financial operation is quintessential.

The innovation and challenge lies in identifying each instance, recording it in an irreversible digital ledger, securing the granularity of each state change, preferably using a unique ID system, in a hash like function, which can id each state change, the time stamp and its point of origin. The latter is key if the data must be audited or if the command origination is in question, if cyber-threat from an intruder is suspected. The concept of creating a cascade of “locks” is an idea, which has been proposed but yet to be explored.

The format of identification of each sequence, and logging each unit activity for payment, may find something important in the conceptual implication of 3.4×10^{38} unique addresses, generated using the hexadecimal routing structure of IPv6.



Convergence of IP routing format, with business models, standards, nomenclature, semantics and financial technologies, such as, blockchain, is likely to evolve. It provides ample room for innovation and leadership for adoption. The monetization tools, capable of converting the granularity of service delivery to currency, are missing. Batch processing may be the closest approximation and that leaves out the pay-per-use billions. For diffusion and broad spectrum adoption of IoT type services, each unit shall seek payment. Could we build such tools and proceed to nurture their progress to catalyze global standards?

These standards will enable widespread sensing, especially remote sensing, with the intent to detect and perhaps to prevent. Billions of users may be willing to use services if it is a pay-per-service model, which makes capital investment negligible, yet offers them data or information, when they want (pull), compared to fixed price subscription as a service (push). Consider the scope of new business if we can replace fixed insurance rates with pay-per-mile automobile insurance. To transform this idea into practice, we need several points of data to validate the model in terms of duration of drive and associated risks.

In other fields, remote sensing in agriculture, and environment, may be critical for food security and public health. Remote sensing at home may decrease emergency room visits and re-hospitalizations. Sensor data is indeed critical but without pay-per-use, the adoption may be sluggish, at best. Transparency, visibility and security are necessary but there aren't any complete solutions because research and systems integration are lacking.

The example of radio frequency identification (RFID) showed us that when the cost of the RFID tags decreased, adoption increased to billions. The role of the MIT Auto ID Center, where, incidentally, the term IoT was introduced, in 1999, did not re-invent RFID. They simply took the data on the tag and uploaded it to a database accessible via the internet. The RFID tag offered a short (64 bit) alphanumeric identity, which MIT advocated through the academic-industry-government consortia. MIT helped in the standardization of the EPC or electronic product code, along with established standard bodies and industry associations in the US, EU and Japan, in addition to other countries.

Resurgence of RFID is not a perfect example and we need to find new roads. But, the idea of lowering the entry barrier, to gain market penetration, is not a new idea and an idea which is unlikely to change in the next 10 years or in the next 100 years. Cheaper, faster, quicker may be an anathema to academics but the swan song for those on Wall Street who may wish to use money as their preferred choice for wallpaper.



Billions of people who are likely to use these services are unable to invest in capital costs. Hence, the appeal for the “Miss Money Penny” strategy and the growth of social business. Academics and institutions could play a much more involved role, to usher in a semblance of equity. In 2016, only 8 men owned as much as half of the world’s population.

Half of the world’s population is also suffering from energy poverty. It is the commodity that can spell success, simply by its presence, or disaster, by its absence. Energy will re-invent the automobile industry and Tesla is one example. At UF, I would like experts to engage in the automobile industry through energy and then use the knowledge gain from such energy advances to help the billions in the world gain access to energy.

From an energy R&D perspective, we need to explore nano-composites for high density energy storage, nano-materials to convert carbon dioxide to liquid fuel and nano-materials to re-shape automobile parts and body. I wish to predict the rise of the fuel cell vehicle (FCV) and its use of hydrogen as fuel. Scientists and engineers at UF may wish to think about the next automobile evolution as an energy revolution spreading from EV to FCV. I don’t see why UF cannot contemplate manufacturing FCV’s as a global collaboration.

In parallel, research on nano-crystalline photo-voltaic cells for solar energy, high density graphene batteries for storage, and nano-membrane applications (water-less toilets) are bursting at the seams with R&D potential as well as entrepreneurial potential. The UF credo, to make lives better through science and society, can take a giant leap with solar energy for the billions in the world without access to energy. It may offer us global credibility, visibility and a stream of development activities. In a previous year, I had focused on solar energy and connecting the activity with education for girls and women.

Thus far, I have presented to you R&D opportunities and suggested the need to translate some of our activities for long term investment in the future of UF. How do we start to practice what I am preaching? You have started it already. Schools, institutes and departments under the UF are engaged in multiple industry-academic partnerships. Our faculty are creating Centers, with small and large funding, from various agencies.

I think the practice of creating academic-industry partnerships may be enhanced by increasing the sphere of our creativity, expanding our network and finding innovative ways to embrace not only US companies, but corporations in Europe, South America, Asia and Africa. Our alumni and faculty and staff are from all over the world and they can help UF.



The research output of our faculty has great depth. The institutional reward system prefers those who are plumbing deeper and deeper into fewer and fewer domains. As a scientist and engineer, and as an academic, this is music to my ears. Respect for depth is second to none. As a part of a team to run, finance and sustain institutional advancement, I want the depth in our faculty to reach new heights, gain unparalleled excellence and enjoy global credibility. But, in addition, I want a few people at UF to help us practice the art of synthesis, convergence and connecting the dots. These people, the practitioners, must work with the depth, bring value to the depth, improve the academic environment to sustain those who are deeply embedded, and collectively, help UF reach for the luminous summit.

Practitioners may be generalists, people with diverse experience and breadth of expertise, who will serve as UF's instrument of goodwill, to guide, to develop, to better utilize, to bring together, to create bridges and to cross-pollinate the wealth of depth, throughout UF and the external world. Through the work of these practitioners, we need to accelerate our proactive outreach to industry, to government agencies, to foundations, to foreign governments and external organizations, for example, standardization bodies. UF must convey and communicate the potential of our faculty, in order to co-opt these external groups to choose UF as their preferred partner. Practitioners must spread the word about the wealth of depth at UF, uncover areas of synergy, strive to find common grounds and then catalyze engagements between funding groups and faculty. Then, the magic will ensue.

This must be repeated, in principle, over and over again, with a variety of faculty, sub-disciplines, multiple domains and diverse groups. However, in each cycle the principle may remain constant but the practice may depart for any formulaic approach. It is advised that we do not create a formula but entertain new measures, avidly explore uncharted territories and build new roads for development, funding and ethical globalization.

In the global arena, US education is one of our strongest national exports. The private institutions are all over the world, with global campus and collaborations and research partnerships. Science and engineering executive education is in very high demand. The agile business models of the "new" world may not mimic the stoic and traditional US models, or find any interest in case studies of US conglomerates. But, the R&D advances from the US, are still the bread and butter, with jam, for global businesses. This is a new area for academics with depth. Few engineers and scientists, steeped in the pursuit of excellence, can conceive that they can teach and share advances from their fields with business people, through courses, workshops, digital education and online learning.



At the undergraduate and Master's level, UF's role in global education and digital learning needs to be re-defined, re-evaluated and re-structured, repeatedly. If we cannot adapt, we will die. Learning from MicroMaster's and nano-degrees, I think we may wish to explore the Bachelorette, the online mini-Bachelor's degree. We can identify the global supply chain of talent from the exceptional top 1% of Bachelorettes and invite them to UF.

In addition, the depth of our faculty could boost our online resources to explore partnerships abroad, research collaborations, potential joint degree programs and use of our online excellence to specifically empower women's education. The education of a boy will change the fate of a man. The education of a girl may change the destiny of a nation. According to the World Bank, the global economy may experience a surge in the range of \$12 trillion to \$28 trillion if we had a modest level of gender parity and more women were allowed to join the workforce, especially, in India.

The ideas and suggestions I have presented are well within the reach of UF. We will attempt to create collaborations, to invest in our students and faculty and staff, to stimulate trans-disciplinary research and multi-pronged associations, to work towards our credo to improve quality of life, for all. In our pursuit, we must not get into a chest-thumping match about UF. We want to celebrate success, encourage failures but never to give up and inspire the young to aspire. But, we must remain cognizant of the problems that we didn't address, we couldn't address, problems we may not be able to solve. Hence, I also wish to suggest to keep your inner eye open, indulge in modesty and abide by another credo, *esse non videri*.

Before I conclude this commencement address, I wish to go on the record, and mention a few things that we, UF and the world, may wish to re-think. Perhaps one or more leaders will emerge, who will have the audacity and ability, to take on these ideas and move forward. The grand challenges, I have mentioned thus far, may pale by comparison.

Sahara presents us with unlimited but immobile solar energy. We must add mobility to energy. We must move beyond the metaphor, atoms to bits. We must embrace the paradox of swappable groups of atoms. We must design a new, inevitable, paradigm shift.

Based on transaction cost economics, is it feasible to capture solar energy, store it in a near non-perishable state, in high density modular (nanomaterial or graphene) credit card size batteries and distribute the batteries, worldwide? Slide in the credit card form, or even smaller USB sized, battery in a USB-like slot in any equipment, machine, automobile, smartphone, washer-dryer, tractor or laptop or cooking stove for grid-free mobile power.



EV's carry 200kg – 600kg (400–1200lbs) of weight in batteries. This is absurd and wasteful and ripe for innovation. The battery in an automobile must be a modular form factor similar to a credit card or USB flash drive or at the maximum, the size of a smartphone. For a rickshaw-taxi, in China or India, or a taxi cab in US or EU, the 'smartphone-size' battery may provide sufficient energy to travel 20-30 miles or about 10 trips. An average taxi ride in New York City is 2.3 miles. Why carry a 200kg battery for a 2.3 mile taxi ride? After ten rides, drop off the "empty" "smartphone" battery in any local convenience store and swap it for a fully charged battery.

Hence, transforming the paradox of swappable atoms to create a new paradigm shift. In the next decade, fuel cell batteries, may assume form factors similar to a smartphone. If you are a long distance lorry driver, carry a six-pack of batteries and that will get you at least a couple hundred miles, may be a lot more. It is a global ecosystem that must get involved in this paradigm shift. It is a complex challenge and I hope UF shall lead.

The wealth of the Sahara, in terms of insolation, is offset by its poverty of water and food. Sahara is both an asset and a liability, in advancing the world's next frontier, the great continent of Africa. Malnutrition, disease and social disequilibrium are oozing out of every corner and crevice. The vast natural resources of the land may be better utilized if we had a bridge and/or tunnel between Puerto de Tarifa, Spain and Eurogate Tangier, Morocco. The shortest physical distance between Europe and Africa is less than 10 miles (about 14 km).

To partially address these issues, I think it is time to re-discover and invoke an idea suggested in the 19th century. Inspired by the successful completion of the 102 mile long Suez canal, in 1869, a few years later, in 1874, Captain Francois-Elie Roudaire, an army geographer from France, suggested the creation of a 120-mile-long canal to connect the Mediterranean Sea to Chott Melrhir, an endorheic salt lake in northeast Algeria, covering an area of 3,000 square miles (~7000 km²), which lies 40 meters (130 feet) below the sea level. It is usually longer than 80 miles from east to west.

If flooded, such a huge body of water in the interior of North Africa and the Sahara Desert, may present opportunities for agriculture, improve sanitation and may change the climate. Can a few degrees drop in the temperature of the Sahara reduce the number of Cape Verde hurricanes? In 2016, we encountered Hurricane Irma, a Cape Verde hurricane, the most powerful Atlantic hurricane, yet recorded, outside of the Caribbean Sea or Gulf of Mexico. The prevention of billions of dollars in damage, due to these Cape Verde hurricanes is sufficient financial return, on the investment necessary to flood the Sahara.

Rosalyn Sussman Yalow & Norman Ernest Borlaug Memorial Commencement Address
by J. Fox Kenneth, President of the University of the Future (UF), on November 3, 2018



If flooded, can it help to prevent, at least a few, of the 11 million children who die each year, mostly in Sub-Saharan Africa, due to preventable causes? Improvement in sanitation and sewer systems can reduce the vector borne diseases and spread of infection. About a billion people in the world, today, have no access to a toilet and must defecate in the open. About half of a billion are in Africa, and 569 million people in India, defecate in the open. Bill Gates' water-less nano-membrane toilets are innovative, expensive and may not be a long term solution. If flooded, it may help half a billion people in Africa to find a way out of defecating in the open.

If flooded, the water from the Mediterranean Sea may pass through giant nano-membrane desalination sieves, attached to water gates, to reduce the natural salinity from about 3.5% to 0.5% in the filtered water? The volume of fresh water in 3,000 square mile area, cannot be anything but a lifesaver, if used and distributed, appropriately.

The financial risks aside, the debate of the future flooding of the Sahara, and other similar projects, must weigh human benefits in light of potential ecological disturbances and environmental changes. With the world population reaching 10 billion around 2050, production of food must assume "Borlaug-ian" significance. Is Sahara a part of the solution?

Sahara's abundance of untapped energy and lack of running tap water, are triggers for world changing events. Re-shaping the geography of the Sahara may improve quality of life, for billions. Sahara is a story of rags to riches. Can UF become a co-author of the new book "Peddling The Flood of Prosperity – The Sahara Solution" published by UF Press?

We don't get what we wish for, we may get what we work for. I urge UF students, to pay heed to the words of Mahatma Gandhi, "be the change you wish to see in this world."

May God bless you.

Please remain seated as the students exit the auditorium. The UF Marching Band will play the Commencement theme.

"When I'm Sixty-Four"

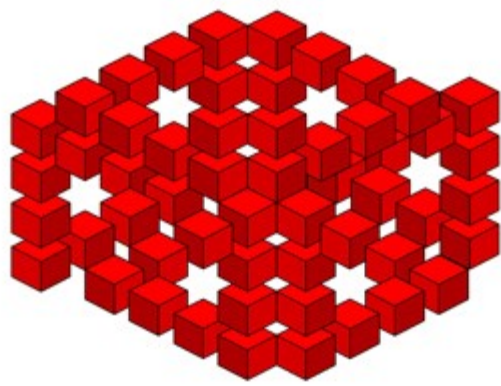
Thank you.



This is the true joy in life, the being used for a purpose you consider a mighty one, the being a force of nature rather than a feverish, selfish clod of ailments and grievances complaining that the world will not devote itself to making you happy. (GBS)

The best people possess a feeling for beauty, the courage to take risks, the discipline to tell the truth, the capacity for sacrifice. Ironically, their virtues make them vulnerable; they are often wounded, sometimes destroyed. (EH)





COMMENTARY [C]

Shoumen Datta

HAPHAZARD REALITY – IOT IS A METAPHOR

THIS PAGE IS LEFT BLANK

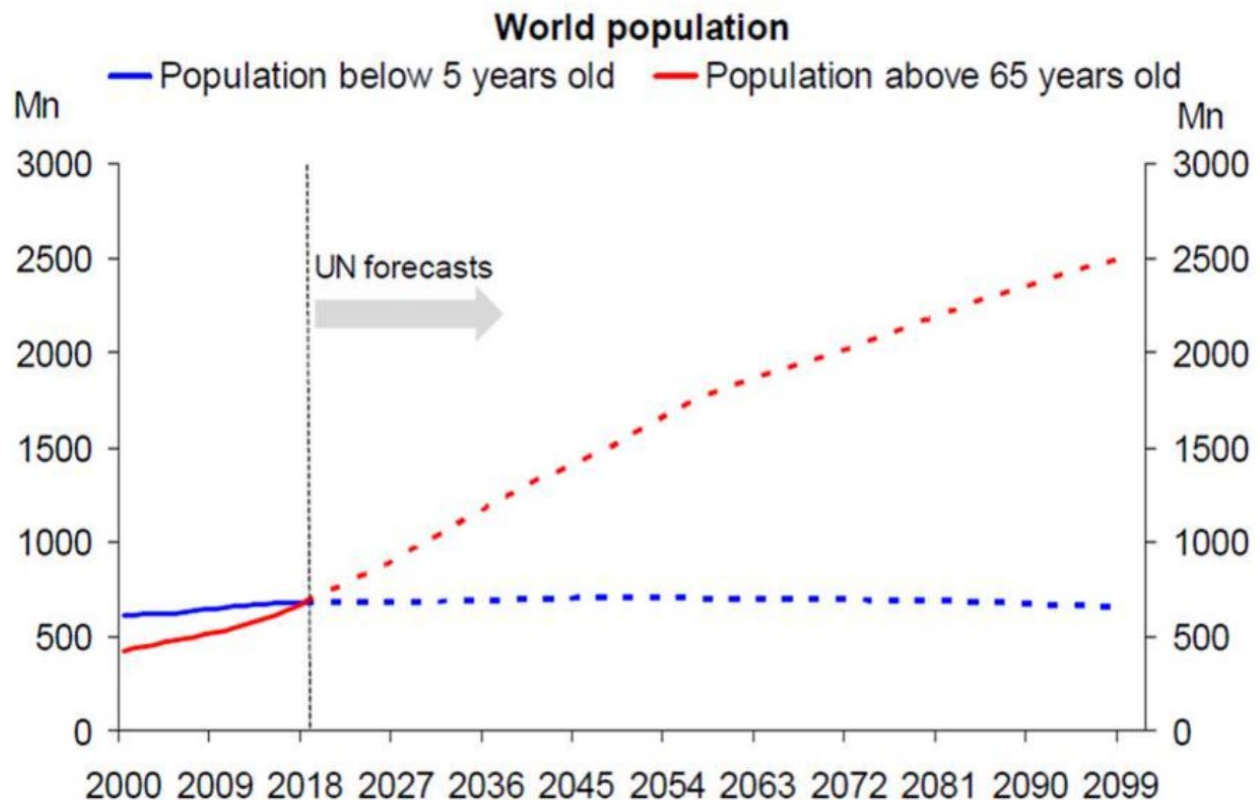
SENSORS

Sense and sensibility or just another snake-oil sales spiel for the affluent salons?

A few months ago, searching only one source (Science Direct), revealed more than 719,000 papers on sensors, during the period 2010-2018. That is, on average, about one paper on sensors, almost every six minutes, for the last decade. Naturally, skepticism follows, about sensors, sensor research, shoddy science, the enormous waste of global resources and the quest for value or if it is a tall “*tale, told by an idiot, full of sound and fury, signifying nothing.*”

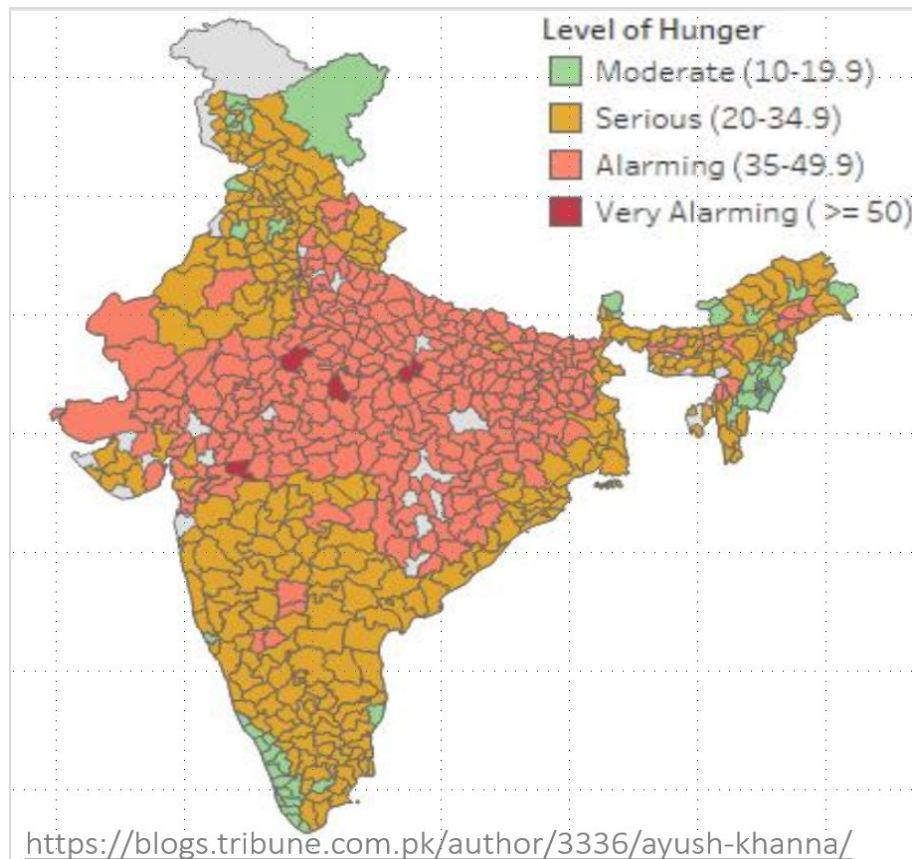
Value is relative. Opinions about value are of little value unless we evaluate value in context of the application, society and economics of technology. The latter is important if we wish to deploy science in the service of society (<http://bit.ly/Economics-of-Technology>).

Demographics is the ultimate purveyor of civilization and a prime driver of the global economy. For context of value, from a global perspective, demographics induces and presents diabolically divergent fields. An incessant drive in the West to automate everything to minimize involvement of people. On the other hand, the plight of the East to create value through including people in most endeavors to maximize meaningful engagement for the burgeoning workforce. It is not difficult to understand the fear in the West, which drives this penchant for automation. There are more people in the world older than 65 compared to under 5 population. Majority of the over 65 people reside in the West. Is the mortal fear of workforce shrinkage the *raison d'être*?



Source: United Nations, Haver Analytics, DB Global Research

Ageing is one reason why the ideas and education offered by Western business schools and enterprise management may be driving the *nail on the coffin* of Eastern commercial strategy. Eastern individuals covet Western insignias. These “agents” perpetuate the egregious errors of Western thoughts in Eastern societies when applying business ideas to nations with ~1.5 billion people and societies which are steeped in a milieu of difficult problems of varying complexities.



It will be remiss of me to leave this discussion with the impression that West can't meet East. Untrue. Both can meet and have met and shall continue to meet, embrace and co-exist. The caveat, in my opinion, is the corporate greed-saturated strategies that accompanies the business school ideas peddled as truth. Whose truth is it? Largely, for the West. Why not? It is a Western B-school. The East may find cryptic nuggets in that quagmire with universal potential or can be adapted for the East. But, taken, as is, it may not be a wise move for the Eastern context, for about 80% of the world's population.

The source of the brilliance that radiates from the West is from science and engineering advances. Science is agnostic of geography or location. Hence, application of the principles of science and engineering to create tools, adapted to serve the East, is certainly an advantage, for which we must be grateful to the West. Stepping beyond STEM, however, lands us in murky waters, for example, marketeers, magazines and muppets, talking about artificial stupidity or AI (there is no intelligence in artificial intelligence <https://arxiv.org/abs/1610.07862>).

Divorced from the science of artificial intelligence, glib and smug hype-stars are creating new terms, buzz words and catch phrases (for example, “disruptive”). AI is a common example from the social media circus, but other hackneyed terms include digital twins, IoT, blockchain. Consider these AI flavors, now available in grocery stores in the ‘Augmented Imbecility’ aisle:

Ambient AI
Cognitive AI
Reactive Machines AI
Limited Memory AI
Theory of Mind AI
Self-aware AI
Semantic AI
General AI
Artificial Narrow Intelligence (ANI)
Artificial General Intelligence (AGI)
Artificial Superhuman Intelligence (ASI)

Perhaps, this is not at all about science or truth or AI. This is about insecurity, ego and the fear of being left behind. Companies and corporations are re-inventing words and lying about the potential capabilities (eg AI) because they are desperate to claim “fame” for something “more” (for example, Kevin Ashton and the “*term*” IoT). These people and businesses may feel “small” and left out because they missed the boat (for example, Steve Ballmer and iPhone). They are trying to synthesize words and craft portmanteaus to unleash novel ways to amplify “billable hours” by percolating “new” acronyms – triggered by the fear of being a *has-been*. True in-depth advances and people who transform the world, are rarely in the picture or in the media or on FB.



The team that synthesized element 104 in 1969, along with Glenn Seaborg, then head of the US Atomic Energy Commission. From left: Matti [Nurmi](#), James Harris, Kari [Eskola](#), Glenn Seaborg, [Pirkko Eskola](#), Albert [Ghiorso](#) (Photo courtesy of LBL)

After boiling the ocean – what's next?

The depressing discussion in the past few pages seems out of place for an essay which embarked to address sense and sensibility from sensors. Compared to the vast expanse of the problems and issues mentioned above, the topic of sensors seems extremely narrow and limited.

It is narrow. In my incapable style, I have tried to present the widest funnel with the narrowest neck. My cumbersome attempt aimed to point out the treasures of science and sensors, which can provide value, even for the less affluent masses, if they can afford to use sensors.

Sensors will not solve world hunger. It will neither provide clean water to 2 billion people who lack access to water nor can it help one billion people who do not have access to toilets. Sensors are tools, sensors are a part of some solutions but sensors *per se* are of limited value.

The bulk of the value, for billions who are still struggling to survive on \$2 per day, are in commodities and global public goods: food, water, and energy, may be followed by healthcare.

The caustic disappointment that surfaces in the discussion in the past few pages, is a haphazard way to point out that 80% of the world may care less about robots, blockchain and AI. As a scientist, these are attractive, but, as a pragmatist in the real world, it seems to be a luxury.

Sensor engineering is rooted in hard sciences. It could not have happened without major investment in STEM education. The outcome from research may benefit all, but especially the East, if some of these ideas and tools can be transformed from the vision and concept stage, to **products**, which are **affordable** and sustainable, for **routine use** by low-income communities.

Hence, we are not thinking about \$100 or \$1000 sensors made by Bosch AG. Rather, less-than-a-dollar sensors manufactured by *Yunus Sensors*, a social business start-up which may germinate in 2020. These sensors will be for commodities – food and water. These sensors may not change the fabric of life but may save a few lives. These sensors may alert consumers about the dangers lurking in their food or water (more information <http://bit.ly/SIGNALS-SIGNALS>).

Sensors may change **lifestyle** approaches. The ability to manufacture, install and maintain these sensors, and use the data from sensors for **actionable information**, sows the seeds for a growth industry. Thus, it creates jobs, job training, catalyzes economic growth and education.

Critics may be correct in pointing out that an alert about the content of arsenic in drinking water is an exercise in futility if the consumer is dying of thirst, in a geography where there are no other sources of water. In a similar vein, an indicator of food spoilage or contamination is less likely to be heeded if the only other option for the adult or the child is to starve and stay hungry.

These are likely scenarios. Sensors will be impotent and useless in such situations. In these locations, one may not even venture to suggest the use or investment for sensors, no matter how small. In this case, it is a far more complex infrastructure problem and socio-economic issues related to basic rations, public goods and survival.

In our narrow world view, we will have to put on blinders and assume that people will appreciate the value of the information from sensors related to consumption of food, water, air.

Investment in Global Public Goods – The PAPPU Paradigm (Pay A Penny Per Use)

Adopt low cost nano-bio sensors for pay-per-use micro-revenue from mobile data-informed decision as a service

Dr Shoumen Palit Austin Datta, Massachusetts Institute of Technology and Massachusetts General Hospital, Harvard Medical School (shoumen@mit.edu or sdatta8@mgh.harvard.edu)

What is it?

Low-cost sensors can detect pollutants in water (lead, arsenic) and food (bacteria in spinach, lettuce). Proven to work in the lab, at an approximate cost of about 50 cents (US), these sensors may be mass fabricated using commercial 3D printers using laser-scribed graphene (nano-carbon) as a key material.

How can it help?

Water and food safety are principal areas of application. It can be used at home to detect if your water contains certain pollutants (lead in water in Flint, Michigan). Consumers can drive the adoption of these sensors on perishable goods (spinach, lettuce, fish, meat) which means that the quality/status of the food purchased is clearly (and scientifically) visible. Adoption of these sensors in the upstream food supply chain and transport, makes it easier to identify contaminated food ahead of retail distribution.

Return on Investment – ROI in the future?

The toll on the bridge between academic output and commercial transformation is often paid in terms of margin of profit. These sensors, and the intended use, makes it imperative that we keep the cost and the profit lower than conventional practices. Lower cost may remove the barrier to entry into global markets in emerging economies where we can reach about 4 billion users in 8 countries shown below. It is our hypothesis that profit from micro-revenues and economies of scale will far out-weigh the high cost, small market (Western) approach. Service-based financial innovation is a part of this effort.

1. China	1,389,618,778	6. Brazil	210,301,591
2. India	1,311,559,204	7. Nigeria	208,679,114
3. United States	331,883,986	8. Bangladesh	161,062,905
4. Indonesia	264,935,824	9. Russia	141,944,641
5. Pakistan	210,797,836	10. Mexico	127,318,112

Weaving sensors into everyday lives, using the smartphone as a simple “yes/no” data-informed decision as a service (DIDA’S) support tool, makes the use of sensors ubiquitous. Using sensors for quality of water and food makes the tool useful to monitor commodities. Social integration of commodity sensors and the value of sensor data in *data-informed decision as a service* (DIDA’S) in daily life, may help mass adoption. By lowering the barrier to entry, the latter may be accelerated by a low-cost, pay-per-use, micro-revenue, service model.

In one approach, each time a user uses sensor data, the user pays one tenth of a cent (0.1 cent US). In a pay-per-service model the end user may not buy the sensor but pays for use. In this scenario, if we can reach 1% of the market of 4 billion users, and if consumers in the impoverished nations (earning less than \$2 per day) uses 1 sensor (data) 10 times (events) each day (1 cent per day) then the annual revenue is \$146 million. If they use 10 sensors, each 10 times per day, the revenue will be \$1.46 billion.

What type of funding is necessary for what purpose?

Funding from individuals who are interested in investing in social benefits from science and technology, locally and globally. The funding may be a 501c(3) non-profit approach or institutional partnership or any format that satisfies the donor organization or financial sponsor or collaborators who are investors.

The lab tools must be converted to an integrated product, where the hardware and software works in synergy, to deliver a *solution*, not merely a widget. The solution must offer *synergistic integration* of sensor engineering, data collection, analysis and data visualization, on a mobile platform for access via smartphones, to aid the decision of the end user or customer at the point of use (point of contact). The aim is to generate and evaluate the solution. Financial support is key to achieve that goal.

The categories and amount of funding solicited?

The total amount is difficult to estimate because of the non-linear dynamics of the process but the solution demands a fail-proof public domain outcome. It must be credible, professional and acceptable for deployment. A large pilot is essential for public proof of concept and to build a community of trust.

YEAR 1 - crucial to secure skilled HR to start the translation process. For a robust commercial product, we need to hire specific skills but some of these skills may be available in PhD students (the operational base of this translation is in academia). Without foundational experts with experience, the process may be ineffective. Salaries for real experts must be generous but investment amount can change depending on the location of the operation, for example, US or EU versus India (US estimates are suggested here).

Essential categories representing fundamental skills (which must converge to create the solution) may include (but not limited to) the following:

- [1] Sensor hardware engineer
- [2] Solution Chemist
- [3] Telecom engineer
- [4] Database expert
- [5] Data Analytics
- [6] Software support
- [7] Consultants [a] material science [b] machine learning [c] visualization and applications [d] strategy
- [8] Organizational [a] communications [b] travel [c] salary contributions for academics [d] equipment

■ YEAR 1 investment in these categories may approach or exceed US\$1million (development in USA).

■ YEAR 2 will be the transition to manufacturing the publicly usable prototype. Therefore, in addition to maintaining the YEAR 1 expenses, additional funding for YEAR 2 will be necessary for [a] machine shop [b] fabrication workshops [c] design experts [d] usability testing. YEAR 2 estimated (US) ~\$2million.

■ YEAR 3 should be the public deployment of large-scale pilot in at least 3 different environments where water and food are involved. Some exploratory discussions will be necessary to determine these public proof of concept sites. The scale of deployment will determine YEAR 3 funding in US, approx. \$3 million.

How will investors benefit from this venture?

Philanthropic support is not sustainable for any effort that aims to provide global public goods. We are interested in investors who wish to pursue *gentle* ways for *ethical* profitability. The question of IP are less applicable here because proposed solutions are synergistic systems integration based on chemistry, molecules, tools and technologies which exist. We are not pursuing this activity as invention but R&D (YEAR 1) toward innovation to create platforms and aggregate sensor and data tools which will enable information integration to offer value to customers. Development of analytical engines is subject to IP.

The path to profitability is in creating local and global strategic liaison with the “middle-man” corporate users, who may adopt these tools, as a part of their product and consumer strategy and marketing. Sales and service integration of mass-produced sensor solutions may be helpful for the advanced economies (quick ROI from US, EU, JP) in terms of business development, implementations and maintenance.

The mega-rewards from the next billion users is a near-future strategy that is based on the design metaphor of the internet of things (IoT). In this case, the principles and practice of connectivity are the key performance drivers. We aim to help investors in this domain, due to our experience with IoT. In addition, development of analytical tools, to create IP, is an option for advanced users, in other fields.

Investors are free to take the production to the corporate level and pursue monetization of the outcome, in OECD nations. If a for-profit entity is profitable, we request that academic partners are rewarded with a portion of the profit, to re-invest in research, student fellowships, teaching, extension activities and STEM outreach with public schools. Investors can pursue any form of business in OECD nations but may not pursue this specific low-cost sensor system business, independently, in emerging economies. We aim to equip the less affluent nations with these tools at a minimal profit and extend the concept of IoT not only for food and water, but also to energy and healthcare, in the developing world (the ABCDE approach in healthcare – sensors for asthma, bone density, diabetes, cholesterol, and eye).

What is our ethos?

To enable investors to make money from their investments, so that we can gain a share from their future profit, and re-invest in education and research, as well as science for the service of society. We recognize that investment must generate ROI for investors. One distinction we wish to make is in the geographies we aim to serve. We request that investors agree that we, too, can pursue the outcome of our effort through social businesses in poor parts of the world. Investors can choose affluent nations for their business. We wish to develop businesses and expect 1% in return. Businesses may use our help with science and technology to create services to penetrate mega-markets of billions to harvest micro-revenue. We expect that these businesses will re-invest this 1% in our academic efforts and R&D mission to train the next generation. This 1% mantra may help science to serve society through education, job creation, economic growth, workforce development and online education to lift many more boats.

For more information and a strategic sense of the future (in a few select domains) please read:

HAPHAZARD REALITY – IoT IS A METAPHOR

Book is available in PDF format from the MIT Library. Please use this URL to access the PDF.

The short title of the PDF is “IoT is a Metaphor” <https://dspace.mit.edu/handle/1721.1/111021>

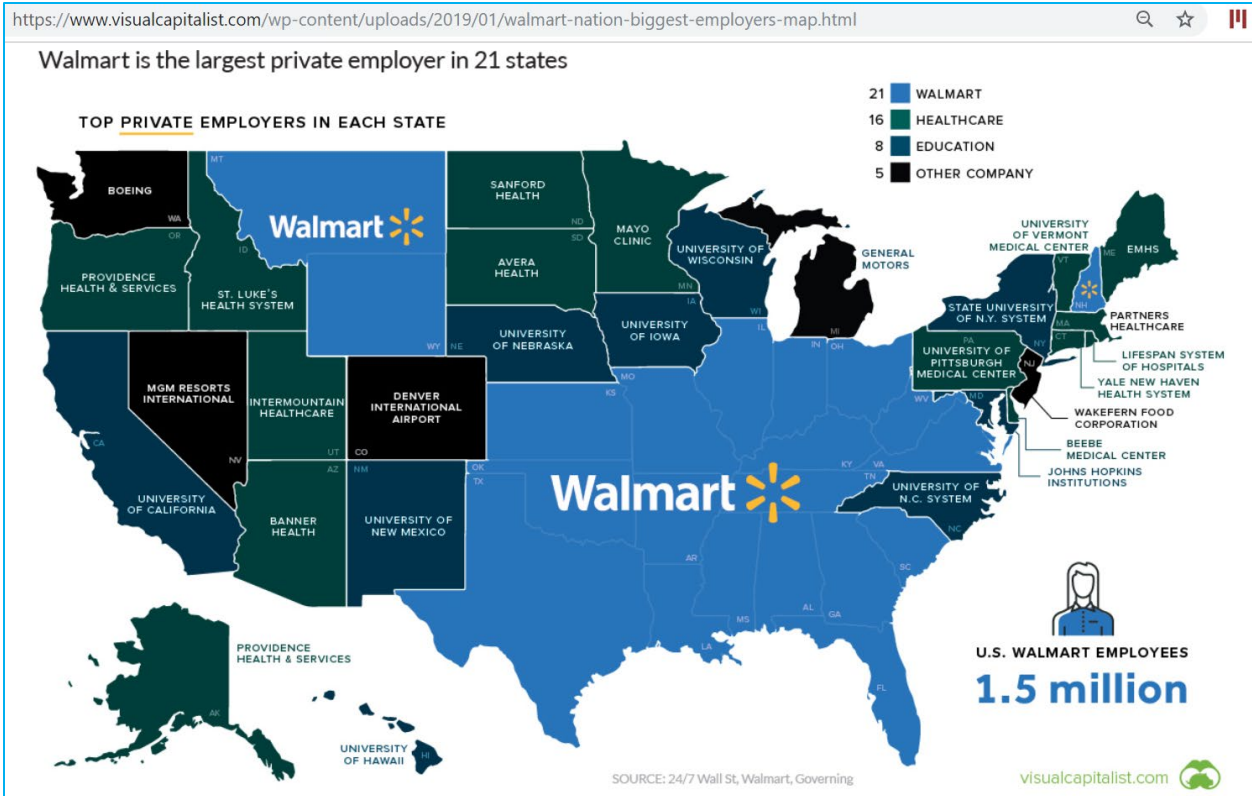
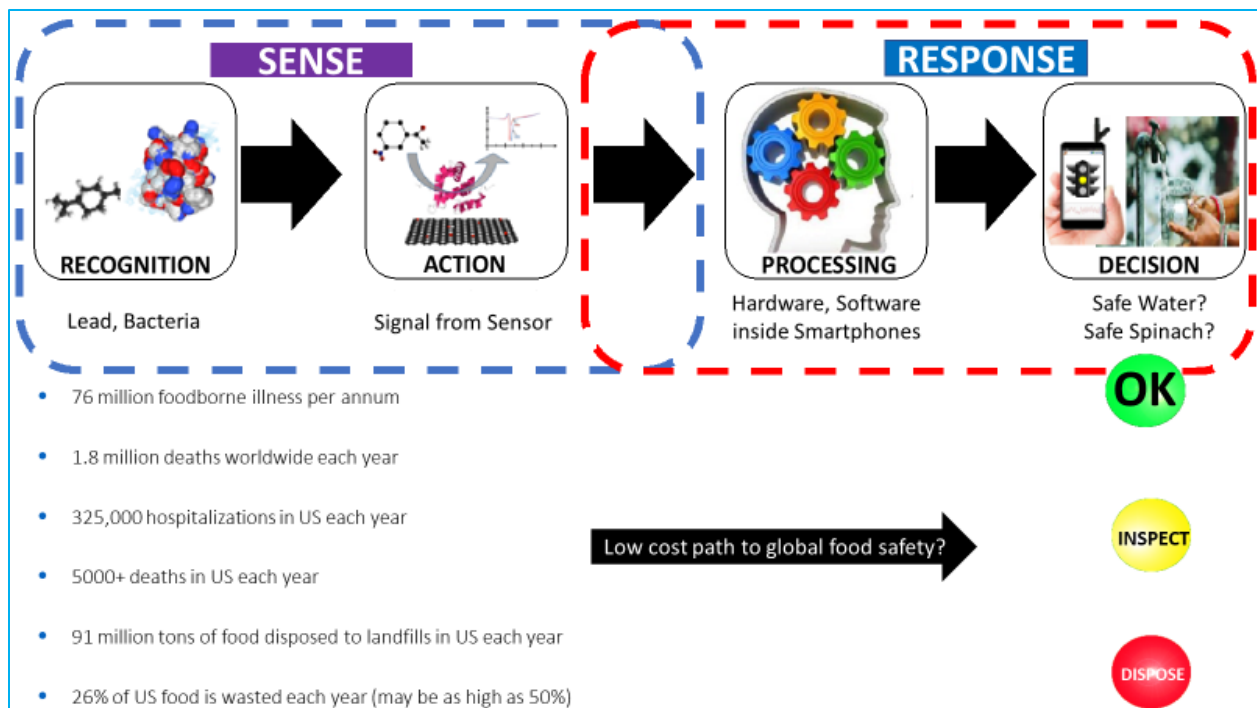
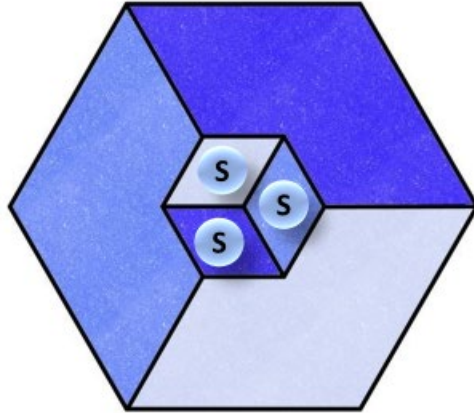


Fig 1 - Adoption of low-cost sensor *data use in daily life* for retail & healthcare unleashes mega-markets



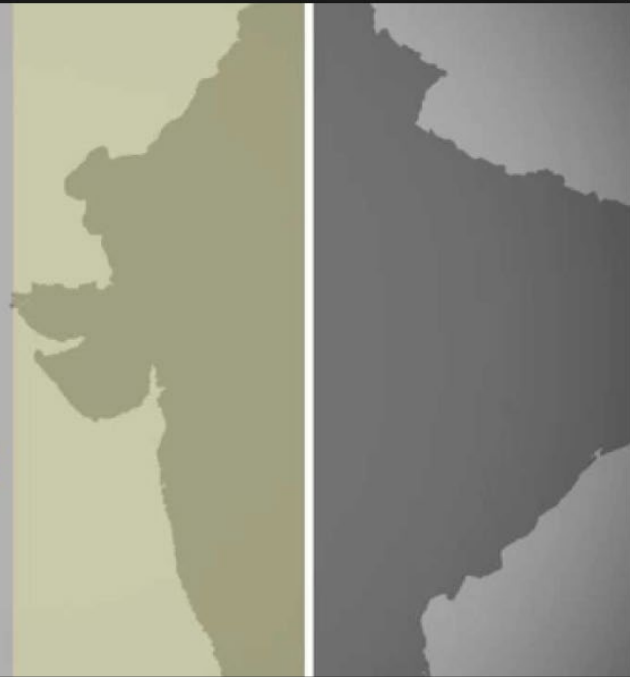
Summary Cartoon – Professor Eric S. McLamore, Department of Agricultural and Biological Engineering, IFAS, University of Florida, Room 105 Frazier Rogers Hall, 1741 Museum Road, Gainesville, Florida 32611

Sensible Science for Society

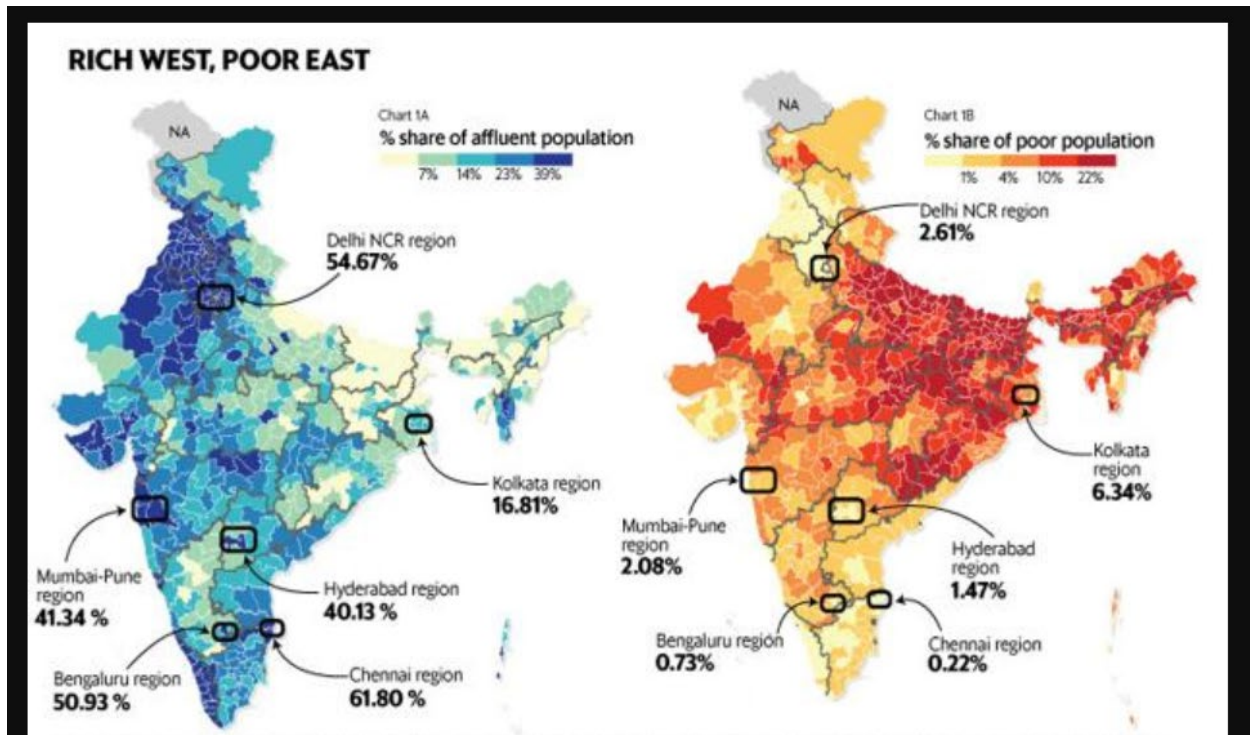


Integrating science to better serve society using a community approach. But, who can afford it?

**THIS LINE
DEFINES INDIA'S
AXIS OF WEALTH,
AS MOST OF INDIA'S
BETTER OFF
DISTRICTS LIE TO THE
LEFT OF THIS LINE**



Will some people feel left out from sensible science for society?



Sensible Science for Society

Integrating science to better serve society using a community approach including internet of things (IoT)

PREFACE

Where affordable, we may better serve communities, by creating infrastructure to support social diffusion of STEM, to make it an integral part of our daily routine, as a lifestyle choice. It will help to promote the concept that the educated consumer is our best customer. If implemented, with this long term strategic vision, infrastructure acts as a catalyst to spur economic growth through lifestyle improvements and workforce development, to create skilled jobs of the future. Deploying these systems may stimulate entrepreneurial opportunities, encourage local enterprises, help germinate start-ups, energize existing small-medium businesses and pave the way for high paying jobs and job security.

AIM

Sensible science in society may encompass a variety of endeavors. For this discussion we will focus on the diffusion of tools for scientific measurements which may inculcate new habits for the connected world. The need for scientific measurement must evolve as an integral part of our behavior, metrics may become a part of our vernacular and real-time data may inform our responses. These experiences are germane to the networked society and a part of the future, in affluent communities. Measurement and metrics are yardsticks of science. Since science is all around us, in every walk of life and living, we must increasingly engage citizens with science, to turn **qualitative** expressions (water does not taste good, fish smells funny) to **quantitative** experiences (data from water sensor indicates mercury¹ concentration of 5 parts per billion, data from food sensor shows concentration of biogenic amines² in fish is twice the acceptable level). Mobility, data and information must converge in real time to trigger evidence-based outcomes, to precipitate positive **lifestyle choices**.

IoT – Internet of Things

Sensors can act as a bridge to connect familiar (for example, water, food, air) substances with the fundamental qualities that makes them either a friend, or a foe, for humans and animals. Polluted water, infected food and air borne particulate matter, can wreak havoc in communities, unless detected, measured and mitigated, before the situation reaches an emergency status or claims lives.

Connecting sensor data, and information, from things and substances to mobile devices, such as smartphones, is the essence of the digital-by-design metaphor that underlies the concept³ of internet of things (IoT). Implementation of the IoT concept enables communities to visualize sensor data and extracted information in the palm of their hand (smartphones). Making sense of the data using data analytics tools (for example, machine learning techniques) and auto-publishing information in real-time, empowers communities to remain vigilant about the quality of the water they are drinking, determine the status of the food they are purchasing and the level of pollutants in the air⁴ they are breathing.

Using open source platforms and time series databases, data can be uploaded and shared. Crowd-sourced data can reveal micro-environments, starting point of potential problems, origin of contamination and a variety of other unknown attributes, which may surface, if we could use the tools of IoT to motivate citizens to help data scientists, track and trace things that define our environments.

¹ <https://pubs.rsc.org/en/content/articlelanding/2018/an/c8an00065d>

² https://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=1284&context=me_pubs

³ http://cocoa.ethz.ch/downloads/2014/06/None_MIT-AUTOID-WH-001.pdf

⁴ <https://gispub.epa.gov/airnow/>

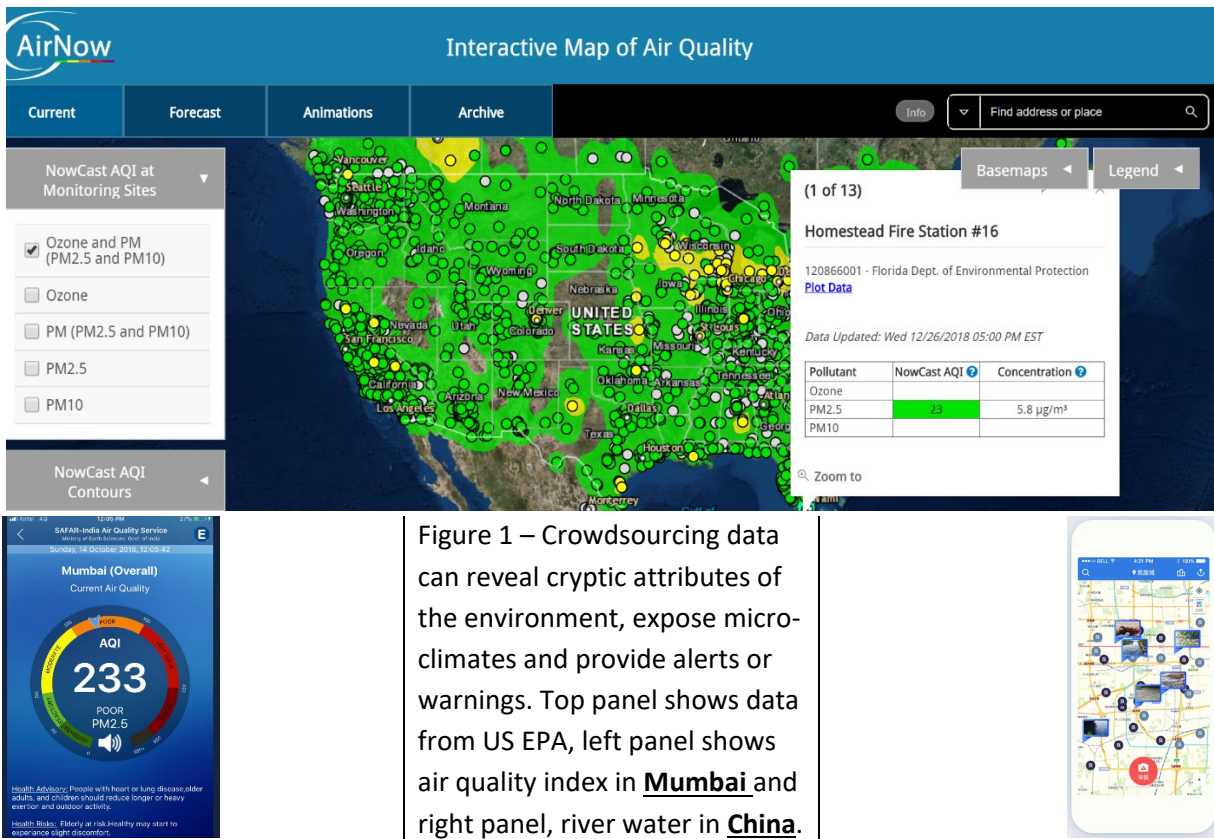


Figure 1 – Crowdsourcing data can reveal cryptic attributes of the environment, expose microclimates and provide alerts or warnings. Top panel shows data from US EPA, left panel shows air quality index in **Mumbai** and right panel, river water in **China**.

IoT and Sensors

In the scientific, engineering and industrial domains, sensors are an everyday fact of life and ubiquitous. Yet, communities have very little clue about real-time usage data and information about everyday common things (food, energy, water, sanitation). The valuable outcome from basic science and engineering research on sensor development remains cryptic from the public. The community remains oblivious of the immense value of sensors in our lives. Sensible science for society attempts to bridge this chasm between science and society (current approach is unsuitable for low-income communities).

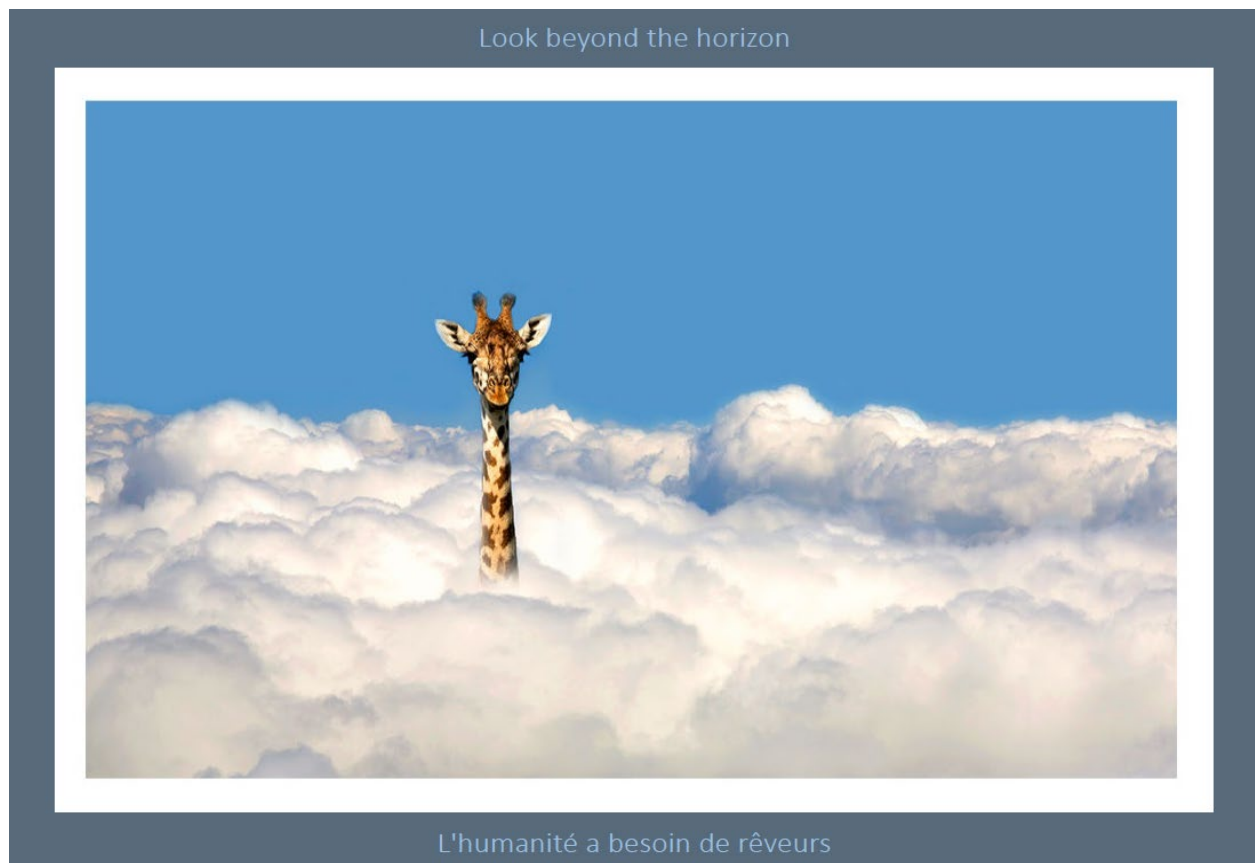
Suggested Deployment Plan

Semi large-scale implementation may cover 1000 houses, including schools and colleges, deploying [1] water sensor for heavy metal and [2] food spoilage sensor (biogenic amines). Plan may include other sensors to suit the needs of the community, if we can afford the infrastructure cost. Sensors can be used at will (discretion of user) or set up as a time series data generator. Data can be visualized on mobile phone with access restricted (privacy) by user. Data analytics at the edge or via cloud servers will generate information, which will be distributed to users (publish/subscribe tools).

Education will be a key component of this effort. Sensor Network Academies Program (SNAP) will be created as a hands-on STEM Lab for students in high schools and colleges for job training. Students will learn to create end-to-end systems for nano-bio sensors (data capture, transmission, analytics and visualization). Nano-bio sensor engineering will also expose students to 3D printing (sensors are made of 3D printed graphene), the software components of the sensor data architecture and the tools of data analytics (statistical tools, machine learning techniques, including AI).

OUTCOME

Students will learn how to create large scale sensor networks and drive the data to users. Community and households will develop the habit of checking for quality of water or food, no matter where they are. Creates a platform for aggregating other services (home health, remote monitoring). Businesses and enterprises will explore providing commercial services, if demand for real-time data offers value and customers are willing to pay for services. For example, crowd-sourced data may reveal that fish in the market at the corner of Happy and Healthy has biogenic amine concentration $1/20^{\text{th}}$ of the approved acceptable level. Telecommunication providers will find use for mega-bandwidth and low latency with the advent of 5G. Middleware and hardware providers will find new sources of revenue from the diffusion of IoT-type of applications. Innovators may create start-ups to provide new types of sensors which may be a part of the smartphone, eliminating the temporary inconvenience of carrying a sensor. New ideas may create new jobs and grow the economy.



BBC didn't change media. YouTube did. NASA did not reinvent space exploration. SpaceX did. GM didn't innovate electric car. Tesla did. AT&T didn't create smart phones. Apple did. Walmart didn't innovate retail. Amazon did. Rules are for robots. Deconstruct dogmas. Think different.

SNAP is the high school and community college section of the “Sensible Science for Society” proposal.

	Description	Comment
Goal	Accelerate the diffusion of multi-disciplinary education embracing STEM, as well as pragmatic applications to answer questions about data and data analytics. The science and engineering behind the tools for the future must be integrated early.	The most successful model in this vein was the development of the Cisco Networking Program which started in 1995 in a high school in San Francisco (http://bit.ly/FIRST-CNA). It was the cover story (http://bit.ly/1996-USNWR). 25 years later it is a global force in education (https://www.netacad.com).
Outcome	Hands-on multi-disciplinary education and labs to create nano-bio sensors (chemistry, engineering). Use graphene to produce 3D printed nano-sensors. Biochemistry of sensing, signal generation and transmission of signal to mobile smartphone. Data display and data analytics (computer science, programming).	Grass roots approach through academic-industry partnership. Implementation may be a few sensors and data from these sensors (water, food) but the model is applicable to energy, healthcare and manufacturing (vibration, pressure).
Aim	Improve STEM, hands-on lab, 3D printing. Educate the future customer and build awareness as well as market demand for data (hence, the business of sensor networks, tools and services, which leads to skilled workforce development, job re-training, start-ups, entrepreneurial innovation and new jobs. The tutorials may captured as online learning modules for digital education in nano-bio sensor engineering and IoT applications.	SNAP may mimic CNA format for high school and community college students (the same way that John Morgridge of Cisco Systems started Cisco Networking Academy ^{***} in TMAHS, SFUSD). The scope of SNAP and its day to day structure and function will evolve, in the same way that CNA started, adapted and evolved.

Cisco Systems initiated Cisco Networking Academy which started as a network lab (1995) at the Thurgood Marshall High School in San Francisco, with help from a talented teacher (Dennis Frezzo, from UC Berkeley) and John Morgridge (https://en.wikipedia.org/wiki/John_Morgridge). It gained global acclaim and cited by the White House as a key instrument of IT workforce creation. It was the cover story of US News & World Report (2 December 1996). A quarter century later, we have moved ahead from ‘computers’ as boxes and ‘network’ as the transmission backbone to pervasive or ‘ubiquitous’ computing as a conduit for providing services. Computing depends on data. Sourcing of data relies on sensors. We need sensor networking academies program (SNAP), to educate the future consumer.

COMMENTARY [C] - Part II

Shoumen Datta

HAPHAZARD REALITY – IOT IS A METAPHOR

THIS PAGE IS LEFT BLANK

World Sensor Organization

ScienceDirect

sensor

Journal/book title

719,719 results

Refine by:

Years

- 2018 (7,414)
- 2017 (63,791)
- 2016 (55,148)
- 2015 (51,673)
- 2014 (46,657)
- 2013 (43,042)
- 2012 (37,748)
- 2011 (35,101)
- 2010 (30,296)
- 2009 (29,256)

PROPOSAL

To create the World Sensor Organization, WSO, a global collaborative entity where scientists and engineers may contribute their findings, and methods, for sensors. WSO will try to transform proof of concepts to field deployable sensor *systems*. Successful sensor *systems* may be converted to market ready phase and implemented for designated use, if feasible.

VISION

Thousands of publications, perhaps millions, are generated each year on topics related to sensors. Scientists and engineers are producing laboratory versions of sensors for humans and healthcare, veterinary medicine, environmental and industrial purposes. From this wealth of knowledge, (see <http://bit.ly/PLASMONICS>) few sensors make it to the market, if transaction costs spell profit. What happens to the outcome of sensor related research?

It may collect dust or loiter in cyberspace or found hidden on the second page of Google search. Yet, critical issues for detection, which could save lives or improve the environment, remain unsolved. Translation from vision to market reality, is the rate limiting factor, for many sensor related research results.

World Sensor Organization (WSO) aims to partially alleviate this problem through a global consortia (center). WSO will catalyze the convergence of expertise necessary for the sensor to evolve as an integrated sensor *system* including, but not limited to, signal transduction/capture, data collection software, mobile interface, analytics, visualization, secure access via smartphone apps, delivery of information to the user, cybersecurity and transmission for global connectivity.

RATIONALE

The infectious enthusiasm for entrepreneurial innovation calls for confluence of multiple factors to create the optimum ecosystem. Few locations in the world are able to capture the key factors. Even fewer scientists and engineers possess the attributes necessary to shepherd their research results to a market deployable product, or service, through the entrepreneurial grind.

Grand imagination often generates great inventions but too many good inventions die without a proper path to innovation. The latter may not succeed without entrepreneurial skills. We are left with an embarrassment of riches, millions of published papers and unpublished ideas, but the fruits of labor are few, and far between, because the continuum is difficult to coalesce. What can we do to drive more ideas to fruition?

Inventors are keen to patent their findings and rush to create start-ups. Stand-alone start-ups ignore the fact that a sensor, no matter how profound in scope, is simply a tool for detection. The ecosystem and local/global connectivity is germane to function. Sensor data/information must trigger action, based on appropriate data analysis after sensor data is available to the system. If the sensor data does not contribute to the decision, its value may perish, rapidly. The integrated system of systems, and transaction costs associated with each event in this cascade, reflects a convergence of technical issues with economics, which must be navigated, in order to arrive at a feasible solution, affordable by the end user and the end-user community.

Solutions, for example, GE Pharmacia BiaCore (old) and Genalyte (new), are marketed as high cost products, suitable for affluent users in wealthy nations (about 10% of the world population). Investors and inventors of sensors, are keen to follow the patent protected profitable path, vying for the 10% of the global population in US, EU and JP (approx. 700 million), in their elusive quest for personal wealth, as a reward for their imagination, invention and innovation.

THE ROAD NOT TAKEN

WSO wishes to “think different” but as an initiative in the US, its germination may face hurdles. World Sensor Organization (WSO) wants to remind the women and men, involved in sensor research, that their work, and outcome, may not have to bite the dust. There is a path to immortality. By contributing their research to WSO and pursuing a collaborative “open source” approach, for translating their sensor ideas, to a deployable sensor *system*, they may reap the reward of gratification, the reward for enabling science to serve society, the reward for their labor to improve quality of life, the reward for contributing to global public goods.

Few efforts survive in the public domain, without economic incentives. WSO is cognizant of this fact and wishes to introduce the financial reward named “Miss Money penny.”

For every sensor event, triggered by every user, WSO will attempt to find a path to extract one penny, in profit, from every transaction. In other words, extracting 1 penny (US one cent) as net profit, by using the “pay-per-use” concept, we monetize “sensor-as-a-service” rather than the sensor-as-a-product, sold as an one-time product. By reducing the barrier to entry into world markets, WSO promotes social business entrepreneurship. WSO can penetrate the global market of 7 billion people. WSO envisions a paradigm shift from the product lifecycle mindset to arrive at the user lifecycle paradigm. The user does not pay for the product but pays for “service” as long as the user lives and uses the service based on this or related products. The product lifecycle may be 2-10 years but the user lifecycle may be 50 years. Hence, micro-payments and micro-revenue for services, provided as micro-payments, during the life of the user, ~50 years.

WSO “sensor-as-a-service” aims to rake in net profit of one penny per use, per person, per day. That translates to 700 million pennies per day, or US\$7 million per day in revenue, if only 10% of the global population (700 million) uses a WSO certified sensor, once, each day.

ETHICAL GLOBALIZATION AND ETHICAL PROFITABILITY

In this example, the micro-revenue from ethical profitability, due to economies of scale, from only 10% market penetration, may exceed US\$2.5 billion per year.

Development and modularization of product, segmentation of the sequence, work unit synthesis and structuring the alliances to aggregate the end-to-end ecosystem to capture the pay

per use billing granularity, are difficult tasks, but nothing that violates any laws of physics or thermodynamics. Hence, it is possible.

Micro-payment based pay-per-use service model can be applied to almost any product if analyzed and dissected with the tools of transaction cost economics. The billing granularity and evidence of use may be captured in a digital ledger. Unique id of each transaction may use the internet protocol version 6 (IPv6) format using a 128-bit hexadecimal system which is capable of generating 2^{128} or 340,282,366,920,938,463,463,374,607,431,768,211,456 or 3.4×10^{38} unique addresses [ref 13].

The technical convergence in combination with the business model paradigm shift has the immense potential to unlock the power of social business entrepreneurship. The benefits due to WSO may reach remote corners of the world. The barrier to entry is probably low enough to penetrate markets of billions where the per capita earning barely approaches US\$1.90 per day.

One cent profit may be too much or too little, depending on the value delivered by the sensor data, demographics of the market and economic bandwidth of the end user community.

The micro-payment model is nothing new and originates from micro-loans and micro-investment practices. It is the dominant model for business wealth created by MacDonald's and PayPal. Grameen Bank of Dhaka, Bangladesh pioneered micro-loans to women, only. In recognition, Dr Yunus, Chairman of the Grameen Bank, was awarded the 2006 Nobel Prize.

Micro-payments may lead to mega-profits and the model is not limited to sensors. It can be applied to 3D printed automobile or aviation industry spare parts, transplanted hip or knee joints, bidirectional energy arbitrage, autonomous vehicle services, energy storage, home

appliances, jet engines, and security-as-a-service for modular, mobile, retail cybersecurity offerings, delivered online or purchased from a corner grocery store or neighborhood Walmart.

For related ideas, please explore “18.Commencement” which is a PDF in the zipped folder ‘CHAPTERS’ available from MIT Library <https://dspace.mit.edu/handle/1721.1/111021>.

FINANCIAL INCENTIVES

WSO proposes that [a] a quarter of the earnings are distributed to scientists and engineers involved in the sensor system development [b] a quarter of the earnings are re-invested in WSO and its affiliated institutional R&D and [c] a quarter of the earnings are used in projects to spur education and economic growth in the less fortunate nations (our future markets, the emerging economies, for example, sub-Saharan Africa) and [d] a quarter of the earnings are used to strengthen the WSO organization, its foundation or endowment, to ensure uninhibited progress.

WSO is a solution for the vast majority of the global sensor scientists whose work may serve humanity. Aggregating sensor data on open source platforms, with adequate cybersecurity and data analytic tools, will allow sensor information arbitrage in near real-time, at the point of need. What happens when we can measure? We can establish metrics, generate quantitative performance indicators, inform decisions to direct policy, structure appropriations based on information rather than the *pork barrel* approach practiced by politicians. Policy measures, if pursued ethically, can lead to social re-engineering of communities through distribution of social services, prioritized restructuring of access to healthcare, education and workforce development.

EXTENDED MISSION

WSO is an idea, which, if implemented, may change the world through ubiquitous sensing, at a cost which will grow the global economy, rather than sap its economy by charging \$100 for a sensor. It will lift many boats, not just a few yachts. It will empower social business.

WSO will serve as an educational platform, for inspiring undergraduate and graduate students, to train for the steps necessary to transform ideas into reality. The collaboration of global scientists may enable paths to include rigor, innovation and exposure to diverse problems. The potential for successful outcomes through WSO will remind students that completion of their degrees and graduation may lead to that proverbial “light” at the end of the tunnel. The impact of student motivation on graduation rates and research funding may be significant.

WSO may serve secondary education outreach. Almost every discipline, and their convergence, may be exemplified by sensors, sensor systems and sensor networks (similar to the significance of “energy” as a theme for science and engineering). In a manner similar to the Cisco Networking Academy (CNA), which commenced in 1996, as a high school networking lab project (I helped to start CNA at Thurgood Marshall High School in San Francisco, CA), WSO can help to start the Sensor Networking Academy Program (SNAP) in high schools, worldwide.

Hence, WSO is a tool for workforce development through SNAP for secondary and tertiary education. WSO may offer students a variety of opportunities for research in basic sciences, materials science, nanotech, biotech, medical instrumentation, electronics, ASICS, devices, systems engineering, embedded systems, sensors, time sensitive networks, signal transduction, networking, data, analytics, statistics, mathematics, simulation, computer science, programming, AI, telecommunications, cyberphysical systems, standards, cybersecurity and IoT.

BUILDING ORGANIZATIONS

World Sensor Organization is a grand challenge, an idea which will only grow if fertilized with credibility, cooperativity and collaboration. Global community of scientists and engineers, must work with industry, government and non-government organizations (NGOs). Support from the parent institution must be uncompromising and unequivocal.

Building the structure of the infrastructure, necessary to create this organization, in a sustainable manner, will require greed-free leadership. Individuals who are oblivious to not receiving credit, individuals who are dedicated to serve as an instrument, individuals who are committed to science as a tool for social progress, individuals who are not prioritizing personal wealth creation, individuals who believe in creating economic growth, individuals who are capable of excellence in communication across a very diverse spectrum of stakeholders, globally, at multiple levels, including science and engineering, engaging the public, as well as cultural respect, diplomatic finesse and political-context awareness. Building trust is the secret sauce.

As with any consortia, seed funding for organizational nodes may be quintessential for lift-off. The primary step is to build the foundational coalition with appropriate credibility and “hooks” to reflect the vision of the World Sensor Organization, at a global scale. Unlike traditional consortia, WSO may not operate on an “entry fee” mechanism, in order to uphold its claim for public goods. Hence, “joining” the consortia and “member finances” for the WSO, must be *separate* operations, *without* dependencies. This will make our task hard, financially. The leadership must remain cognizant of the steep path which we must scale for future success.

WSO members are expected to be individual engineers/scientists/students, institutions, NGOs, organizations, corporations, government agencies, governments, international standards bodies and associations.

WSO may be financed by gifts, seed funding, endowments, grants, foundations, and these categories (listed to show increasing amounts) “friends” (\$1K+), “partners” (\$10K+), “contributors” (\$100K+), “patrons” (\$1M+), “sponsors” (\$10M+) and “donors” (\$100M+).

Working groups (WG) and special interest groups (SIG) will be created to modularize and distribute the operations, starting with sourcing (when an idea is contributed) and extending to systems oversight.

Liaison with standards bodies may be required to ensure that the work and outcome from WSO is in compliance, or creates new standards, which must be interoperable with other existing standards, or possesses the requisite characteristics for pursuing global adoption.

WSO use cases for sensor research, development and applications must offer a broad portfolio, to attract membership from diverse industries and government agencies, for example, [a] machine, tools, 3D manufacturing [b] oil, gas, water, energy, desalination, natural resources [c] environment, communities, smart cities, sewer systems, emergency management systems [d] healthcare and medical IoT (<https://dspace.mit.edu/handle/1721.1/107893>) [e] Digital Twins in manufacturing systems, maintenance, transportation, aviation, (please see “04.Digital Twins” PDF in the “CHAPTERS” folder accessible from <https://dspace.mit.edu/handle/1721.1/111021>) and [f] agriculture including animal farming (micro-robots in cows to monitor metabolomics of lactation).

WSO may evolve in ways we may not anticipate due to the plethora of unknown unknowns. But, WSO must be capable of generating value from research, education, students and applications. The primary goal of the coalition is to advance research outcomes and promote education which can create new leaders, endowed equally with scholarship and leadership.

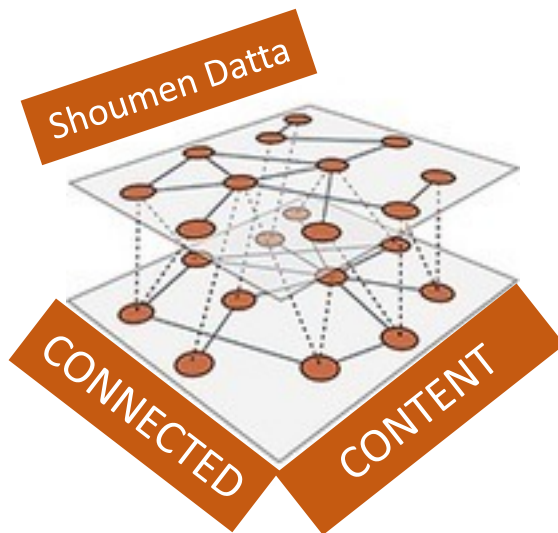
RISK

The central thesis of WSO is to “apply” the research outcome from scientists, and shape it through further R&D, to serve a purpose, which generates value through sensing. By connecting the sensor data with the sensor ecosystem, we make sense of the data and extract actionable information. The information may improve a function or performance, in near real-time. By connecting this data and/or information to real world situations or by connecting a “swarm” of sensors, we may optimize processes, workflows, automation or improve accuracy, and/or precision, of diagnostic, predictive or prescriptive analytics. Taken together, using control feedback loops or decision support, we deliver dynamic optimization, due to the sensor.

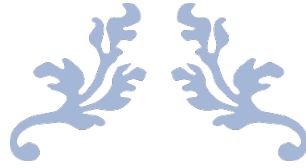
The central problem in this proposed concept of WSO is the assumption of the existence of trust and altruism, not only in sourcing the sensor idea or scheme, but also in working with the partners in the ecosystem, which is salient to the delivery of value from sensing to the end user.

[a] Why will an engineer or scientist trust WSO to contribute her/his research? [b] Why will the partners of the ecosystem (for example, manufacturing execution systems or MES) allow WSO to work with its systems? [c] Can we identify and define the transaction costs associated with each stage? [d] What degree of systems interoperability do we need, to uniquely track and trace every change of state, in order to bill the client for the service used, according to pay-per-use?

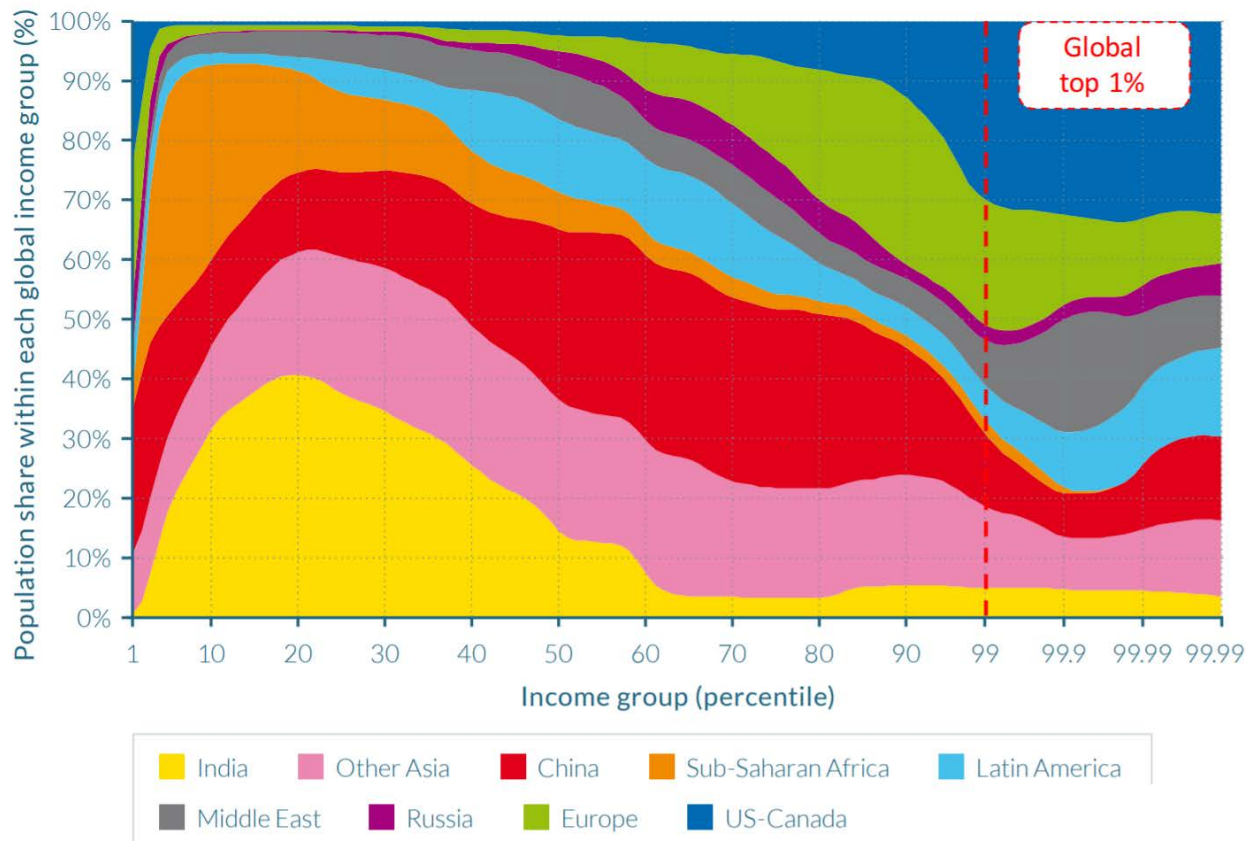
Question [a] is crucial. If WSO cannot be trusted serve as the global sensor research repository, then the central thesis is null and void. Explicit institutional support and the ability to bring together a team of pioneering global leaders, as co-founders, may be the first step to earn trust. For question [b], gaining agreement to create a few real world test beds with industry and corporations, may elevate the trust level. The latter may help to engage with governments and agencies, at home and abroad. Can we get a critical mass of pioneers to support the WSO vision?



APPENDIX - A



FORUM FOR GLOBAL PUBLIC GOODS APPLICATIONS



FORUM
FOR
GLOBAL
PUBLIC
GOODS
APPLICATIONS

FPGA

FEWSH ideas for 99% of the global population.

FPGA ⇒ CONVERGENCE

CONTEXT ⇒ The principle of convergence is a compass for synergistic integration and key to applications

“Meandering” was the word used, aptly, by a Dutch scientist from Delft (DUT), to describe my attempt to collect and connect the dots (especially outlier events, which may be even more informative). With that badge of honor, in hand, I continue to narrate one example of how things can come together. Wandering through diverse and disparate thoughts, may, occasionally, prove to be beneficial. It reveals the allusion and the allegory of the words “*not all those who wander are lost*” from the poem¹ by Tolkien.

Convergence is a common word with an uncommon semantics. The practice of convergence is an everyday occurrence. Almost all physical activities involve multiple domains and thought. These processes are, quintessentially, a confluence of facts, knowledge and experience. The act of drinking a cup of tea or sipping soda from a glass, using a straw, is made possible by convergence. Over the past decade, several groups have put forward frameworks to emphasize the principles of convergence. The latter are aimed to accelerate multi-disciplinary approaches. However, the organizational matrices are still sterile, devoid of imagination and lacks the solutions approach. When such organizations are constructed, *by design*, to function (Amazon, Apple), they are intensely, and almost exclusively, focused on profit optimization.

Hence, convergence for the less fortunate, is few and far between. But, convergence remains the solution-seekers battle cry and may be driven by necessity. Framing *necessity* in the question is a pivotal step. For example, how do we ensure that drinking water is reasonably safe² from harmful agents? The answer cannot even take shape unless we have a *source* of water³ accessible to the consumer. About every ninety seconds a child dies⁴ due to water-borne illness. Water safety is of paramount importance for billions, in nations where >90% of the global population resides. The key performance indicator is the degree of saturation with respect to the “*last mile*” infrastructure and ease of access to water for the consumer. The fact that lack of installed *infrastructure* is the dominant rate limiting inhibitor is easy to understand when considering the observation that more people have a mobile phone than a toilet (1 in 3 people in the world lack access to a toilet and/or managed sanitation services).

Water safety decision support systems (DSS) require⁵ quantitative data with respect to detection⁵ of biological and chemical contaminants (sensors). The data must be communicated (telecom networks) and analyzed in near real-time to inform distributors (water supply chain, systems and infrastructure) as well as consumers (mobile visualization of data). Quantitative information about harmful agents must be published in a user-friendly format, to inform and instruct, in the *context* of the community, in a manner that inspires users to *act* with confidence, *respond* with prudence, rather than react or sow confusion.

Connectivity between tools, infrastructure and organizational domains, reflects the principle of convergence. When practiced, it benefits society. Thus, convergence of science and engineering serves society, by enabling applications to benefit all societies, under the broad spectrum of global public goods.

¹ https://en.wikipedia.org/wiki/The_Fellowship_of_the_Ring

² https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/PCAST/pcast_drinking_water_final_report_20161221.pdf

³ http://www.who.int/water_sanitation_health/monitoring/fast_facts/en/

⁴ <https://water.org/our-impact/water-crisis/>

⁵ <http://pubs.rsc.org/en/journals/articlecollectionlanding?sercode=lc&themeid=4c264945-7660-4eb1-942d-2561325a2733>

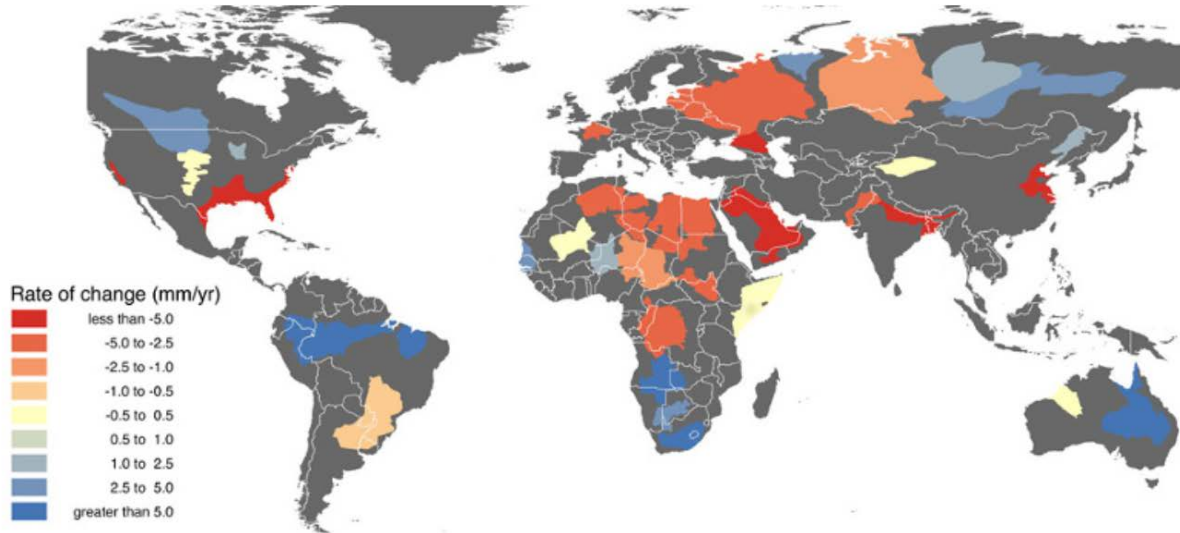


Fig 1: Trends⁶ in groundwater storage 2003-2013 (Source: NASA)

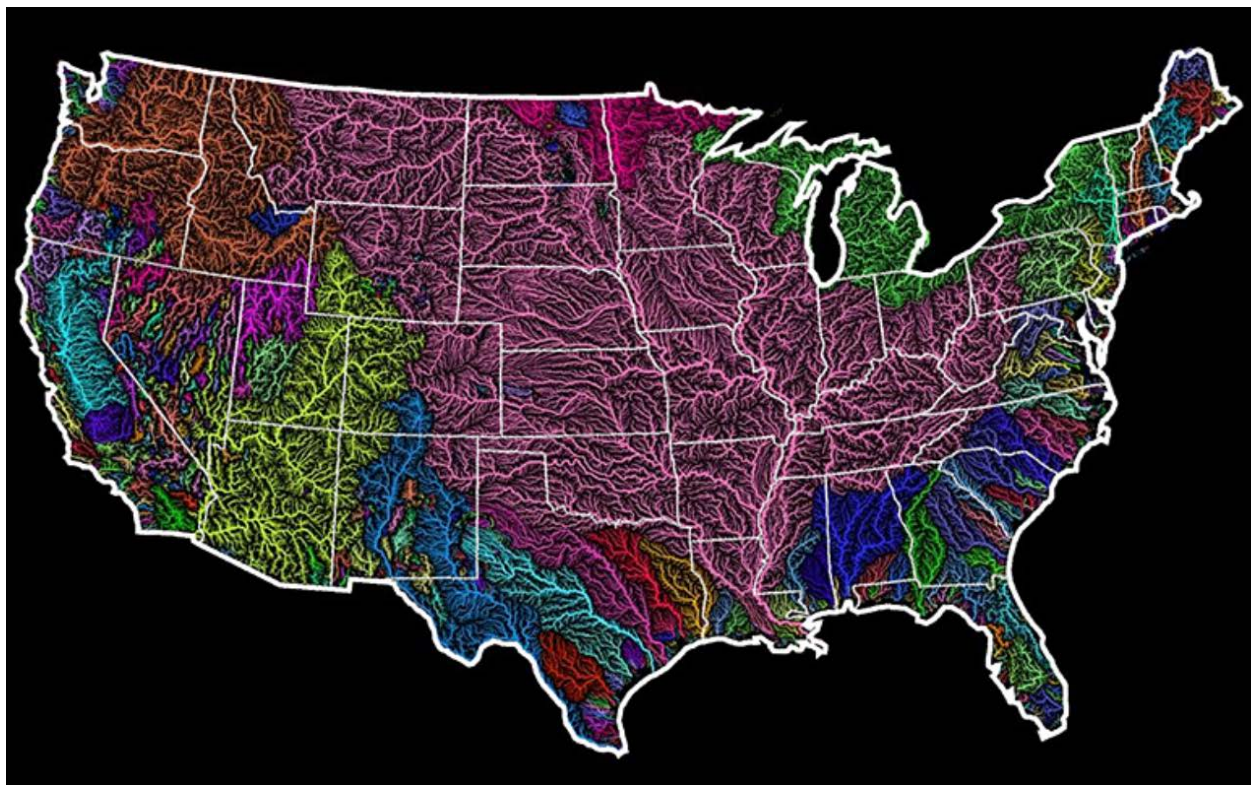


Fig 2: The dominant drainage basin in the US⁷ is the Jefferson-Mississippi-Missouri River system (pink). This massive basin collects water from over 40% of the US and is in contact with 2 Canadian provinces and 31 states, before terminating at the Gulf of Mexico.

⁶ <http://www.visualcapitalist.com/nasa-satellites-show-disturbing-trends-in-water-supply/>

⁷ <http://www.visualcapitalist.com/maps-worlds-watersheds/>

HISTORY ⇨ Stretching to weave an example of convergence spanning ~1000 years ⇨ 1000 to 1995

The debate about pros and cons about convergence⁸ may continue⁹ and evolve¹⁰ in many different disciplines¹¹ (medicine¹², environment¹³), in many countries¹⁴, and in different¹⁵ directions¹⁶ but drivers of convergence, generally, may not appear as obvious or carry a label or found in neat packages.

The standard operating procedure for convergence is quintessentially one of “*haphazard reality*” and likely to be represented by amorphous amalgam of instances, knowledge, developments, from vastly different domains. It may include, directly or indirectly, an array of technologies, based on mathematics, science and engineering, loosely coalesced in the context of the question or purpose. It may offer clues to solutions or pose more questions. It may be driven by unanticipated forces, outlier events, unexpected results, to create what no one had expected, in terms of outcome, or answer, or direction for new roads!

This is one such example, evolving over centuries.

Circa 1593-1594, Carolus Clusius, (Charles de l'Ecluse, 1526-1609) a botanist, begun a botanical garden at the University of Leiden, to cultivate tulips¹⁷ in Netherlands¹⁸. Originally a wildflower, tulips were cultivated in the Ottoman Empire (Turkey, *-stan* states), as early as 1,000 AD and later imported to Holland in the 17th century, where they became a formidable economic force. It was also the first economic bubble to explode¹⁹ circa 1637. Tulips were a key element of the Dutch economy²⁰ in the form of auctions. *Tulipmania* coincided with the formal establishment of the Amsterdam Stock Exchange in 1602. Tulip trade was a catalyst for the Dutch economy, which achieved a high standard of living in Europe by the middle of the 17th century. The newly found affluence spawned a Golden Age, for the Dutch, typified by the great artist Rembrandt van Rijn (1606–1669).

The bursting of the bubble of the tumultuous tulip economy may have been evident from the price of *Semper Augustus*, a variegated tulip with distinct striations on its petals. Around 1636, the price of the bulb of *Semper Augustus* may have been about \$34,584 and as high as \$97,200 (based on other forms of valuation). These colorful patterns are caused by infection due to potyviruses²¹ which are plant viruses with positive-strand RNA genomes, which alters distribution of pigments in the petal due to virus replication. A specific potyvirus, the tulip-breaking virus, causes successive generations of the bulb to shrink until it can no longer flower. Hence, the incredible price²² of the *Semper Augustus* bulb.

⁸ <http://www.aplu.org/projects-and-initiatives/research-science-and-technology/hibar/resources/MITwhitepaper.pdf>

⁹ <https://www.nap.edu/download/18722>

¹⁰ https://www.cmu.edu/nanotechnology-forum/Forum_14/US_Presentation/1_C%20Roco%20NNI_17-0911_NT%20&%20IT%20Convergence_MC%20Roco%20@US-KOREA%20NanoForum_20m.pdf

¹¹ <http://www.convergenceevolution.net/media/>

¹² <http://iopscience.iop.org/article/10.1088/2057-1739/1/2/026001/pdf>

¹³ <http://pubs.acs.org/doi/pdf/10.1021/es503585u>

¹⁴ http://blogs.helsinki.fi/changingdynamics/files/2010/09/Lemola_Convergence_of_ST_policies.pdf

¹⁵ https://www.scienceeurope.org/wp-content/uploads/2015/12/Workshop_Report_Convergence_FINAL.pdf

¹⁶ http://www.nsf.gov/crssprgm/nano/MCR_13-0831_ConvergenceKTS_Roco+Bainbridge_17p.pdf

¹⁷ http://penelope.uchicago.edu/~grout/encyclopaedia_romana/aconite/tulipomania.html

¹⁸ <https://www.press.uchicago.edu/ucp/books/book/chicago/T/bo5414939.html>

¹⁹ <http://www.econ.ku.dk/okocg/Students%20Seminars%C3%98kon-%C3%98velser/%C3%98velse%202007/artikler/Garber-Famous-First-Bubbles-JEP-1990.pdf>

²⁰ <http://www.jstor.org/stable/j.ctt128783w>

²¹ <http://www.virology.ws/2012/03/14/tulips-broken-by-viruses/>

²² <https://tuecontheoryofnetworks.wordpress.com/2013/02/25/the-origin-of-the-dutch-auction>

Tulipmania was brought to its knees by potyviruses (circa 1636-1637) and it contributed to the destruction²³ of the Dutch economy. These viruses still circulate, globally, transmitted by aphids. It is ironic that the decline of the Dutch economy, due to potyviruses, albeit, in part, coincided²⁴ with the bubonic plague, which ravaged Netherlands, a fifth of the population dying in Amsterdam in 1635-1636.



Fig 3: Colorful striations of *Semper Augustus* caused by infection due to the potyvirus, tulip-breaking virus.

Convergence, catalyzed by tulips, dates back to its cultivation circa 1,000 AD. Tulips from Turkey created turbulence within the economies of Europe in the 17th century. The Dutch flower markets did not invent or create auctions, but it certainly made “auction” a household name. It continues at Aalsmeer, NL.

But, the icing on the cake was the auction²⁵ inspired technological amalgam conceived by Pierre Omidyar, who *converged* auctions with the medium of the internet, to establish the first online auction platform, **eBay**, in 1995 (about one year after the establishment of Amazon in 1994).

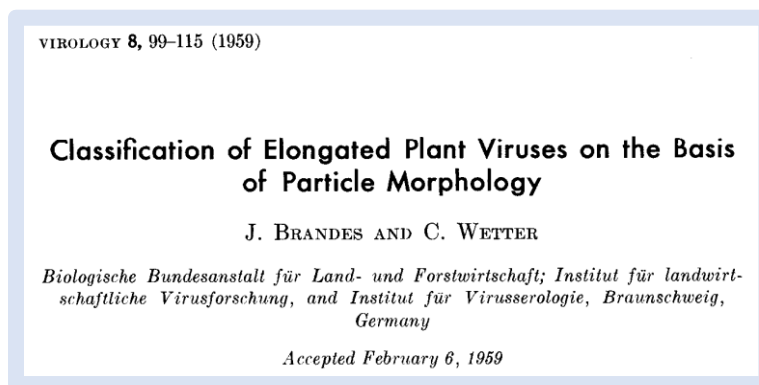


Fig 4: Identification²⁶ of potyvirus (1959) was a biological triumph directly due to tulipmania.

²³ <https://io9.gizmodo.com/5905247/the-virus-that-destroyed-the-dutch-economy>

²⁴ http://penelope.uchicago.edu/~grout/encyclopaedia_romana/aconite/tulipomania.html

²⁵ <https://mikebrandlyauctioneer.wordpress.com/auction-publications/history-of-auctions/>

²⁶ [https://doi.org/10.1016/0042-6822\(59\)90022-4](https://doi.org/10.1016/0042-6822(59)90022-4)

Forum for Global Public Goods Applications → FEWSH ideas for 99% of the global population

Shoumen Palit Austin Datta

PROLOGUE

The “tulip” tales are not structured frameworks, yet convergence is shaped by socio-economic forces and enhanced through science, engineering and technology. Food, energy, water, and the other related pillars of sanitation and healthcare (FEWSH), in combination, are purveyors of civilization. It is a fact, rarely acknowledged, that such grand ideas, to advance civilizations, may often die, a premature death. Under the combined pressure of myopia, analysis and greed, perhaps known as pragmatism, ideas, no matter how profound, crumbles at 495 gigapascals²⁷ or less. This may be one such collection of ideas.

PREFACE

Imagination, invention and innovation, in the affluent 1% world, are born, perhaps, only to race in wealth creation competitions. The incessant drive to create for-profit start-ups, with the tiniest bit of new contribution, is an epidemic that may asphyxiate economic growth for 99% of the population. From life-saving drugs, to basic food and drinking water, existing solutions may partially alleviate global suffering. These are prevented, by deliberate design to desist dissemination, from enriching public goods, by the tentacles of patents, high cost of technology licensing and legal threats from intellectual property rights. The proponents for human rights for economic development, therefore, must seek solutions from scientists and engineers [a] actively contributing their patent-free²⁸ discoveries, [b] enabling no-cost or low-cost technology licensing and [c] creating²⁹ systems feasible for deployment³⁰ in 99% of the world.

INTRODUCTION

Global public goods are goods which may benefit all people, in any nation. Core pillars are food, energy and water (FEW). Water is essential for sanitation, food is inextricably linked with health, and public health connects to food and water. Problems due to lack of sanitation³¹ and access³² to healthcare, makes it imperative to add sanitation and health to the core. Hence, FEW becomes FEWSH, and presents immense problems, in need of solutions. In this proposal we may barely even ‘touch’ the surface. We plan to discuss a few suggestions. Topics may be restricted to things and steps we think may be actionable, if we can find leaders who are willing to assume the risks of leadership. Making food available is the most pressing need³³ in many parts of the world but for this discussion, at present, we will focus on water quality, due to our familiarity with positive outcomes from a few scientists and engineers. The idea is to ***institutionalize change within the infrastructure***, rather than pursuing “flash in the pan” pilot projects.

²⁷ <http://science.sciencemag.org/content/early/2017/01/25/science.aal1579>

²⁸ <https://tatacenter.mit.edu/portfolio/rohit-karnik/>

²⁹ <https://abe.ufl.edu/Faculty/mclamore/index.shtml>

³⁰ <https://pubs.rsc.org/en/content/articlelanding/2018/an/c8an00065d#!divAbstract>

³¹ <https://www.nationalgeographic.com/magazine/2017/08/toilet-defecate-outdoors-stunting-sanitation/>

³² <https://www.newsweek.com/world-bank-who-health-care-poor-global-access-748117>

³³ <https://www.weforum.org/agenda/2017/10/a-plate-of-bean-stew-costs-320-in-this-country/>

Wii

BACKGROUND

Forum for Global Public Goods Applications (FPGA) is a platform approach to deliver systems or solutions which may benefit communities. The emphasis is on applications which may improve quality of life. FPGA is not a basic research platform. It expects to coordinate application related applied R&D in research institutions, to harvest the fruits of science, in order to serve society.

Any solution within the broad spectrum of FEWSH may be of interest to FPGA. The outcome, perhaps through multi-disciplinary convergence, must offer solutions, with these attributes: [a] feasible for mass deployment, [b] lends itself to synergistic integration for humans and/or animals, [c] application specificity respects the *context* of the community, [d] possesses potential to be a part of the sustainable infrastructure and [e] may deliver long-term socio-economic growth. The current suggestion focuses on a few issues relevant to water purification and detection of contaminants.

WATER

Society without clean water infrastructure is economically handicapped. It shifts the water burden to women³⁴ and further diminishes economic³⁵ output. Sanitation³⁶ services³⁷ suffer due to water and exacerbate public health issues in communities which lack access to healthcare. Lack of usable water for irrigation influences food production. Natural³⁸ and human³⁹ contamination of water introduces risk for humans, animals and plants. Hence, water purification and detection⁴ tools (sensor systems linked to mobile devices) must evolve as a part of the daily life and routine practices, for affected communities.

Hence, FPGA-FEWSH may wish to prioritize a water initiative, Wii. One “pro” for Wii stems from the results of using plant xylem as a filter. The latter is no longer a lab⁴⁰ experiment but a feasible water purification tool. Can it move beyond the project⁴¹ phase to help install systemic water infrastructure?

³⁴ <http://theconversation.com/women-still-carry-most-of-the-worlds-water-81054>

³⁵ https://www.huffingtonpost.com/shail-khiyara/why-the-global-water-cris_b_12450260.html

³⁶ <http://www.washadvocates.org/2012/07/27/the-silent-barrier-women-water-and-sanitation/>

³⁷ <https://www.nytimes.com/2017/09/03/world/asia/india-toilet-movie.html>

³⁸ <https://www.theguardian.com/global-development-professionals-network/2016/oct/18/arsenic-contamination-poisoning-bangladesh-solutions>

³⁹ https://wp.nyu.edu/gallatin_human_rights_fellows/2017/05/15/gold-gold-mining-and-a-gallatin-human-rights-fellow-in-colombia/

⁴⁰ <https://arxiv.org/ftp/arxiv/papers/1310/1310.4814.pdf>

⁴¹ https://twitter.com/dlab_mit/status/765505700269203457

WATER PURIFICATION – AN INFRASTRUCTURE APPROACH TO INSTITUTIONALIZE CHANGE FOR GOOD

We may eventually explore a variety of low cost tools with reasonable efficiencies, but, at this time, we expect to focus on one⁴² proven approach (Figure 6). In this vein, plant xylem act as a natural system for water purification and produces safe drinking water, albeit in low volumes. One goal of Wii is to build capacity to deploy xylem based water purification process to meet the basic needs of end users (households) in terms of sufficient clean water for daily needs.

The first problem may be sourcing the water (assume it is unclear). Many communities do not even have access to water. FPGA aims to address this issue in communities where FPGA may be involved. If water sourcing is available, the second issue concerns the infrastructure that connects the source to the end user. Many communities do not have basic infrastructure. FPGA aims to address this issue in communities where FPGA may be involved, perhaps indirectly through NGO's working on-site.

If there is limited infrastructure which terminates at nodes (no "last mile" access for end users), the third issue is to explore how xylem-based purification may be applied at these nodes (scale to greater volume). After water purification at the node, clean water will flow through the "last mile" to end-users. This leads to the fourth issue of water purification volumes, rates, flows and efficiencies. The xylem system is efficient for low volume usage in homes and that is the single greatest value of this approach. It solves a problem. However, "multiplying" the system to scale, may be helpful for the ultimate goal of installing clean running water, as a part of the city/town/village *utilities infrastructure*.

The left panel in Figure 5 illustrates the highly effective and strikingly simple solution. The right panel suggests the potential for developing a cartridge which can fit in/out of traditional water pipes. R&D may be necessary to construct and evaluate the performance of this cartridge, which is an aggregate of the narrow tubes with the xylem filter, in a water pipe with a larger diameter. A *modular* cartridge, which may be slipped in/out of pipes with bespoke joints, may enable robotic manufacturing and ease of transportation. The "drag and drop" feature may catalyze "plug-n-play" usage for widespread adoption.



Fig 5: The measured flow rates⁴² of about 0.05 ml per second using only $\sim 1 \text{ cm}^2$ filter area (left panel) correspond to a flow rate of >4 litres per day, sufficient to meet the drinking water requirements of one person. If a branch with a greater circumference was used to increase the filter area, will it affect the flow rate and quality of the filtered water? If xylem filter containing (narrow) tubes (left panel) were packed in a pipe with a larger diameter (right panel, illustration copied from laminar flow diagrams), can it help to scale and increase the volume of filtered water? Will the flow rate decrease? Will it affect water quality?

⁴² <https://dspace.mit.edu/openaccess-disseminate/1721.1/86082>

One task of FPGA is to promote Wii's R&D mission of developing tools to facilitate clean water infrastructures. FPGA may aid in the global diffusion of tools at hand, to prevent morbidity and mortality, due to contaminated water. The work of FPGA will be agnostic of geography, from Cali to Calcutta.

FPGA Wii expects to interact, create and maintain dialogues with "network of bridges" involving national governments, local governmental agencies, NGOs (non-governmental agencies), global organizations (UN, WHO, World Bank, Asian Development Bank, African Development Bank, European Bank for Reconstruction and Development), global and local foundations, research institutions and academics. In one or more ways, collective and collaborative efforts will bring to the table, proposals, debate solutions and discuss how to fund implementation and installation of clean water infrastructure.

FPGA-FEWSH anticipates that some of the interactions, with appropriate agencies, organizations, and industries, will involve funding requests, to enable and sustain the organization of FPGA-FEWSH. Without a stable FPGA, the knowledge backbone for Wii and other future efforts, may cease to exist.

FPGA expects to [a] assist as "cheerleaders" and proselytizers for local chapters, [b] offer expert R&D guidance for on-site teams, and [c] act as a bridge, case by case basis, for the group or organization or not-for-profit LLC (limited liability corporation), in charge of the local operation. The local body will execute local implementations, and install infrastructure, in the context of the needs of the community. This body will have, or secure, independent fiscal means and human resources to execute the operation.

FPGA is under no illusion that the scale of this endeavor and the bureaucracy surrounding any infrastructure effort, may pose insurmountable barriers. The strength of FPGA is rooted in its credibility and the ethos of the founders. The latter are not racing to patent every iota of invention to pursue start-ups or other enterprises for personal wealth creation. The aim is to lift many boats, not just a few yachts.

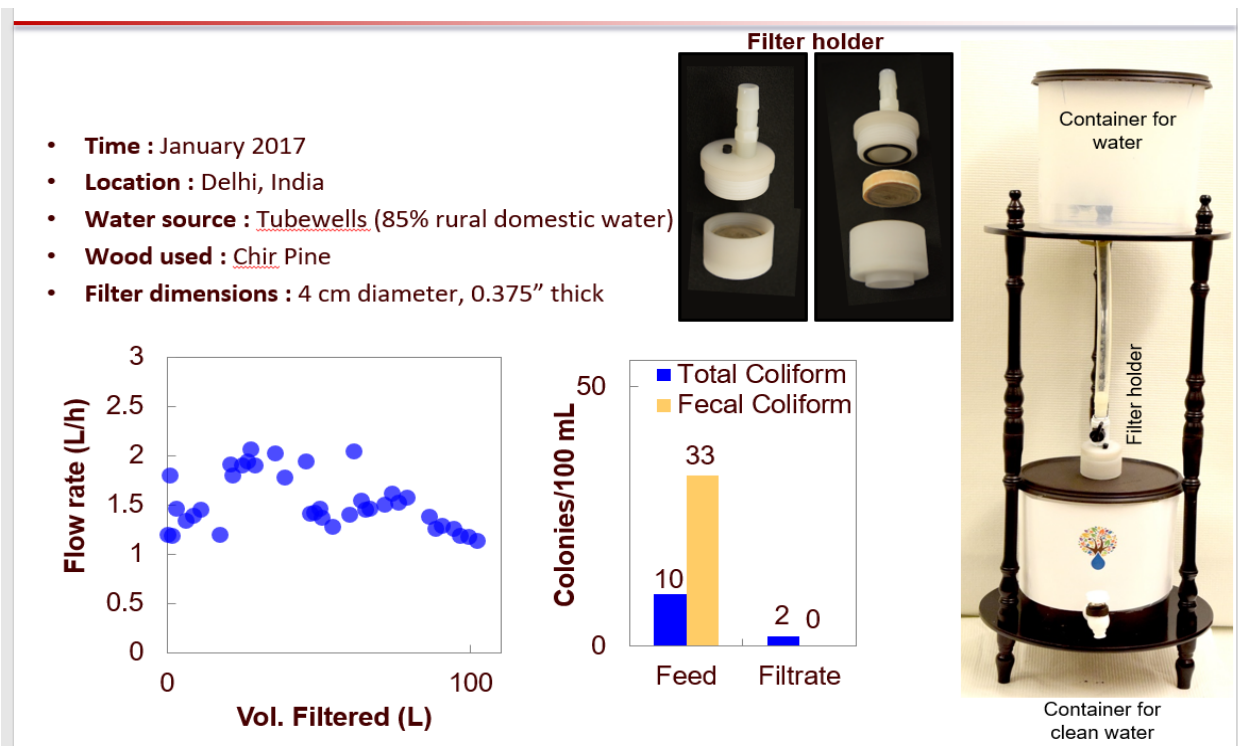


Fig 6: Domestic water purification using wood. Patent-free processes developed by Rohit Karnik, MIT.

WATER QUALITY – MEASUREMENTS, MOLECULES AND METRICS FOR A SENSE AND RESPONSE SYSTEM

Mortality and morbidity may exponentially escalate and epidemics can rapidly turn into full blown pandemics, without near real-time data from sense and response⁴³ systems. Drinking water⁴⁴ and food are mediums for spread of disease and public health disasters. The list of benefits from water purification may be considerably shortened without a sensitive, pro-active and agile water quality *detection system*.

Detection is often synonymous with sensors. Mountains of research⁴⁵ to create novel sensors are of limited use unless the sensors are deployed, in action, as a part of detection systems, for purposes that may benefit billions of people. Equally, patenting⁴⁶ every sensor created, solely for the purpose of wealth creation, is unlikely to be useful for the mission of FPGA and initiatives it may wish to champion.

Tools for detection are essential to help mitigate risks exposed by the incredible statistic that 92% of pollution-related deaths⁴⁷ occur in low-income and middle-income countries. Importantly, detection can save the next generation. Extremely low-dose exposures to pollutants *in utero* and in early infancy can result in disease, disability, and death, of children.

Element	Max. acceptable limit (ppm)	Health effects
Arsenic	0.010	Kidney and liver cancer
Cadmium	0.003	Kidney disease and cancer; edema (acutely)
Chromium	0.05	Nasal and lung cancer
Copper	0.05	Liver damage; kidney disease
Lead	0.10	Developmental abnormalities
Mercury	0.001	Nervous system disorders
Nickel	0.02	Cancers
Zinc	5	Digestive disorders

Fig 7: Trace⁴⁴ contaminants in water – a grave and global concern, for adults, children and the unborn.

FPGA wishes to create and deploy low-cost sensor systems⁴⁸ which will contain the sensor, tools for data capture and transmission, near real-time data analytics and rapid display on a mobile device for visualization by system administrators, alert managers, early responders and end-users or consumers at the edge or point-of-service. R&D is necessary to create robust systems, tools for calibration and increase sensitivity. Connectivity of the detection system with the response team will be an important function. It may be viewed as an internet of things (IoT) approach for water and ecosystem of water related nodes.

⁴³ <http://bit.ly/SIP-SAR>

⁴⁴ http://www.who.int/water_sanitation_health/publications/2011/dwq_guidelines/en/

⁴⁵ <http://www-analytik.chemie.uni-regensburg.de/wolfbeis/P2-www.pdf>

⁴⁶ <http://www.c2sense.com/>

⁴⁷ [https://www.thelancet.com/journals/lancet/article/PIIS0140-6736\(17\)32345-0/fulltext](https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(17)32345-0/fulltext)

⁴⁸ <https://pubs.rsc.org/en/content/articlelanding/2018/an/c8an00065d#!divAbstract>

These 3D printed nano-bio sensors cost only a few cents and may be made from locally sourced materials⁴⁹ (need not use any special materials or chemicals). But, the systemic costs may be higher. However, single use sensors, no matter how inexpensive, pose logistical issues if continuous remote monitoring is necessary. Successfully re-calibrating multi-use sensors in the field, after deployment, is a challenge that researchers must address and resolve, successfully.

General multi-use sensors, which can bind with analytes and reverse to the basal state (without the need for expensive microfluidics flushing system) may be more expensive to create but of far greater value. Research is necessary to explore if molecular engineering may create binding sites, for specific and critical analytes (see table in Figure 7), perhaps, using lessons from biomimicry (for example, allosteric⁵⁰ transitions). In an ideal scenario, binding of the analyte may induce conformational changes (in the "active site" on the sensor) which may reduce the affinity (association/dissociation constants) and eject the analyte (due to reduced affinity) just after the signal (impedance⁵¹ or plasmonic⁵² transduction) is communicated (wireless sensor gateway). Elimination of the analyte, may reverse the configuration, increase the affinity, and the cycle repeats (sensor is refreshed). Engineering molecules with steric properties may create sensors for detection of analytes in any medium (air, blood, urine, oil, gas). Further research may improve molecular specificity for identification of analytes, (for example, enantiomeric profiling⁵³ of illicit drugs in sewer water). Nano-wire arrays are emerging for broad spectrum use in environmental health and toxicology. Novel advances⁵⁴ are creating 3D printed electronic sensors using materials that couple, sense, actuate, compute and communicate. The challenge is to go beyond the sensor and create an end to end *system*. It must be feasible for mass use and user-friendly for the client.

Under the auspices of WII, water purification and detection systems may proceed simultaneously. Infrastructure may surface as a rate limiting factor. But, since there are more mobile phones in the world compared to toilets, perhaps communication or transmission of data may not be an arduous task. Sensor detection systems must be able to transmit the data in near real-time. The data must be analyzed before its value perishes. The information extracted from the data must be accessible to the stakeholders within the right time frame. The response, if needed, must have a mechanism to be executed. Multiple and false alarms⁵⁵ due to poor design, system performance and analytical inefficiencies (set range is too narrow for real world fluctuations) often generate detrimental results (as a consequence, alerts are ignored, often).

Synergistic integration of multiple components are necessary to make sense of the data from sense and response systems. Patent-free, low cost systems and open-source platforms, are not usual. The business model for deploying massive scale detection systems must account for service providers who must earn revenue. The *pay-a-penny-per-use* (micro-revenue/micro-payment) model⁵⁶ may stand the test of time. By lowering barriers to entry, these IoT concepts can penetrate low-income nations and capture markets of billions. The micro-earnings model depends on economies of scale, i.e., the next billion users.

⁴⁹ <http://www.mdpi.com/2079-6374/8/2/42>

⁵⁰ <https://users.wfu.edu/~shapiro/Biophysics14/mwc.pdf>

⁵¹ <https://www.hindawi.com/journals/js/2017/7638389/>

⁵² <https://www.nature.com/articles/s41598-017-08141-4>

⁵³ <https://doi.org/10.1016/j.watres.2017.11.051>

⁵⁴ <http://science.sciencemag.org/content/347/6228/1261689>

⁵⁵ <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3672485/pdf/cc12525.pdf>

⁵⁶ <https://dspace.mit.edu/handle/1721.1/111021>

TEMPORARY CONCLUSION

FPGA may be fraught with pragmatic growing pains, it is easy to be dismissed due to its immense complexity and perhaps too far removed for most decision makers, to feel sufficiently comfortable to invest in benevolent ideas, and altruistic ideals of FPGA. Although far from unique, its plight to address fundamental issues, which are “wicked problems” rather than grand challenges, channels convergence of camaraderie from honorable institutions. We must undertake the mission of FPGA because the misery from lack of global goods is a thorn in our conscience, because it’s a very hard⁵⁷ task and a fatiguing climb.

The task of FPGA must be a pledge, not a job. Founders must engage their brain, with their heart and soul, in order to face the avalanche of naysayers. Pundits, critics, as well as, well-wishers, may opine that it cannot be done, or we must wait for Google or Amazon to do it. We propose, against all odds, to move forward, with humility, dignity and with the sense, that we can help create the future.

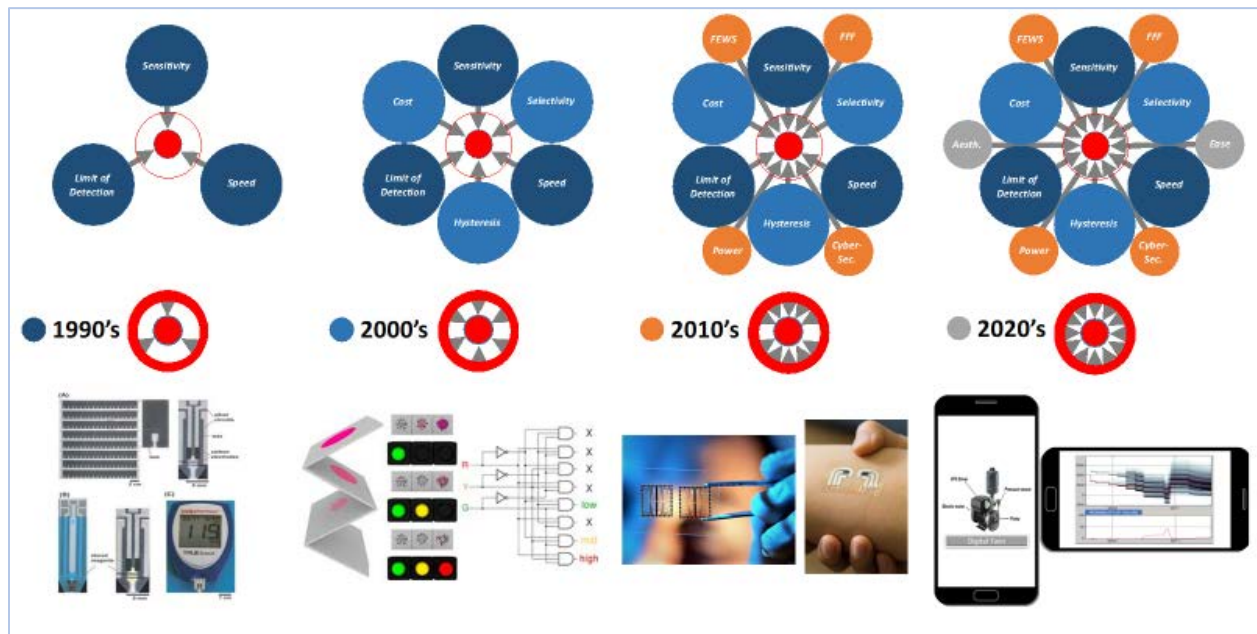


Fig 8: Evolution of sensor engineering to mobile detection systems. Eric McLamore, University of Florida.

We choose to go to the moon in this decade and do the other things, not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone.

JFK

⁵⁷ <https://er.jsc.nasa.gov/seh/ricetalk.htm>

FPGA-FEWSH.ORG

Discussion on FPGA is included as **APPENDIX-A** which is a part of **COMMENTARY-C** (World Sensor Organization) in the book **“HAPHAZARD REALITY – IoT IS A METAPHOR”** which is available (PDF) from the MIT Library <https://dspace.mit.edu/handle/1721.1/111021>

TWO KEY PAPERS ARE ATTACHED TO THIS SECTION

1 – Rohit Karnik, MIT

2 – Eric McLamore, University of Florida



Fig 9: A “sense” of the molecular symbiosis⁵⁸ between microbes, water and plants, is pivotal for increasing the quantity, and improving the quality, of food. Data, information and analytics, from the science⁵⁹ of the path from *the seed to the shelf* is essential for advancing agricultural technology and farming related IoT. The combination and convergence is key for the supply chain required to feed ~10 billion people in 2050.

⁵⁸ <https://video.nationalgeographic.com/video/decoder/how-trees-secretly-talk-to-each-other-in-the-forest>

⁵⁹ <http://bit.ly/CONFOMA-TALKS>

Water Filtration Using Plant Xylem

Michael S. H. Boutillier¹, Jongho Lee¹, Valerie Chambers, Varsha Venkatesh, Rohit Karnik*

Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts, United States of America

Abstract

Effective point-of-use devices for providing safe drinking water are urgently needed to reduce the global burden of waterborne disease. Here we show that plant xylem from the sapwood of coniferous trees – a readily available, inexpensive, biodegradable, and disposable material – can remove bacteria from water by simple pressure-driven filtration. Approximately 3 cm³ of sapwood can filter water at the rate of several liters per day, sufficient to meet the clean drinking water needs of one person. The results demonstrate the potential of plant xylem to address the need for pathogen-free drinking water in developing countries and resource-limited settings.

Citation: Boutillier MSH, Lee J, Chambers V, Venkatesh V, Karnik R (2014) Water Filtration Using Plant Xylem. PLoS ONE 9(2): e89934. doi:10.1371/journal.pone.0089934

Editor: Zhi Zhou, National University of Singapore, Singapore

Received: October 17, 2013; **Accepted:** January 23, 2014; **Published:** February 26, 2014

Copyright: © 2014 Boutillier et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Funding: This work was supported by the James H. Ferry, Jr. Fund for Innovation in Research Education award to R.K. administered by the Massachusetts Institute of Technology. SEM imaging was performed at the Harvard Center for Nanoscale Systems, a member of the National Nanotechnology Infrastructure Network (NNIN), which is supported by the National Science Foundation under NSF award no. ECS-0335765. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing Interests: The authors have declared that no competing interests exist.

* E-mail: karnik@mit.edu

† These authors contributed equally to this work.

Introduction

The scarcity of clean and safe drinking water is one of the major causes of human mortality in the developing world. Potable or drinking water is defined as having acceptable quality in terms of its physical, chemical, and bacteriological parameters so that it can be safely used for drinking and cooking [1]. Among the water pollutants, the most deadly ones are of biological origin: infectious diseases caused by pathogenic bacteria, viruses, protozoa, or parasites are the most common and widespread health risk associated with drinking water [1,2]. The most common waterborne pathogens are bacteria (e.g. *Escherichia coli*, *Salmonella typhi*, *Vibrio cholerae*), viruses (e.g. adenoviruses, enteroviruses, hepatitis, rotavirus), and protozoa (e.g. giardia) [1]. These pathogens cause child mortality and also contribute to malnutrition and stunted growth of children. The World Health Organization reports [3] that 1.6 million people die every year from diarrheal diseases attributable to lack of access to safe drinking water and basic sanitation. 90% of these are children under the age of 5, mostly in developing countries. Multiple barriers including prevention of contamination, sanitation, and disinfection are necessary to effectively prevent the spread of waterborne diseases [1]. However, if only one barrier is possible, it has to be disinfection unless evidence exists that chemical contaminants are more harmful than the risk from ingestion of microbial pathogens [1]. Furthermore, controlling water quality at the point-of-use is often most effective due to the issues of microbial regrowth, byproducts of disinfectants, pipeline corrosion, and contamination in the distribution system [2,4].

Common technologies for water disinfection include chlorination, filtration, UV-disinfection, pasteurization or boiling, and ozone treatment [1,2,5]. Chlorine treatment is effective on a large scale, but becomes expensive for smaller towns and villages. Boiling is an effective method to disinfect water; however, the

amount of fuel required to disinfect water by boiling is several times more than what a typical family will use for cooking [1]. UV-disinfection is a promising point-of-use technology available [1], yet it does require access to electricity and some maintenance of the UV lamp, or sufficient sunlight. While small and inexpensive filtration devices can potentially address the issue of point-of-use disinfection, an ideal technology does not currently exist. Inexpensive household carbon-based filters are not effective at removing pathogens and can be used only when the water is already biologically safe [1]. Sand filters that can remove pathogens require large area and knowledge of how to maintain them [1], while membrane filters capable of removing pathogens [2,4] suffer from high costs, fouling, and often require pumping power due to low flow rates [6] that prevents their wide implementation in developing countries. In this context, new approaches that can improve upon current technologies are urgently needed. Specifically, membrane materials that are inexpensive, readily available, disposable, and effective at pathogen removal could greatly impact our ability to provide safe drinking water to the global population.

If we look to nature for inspiration, we find that a potential solution exists in the form of plant xylem – a porous material that conducts fluid in plants [7]. Plants have evolved specialized xylem tissues to conduct sap from their roots to their shoots. Xylem has evolved under the competing pressures of offering minimal resistance to the ascent of sap while maintaining small nanoscale pores to prevent cavitation. The size distribution of these pores – typically a few nanometers to a maximum of around 500 nm, depending on the plant species [8] – also happens to be ideal for filtering out pathogens, which raises the interesting question of whether plant xylem can be used to make inexpensive water filtration devices. Although scientists have extensively studied plant xylem and the ascent of sap, use of plant xylem in the context of

water filtration remains to be explored. Measurements of sap flow in plants suggest that flow rates in the range of several liters per hour may be feasible with less than 10 cm-sized filters, using only gravitational pressure to drive the flow [7].

We therefore investigated whether plant xylem could be used to create water filtration devices. First, we reason which type of plant xylem tissue is most suitable for filtration. We then construct a simple water filter from plant xylem and study the resulting flow rates and filtration characteristics. Finally, we show that the xylem filter can effectively remove bacteria from water and discuss directions for further development of these filters.

Materials and Methods

Materials

Branches were excised from white pine growing on private property in Massachusetts, USA, with permission of the owner and placed in water. The pine was identified as *pinus strobus* based on the 5-fold grouping of its needles, the average needle length of 4.5 inches, and the cone shape. Deionized water (Millipore) was used throughout the experiments unless specified otherwise. Red pigment (pigment-based carmine drawing ink, Higgins Inks) was dissolved in deionized water. Nile-red coated 20 nm fluorescent polystyrene nanospheres were obtained from Life Technologies. Inactivated, Alexa 488 fluorescent dye labeled *Escherichia coli* were obtained from Life Technologies. Wood sections were inserted into the end of 3/8 inch internal diameter PVC tubing, sealed with 5 Minute Epoxy, secured with hose clamps, and allowed to cure for ten minutes before conducting flow rate experiments.

Construction of the Xylem Filter

1 inch-long sections were cut from a branch with approximately 1 cm diameter. The bark and cambium were peeled off, and the piece was mounted at the end of a tube and sealed with epoxy. The filters were flushed with 10 mL of deionized water before experiments. Care was taken to avoid drying of the filter.

Filtration and Flow Rate Experiments

Approximately 5 mL of deionized water or solution was placed in the tube. Pressure was supplied using a nitrogen tank with a pressure regulator. For filtration experiments, 5 psi (34.5 kPa) pressure was used. The filtrate was collected in glass vials. For dye filtration, size distribution of the pigments was measured for the input solution and the filtrate. Higgins pigment-based carmine drawing ink, diluted $\sim 1000\times$ in deionized water, was used as the input dye solution. For bacteria filtration, the feed solution was prepared by mixing 0.08 mg of inactivated *Escherichia coli* in 20 mL of deionized water ($\sim 1.6\times 10^7$ mL⁻¹) after which the solution was sonicated for 1 min. The concentration of bacteria was measured in the feed solution and filtrate by enumeration with a hemacytometer (inCyto C-chip) mounted on a Nikon TE2000-U inverted epifluorescence microscope. Before measurement of concentration and filtration experiments, the feed solution was sonicated for 1 min and vigorously mixed.

Imaging

Xylem structure was visualized in a scanning electron microscope (SEM, Zeiss Supra55VP). Samples were coated with gold of 5 nm thickness before imaging. To visualize bacteria filtration, 5 mL of solution at a bacteria concentration of $\sim 1.6\times 10^7$ mL⁻¹ was flowed into the filter. The filter was then cut longitudinally with a sharp blade. One side of the sample was imaged using a Nikon TE2000-U inverted epifluorescence microscope and the other was coated with gold and imaged with the SEM. Optical

images were acquired of the cross section of a filter following filtration of 5 mL of the dye at a dilution of $\sim 100\times$.

Particle Sizing

Dynamic light scattering measurements of particle size distributions were performed using a Malvern Zetasizer Nano-ZS.

Results

Xylem Structure and Rationale for use of Conifer Xylem

The flow of sap in plants is driven primarily by transpiration from the leaves to the atmosphere, which creates negative pressure in the xylem. Therefore, xylem evolution has occurred under competing pressures of providing minimal resistance to the flow of sap, while protecting against cavitation (i.e. nucleation) and growth of bubbles that could stop the flow of sap and kill the plant, and to do this while maintaining mechanical strength [7]. The xylem structure comprises many small conduits that work in parallel and operate in a manner that is robust to cavitation [7,8] (Figure 1). In woody plants, the xylem tissue is called the sapwood, which often surrounds the heartwood (i.e. inactive, non-conducting lignified tissue found in older branches and trunks) and is in turn surrounded by the bark (Figure 1b,c). The xylem conduits in gymnosperms (conifers) are formed from single dead cells and are called tracheids (Figure 1c), with the largest tracheids reaching diameters up to 80 μ m and lengths up to 10 mm [7]. Angiosperms (flowering plants) have xylem conduits called vessels that are derived from several cells arranged in a single file, having diameters up to 0.5 mm and lengths ranging from a few millimeters to several meters [7]. These parallel conduits have closed ends and are connected to adjacent conduits via “pits” [8] (Figure 1d,e). The pits have membranes with nanoscale pores that perform the critical function of preventing bubbles from crossing over from one conduit to another. Pits occur in a variety of configurations; Figure 1d,e shows torus-margo pit membranes that consist of a highly porous part shaped like a donut (margo) and an impermeable part in the center called torus, occurring in conifers [8]. The porosity of the pit membranes ranges in size from a few nanometers to a few hundred nanometers, with pore sizes in the case of angiosperms tending to be smaller than those in gymnosperms [8,9]. Pit membrane pore sizes have been estimated by examining whether gold colloids or particles of different sizes can flow through [8,10]. Remarkably, it was observed that 20 nm gold colloids could not pass through inter-vessel pit membranes of some deciduous tree species [10], indicating an adequate size rejection to remove viruses from water. Furthermore, inter-tracheid pit membranes were found to exclude particles in the 200 nm range [8], as required for removal of bacteria and protozoa.

Since angiosperms (flowering plants, including hardwood trees) have larger xylem vessels that are more effective at conducting sap, xylem tissue constitutes a smaller fraction of the cross-section area of their trunks or branches, which is not ideal in the context of filtration. The long length of their xylem vessels also implies that a large thickness (centimeters to meters) of xylem tissue will be required to achieve any filtration effect at all – filters that are thinner than the average vessel length will just allow water to flow through the vessels without filtering it through pit membranes (Figure 1a). In contrast, gymnosperms (conifers, including softwood trees) have short tracheids that would force water to flow through pit membranes even for small thicknesses (<1 cm) of xylem tissue (Figure 1a). Since tracheids have smaller diameters and are shorter, they offer higher resistance to flow, but typically a greater fraction of the stem cross-section area is devoted to

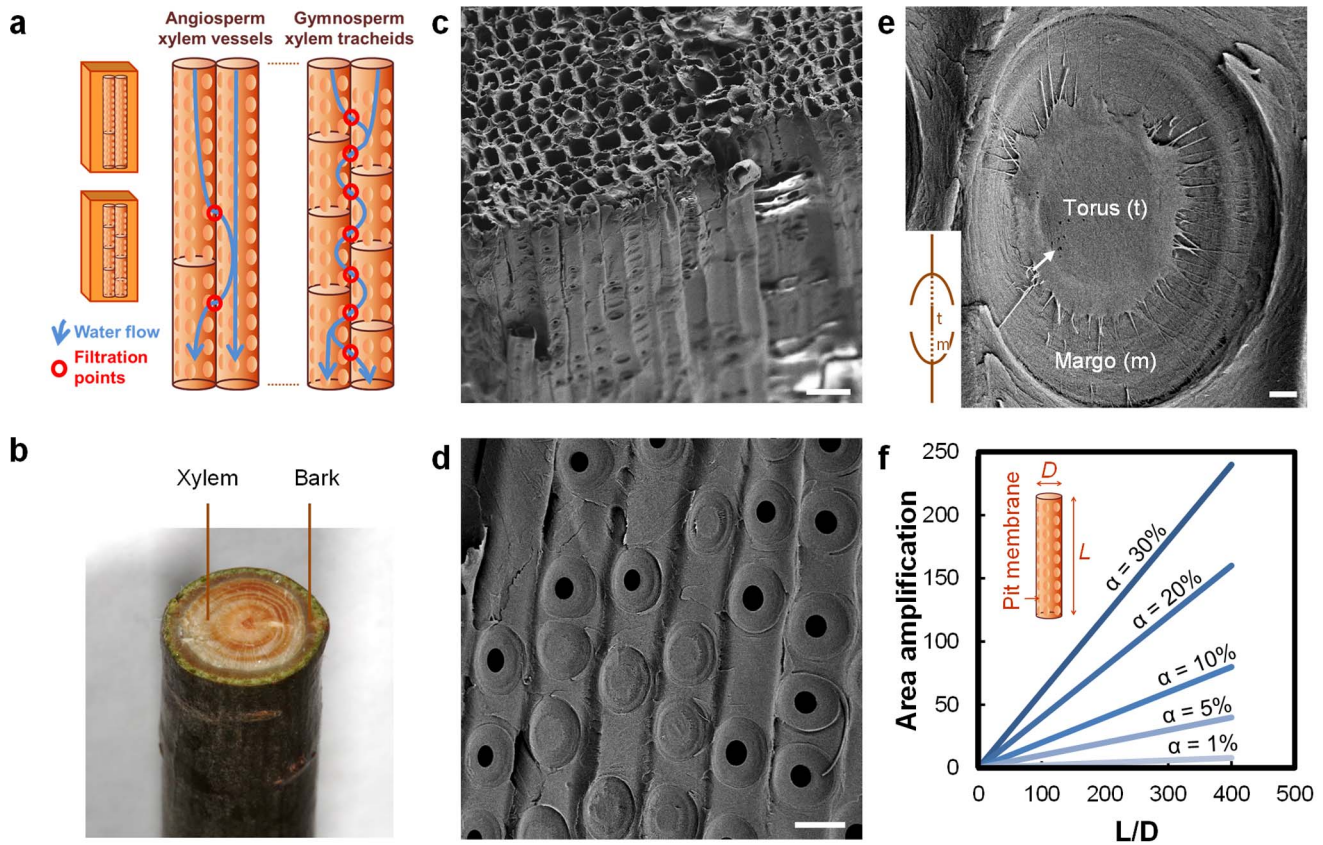


Figure 1. Xylem structure. a) Structure of xylem vessels in flowering plants and tracheids in conifers. Longer length of the vessels can provide pathways that can bypass filtration through pit membranes that decorate their circumference. b) Photograph of ~ 1 cm diameter pine (*pinus strobus*) branch used in the present study. c) Scanning electron microscope (SEM) image of cut section showing tracheid cross section and lengthwise profile. Scale bar is 40 μm . d) SEM image showing pits and pit membranes. Scale bar is 20 μm . e) Pit membrane with inset showing a cartoon of the pit cross-section. The pit cover has been sliced away to reveal the permeable margo surrounding the impermeable torus. Arrow indicates observed hole-like structures that may be defects. The margo comprises radial spoke-like structures that suspend the torus, which are only barely visible overlaying the cell wall in the background. Scale bar is 1 μm . f) Dependence of area amplification, defined as the pit membrane area divided by the nominal filter area, on the tracheid aspect ratio L/D and fractional area α occupied by pit membranes. doi:10.1371/journal.pone.0089934.g001

conducting xylem tissue. For example, in the pine branch shown in Figure 1b used in this study, fluid-conducting xylem constitutes the majority of the cross-section. This reasoning leads us to the conclusion that in general the xylem tissue of coniferous trees – i.e. the sapwood – is likely to be the most suitable xylem tissue for construction of a water filtration device, at least for filtration of bacteria, protozoa, and other pathogens on the micron or larger scale.

The resistance to fluid flow is an important consideration for filtration. Pits can contribute a significant fraction (as much as 30–80%) [7,8] of the resistance to sap flow, but this is remarkably small considering that pit membrane pore sizes are several orders of magnitude smaller than the tracheid or vessel diameter. The pits and pit membranes form a hierarchical structure where the thin, highly-permeable pit membranes are supported across the microscale pits that are arranged around the circumference of the tracheids (Figure 1a). This arrangement permits the pit membranes to be thin, offering low resistance to fluid flow. Furthermore, the parallel arrangement of tracheids with pits around their circumference provides a high packing density for the pit membranes. For a given tracheid with diameter D and length L , where pit membranes occupy a fraction α of the tracheid wall area, each tracheid effectively contributes a pit membrane area of $\pi DL\alpha/2$, where the factor of 2 arises as each membrane is shared

by two tracheids. However, the nominal area of the tracheid is only $\pi D^2/4$, and therefore, the structure effectively amplifies the nominal filter area by a factor of $2\alpha(L/D)$ (Figure 1f). The images in Figure 1c indicate that typical $D \sim 10\text{--}15 \mu\text{m}$ and $\alpha \sim 0.2$ yield an effective area amplification of ~ 20 for tracheid lengths of 1–2 mm. Therefore, for a filter made by cutting a slice of thickness $\sim L$ of the xylem, the actual membrane area is greater by a large factor due to vertical packing of the pit membranes. Larger filter thicknesses further increase the total membrane area, but the additional area of the membrane is positioned in series rather than in parallel and therefore reduces the flow rate, but potentially improves the rejection performance of the filter due to multiple filtration steps as shown in Figure 1a.

Construction of the Xylem Filter and Measurement of Flow Rate

The xylem filter device was constructed by simply peeling off the bark and cambium from a section of the pine branch and inserting it into a tube (Figure 2a). Although a simple tube fastener could provide a leak-tight seal between the tube and the xylem, we used epoxy to ensure that there was no inadvertent leakage. When deionized water was loaded into the tube above the xylem and subjected to pressure in the 0.5–5 psi (3.45 to 34.5 kPa) range, we

found that water readily flowed through the xylem. The flow rate was proportional to applied pressure (Figure 2b), which allowed for the extraction of the hydrodynamic conductivity K ($\text{m}^2 \text{Pa}^{-1} \text{s}^{-1}$) of the filter, defined by

$$Q = KA \frac{\Delta P}{l} \quad (1)$$

where Q is the volumetric flow rate (in $\text{m}^3 \text{s}^{-1}$) under pressure difference ΔP across the filter, while l and A are the thickness and the cross-section area of the filter, respectively. The observed conductivities for three different filters were in the range of $\sim 5\text{--}6 \times 10^{-10} \text{ m}^2 \text{ Pa}^{-1} \text{ s}^{-1}$ (Figure 2c), or equivalently, $\sim 0.5\text{--}0.6 \text{ kg s}^{-1} \text{ m}^{-1} \text{ MPa}^{-1}$ when defined with respect to mass flow rate of water.

Biologists have performed similar flow rate measurements by cutting a section of a plant stem under water, flushing to remove any bubbles, and applying a pressure difference to measure the flow rate [11,12]. Xylem conductivities of conifers [7] typically range from $1\text{--}4 \text{ kg s}^{-1} \text{ m}^{-1} \text{ MPa}^{-1}$, which compares very well with the conductivities measured in our experiments. Lower

conductivities can easily result from introduction of bubbles [11] or the presence of some non-conducting heartwood. We can therefore conclude that the flow rate measurements in our devices are consistent with those expected from prior literature on conductivity of conifer xylem.

Filtration of Pigment Dye

After construction of the filter, we tested its ability to filter a pigment dye with a broad particle size distribution. The red color of the feed solution disappeared upon filtration (Figure 3a) indicating that the xylem filter could effectively filter out the dye.

Since the dye had a broad pigment size distribution, we investigated the size-dependence of filtration by quantifying the pigment size distribution before and after filtration using dynamic light scattering. We found that the feed solution comprised particles ranging in size from $\sim 70 \text{ nm}$ to $\sim 500 \text{ nm}$, with some larger aggregates (Figure 3b). In contrast, the filtrate particle size distribution peaked at $\sim 80 \text{ nm}$, indicating that larger particles were filtered out. In a separate experiment, we observed that 20 nm fluorescent polystyrene nanoparticles could not be filtered by the xylem filter, confirming this size dependence of filtration.

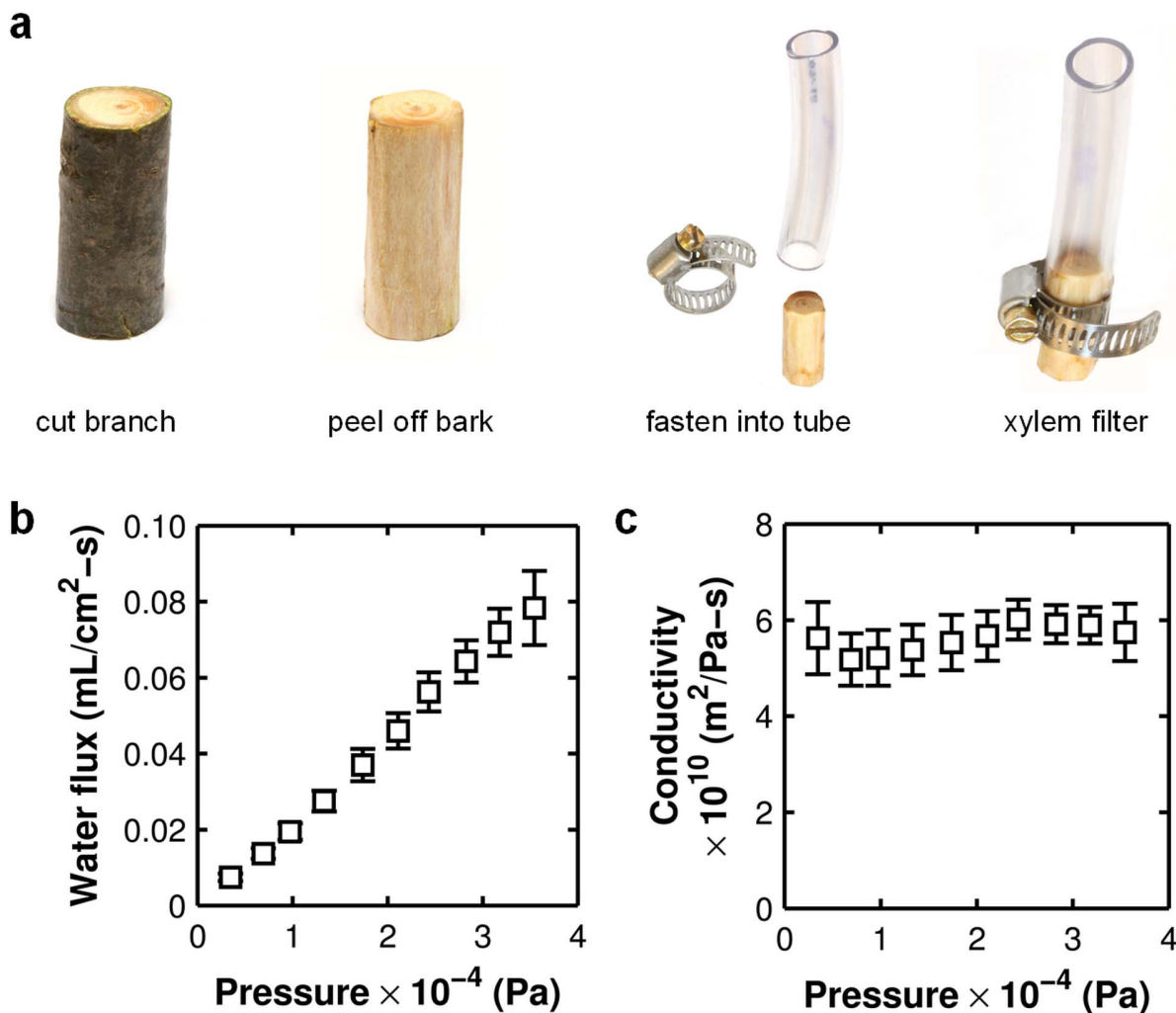


Figure 2. Xylem filter. a) Construction of xylem filter. b) Effect of applied pressure on the water flux through the xylem filter. c) Hydrodynamic conductivity of the filter extracted at each measured pressure using the total filter cross-section area and thickness as defined by Equation 1. Error bars indicate $\pm 5\text{D}$. for measurements on three different xylem filters. doi:10.1371/journal.pone.0089934.g002

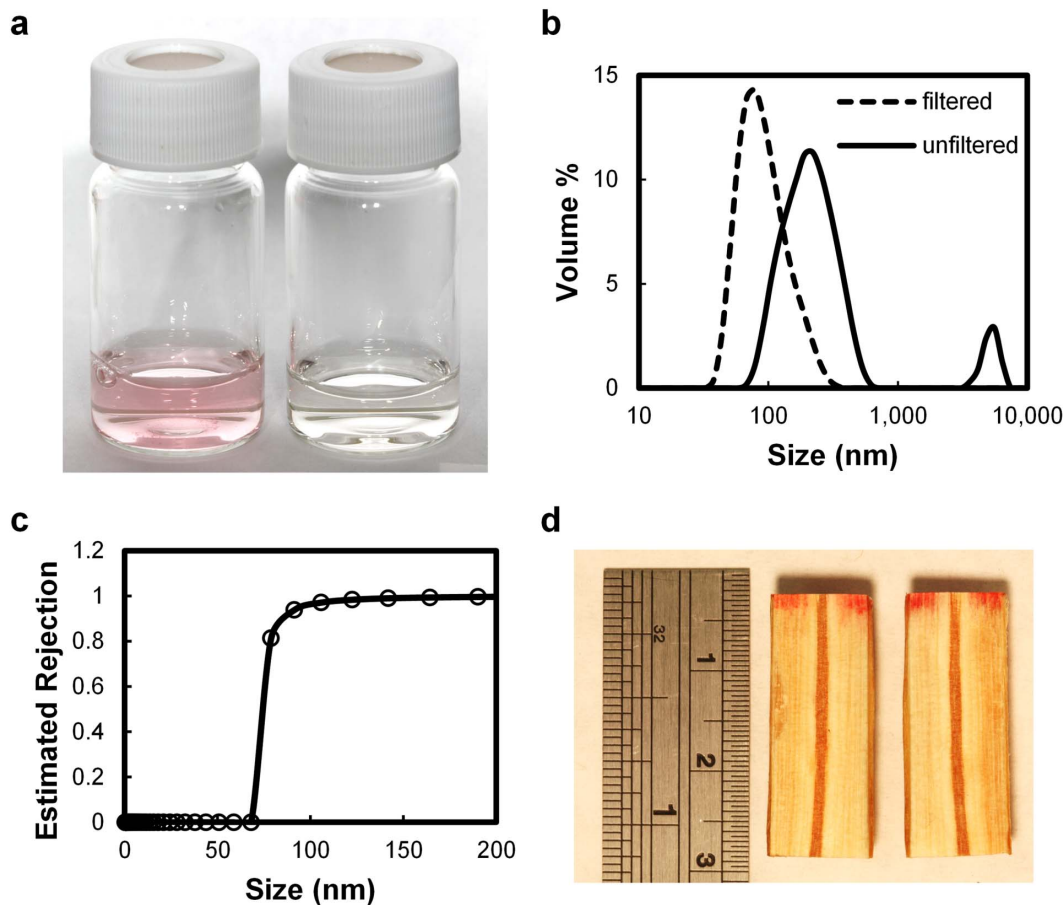


Figure 3. Filtration performance of the xylem filter. a) Feed solution of a pigment dye before filtration (left), compared to the filtrate (right). b) Size distribution of the pigment particles in the feed and filtrate solutions measured by dynamic light scattering. c) Dependence of the rejection on the particle size estimated from the data in (b). d) Cross-section of the xylem filter after filtration. Scale is in centimeters and inches. doi:10.1371/journal.pone.0089934.g003

Assuming that pigment particles 70 nm or less in size were not rejected, the size distributions before and after filtration enable calculation of the rejection performance of the xylem filter as a function of particle size (Figure 3c). We find that the xylem filter exhibits excellent rejection for particles with diameters exceeding 100 nm, with the estimated rejection exceeding 99% for particles over 150 nm. Smaller particles are expected to pass through the larger porosity of the pit membrane: SEM images in Figure 1e indicate sub-micron spacing between the radial spoke-like margo membrane through which the pigment particles can pass, although the porosity is difficult to resolve in the SEM image.

After filtration, we cut the xylem filter parallel to the direction of flow to investigate the distribution of dye in the filter. We observed that the dye was confined to the top 2–3 millimeters of the xylem filter (Figure 3d), which compares well with the tracheid lengths on the millimeter scale expected for coniferous trees [7]. These results show that the majority of the filtration occurred within this length scale, and suggests that the thickness of the xylem filter may be reduced to below 1 cm while still rejecting the majority of the dye.

Filtration of Bacteria from Water

Finally, we investigated the ability of the xylem filter to remove bacteria from water. As a model bacterium, we used fluorescently labeled and inactivated *Escherichia coli* bacteria that are cylindrical in shape with a diameter of $\sim 1 \mu\text{m}$. Use of fluorescently labeled

bacteria enabled easy enumeration of their concentrations, and also allowed us to track the location in the xylem filter where they were trapped. Since filtration is dominated by size-exclusion at this length scale, we do not expect modification with the dye to significantly affect filtration characteristics. Filtration using three different xylem filters showed nearly complete rejection of the bacteria (Figure 4a). Using a hemacytometer to count the bacteria, we estimate that the rejection was at least 99.9%.

To investigate the mechanism of filtration, the xylem filter was cut parallel to the direction of flow after filtration. When examined under a fluorescence microscope, we observed that the bacteria accumulated over the donut-shaped margo pit membranes (Figure 4b). This distribution is consistent with the expectation that the bacteria are filtered by the porous margo of the pit membranes. The distribution of trapped bacteria was not uniform across the cross section of the filter. Similar to the case of the dye, bacteria were observed only within the first few millimeters from the end through which the solution was infused (indicated by the white arrow in Figure 4c). In addition, the low-magnification fluorescence image shows that the bacteria had accumulated primarily over pit membranes at the bottom of the tracheids, which is again not unexpected. Further investigation by SEM clearly showed individual bacterial cells accumulated on the pit membranes over the porous margo (Figure 4d,e). These results confirm the pit membranes as the functional units that provide the filtration effect in the xylem filter.

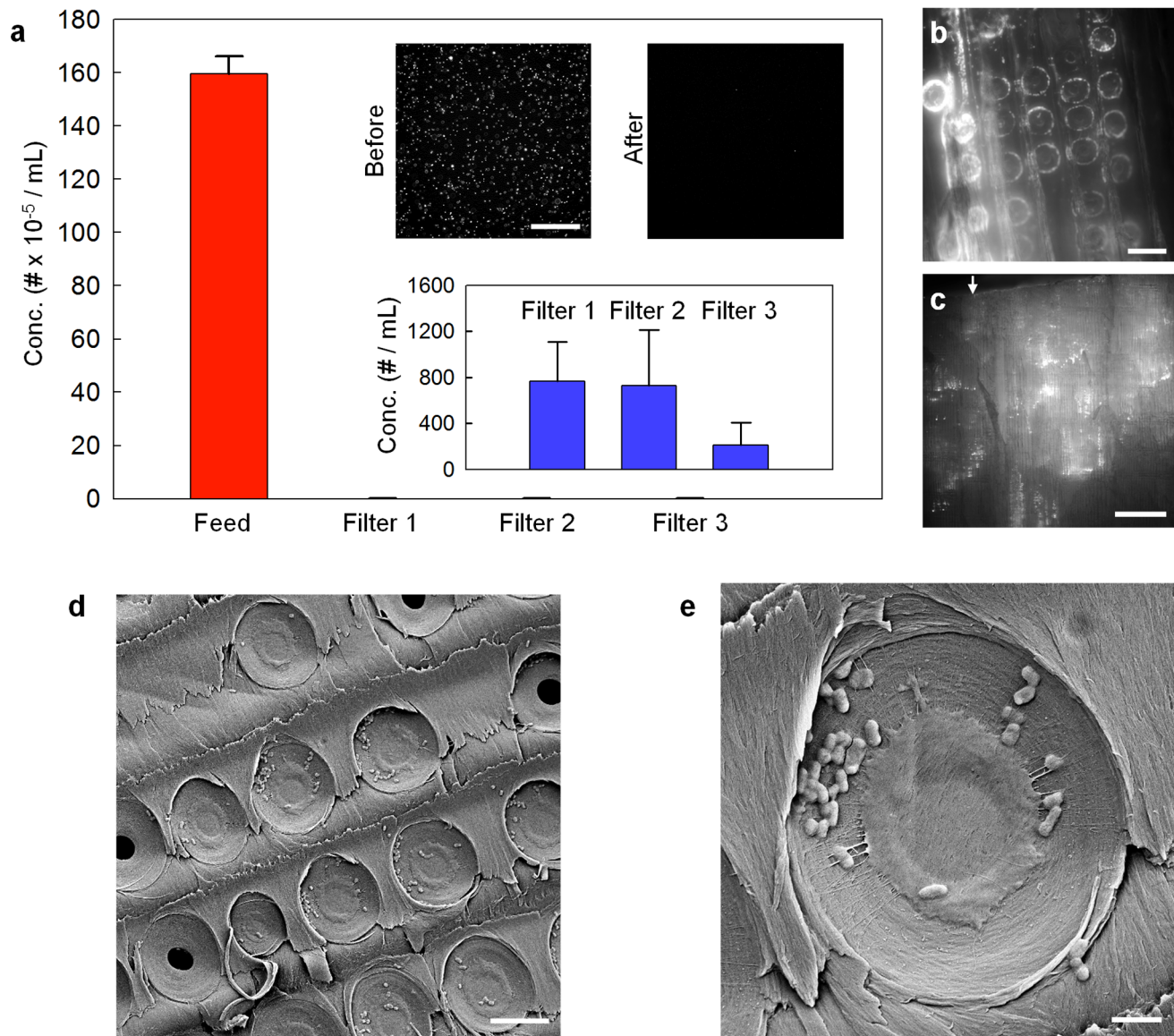


Figure 4. Filtration of model bacteria by the xylem filter. a) Concentrations of bacteria in the feed and filtrate solutions. Inset shows fluorescence images of the two solutions. Scale bar is 200 μm . Error bars indicate \pm S.D. for experiments performed on three different xylem filters. b) Fluorescence image of xylem filter cross-section showing accumulation of bacteria over the margo pit membranes. Scale bar is 20 μm . c) Low-magnification fluorescence image shows that bacteria are trapped at the bottoms of tracheids within the first few millimeters of the top surface. Scale bar is 400 μm . Arrow indicates top surface of the xylem filter and also the direction of flow during filtration. Autofluorescence of the xylem tissue also contributes to the fluorescence signal in (b) and (c). d, e) SEM images showing bacteria accumulated on the margo pit membranes after filtration. Scale bars are 10 μm and 2 μm , respectively. doi:10.1371/journal.pone.0089934.g004

Discussion

Wood has been investigated recently as a potential filtration material [13], showing moderate improvement of turbidity. While we showed filtration using freshly cut xylem, we found that the flow rate dropped irreversibly by over a factor of 100 if the xylem was dried, even when the xylem was flushed with water before drying. We also examined flow through commercially available kiln-dried wood samples cut to similar dimensions. Wood samples that exhibited filtration showed two orders of magnitude smaller flow rates than in the fresh xylem filter, while those that had high flow rates did not exhibit much filtration effect and seemed to have ruptured tracheids and membranes when observed under SEM.

Wetting with ethanol or vacuuming to remove air did not significantly increase the flow rate in the wood samples that exhibited the filtration effect, suggesting that the pit membranes may have a tendency to become clogged during drying. These results are consistent with literature showing that the pit membranes can become irreversibly aspirated against the cell wall, blocking the flow [14]. In fact, the pit membranes in the SEM images (Figure 1d,e and Figure 4d,e), which were acquired after drying the samples, appear to be stuck to the walls. Regardless, our results demonstrate that excellent rejection (> 99.9%) of bacteria is possible using the pit membranes of fresh plant xylem, and also provide insight into the mechanism of filtration as well as guidelines for selection of the xylem material.

Peter-Varbanets et al. [2] have outlined the key requirements for point-of-use devices for water disinfection: a) performance (ability to effectively remove pathogens), b) ease of use (no time-consuming maintenance or operation steps), c) sustainability (produced locally with limited use of chemicals and non-renewable energy), and d) social acceptability. Meeting all of these requirements has proved to be challenging, but point-of-use methods that have been successfully used for low-cost water treatment in developing countries include free-chlorine/solar disinfections, combined coagulant-chlorine disinfection, and biosand/ceramic filtrations [5]. While chlorine is a very effective biocide, its reaction with organic matter can produce carcinogenic by-products [15] and some waterborne pathogens such as *Cryptosporidium parvum* and *Mycobacterium avium* are resistant to the chlorine [16]. Solar disinfection based on ultraviolet irradiation can effectively inactivate *C. parvum*, but this requires low turbidity of source water [17] and is not effective for control of viruses [16]. Filtration based on biosand and ceramic filters is also effective at removing pathogens, but the effectiveness against viruses is low or unknown [18]. Coagulation combined with chlorine disinfection removes or inactivates viruses and pathogens effectively. However, necessity of an additional filtration step and relatively high cost are potential barriers for practical use [18]. Among these methods, a review on field studies by Sobsey et al. [5] suggested that biosand and ceramic filtration are the most effective methods in practice, because once the apparatus is installed, the effort for use and dosage is significantly reduced and therefore promotes persistent use compared to disinfection approaches. Although membrane-based filtration is the most widely used for water treatment in industrialized nations and the cost of membranes has significantly decreased, membranes are still unaffordable to poor communities in the developing world [2]. Ultrafiltration systems run by hydrostatic pressure [19] and some recently invented point-of-use devices using ultrafiltration membranes may provide water to developing regions at reasonable cost [2]. However, membranes still require specialized chemicals and processes for manufacture, and need cleaning or replacement.

Xylem filter technology could be an attractive option for low-cost and highly efficient point-of-use water treatment by filtration, overcoming some of the challenges associated with conventional membranes. Xylem filters could provide the advantage of reduced human effort compared to existing point-of-use water treatment options, requiring only simple periodic filter replacement. In addition, the pressures of 1–5 psi used here are easily achievable using a gravitational pressure head of 0.7–3.5 m, implying that no pumps are necessary for filtration. The measured flow rates of about 0.05 mL/s using only ~ 1 cm² filter area correspond to a flow rate of over 4 L/d, sufficient to meet the drinking water requirements of one person [20]. This is comparable to chlorination and biosand filtration, which have the highest production rates of prevalent point-of-use water treatment methods, and far exceeds typical production rates for solar disinfection. Xylem filters could potentially be produced locally and inexpensively, and disposed of easily owing to their biodegradability. The high flow rates and low cost would certainly help address the issues of maintenance and replacement. For example, 200 filters of 10 cm² area and 0.5 cm thickness could be packaged into a volume of about 1 L, which will be inexpensive and last a few years even with weekly replacement. Furthermore, as suggested by the dye filtration experiment, xylem filters should be able to significantly reduce water turbidity, enhancing the aesthetic qualities of the drinking water, which is hardly achieved by chlorination and solar disinfection.

Wood is an easily available material. While use of fresh xylem does not preclude its use as a filter material, dried membranes have definite practical advantages. Therefore, the process of wood drying and its influence on xylem conductivity needs further study. In particular, processes that yield intact yet permeable xylem tissues that can be stored long-term will be helpful for improving the supply chain if these filters are to be widely adopted. In addition, flow through xylem of different plants needs to be studied to identify locally available sources of xylem, which will truly enable construction of filters from locally available materials. In the present study, we report results using xylem derived from only one species. These xylem filters could not filter out 20 nm nanoparticles, which is a size comparable to that of the smallest viruses. It will be interesting to explore whether there exist any coniferous species that have pit membranes with smaller pore sizes that can filter out viruses, or whether conifer xylem can be impregnated with particles such as carbon black to improve rejection of viruses. In their absence, angiosperms with short vessels that yield practical filter lengths may be the best alternative due to their smaller pit membrane pore sizes [8]. Further exploration of xylem tissues from different plants with an engineering perspective is needed to construct xylem filters that can effectively reject viruses, exhibit improved flow rates, or that are amenable to easy storage. It is also conceivable that plants could be selected or developed for enhanced filtration characteristics, as has been the norm in agriculture for enhancement of many desirable characteristics including resistance to pests, flavor, or productivity.

Conclusions

Plant xylem is a porous material with membranes comprising nanoscale pores. We have reasoned that xylem from the sapwood of coniferous trees is suitable for disinfection by filtration of water. The hierarchical arrangement of the membranes in the xylem tissue effectively amplifies the available membrane area for filtration, providing high flow rates. Xylem filters were prepared by simply removing the bark of pine tree branches and inserting the xylem tissue into a tube. Pigment filtration experiments revealed a size cutoff of about 100 nm, with most of the filtration occurring within the first 2–3 mm of the xylem filter. The xylem filter could effectively filter out bacteria from water with rejection exceeding 99.9%. Pit membranes were identified as the functional unit where actual filtration of the bacteria occurred. Flow rates of about 4 L/d were obtained through ~ 1 cm² filter areas at applied pressures of about 5 psi, which is sufficient to meet the drinking water needs of one person. The simple construction of xylem filters, combined with their fabrication from an inexpensive, biodegradable, and disposable material suggests that further research and development of xylem filters could potentially lead to their widespread use and greatly reduce the incidence of waterborne infectious disease in the world.

Acknowledgments

The authors thank Yukiko Oka for assistance with preparation of illustrations and Sunandini Chopra for help with dynamic light scattering measurements.

Author Contributions

Conceived and designed the experiments: MSHB JL VV VC RK. Performed the experiments: MSHB JL VV VC. Analyzed the data: MSHB JL RK. Contributed reagents/materials/analysis tools: VC. Wrote the paper: MSHB JL RK.

References

- Gadgil A (1998) Drinking water in developing countries. *Annual Review of Energy and the Environment* 23: 253–286.
- Peter-Varbanets M, Zurbrugg C, Swartz C, Wouter Pronk W (2009) Decentralized systems for potable water and the potential of membrane technology. *Water Research* 43: 245–265.
- World Health Organization. Available: http://www.who.int/water_sanitation_health/mdg1/en/. Accessed 2014 Jan 14.
- Madaeni SS (1999) The application of membrane technology for water disinfection. *Water Research* 33: 301–308.
- Sobsey MD, Stauber CE, Casanova LM, Brown JM, Elliott MA (2008) Point of use household drinking water filtration: A practical, effective solution for providing sustained access to safe drinking water in the developing world. *Environmental Science and Technology* 42: 4261–4267.
- Loo SL, Fane AG, Krantz WB, Lim TT (2012) Emergency water supply: A review of potential technologies and selection criteria. *Water Research* 46: 3125–3151.
- Sperry JS (2003) Evolution of water transport and xylem structure. *International Journal of Plant Sciences* 164: S115–S127.
- Choat B, Cobb AR, Jansen S (2008) Structure and function of bordered pits: new discoveries and impacts on whole-plant hydraulic function. *New Phytologist* 177: 608–625.
- Jansen S, Choat B, Pletsers A (2009) Morphological variation of intervessel pit membranes and implications to xylem function in angiosperms. *American Journal of Botany* 96: 409–419.
- Choat B, Ball M, Lully J, Holtum J (2003) Pit membrane porosity and water stress-induced cavitation in four co-existing dry rainforest tree species. *Plant Physiology* 131: 41–48.
- Espino S, Schenk HJ (2011) Mind the bubbles: achieving stable measurements of maximum hydraulic conductivity through woody plant samples. *Journal of Experimental Botany* 62: 1119–1132.
- van Ieperen W, van Meeteren U, van Gelder H (2000) Fluid ionic composition influences hydraulic conductance of xylem conduits. *Journal of Experimental Botany* 51: 769–776.
- Sens ML, Emmendoerfer ML, Muller LC (2013) Water filtration through wood with helical cross-flow. *Desalination and Water Treatment*.
- Petty JA (1972) Aspiration of bordered pits in conifer wood. *Proceedings of the Royal Society Series B-Biological Sciences* 181: 395–+.
- Dunnick J, Melnick R (1993) Assessment of the carcinogenic potential of chlorinated water - Experimental studies of chlorine, chloramine, and trihalomethanes. *Journal of the National Cancer Institute* 85: 817–822.
- Shannon M, Bohn P, Elimelech M, Georgiadis J, Marinas B, et al. (2008) Science and technology for water purification in the coming decades. *Nature* 452: 301–310.
- Mintz E, Bartram J, Lochery P, Wegelin M (2001) Not just a drop in the bucket: Expanding access to point-of-use water treatment systems. *American Journal of Public Health* 91: 1565–1570.
- Lantagne DS, Quick R, Mintz ED (2006) Household water treatment and safe storage options in developing countries: A review of current implementation practices. Woodrow Wilson International Center for Scholars. Environmental Change and Security Program.
- Arnal J, Fernandez M, Verdu G, Garcia J (2001) Design of a membrane facility for water potabilization and its application to Third World countries. *Desalination* 137: 63–69.
- Reed B, Reed B (2011) How much water is needed in emergencies. World Health Organization. Available: http://www.who.int/water_sanitation_health/publications/2011/t9_how_much_water_en.pdf. Accessed 2014 Jan 14.



Cite this: *Analyst*, 2018, **143**, 2066

Post hoc support vector machine learning for impedimetric biosensors based on weak protein–ligand interactions†

Y. Rong,^a A. V. Padron,^a K. J. Hagerty,^a N. Nelson,^b S. Chi,^{c,d} N. O. Keyhani,^d J. Katz,^e S. P. A. Datta,^{f,g} C. Gomes^h and E. S. McLamore^h   ^{*a}

Impedimetric biosensors for measuring small molecules based on weak/transient interactions between bioreceptors and target analytes are a challenge for detection electronics, particularly in field studies or in the analysis of complex matrices. Protein–ligand binding sensors have enormous potential for biosensing, but achieving accuracy in complex solutions is a major challenge. There is a need for simple *post hoc* analytical tools that are not computationally expensive, yet provide near real time feedback on data derived from impedance spectra. Here, we show the use of a simple, open source support vector machine learning algorithm for analyzing impedimetric data in lieu of using equivalent circuit analysis. We demonstrate two different protein-based biosensors to show that the tool can be used for various applications. We conclude with a mobile phone-based demonstration focused on the measurement of acetone, an important biomarker related to the onset of diabetic ketoacidosis. In all conditions tested, the open source classifier was capable of performing as well as, or better, than the equivalent circuit analysis for characterizing weak/transient interactions between a model ligand (acetone) and a small chemosensory protein derived from the tsetse fly. In addition, the tool has a low computational requirement, facilitating use for mobile acquisition systems such as mobile phones. The protocol is deployed through Jupyter notebook (an open source computing environment available for mobile phone, tablet or computer use) and the code was written in Python. For each of the applications, we provide step-by-step instructions in English, Spanish, Mandarin and Portuguese to facilitate widespread use. All codes were based on *scikit-learn*, an open source software machine learning library in the Python language, and were processed in Jupyter notebook, an open-source web application for Python. The tool can easily be integrated with the mobile biosensor equipment for rapid detection, facilitating use by a broad range of impedimetric biosensor users. This *post hoc* analysis tool can serve as a launchpad for the convergence of nanobiosensors in planetary health monitoring applications based on mobile phone hardware.

Received 11th January 2018,

Accepted 15th March 2018

DOI: 10.1039/c8an00065d

rsc.li/analyst

^aAgricultural & Biological Engineering, Institute of Food and Agricultural Sciences, University of Florida, USA. E-mail: emclamor@ufl.edu

^bBiological & Agricultural Engineering, North Carolina State University, USA

^cInstitute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences; Key Laboratory of Microbial Resources, Ministry of Agriculture, Beijing, China

^dDepartment of Microbiology and Cell Sciences, Institute of Food and Agricultural Sciences, University of Florida, USA

^eDepartment of Oral and Maxillofacial Diagnostic Sciences, University of Florida, USA

^fMIT Auto-ID Labs, Department of Mechanical Engineering, Massachusetts Institute of Technology, USA

^gBiomedical Engineering Program, Department of Anaesthesiology, Massachusetts General Hospital, Harvard Medical School, USA

^hDepartment of Mechanical Engineering, Iowa State University, USA

†Electronic supplementary information (ESI) available. See DOI: 10.1039/c8an00065d

Introduction

Biosensors offer a rapid analysis of targets ranging from small molecules, to biomolecules or cells, and can be applied across a wide variety of planetary health applications in medical, agricultural and environmental analysis.^{1,2} With the advent of mobile phone electrochemical and plasmonic acquisition systems,^{3–5} the portfolio of biosensors used in applied field studies is rapidly expanding. Biosensor accuracy, speed, range and limit of detection are a function of the nature of the molecular interactions between target analytes and bioreceptor structures, the transduction mechanism, the inclusion of nanomaterials which enhance transduction, the type of detection hardware and acquisition approach (including *post hoc* analysis).

Among the various transduction approaches, electrochemical biosensors are one of the most popular device types,

and most current devices combine electroactive nanomaterials (*e.g.*, graphene, nanometal, electropolymers) with bio-recognition structures such as enzymes, antibodies or aptamers, among others.^{6–10} The use of transducer nanomaterials enhances signal acquisition, while the biological material is used to impart selective targeting and in some cases, catalyze a reaction.^{11–13} Impedimetric biosensors are most commonly developed based on Faradaic impedance (with a redox couple in solution), but label-free biosensors, using non-Faradaic impedance (absence of a redox couple), are increasing in popularity.^{14,15} In either case, the output impedance depends on changes in the interfacial electron transfer resistance and/or electrostatic repulsion that result from the steric hindrance caused by the interactions of the target and bioreceptor.^{16–18}

Interpretation of impedimetric biosensor data is often not trivial, particularly for fast electron transfer processes in nanomaterial-modified electrodes, non-Faradaic impedance or weak/transient interactions between bioreceptor and target. Impedance data are usually fit to an equivalent circuit model using χ^2 testing, and the parameters are derived from the model to describe the underlying electrochemistry. Changes in equivalent circuit parameters are commonly reported as sensor output, although impedance at a single frequency is occasionally used as sensor output.¹⁴ Equivalent circuit analysis is based on combinations of the Principle of Superposition, Ohm's Law and Kirchoff's Laws and is very accurate for simple electrode geometries with homogeneous surfaces. However, as circuit models are assumed *a priori*, there is not necessarily a correspondence between the circuit elements and the underlying physico-chemical processes.¹⁹ Furthermore, the inclusion of transducer nanomaterials on the sensor surface complicates the equivalent circuit model, requiring additional "fitting" elements. Thus, interpreting impedance data in complex solutions or with complex electrode geometries is challenging and is sometimes more art than science.²⁰ The main challenge for planetary health biosensors is to balance enhancing conductivity with transducer nanomaterials (improving the limit of detection) while limiting computational cost (maintaining speed), and at the same time developing simple label-free devices that can be used in diverse applications (ensuring robustness).

To improve the limit of detection, many labs coat electrodes with nanomaterials such as graphene and/or nanometal, which is known to significantly enhance conductivity and electroactive surface area^{21–23} while significantly decreasing charge transfer resistance (R_{ct}). This results in fast electron transfer processes, where Faradaic current is represented by a near-linear Nyquist plot. In a classic Randles–Ershler equivalent circuit, *post hoc* sensor analysis is usually constrained to R_{ct} , as other circuit parameters are a function of the solution resistance or inductance, which are not strong indicators of molecular interactions between bioreceptor and target analyte. This situation is particularly challenging for weak/transient interactions, where more complex circuit models with fitting

parameters are required, increasing the computational cost while producing output parameters that have no physico-chemical meaning in the electrochemical circuit. There is a need for simple *post hoc* analytical techniques that can be used for point of need biosensors, particularly for field applications.

Machine learning has emerged as a powerful *post hoc* analytical tool for a wide range of sensor applications, including flow cytometry,²⁴ electronic tongue/nose,^{25–27} wearable sensors,^{28,29} whole organism biosensing,^{30,31} protein detection,³² sensor material optimization,³³ food safety risk analysis,³⁴ environmental pollutant monitoring³⁵ and multiplexing sensor arrays.^{36–38}

Here, we present an open source machine learning algorithm applied for label-free biosensors based on weak/reversible interactions that can be used with common mobile hardware such as a mobile phone or tablet (Fig. 1). We first test the classifier for well-known binding interactions between proteins and DNA as a proof of concept. Next, we challenge the algorithm for classifying impedimetric data from a biosensor based on reversible interactions between a small molecule (acetone) and an insect-derived chemosensory protein. Acetone is an important biomarker in salivary diagnostics of diabetic ketoacidosis (DKA), which is a potentially fatal outcome from complications associated with diabetes. Rapid diagnostic tools are vital, as the overall mortality rate for DKA ranges from 1 to 10% of all patient admissions, and an even higher mortality rate is found among non-hospitalized patients and children under the age of 10.⁵⁹

The machine learning tool is based on Jupyter notebook (open source computing environment available for mobile phone, tablet or computer use) and the code was written in Python. For each of the applications we provide step-by-step instructions in English, Spanish, Mandarin and Portuguese to facilitate widespread use for a variety of applications. The open source tool can easily be integrated with mobile biosensor equipment for rapid detection, facilitating use by a broad range of biosensor users.

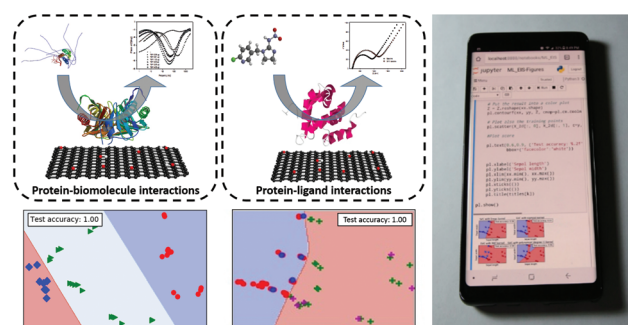


Fig. 1 An open source support vector machine learning algorithm was developed for analyzing impedimetric biosensor data. Interactions: we tested the tool for analyzing weak/transient interactions including protein–DNA, protein–protein and protein–small molecule. The cloud-based tool can be used for point of need applications with a mobile phone or tablet.

Methodology

Strains and reagents

The *Escherichia coli* strain Rosetta DE3 (Promega, Madison WI, USA) was routinely grown in Luria–Bertani broth (LB) and/or on LB-agar (1.5%) plates containing 50 $\mu\text{g mL}^{-1}$ kanamycin. All reagents and chemicals were purchased from Sigma-Aldrich (St Louis, MO, USA) or Thermo Fischer Scientific (Waltham, MA, USA) except as noted. Potassium ferrocyanide ($\text{K}_4\text{Fe}(\text{CN})_6$), potassium ferricyanide ($\text{K}_3[\text{Fe}(\text{CN})_6]$) and potassium chloride (KCl) were purchased from EMD Chemicals (Billerica, MA, USA). Ni- and Co-NTA agarose was purchased from Gold Biotech (St Louis, MO, USA). Thrombin was purchased from Amersham-Pharmacia Biotech (Little Chalford, UK). Polycrystalline diamond suspensions (3 and 1 mm) and alumina slurry (0.05 mm) were purchased from Buehler (Lake Bluff, IL, USA).

Electrochemical analysis

For all electrochemical analysis, a three-electrode system was used together with an electrochemical impedance analyzer (ERZ100, eDAQ, Colorado, USA). All electrochemical impedance spectroscopy (EIS) studies used Pt/Ir working electrodes (MF-2013, 1.6 mm diameter, BASi, West Lafayette, USA), Ag/AgCl reference electrodes (BASi, West Lafayette, USA) and platinum auxiliary electrodes (BASi, West Lafayette, USA) with nanoplatinum deposited as previously described.^{41,42} Before all experiments, the Pt/Ir working electrodes were polished with two sizes of polycrystalline diamond suspensions (3 and 1 μm), rinsed with methanol, polished with alumina slurry (0.05 μm) and then rinsed with deionized water. Probes were cleaned in a sonication bath in DI water for 15 min, then with 0.1 M H_2SO_4 using cyclic voltammetry (CV) at a potential range of -1.0 V to $+1.0$ V until the peak current changed by less than 1%, and then finally cleaned in a sonication bath in DI water for 15 min. To ensure consistency during adsorption studies, electrodes were fitted with a plastic cap that was 3D printed on a Makerbot Replicator 2 Desktop 3D printer (see the ESI Fig. S1† for specifications).

EIS analyses were conducted at 0.25 V (DC), with a 100 mV (AC) amplitude in the range of 100 kHz to 1 Hz in a solution with 2.5 mM potassium ferrocyanide ($\text{K}_4[\text{Fe}(\text{CN})_6]$), 2.5 mM potassium ferricyanide ($\text{K}_3[\text{Fe}(\text{CN})_6]$) and 100 mM potassium chloride (KCl). For equivalent circuit analysis, all EIS data were transformed to Nyquist plots and analyzed using ZMAN 2.2 software (WonATech, South Korea) or support vector classification analysis as noted.

Protein expression and purification

Recombinant insect chemosensory proteins (CSP) derived from *Glossina morsitans* (Gmm, tsetse fly) were heterologously expressed and purified from *E. coli* hosts using the methods described in detail by Song *et al.*⁴³ Briefly, GmmCSP3 sequences were identified from genomic databases, codon optimized for *E. coli* expression, and synthesized/cloned into a pUC vector (Genewiz, Plainfield, NJ). Expression constructs

were synthesized with a 10 \times -histidine (10 \times C terminal His) tag and transformed into *E. coli* host cells. A single colony was isolated *via* selection for ampicillin resistance on LB/ampicillin plates (100 $\mu\text{g mL}^{-1}$). Cells were harvested by centrifugation, washed with Co^{2+} equilibrium buffer and suspended in the buffer. Protein purification was achieved using Co^{2+} affinity chromatography and elution of the bound protein with increasing concentrations of imidazole as described in detail by Song *et al.*⁴³ The purity of the protein was assessed by SDS-polyacrylamide gel electrophoresis (SDS-PAGE) and pure fractions were pooled and dialyzed (3000 kDa) against buffer (20 mM HEPES, pH 7.5). Protein concentration was quantified with SDS-PAGE, and samples were frozen at -80 °C until used.

Expression and purification of TATA binding protein (TBP) and multiprotein bridging factor 1 (MBF1) from *Beauveria bassiana* have been described in detail previously.⁴³ Briefly, the coding sequences for both genes were codon optimized for expression in *E. coli* and synthesized (Genewiz) as above for the CSP proteins. Expression plasmids were transformed into competent *E. coli* Rosetta DE3 cells for expression and purification as above. Purified proteins were dialyzed, aliquoted and stored at -80 °C until use. After protein elution, purity was confirmed by SDS-PAGE. Protein concentration was determined using Pierce™ BCA Protein Assay Kit (Thermo Scientific).

PCR products were digested, and then cloned into respective sites of an expression vector to produce plasmids. Expression plasmids were transformed into competent *E. coli* Rosetta DE3 cells and transformed *E. coli* were cultured in LB broth, harvested, lysed and then purified using Ni- or Co-NTA agarose columns. Purified 10 \times His-tagged proteins were aliquoted and stored at -80 °C until used. After protein elution using imidazole buffers, purity was confirmed by SDS-polyacrylamide gel electrophoresis (SDS-PAGE) and protein concentration was determined using Pierce™ BCA Protein Assay Kit (Thermo Scientific).

Protein adsorption onto sensor surface and sensor characterization

For characterizing acetone–CSP interactions, the optimal CSP concentration from previous studies⁴⁴ was used for all testing. Briefly, 2 μL of His-tagged GmmCSP3 (9.23 mg mL^{-1}) was dropcast on the surface of an electrode, dried at 20 °C for 5 minutes and rinsed three times with DI water. A 5 mM acetone stock solution was prepared in DI water, which is representative of salivary acetone levels for patients with DKA.⁴⁵ Where noted, aliquots (2 μL) of acetone stock solution were dropcast on the surface of the biosensor, stored at 20 °C for 2 minutes and rinsed with DI water three times prior to testing.

For biosensors based on protein–biomolecule interactions, the concentration in each experiment was based on Song *et al.*⁴³ A 2 μL aliquot of His-tagged TBP was first dropcast on the surface of the electrode, agitated gently, allowed to dry at 20 °C for 5 minutes and rinsed with DI water prior to impedance analysis. Next, 2 μL aliquots of MBF1 (no His-tag)

or TATA¹ (a 40 bp DNA sequence containing two potential TATA motifs) was drop cast onto the TBP-functionalized electrode, dried at 20 °C for 5 minutes and then rinsed with de-ionized water three times prior to impedance analysis. Control experiments included using uncoupled (no TBP) surfaces as well as TBP-coupled + bovine serum albumin (BSA) solutions and TBP-coupled + TATA⁰ (a 35 bp DNA sequence lacking the TATA sequence in TATA¹).

Data analysis and statistics

EIS plots were analyzed with ZMAN 2.2 using an equivalent circuit model based on Chi² analysis. Equivalent circuit parameters, namely solution resistance (R_s), charge transfer resistance (R_{ct}), Warburg impedance (Z_w), double layer capacitance (C_{dl}) and constant phase element (Q) were estimated using Chi² fitting in ZMAN software.

Nyquist and Bode plots were generated with ZMAN 2.2 and several key values were extracted within the software from equivalent circuit analysis. Namely, the Nyquist plots with equivalent circuit analysis were used to extract R_s , R_{ct} , Z_w and C_{dl} from a Randles–Ershler equivalent circuit. Bode plots were used to extract the impedance at a given cutoff frequency and associated phase angle. In addition to the Randles–Ershler circuit, various equivalent circuit models (shown in ESI S5†) were tested with the model search function in ZMAN software where noted.

Support vector machine (SVM) classification

For protein–ligand interactions, EIS data were exported and transformed into samples with 152 features that represent both real and imaginary impedance at frequencies from 100 kHz to 1 Hz. The number of features was selected to satisfy expected confidence levels for principal components analysis. A total of 54 EIS scans were randomly split into two groups, with 80% of the data used as the training set and 20% used as the testing set. Each of the 54 datasets were binary labeled, with baseline impedance data in the absence of acetone labeled as “0”, and labeled 1 in the presence of 5 mM acetone. EIS data for both baseline (no acetone) and positive (5 mM acetone) experiments were standardized and transformed into a two-dimensional dataset, and then mapped in a new data space. To initially screen the data, the four most common types of SVM kernels⁴⁶ were used. A shuffled K-fold cross validation was used for all applications of SVM in this study;⁴⁷ the training dataset was divided into ten parts and shuffled, with 20% of the total data used for testing. The test accuracy shown for each kernel is the percentage of the prediction accuracy based on the decision boundaries.

Prior to running the SVM algorithm, principal component analysis (PCA) was applied through singular value decomposition (SVD) to reduce the 152 features to two principal components. PCA was used to reduce the dimension of 152 features in the raw EIS data to a two-dimensional principal components matrix. Depending on the number of components to extract, full or randomized truncated SVD was used; this procedure was performed in LAPACK.⁴⁸ To ensure generalizability

across other varied application-specific biosensors, code screens were prepared for four types of SVM kernels (linear, sigmoidal, radial basis function and polynomial) to identify which approach best segregates the training data. This feature of the open source algorithm allows the user to select the most appropriate kernel for a given analysis by comparing the cross-validation results across kernel types. SVM hyperparameters (C and γ) were optimized using grid search and random search methods.^{46,49} C is a tradeoff between misclassification and simplicity of the decision surface. γ is proportional to the radius of influence for selected support vectors.⁵⁰ All SVM codes were produced with “scikit-learn”, an open source machine learning library in Python⁵⁰ and were processed with Jupyter notebook, an open-source web application for Python (see the ESI† for step-by-step instructions in English, Spanish, Mandarin and Portuguese and Python code). Heatmaps were generated using the built-in visualization feature in scikit-learn (see the user’s manual for details).

To validate the functionality of the SVM classifier for a well-known detection system, a TBP–protein and TBP–DNA biosensor were fabricated based on published methods.⁴³ The biosensor is based on interactions between TBP and either multiprotein bridging factor 1 (MBF1) (protein–protein binding) or TBP and TATA (protein–DNA). His-tagged TBP was first adsorbed onto the electrode surface, and then EIS was used to study the interactions of TBP with either MBF (a 17 kDa protein) or TATA¹ (a TBP-binding 40 mer DNA sequence). As a control, EIS data were also recorded after the addition of buffer, a non-binding protein (BSA), and a non-binding 35 mer sequence (TATA⁰). To challenge the approach for the detection of small molecules, a CSP biosensor for detecting acetone was also developed. The experimental conditions were based on levels relevant to the diagnosis of DKA.

All experiments were repeated in triplicate, resulting in a total of 54 datasets. Analysis of variance (one-way ANOVA with Games–Howell method and 99% confidence) and Student’s t -test (two-sample t -test with 99.9% confidence) were performed for analyzing EIS data derived from equivalent circuit modeling as noted. All error bars represent the standard deviation of the arithmetic mean.

Results & discussion

First, the functionality of the SVM classifier was validated for a well-known detection system using TBP–protein and TBP–DNA based on Song *et al.*⁴³ This well-documented biosensor produces large changes in impedance after target binding and serves as a simple case study for the machine learning tool. The biosensor is based on interactions between TBP and either MBF (protein–protein binding) or TBP and TATA¹, a 40 mer nucleotide sequence containing the TATA motif that is the recognition sequence bound by TBP (protein–DNA). His-tagged TBP was first adsorbed onto the electrode surface, and then EIS was used to study the interactions of TBP with either MBF (a 17 kDa protein) or TATA¹. As a control, EIS data were

also recorded after the addition of buffer, a non-binding protein (BSA), and a 35-mer nucleotide sequence lacking the TATA motif (TATA⁰).

Representative Nyquist plots show that the adsorption of His-tagged TBP on the sensor surface caused a significant increase in R_{ct} , as expected (Fig. 2a). Binding between TBP and MBF also resulted in a significant change in charge transfer resistance, as did binding between TBP and TATA¹. A Randles–Ershler equivalent circuit ($\chi^2 = 1087 \pm 212$) was used to extract R_s , R_{ct} , Z_w , and C_{dl} for each experiment (see the ESI Table S1† for details). Similar to other manuscripts in the literature,⁵¹ R_{ct} was used as the most accurate parameter for characterizing protein–biomolecule interactions (Fig. 2b). For comparison, the addition of BSA or buffer did not result in any significant change in impedance due to non-specific binding (see the ESI Fig. S2†). EIS data were further analyzed by SVM classification by dividing the dataset into groups of TBP, TBP + MBF and TBP + TATA¹. Of the screened kernels, the linear type successfully classified each of the interactions (test accuracy = 100%) and was the simplest of the considered kernel types. Such accuracy was not surprising given the large change in R_{ct} for a protein–biomolecule interaction of this type. Results associated with the other common, but more complex, kernels and their optimization parameters are shown in the ESI Fig. S3–S4.†

The molecular interactions between TBP and MBF/TATA¹ shown in Fig. 2 can be viewed as between transient and permanent interactions.⁵² For these moderate to tight biomolecule

interactions, a basic Randles–Ershler equivalent circuit or SVM (linear kernel) analysis can be used to analyze the data. In the following section, we show that for the analysis of much weaker reversible protein–ligand interactions, equivalent circuit analysis is not sufficient and more complicated SVM classification must be used for accurate analysis.

Reversible protein–ligand interactions

To further challenge the machine learning tool, a CSP biosensor for detecting acetone at levels relevant for DKA triage diagnosis was developed and tested. DKA is a potentially fatal outcome from complications associated with diabetes, and accurate measurement of acetone is challenging. CSP is an excellent candidate for binding volatiles such as acetone, but to date, the technology has not been proven. *In vivo*, CSP solubilizes volatile odorants and facilitates transport to downstream odorant receptors (ORs) through reversible association/disassociation.^{39,40} This represents a model impedimetric biosensor based on interactions between low molecular weight binding proteins and small molecules. Biosensors based on CSP are becoming popular, but the transient ligand interactions and relationship to the underlying electrochemistry are not well documented. Protein size, surface charge, and the nature of any conformation changes/ligand displacement upon binding have not yet been described in detail, although CSPs in general are smaller than 15 kDa and the acetone levels critical to DKA (>5 mM) are below protein denaturing levels.

Representative Nyquist plots (Fig. 3a) and Bode plots (Fig. 3b) show that the adsorption of CSP onto the electrode caused a significant change in EIS spectra, but the change after the addition of clinically relevant acetone (5 mM) was less pronounced. Phase plots (see the ESI Fig. S5†) had similar behavior, with the most pronounced change in the phase angle at a frequency of approximately 1 kHz. A Randles–Ershler equivalent circuit was used to derive R_s , R_{ct} , Z_w and C_{dl} as previously described (Fig. 3c). In addition, net impedance at various cut-off frequencies was extracted from Bode plots (Fig. 3d). Using a 99.9% confidence level, there was no significant difference between baseline measurements and average R_s ($p = 0.015$), R_{ct} ($p = 0.002$), Z_w ($p = 0.016$), or impedance at any cut-off frequency ($p < 0.002$) after the addition of 5 mM acetone.

To further analyze the spectra, more complex equivalent circuit models were analyzed using ZMAN software with χ^2 fitting. All equivalent circuits with improved χ^2 fit (relative to Randles–Ershler) had more than four elements in various parallel/series connections, including at least one resistive element (R), capacitive element (C), constant phase element (Q) and inductive element (I) (see the ESI Fig. S6†). However, statistical analysis of the output parameters for these circuits also showed no significant difference in baseline and in the presence of acetone for replicate biosensors. Furthermore, there is no direct physical analogous biological structure to the constant phase elements (Q) produced by the model, further complicating the interpretation of the results and inducing bias on the interpretation. Two important factors that could

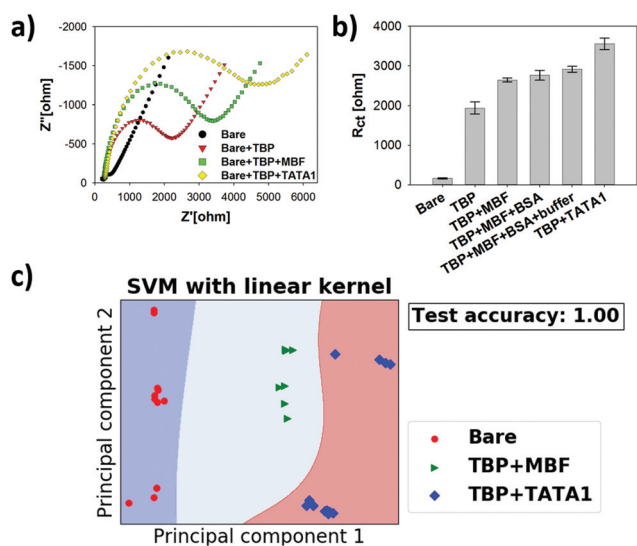


Fig. 2 Impedimetric biosensor for the detection of protein–protein or protein–DNA interactions. (a) Representative Nyquist plots for TBP–MBF interactions or TBP–TATA interactions clearly show an increase in charge transfer resistance after the addition of target. (b) Average R_{ct} derived from Randles–Ershler equivalent circuit model shows significant results for TBP–biomolecule interactions but no significant change after the addition of buffer or BSA (p values shown for each test group). (c) Support vector machine (SVM) classification results with linear kernel. Additional Nyquist plots, average charge transfer resistance and other SVM kernels are shown in the ESI.†

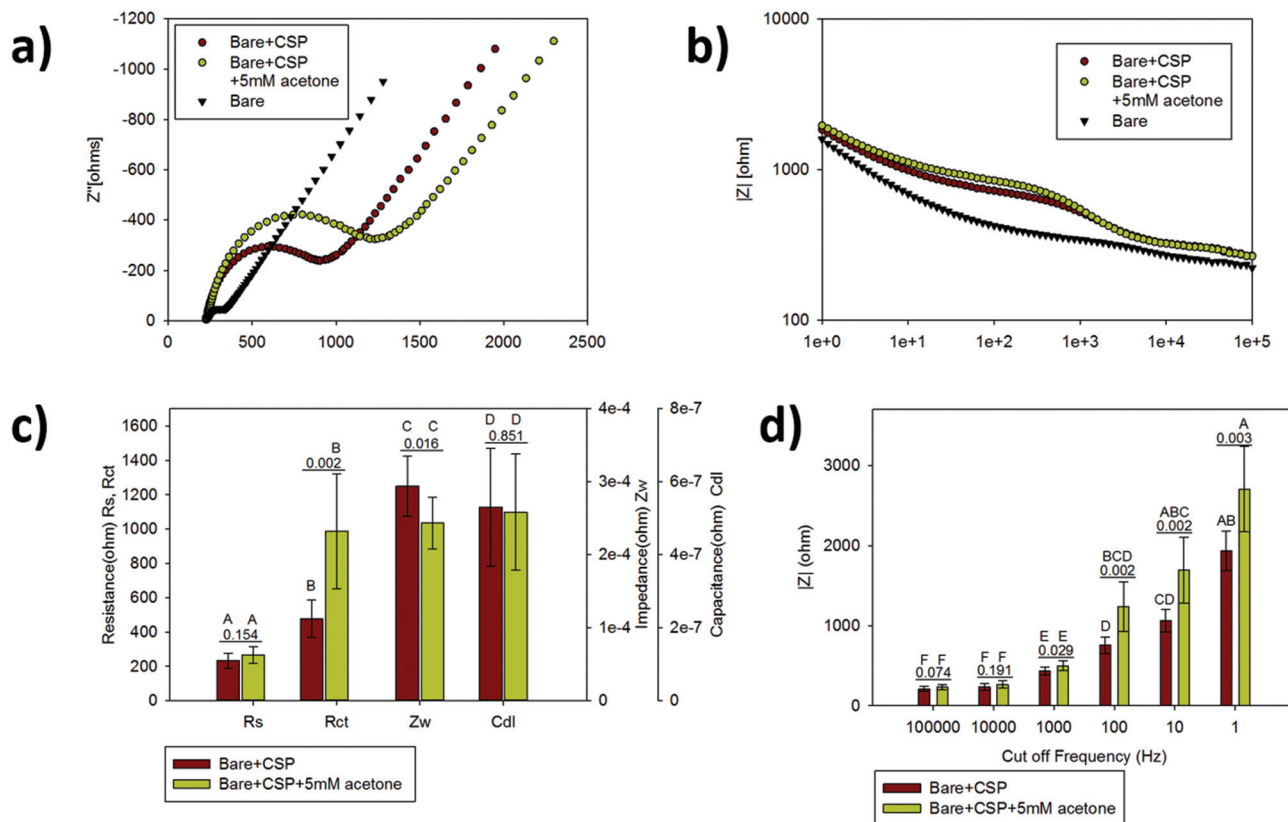


Fig. 3 EIS analysis of CSP–acetone interactions in the presence and absence of 5 mM acetone. Representative (a) Nyquist plots and (b) Bode plots. (c) Average parameters from Randles–Ershler equivalent circuit analysis (R_s , R_{ct} , Z_w and C_{dl}) from Randle's equivalent circuit, baseline data and EIS in the presence of 5 mM acetone. (d) Net impedance at representative cut off frequencies. In panels a, c and d, numbers denote the p -value and upper-case letters denote statistically significant groups.

lead to the lack of statistical significance in equivalent circuit parameters are the possibility of CSP conformation changes upon binding, or dislocation of the ligand. For this study, we assume that ligand dislocation is insignificant due to the relatively high concentration of acetone (5 mM), but a conformation change cannot be ruled out. While these acetone concentrations are significantly lower than denaturing conditions, the levels are high enough to possibly induce CSP conformation changes. Khabiri *et al.* (2013) have shown in other protein–ligand systems that the repulsion of water molecules from the first solvation shell of the protein causes polar amino acid side chains to be more rigid and less likely to interact with water (Khabiri, *et al.*, *J. Mol. Model.*, 2013, **19**, 4701–4711). More detailed studies are needed to understand the detailed interactions between acetone and CSPs, although in the next section we show that CSPs are a useful biorecognition structure for acetone detection when applying the machine learning tool developed here.

The case study in Fig. 3 represents a common issue in non-Faradaic impedimetric biosensing where the device is based on the interaction of proteins and small molecules. In such a case, the individual biosensor responds to the target analyte, but the variability of replicate sensors is high and an interpretation of results at relevant levels is challenging. This is particu-

larly true for weak/reversible interactions between small molecules and proteins where there is not an inherent reaction (as is the case for CSP–ligand binding). The CSP biosensor system is a promising biomimetic sensor system, but more accurate *post hoc* tools are needed for accurate detection of target biomarkers. As described by Liu *et al.*,⁵³ the underlying cause for this challenge is likely a result of the nature of CSP–ligand binding in sensors. Liu *et al.* showed that protein conformation change (backbone displacement) plays a major role in the electrical (Faradaic) properties of the sensor; this work was based on the honeybee protein Ac-ASP3. Since conformation changes can occur with non-specific interactions such as hydrogen bonding, CSP biosensors are subject to erroneous outputs due to non-specific interactions. To alleviate the false negative issue shown in Fig. 3, EIS data were further analyzed by SVM classification.

SVM classification for acetone–CSP interactions

The decision boundaries for each kernel are shown in Fig. 4, where testing data that fall into blue areas are predicted as negative (no acetone) and those that fall in red areas as positive (≥ 5 mM acetone). As discussed by Liu *et al.*,⁵⁴ other *post hoc* algorithms not analyzed here, such as random forest, may be more accurate in some cases. However, these approaches

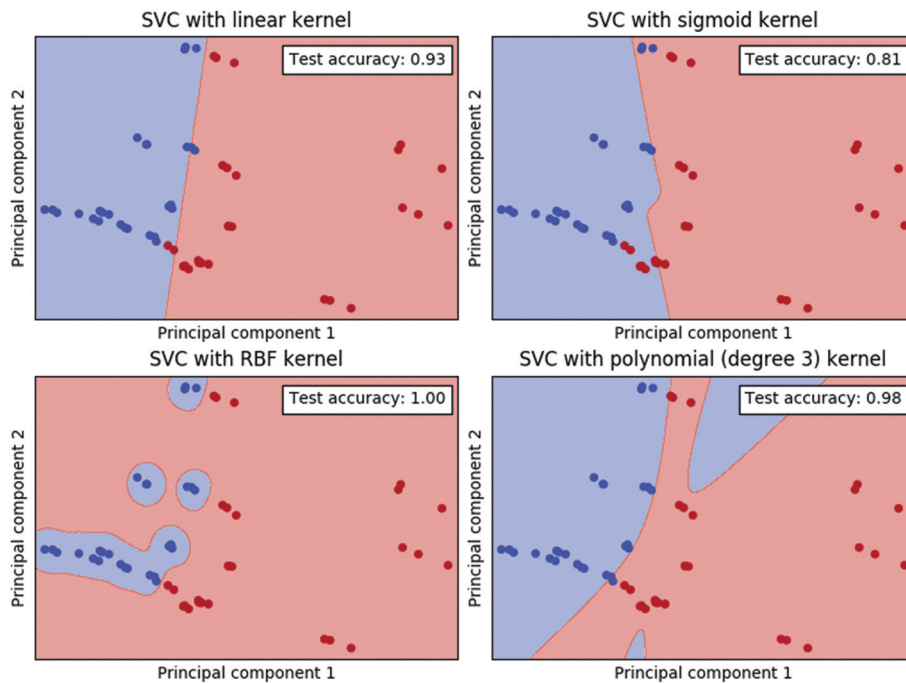


Fig. 4 SVM classification for CSP-acetone biosensors using four common kernels. (a) Linear kernel (test accuracy = 96%), (b) sigmoidal kernel (test accuracy = 83%), (c) radial base function kernel (test accuracy = 98%) and (d) polynomial kernel (test accuracy = 96%). Blue dots represent baseline EIS signals (no acetone in samples) and red dots represent positive EIS signals (5 mM acetone in samples). The decision surfaces of these four SVM classifiers are plotted by red and blue regions.

often increase accuracy by overfitting the data,⁵⁵ which ultimately decreases the robustness of the classifier. Moreover, many of these are computationally expensive and cannot be analyzed using mobile hardware such as a mobile phone or tablet. The Gaussian radial base function (RBF) kernel (accuracy = 98%) had the highest test accuracy for classifying the training dataset. However, using the default kernel settings, the dataset was not linearly separable and the RBF kernel had an overfitting issue, requiring further analysis and tuning of the parameters.

To tune the RBF kernel parameters, a grid search and cross validation were performed. In cross validation, the original dataset was shuffled and divided into ten different training and testing sets, with 20% of the total data used for testing. Next, each training set was used to fit the SVM classifier and average test accuracy calculated for each split training set. In the RBF kernel, the two governing hyper-parameters are the penalty parameter (C) and non-linear kernel coefficient (γ). The penalty hyper-parameter trades off misclassification against the simplicity of the decision surface, where lower C values tolerate more mistakes. The non-linear parameter defines the influence of a single training example on the output and can be seen as the inverse of the radius of the influence of support vectors.⁵⁰ Each of these parameters were optimized using a grid parameter search function using the RBF kernel (Fig. 5). In the top left panel of Fig. 5, where C is low, the penalty for misclassification is small and the decision surface is simple relative to the values in the first column with

higher C values. As the nonlinear hyper-parameter increases (from left to right in Fig. 5), the influence radius decreases, causing over-fitting. The protocol described herein resolves this issue by creating a visualization tool to select the optimum hyper-parameters.

The Python code has a built-in function to optimize the hyper-parameters from data such as that shown in Fig. 5. Based on this heat map (Fig. 6), the optimum value of γ was 0.01, and the optimum value of C was 10. Using these parameters, the Python code is then modified (see details in the step-by-step user guide) and the data are analyzed. Using the optimized kernel selection and hyper-parameters, the SVM demonstrated an accuracy of $95 \pm 4\%$ in cross validation and prediction of test samples.

Decomposition of high dimensional EIS data to two-dimensional data with PCA is known to improve sensor/detector accuracy due to the identification of uncorrelated variables from a large set of data.⁵⁶ PCA explains the maximum amount of data variance with the fewest number of principal components. For a semi-quantitative biosensor application such as the data in Fig. 1–6, the use of only two principal components can lead to loss of useful information during data decomposition. However, for the RFP kernel with optimal tuning parameters, the results were statistically significant at the 95% confidence interval. To further analyze the dataset, classifiers with 3 and 10 principal components were built and the cross-validation accuracy was improved ($97 \pm 3\%$), which is expected as less information was lost during decomposition (a 3D data rep-

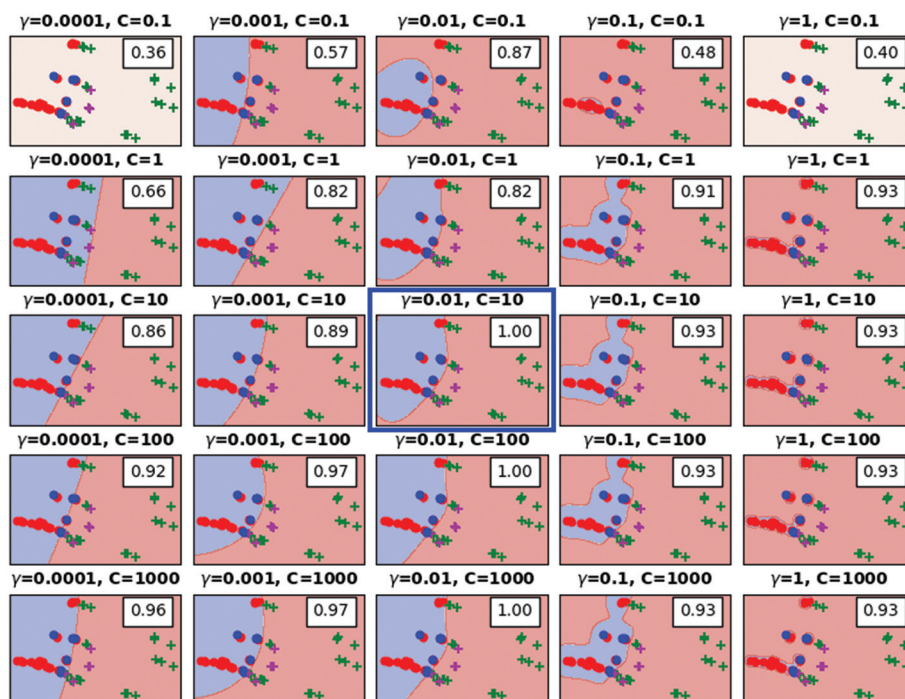


Fig. 5 Tuning of RBF hyper-parameters (C and γ) for CSP and acetone interactions. Representative SVM classification results for one training and testing set show the effects of parameters C and γ in the output of the RBF kernels. Red and blue circles represent the baseline samples in training and testing sets; green and purple plus symbols represent the positive signals in training and testing sets. The background blue and red region indicated the classifier decision surface, where all data fall into the red region are predicted as positive. Cross-validation scores are shown in the top right corner of each subplot. The optimal classifier zone is highlighted with a blue rectangle in the center of the image.

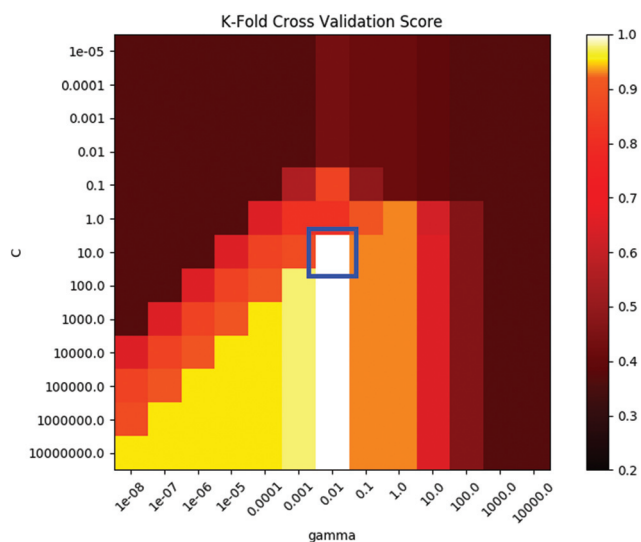


Fig. 6 Heatmap of validation accuracy as a function of RBF parameters C and γ . The color indicates the cross-validation accuracy, where lighter colors represent a higher cross-validation score. Optimal parameters are highlighted with a blue rectangle in the center.

resentation for data analyzed with three principal components is shown in the ESI Fig. S7†). This result was expected, as use of reductionist clustering (*i.e.*, using two-dimensional PCA) increases the risk of eliminating important outliers within the

data. For example, over-clustering could result in important deviations from the “normal”, for example, in the case of silent ischemia.⁵⁷ In this case, the data curation can be improved by analyzing polar coordinates in lieu of, or in addition to, Cartesian coordinates from impedimetric sensor data. However, analysis of classifiers with a dimension larger than two is computationally expensive, and this can make the use of mobile phone-based analytical systems challenging. Care should be taken to discern as to whether the computational need outweighs the ability to analyze data on site using mobile equipment such as a tablet or mobile phone. To maintain focus on mobile-enabled diagnostic systems in this study, we used a two-dimensional PCA analysis, which is valid for semi-quantitative biosensor data where a regulatory or diagnostic metric is known (such as the case of DKA salivary biomarkers shown here).

Although not used here, computational speed and memory requirement can be improved by using more advanced computational tools such as the tensor compiler by Kjolstad *et al.*⁵⁸ This approach is particularly useful for multidimensional data analysis, and provides a generic mechanism that can generate code for compound tensor operations with sparse tensors, eliminating the need for writing optimized code for a specific problem. This tensor algebra compiler library represents an excellent next step forward to improve the work herein.

The SVM tool shown here is highly useful for point of need small molecule analysis using mobile detection and analysis

systems (see the ESI Fig. S8†). Rapid triage analysis of breath disease state biomarkers is vital for triage analysis, and mobile phone solutions can bring this diagnosis to rural areas where healthcare is limited. Convergent technologies for triage diagnostics require systems-level solutions that are based on readily accessible hardware such as mobile phones or tablets.⁶⁰

Conclusions

Biosensors based on weak/transient interactions between small molecules and bioreceptors are a challenge for detection electronics, particularly in field studies or in the analysis of complex matrices (*e.g.*, body fluids, food, river water, *etc.*) using non-Faradaic impedimetric sensors. Support vector machine learning tools are facile *post hoc* analysis tools that do not require significant computational power and can be used for *in situ* analysis with mobile hardware such as a mobile phone or tablet. Here, we show the use of a simple, open source machine learning algorithm for analysing such impedimetric data, and we show that the tool can be used for point of need applications.

Conflicts of interest

There are no conflicts to declare.

Acknowledgements

The authors would like to thank the Agricultural & Biological Engineering PhD Fellowship (YR), the UF Opportunity Fund grant (ESM, NOK), the National Science Foundation Nanobiosensors program (ESM; Grant No. CBET-1511953, Nanobiosensing) and the China Scholarship Council Fellowship (CS; No. 201303250074). The authors thank Dr Diana Vanegas for assistance with the translation of the user's manual.

References

- 1 A. P. F. Turner, *Chem. Soc. Rev.*, 2013, **42**, 3184–3196.
- 2 A. R. Demaio and J. Rockstroem, *Lancet*, 2015, **386**, E36–E37.
- 3 D. Z. Ji, L. Liu, S. Li, C. Chen, Y. L. Lu, J. J. Wu and Q. J. Liu, *Biosens. Bioelectron.*, 2017, **98**, 449–456.
- 4 L. Liu, D. M. Zhang, Q. Zhang, X. Chen, G. Xu, Y. L. Lu and Q. J. Liu, *Biosens. Bioelectron.*, 2017, **93**, 94–101.
- 5 D. M. Zhang, J. Jiang, J. Y. Chen, Q. Zhang, Y. L. Lu, Y. Yao, S. Li, G. L. Liu and Q. J. Liu, *Biosens. Bioelectron.*, 2015, **70**, 81–88.
- 6 A. Hayat and J. L. Marty, *Front. Chem.*, 2014, **2**, 41.
- 7 D. Vanegas, C. Gomes and E. McLamore, *Biosens. J.*, 2016, **5**, 2.
- 8 A. Walcarius, S. D. Minter, J. Wang, Y. Lin and A. Merkoçi, *J. Mater. Chem. B*, 2013, **1**, 4878–4908.
- 9 A. Bonanni, A. H. Loo and M. Pumera, *TrAC, Trends Anal. Chem.*, 2012, **37**, 12–21.
- 10 T. Yin and W. Qin, *TrAC, Trends Anal. Chem.*, 2013, **51**, 79–86.
- 11 M. A. Daniele, M. Pedrero, S. Burrs, P. Chaturvedi, W. W. A. Wan Salim, F. Kuralay, S. Campuzano, E. McLamore, A. A. Cargill, S. Ding and J. C. Claussen, in *Nanobiosensors and Nanobioanalyses*, ed. M. d. C. Vestergaard, K. Kerman, I. M. Hsing and E. Tamiya, Springer, Japan, Tokyo, 2015, pp. 137–166, DOI: 10.1007/978-4-431-55190-4_8.
- 12 C. Z. Zhu, G. H. Yang, H. Li, D. Du and Y. H. Lin, *Anal. Chem.*, 2015, **87**, 230–249.
- 13 E. S. McLamore, M. Convertino, I. Ocsoy, D. C. Vanegas, M. Taguchi, Y. Rong, C. Gomes, P. Chaturvedi and J. C. Claussen, in *Semiconductor-Based Sensors*, WORLD SCIENTIFIC, 2016, pp. 35–67, DOI: 10.1142/9789813146730_0002.
- 14 J. S. Daniels and N. Pourmand, *Electroanalysis*, 2007, **19**, 1239–1257.
- 15 E. B. Bahadir and M. K. Sezginurk, *Artif. Cells, Nanomed., Biotechnol.*, 2016, **44**, 248–262.
- 16 M. I. Prodromidis, *Electrochim. Acta*, 2010, **55**, 4227–4233.
- 17 J.-G. Guan, Y.-Q. Miao and J.-R. Chen, *Biosens. Bioelectron.*, 2004, **19**, 789–794.
- 18 R. Elshafey, A. C. Tavares, M. Sijaj and M. Zourob, *Biosens. Bioelectron.*, 2013, **50**, 143–149.
- 19 D. D. Macdonald, *Electrochim. Acta*, 2006, **51**, 1376–1388.
- 20 M. E. Orazem, P. Agarwal and L. H. Garciarubio, *J. Electroanal. Chem.*, 1994, **378**, 51–62.
- 21 S. R. Das, Q. Nian, A. A. Cargill, J. A. Hondred, S. W. Ding, M. Saei, G. J. Cheng and J. C. Claussen, *Nanoscale*, 2016, **8**, 15870–15879.
- 22 W. J. Yuan, Y. Zhou, Y. R. Li, C. Li, H. L. Peng, J. Zhang, Z. F. Liu, L. M. Dai and G. Q. Shi, *Sci. Rep.*, 2013, **3**, 2911.
- 23 I. I. Suni, *TrAC, Trends Anal. Chem.*, 2008, **27**, 604–611.
- 24 H. Song, Y. Wang, J. M. Rosano, B. Prabhakarandian, C. Garson, K. Pant and E. Lai, *Lab Chip*, 2013, **13**, 2300–2310.
- 25 R. Kumar, A. P. Bhondekar, R. Kaur, S. Vig, A. Sharma and P. Kapur, *Sens. Actuators, B*, 2012, **171**, 1046–1053.
- 26 Q. Dong, L. Du, L. Zhuang, R. Li, Q. Liu and P. Wang, *Biosens. Bioelectron.*, 2013, **49**, 263–269.
- 27 L. Lu, S. P. Deng, Z. W. Zhu and S. Y. Tian, *Food Anal. Method.*, 2015, **8**, 1893–1902.
- 28 Y. X. Dai, X. Wang, P. B. Zhang and W. H. Zhang, *Measurement*, 2017, **109**, 408–424.
- 29 R. Matias, V. Paixão, R. Bouça and J. J. Ferreira, *Front. Neurol.*, 2017, **8**, 677.
- 30 Z. Qin, B. Zhang, K. Gao, L. Zhuang, N. Hu and P. Wang, *Sens. Actuators, B*, 2017, **239**, 746–753.
- 31 O.-P. Smolander, A. S. Ribeiro, O. Yli-Harja and M. Karp, *Sens. Actuators, B*, 2009, **141**, 604–609.
- 32 E. Akbari, Z. Buntat, E. Shahraki, R. Parvaz and M. J. Kiani, *J. Biomater. Appl.*, 2016, **30**, 677–685.

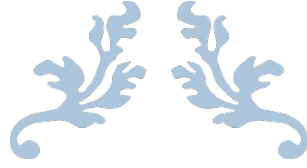
- 33 F. F. Gonzalez-Navarro, M. Stilianova-Stoytcheva, L. Renteria-Gutierrez, L. A. Belanche-Muñoz, B. L. Flores-Rios and J. E. Ibarra-Esquer, *Sensors*, 2016, **16**, 1483.
- 34 Z. Q. Geng, S. S. Zhao, G. C. Tao and Y. M. Han, *Food Control*, 2017, **78**, 33–42.
- 35 S. De Vito, E. Esposito, M. Salvato, O. Popoola, F. Formisano, R. Jones and G. Di Francia, *Sens. Actuators, B*, 2017, **255**(2), 1191–1210.
- 36 O. Sadik, W. H. Land, A. K. Wanekaya, M. Uematsu, M. J. Embrechts, L. Wong, D. Leibensperger and A. Volykin, *J. Chem. Inf. Comput. Sci.*, 2004, **44**, 499–507.
- 37 T. Alizadeh and S. Zeynali, *Sens. Actuators, B*, 2008, **129**, 412–423.
- 38 Y. Zuo, S. Chakrabartty, Z. Muhammad-Tahir, S. Pal and E. C. Alocilja, *IEEE Sens. J.*, 2006, **6**, 1644–1651.
- 39 R. G. Vogt, in *Comprehensive Molecular Insect Science*, Elsevier, Amsterdam, 2005, pp. 753–803, DOI: 10.1016/B0-44-451924-6/00047-8.
- 40 A. Sanchez-Gracia, F. G. Vieira and J. Rozas, *Heredity*, 2009, **103**, 208–216.
- 41 D. C. Vanegas, M. Taguchi, P. Chaturvedi, S. Burrs, M. Tan, H. Yamaguchi and E. S. McLamore, *Analyst*, 2014, **139**, 660–667.
- 42 S. L. Burrs, D. C. Vanegas, Y. Rong, M. Bhargava, N. Mechulan, P. Hendershot, H. Yamaguchi, C. Gomes and E. S. McLamore, *Analyst*, 2015, **140**, 1466–1476.
- 43 C. Song, A. Ortiz-Urquiza, S.-H. Ying, J.-X. Zhang and N. O. Keyhani, *PLoS One*, 2015, **10**(10), e0140538.
- 44 Y. Rong, J. Kieran-Lewis, N. O. Keyhani and E. S. McLamore, *Trans. ASABE*, 2016, 162460030.
- 45 S. Fujii, T. Maeda, I. Noge, Y. Kitagawa, K. Todoroki, K. Inoue, J. Z. Min and T. Toyo'oka, *Clin. Chim. Acta*, 2014, **430**, 140–144.
- 46 C. W. Hsu, C. C. Chang and C. J. Lin, A Practical Guide to Support Vector Classification. Technical Report, Scientific Research, 2003, pp. 1–12.
- 47 T. Hastie, R. Tibshirani and J. Friedman, in *The Elements of Statistical Learning: Data Mining, Inference, and Prediction*, Springer New York, New York, NY, 2009, pp. 219–259, DOI: 10.1007/978-0-387-84858-7_7.
- 48 N. Halko, P. G. Martinsson and J. A. Tropp, *SIAM Rev.*, 2011, **53**, 217–288.
- 49 J. Bergstra and Y. Bengio, *J. Mach. Learn. Res.*, 2012, **13**, 281–305.
- 50 F. Pedregosa, G. Varoquaux, A. Gramfort, V. Michel, B. Thirion, O. Grisel, M. Blondel, P. Prettenhofer, R. Weiss, V. Dubourg, J. Vanderplas, A. Passos, D. Cournapeau, M. Brucher, M. Perrot and E. Duchesnay, *J. Mach. Learn. Res.*, 2011, **12**, 2825–2830.
- 51 S. W. Ding, C. Mosher, X. Y. Lee, S. R. Das, A. A. Cargill, X. H. Tang, B. L. Chen, E. S. McLamore, C. Gomes, J. M. Hostetter and J. C. Claussen, *ACS Sens.*, 2017, **2**, 210–217.
- 52 I. M. Nooren and J. M. Thornton, *J. Mol. Biol.*, 2003, **325**, 991–1018.
- 53 Q. J. Liu, H. Wang, H. L. Li, J. Zhang, S. L. Zhuang, F. N. Zhang, K. J. Hsia and P. Wang, *Biosens. Bioelectron.*, 2013, **40**, 174–179.
- 54 M. Liu, M. Wang, J. Wang and D. Li, *Sens. Actuators, B*, 2013, **177**, 970–980.
- 55 T. Hastie, R. Tibshirani and J. Friedman, in *The Elements of Statistical Learning: Data Mining, Inference, and Prediction*, Springer New York, New York, NY, 2009, pp. 9–41, DOI: 10.1007/978-0-387-84858-7_2.
- 56 H. Abdi and L. J. Williams, *Wiley Interdiscip. Rev.: Comput. Stat.*, 2010, **2**, 433–459.
- 57 P. F. Cohn, K. M. Fox and C. Daly, *Circulation*, 2003, **108**, 1263–1277.
- 58 F. Kjolstad, S. Kamil, S. Chou, D. Lugato and S. Amarasinghe, The tensor algebra compiler. Proceedings of the ACM on Programming Languages archive, Volume 1, Issue OOPSLA, 2017, Article No. 77: 1–29.
- 59 R. Ganesh, N. Suresh and J. Ramesh, *Natl. Med. J. India*, 2006, **19**, 155–158.
- 60 R. Chiu, C. Ho, S. Tong, K. Ng and C. Lam, *Hong Kong Med J*, 2002, **8**, 172–176.

COMMENTARY [D]

Shoumen Datta

HAPHAZARD REALITY – IOT IS A METAPHOR

THIS PAGE IS LEFT BLANK



Essay by Shoumen Palit Austin Datta, Auto-ID Lab, MIT & MDPnP Lab, Massachusetts General Hospital, Harvard Medical School

UNLEASHING THE NEW WEALTH OF NATIONS



Global economic development through entrepreneurial “systems as a service” supply chain innovations

UNLEASHING THE NEW WEALTH OF NATIONS?

Global economic development through entrepreneurial “systems as a service” supply chain innovations

PREFACE

Economic growth and wealth creation was once exclusively a product based operation, through sale of goods (cattle, cars, planes, trains, parts). Today, it is also based on services. Economic growth through services, naturally, started with financial services¹, circa 1300.

In the 20th century, economic value from the use of “data as a service” was made possible by the creation of the Atanasoff-Berry computer² in 1942. Geographic limits on the export of knowledge was rendered agnostic, when the internet was publicly released by the NSF, in 1995.

In the 21st century, the information economy is still crawling, with 60% of the world not yet connected³ to the internet. Those who are connected⁴ may not have the necessary⁵ access.

Expert knowledge arbitrage, combined with data as a service, are major economic drivers, which is far from its utilization potential, in the US. Therein, lies vast opportunities.

Reasonable weather, low incidences of natural disasters, and basic infrastructure makes certain locations more attractive. Dynamic demographics, academic institutions and cultural liaison to large external markets, are other positive features, for the future of wealth creation.

INFORMATION AS A SERVICE EVOLVES TO SYSTEMS AS A SERVICE

Enterprise creation using advanced R&D generates jobs and economic growth. In the US and some OECD nations, we are eager to probe the bleeding edge. Hence, we aim to lead in robotics, aeronautics and astronautics, high value healthcare tools and similar high end, high margin, high profit, areas. This is welcome news but there is a lot of room left behind the edge!

Think about complementarity in business and strategy, ventures and entrepreneurship, innovation and necessity, systems and solutions. This suggestion is about massive economies of scale, where services are offered for low end, low margin, low R&D solutions, needed by 80% of the world, with the potential for sustained, long term, cumulative, mega profit, for providers.

This note is also about the evolution, from data and information as a service, suitable for OECD nations, to *systems as a service*, for the rest of the (80%) world. The latter demands answers, not numbers. Advanced tools and technologies are catalysts for advanced nations, where infrastructure and skilled resources exist, to *synthesize* the advances, generate solutions, and profit from outcomes. Developing economies (80% of the world) may lack the ability to deal with bleeding edge resources. Their solutions must be synthesized, seamless and integrated, to serve as functional systems. In other words, *outcomes* are preferred over gadgets, and widgets.

Hence, the advanced R&D paradigm, including data as a service (as a subset), is suitable for developed nations. But, immense business opportunities, revenue and “loads of money are left on the table” unless advanced strategies are complemented by parallel approaches. In this prong, solutions are synthesized to fit the ***context of the demand***, economic feasibility and availability of infrastructure.

Systems as a service indicates that “data as a service” is insufficient and must integrate ecosystems, to generate “systems as a service” in order to provide the solution, or the desired outcome. Data and information are a **part** of the solution, and information arbitrage may **still** be a source of profit, but **systems as a service** will be the source of the revenue.

Mobility of information, due to the internet, **where available**, induces unlimited potential for innovation and creativity to shape the “systems as a service” business model, by distributing the tasks, and generating pay-per-use revenue, from *each instance* or event.

There are no 800-lb gorillas (or sharks⁶) as the sole player, in the digital economy. It is a distribution, albeit, often, uneven, skewed and heteroskedastic. Co-creators of systems shall seek to profit from sub-components or sub-sets of the system. Entrepreneurial innovation in systems integration may need access to the ecosystem of R&D, which, in turn, becomes a part of the solution, but, **within** the *systems as a service* paradigm.

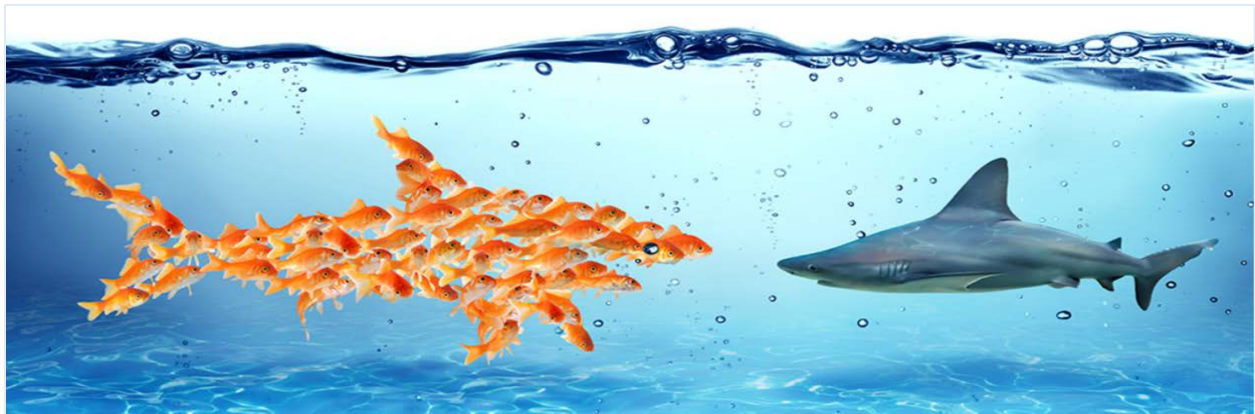


Fig 1: Service SCM - Systems as a service - whole is greater than the sum of the parts (ref 6)

Advanced R&D at the bleeding edge may be sequestered by the upper crust of the supply chain. But, pragmatic innovation can re-shape the outcome to serve the rest of the world, where the mega markets exist – excluding US, EU and JP (which represents 10% of the population).

The distributed digital pay-per-use service economy is a virgin territory. The US-EU *entente* balks at low cost services. The digital economy, catalyzed by the global internet, is the mobile medium, where service businesses can profit, slowly, not only for the lifetime of the product, but for the *lifetime of the customer*. Lifecycle management evolves from product lifecycle (1-10 years) to the lifecycle of the consumer (10-50 years). Is it a significant change?

The digital economy makes it possible to transform the paradox of a product-less world to a new paradigm, where products are leased as services related to the products. The product sale is a fee, not a final event. The service is always “on” and each instance of use, of the product, is logged in as a service, which in turn, generates micro-revenue, one event at a **time**. Billions of instances of pay-per-use, per day, generates trillions in earnings, **over time**. To profit from this paradigm, the focus must be on the business need of the billions. Hence, the complete solutions, through convergence, are more useful than high tech advanced R&D at the bleeding edge, alone.

The time-dependency of digital dividends, may suggest that time series econometrics⁷ may be a potential tool for exploring the digital economy using time series (lagged ? values) data as input⁸ for artificial neural networks, illustrated below. The roots of this line of thinking is not new and can be traced back to the seminal contribution by Sir Clive W. J. Granger (reference 7).

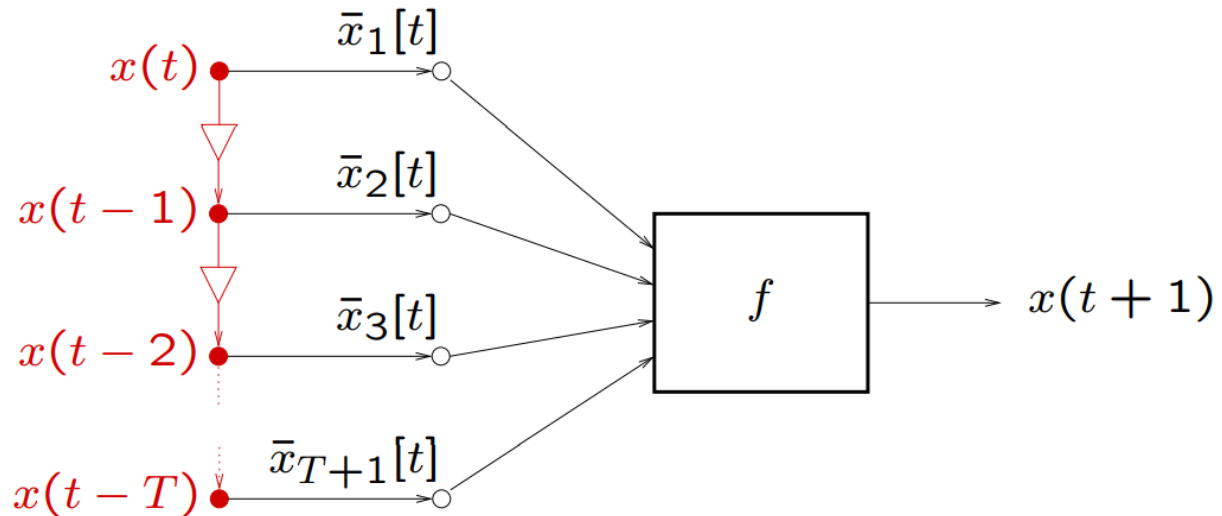


Fig 2: Artificial neural networks & time series econometrics - digital SCM - convergence of tools⁸

Time dependent profitability, from micro-payments, is not a new business equation. It is the underpinning of the 99 cent hamburger, in the American parlance. The digital economy has introduced a dynamic stream of “push-pull” mix of product and services. In this paradigm shift, we have not removed the product, but we have enabled digital transformation of the **business model related** to the product. We have made the product, and the associated service, a part of the **systems as a service** solution pack, using digital threads to track and trace deliveries.

In this model, earnings must be traceable to its lowest common denominator, which is the *pay per each use of each unit of service*. We aim to replace one time purchase of a product, or a block purchase of service (warranty) or block payment from customer (leads to customer unhappiness, fractured loyalty, lowered credibility, tarnished brand image, poor penetration). The granular reach of pay-per-use model was not feasible prior to the medium of the internet. Digital transparency in the digital enterprise can provide secure tools, to document the process of consumption, and related services, in order to charge for what is used, nothing more.

The systems integration necessary for pay-per-use business model demands tools and infrastructure. The latter may be beyond the capacity of the developing economies. This is where the advanced economies and forward looking states, can sow creativity, to coalesce the *systems as a service* model. Harvesting revenue from each customer touch point, from billions of users, creates immense potential for ethical profitability. These models can also work through public-private partnerships, if the providers are interested in both, profit and service of public goods.

Vision, and the application of internet based business tools, when coupled with R&D for products, and access to global ecosystems, creates the critical mass of synergy, which is the foundation of the *systems as a service* approach. New sources of revenue can be realized through local, and global, public-private partnerships and academic-industry joint ventures.

The solution may *contain products* which may serve in the geography where it is needed, thousands of miles away from its provider. But, the **service** link to the product in use, that is – data and information – will be linked to the business. Hence, local job creation. Businesses will profit each time its products or service is used, as a part of the *systems as a service* solution package, agnostic of its location. The data and information related to the service offers value. The value is embedded in the *systems as a service network*. If shared, this is the source of continuous revenue, for entrepreneurs, businesses, citizens and public-private partnerships.

This is the digital supply chain of data, from network of devices, enabled by connectivity, globally integrated, to provide *systems as a service*, as a **seamless solution** for the customer. Using jargon, unleashed by MIT in 1999, this is a part of the connected world of IoT, **internet of things**. The networked physical world⁹ is about making decisions about the state of atoms.

Decisions, the good ones, profitable ones, can make a great difference. The ubiquity of decisions (what to eat, wear, drink) makes us oblivious that data is constantly converged, to make decisions. If the decision is incorrect due to error in data processing, the outcome may be trivial or catastrophic or somewhere in between. If the parameters and volume of data is too many, and too large, then, humans may choose to use data processing tools and technologies. Automation, machine learning, artificial intelligence, optimization, predictive analytics and risk estimation are a part of this process. Our increasing reliance on tools has created opportunities for “time spoofing” or “infecting” our decision tools. Cybersecurity risk mitigation strategies may call for humans to be involved in key decisions, including digital supply chain, for critical commands. Therein lies the importance and need for “cognitive” tools¹⁰ to aid in the monitoring, supervision, and validation of **contextual** data, prior to execution of command(s) in a system.

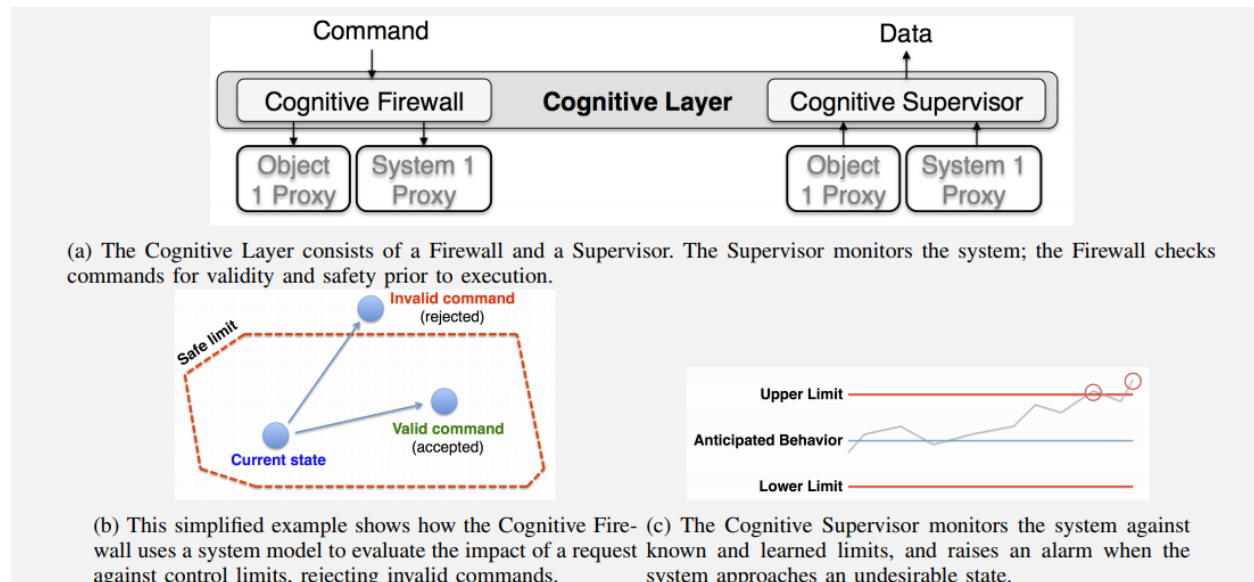


Figure 3: The ‘cognitive layer’ in the digital copy¹⁰ of the physical world - cognitive digital twins?

The digital copy of the physical world (referred to as digital proxy or digital duplicates or digital twins¹¹) may enable real-time visualization of data, metrics and analytics of machines and systems. The sense and response functions in “intelligent” operations may need humans in the loop for mission critical activities. Introducing “cognition” is a prudent cybersecurity measure and risk mitigation strategy. Cognitive monitoring and supervision ensures the decision system is “behaving as expected” and commands do not cause harm. The Data Proxy model [10] applies context information for monitoring faults and validates incoming commands prior to execution.

In the context of the current discussion to aid in improving 80% of the world, one begs to ask if data analytical tools, such as, machine learning, artificial intelligence, neural networks, and cognitive digital twins, are germane to the effort. The answer depends on what (objects, things, products) is at the “edge” of the networked physical world, what decisions we are trying to improve and who or what is involved in that decision process. 80% of the world is in need of answers, not numbers. But, without numbers one may not be able to deliver the “good” answers.

THE NETWORKED PHYSICAL WORLD

Data driven decision systems, if supplied with data, information and intelligent analytics, may make better decisions, perhaps more profitable decisions. But, these systems are not trivial, in terms of systems integration. It may need orchestrated performance from various ecosystems.

Whether it is a rice farmer in Saigon about to plant a rice seedling, or
a child about to drink water from a tap in Bogota, or
a house-husband in Dalian preparing to use electric appliances in the kitchen, or
a septuagenarian in Mysore using a sensor to estimate her blood glucose, or
a surgeon in Addis Ababa requesting a 3D-printed stent for coronary angioplasty,
it is all about decisions and data, which, when, and if, connected, is a **system**.

From Santa Clara, we can tell the farmer in Saigon if the conditions are optimum for planting the seedling. From Boston, we can warn the child in Bogota that the tap water contains more than permissible amounts of mercury. From Detroit, we can inform the house-husband in Dalian that it will be cheaper to use the electrical deep-fryer if he could cook the chicken after 630pm but before 8pm. From Miami, we can tell the patient in Mysore that her blood glucose of 140mg/dl is slightly elevated. From Atlanta, we can send the instruction set to the 3D printer in Addis Ababa for the surgeon to print the stent for the percutaneous coronary intervention (PCI).

Data and information from anywhere may serve local needs. Data can be transformed to information or products, globally. Mobility of the medium, the internet, enables *systems as a service* to offer solutions. If one provides a piece of this pie, one may earn a part of the revenue.

However small the profit may be, billions of pennies each day, can lift many boats. It is this piece of the global pie which can be harvested through the social business model. We need the network of tools, technologies, objects, processes and systems, as a part of our symphony.

Using your phone from Shropshire, UK you can call a cab to pick up your Mom from her home in Santiago, Chile. From Mumbai, India, you can order a pizza for a friend in Miami, FL.

This is the digital supply chain, made possible by reduction in **transaction costs**.

This is *systems as a service*. We connect atoms (things) to bits (data, information).

It may require bleeding edge R&D tools from research but must be connected to yield answers, which can penetrate any market, to provide actionable information and real solutions.

What are these systems or solutions most needed by 80% of the people in the world?

This is a business question and central to the global value network and supply chain.

It is not about drone taxi or robots flipping burgers or the pursuit of asteroid mining.

The quest for fundamental solutions needed by 80% of the world is focused and few.

It is a short FEWS:

F Food

E Energy

W Water

S Sanitation

I am inclined to make it FEWSH and add healthcare. FEWS may aid “prevention” and reduce the need for “correction” but, wear and tear of the human system, needs healthcare. This combination, FEWSH, of commodities, if served through the paradigm of *systems as a service*, presents new lines of business and scope of profitability, never imagined before. But, *systems as a service* is **not** a panacea for all solutions. Cumulative profitability from *systems as a service* is vast, one must remain vigilant about the norms of ethical profitability. To transform these ideas into reality, imagination, invention and entrepreneurial innovation must run in parallel with business creativity, to create global liaisons and penetrate markets where FEWSH is in demand.

There is no one clear approach to FEWSH. It will be a complex and dynamic ecosystem, where we must develop solutions in **collaboration with the markets**¹² where we intend to sell *systems as a service*. Markets must have some “skin in the game” because we need access, adoption and we must retrieve¹³ the data related to *accounting of use*, in order to profit from each granular event, and optimize the economies of scale. This is long term revenue planning.

This is uncharted territory. This is virgin space. This is the digital economy. The classical approach to advanced R&D works well for OECD but it is time to move out of the box. Tools and technologies are parts and components, awaiting integration, to generate a system, which will offer a function. The sum of the parts must be greater than the whole. When you want tea, you actually expect to receive a steaming cup of brewed hot tea. You don’t want an empty cup, a saucer, a spoon, an infuser, Darjeeling tea leaves, electric tea kettle, water, pot of milk, cradle of sugar, malted milk biscuits from Tesco or Fortnum and Mason.

The “whole” in this world, is about systems. Academia, industry and government, plays a critical role as the purveyor of knowledge and tools necessary to install the infrastructure, in order to provide the parts of the system. We profit from components but the **function** of the system, the **outcome**, is a symphony of **structures**, which is of value, if the product supply chain is seamlessly coordinated with the service supply chain, in a manner that the work flow is friendly for consumers, customers and end users. Hence, a **seamless systems as a service**.

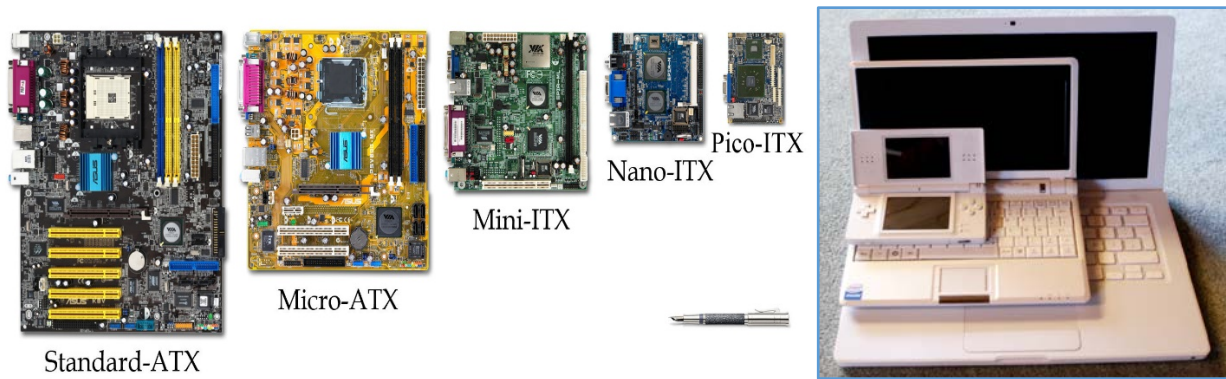


Fig 4: Advanced R&D products and components (structures¹⁴) are essential but not sufficient to create user friendly solutions (functions). End users may only pay if the “function” offers value.

INFORMATION ARBITRAGE

United States has exported knowledge at least since 1835, with the establishment¹⁵ of the American School for Girls, which is now the Lebanese American University in Beirut. The list of American Universities abroad has grown significantly.

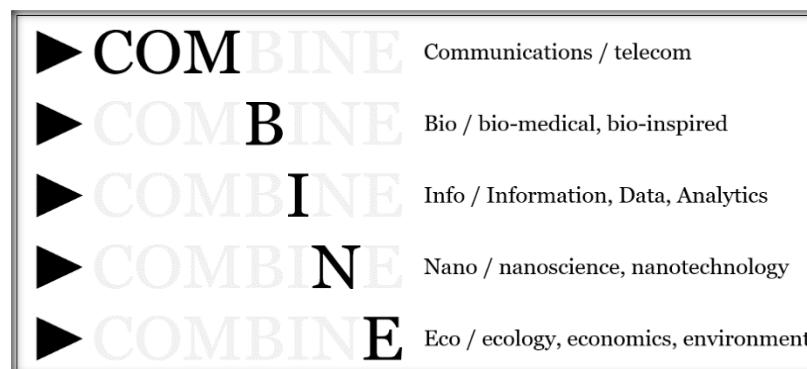
How many foreign universities do we have in the USA? Very few¹⁶, if at all we can label them as universities. The lack of name recognition and the astronomical cost of creating a campus in the US are probably the main deterrents. Can we attempt to change that equation?

Can we offer “data, information and knowledge” as the catalyst to encourage FDI and foreign universities to establish US campuses? How about King Saud University in Maryland, University of Jordan in Michigan, Cairo University in Boston, Qatar University in Oregon?

Can a similar approach work with China, India, Brazil? An IIT in Tallahassee, FL?

Why am I emphasizing the Middle East and the BRIC nations? Because we want to create and sell services, and the gigantic markets are in the Middle East, Asia and Africa. By co-creating some of the services with campuses in the US, we create a direct sales channel for entrepreneurs, to reach these vast markets. Perhaps we may also hold half the IP rights.

Co-creation, collaboration and cooperation are catalytic to create, open, new markets. Can we change the equation, challenge *status quo*, think global systems. Can we combine?



A FEW UNEASY WORDS FOR ACADEMIC DEPARTMENTS DEFINED BY DISCIPLINES? COMBINE, COMPLEMENTARITY, CONFLUENCE, COMMUNITY, AND CONVERGENCE

Convergence is the inescapable truth for systems and the gospel of *systems as a service*. The mantra of convergence meets with a flourish of *lippenbekenntnis* (lip service) but the vision to practice convergence and complementarity, *at the level of departmental operations*, is quite limited, to a select few elite institutions in the US, and even fewer universities in OECD nations. Perhaps this is at the heart of a disconnect. Perhaps it is a reason why we see so few clusters of entrepreneurial excellence and almost all talent trying to flock to such nodes.

Departmental operations managed by “installed” “tenured” leaders (chairs, search committees) are still drinking the same “cool aid” – chemistry department is for chemists, engineering faculty must have a PhD in engineering, management professors must have a business degree. This rigid attempt to preserve disciplines in departments to pursue “pure” and “credible” research is highly laudable, quintessential to the pursuit of knowledge, and required for excellence in science and engineering. This is ***not*** the problem. We ***must not*** dilute rigor.

The problem lies in the failure of departments not to unleash a parallel channel and embrace the view, that, systems and solutions require multi-disciplinary approaches, to solve problems in the real world. Acknowledging this fact requires that departments recruit, at the same ranks, people with non-formal degrees and out-of-the-box experiences as full time faculty members. The pursuit of these faculty members will be unconventional, cannot be subjected to the “publish or perish” dogma¹⁷, they will venture out of the traditional set up, re-define the type of problems to be addressed. These faculty will liaise with other departments, break silos, cross pollinate with industry and reach out to end users, markets and the global ecosystem, at large. These activities may not bode well for departmental “object codes” and create discomfort for the traditionalists who are limited to papers, conferences and grant writing, as performance metrics.

The answer is ***not*** in this HBR article¹⁸ and certainly not about selling out to industry. The answer is far more complicated. It must balance workforce development and academic complementarity with industrial economic growth as well as the creation of new global markets. Cooperation, collaboration and community must share the grounds with economy, science and engineering. Basic research must be supported and the fruits, when possible, must serve society. The erudite faculty dedicated to building “pillars” must find a way to find and accept the need for a breed of people, in traditional departments, who will be building bridges, based on pillars. We must enable some people to see further, even if it is by standing on the shoulders of giants¹⁹.

Institutional lethargy to institute change and embrace convergence at the operational level, runs parallel to the resistance for change for local and state governments entrusted with economic and workforce development. City, county and state economic development offices are staffed with public relations and communications people, generally. Occasionally business experts are in the mix with lawyers occupying the leading roles. Academics, scientists and knowledge resources are few, if any. In the management of state and federal economic development, the old adage²⁰ may still ring true, *scientists on tap²¹ but not on top*.

Hence, a chasm between knowledge (institutions) and workforce silos (economic development agencies) fails to catalyze the bridges essential for cultivation of symbiosis.

The hype about jobs of the future²² and the traditional²³ view of the future²⁴ are, ultimately, somewhere²⁵ bounded²⁶ by demand, on one hand, and remuneration, on the other.

The task of economic development is to create a supply chain of talent, skills and training, to feed the expected demand for labor. SCM is not only about logistics and returns.

The task of the institutional machinery is to inculcate students, in the pre-college pool, with the foundation that the colleges can build upon, to feed the supply chain of talent necessary for economic growth. Supporting the gifted, identifying the outstanding, and the pursuit of excellence, is also the task of the university-research complex. Departments were created to undertake this task, but not be limited to that task. But, often, they are. Hence, the quagmire.

Building bridges is one solution to support excellence, while maintaining the ability to compete globally. The bridge between institutions and economic development agencies are crucial to our progress.

There must be “people” on both sides who can speak both “languages” and politically adept to navigate the bureaucracy, adroitly. In addition, these “people” must understand the broad spectrum of needs with respect to the community (demographics), economics of the business (industry needs) and disciplines (breadth of knowledge in science and engineering).

These are the “people” who are few and far between. Neither the departments nor the agencies are seeking these people – because they don’t belong in any one box which can be fitted to a “job” description. These people must be dedicated to the “mission” and not a job or a task. These people must do all that is necessary, break barriers, and help to lift many boats. These people must give credit to others, refrain from narcissism and believe in altruism. These people must be able to ‘connect the dots’ and convey their purpose with lucidity, dignity, and *humility*.

It is easy to list ideas, pontificate and hide behind platitudes. It is a difficult task to orchestrate knowledge systems, spur technical innovation, implement tools integration, stitch business models, and offer a “seamless systems as a service” to help people and serve society. I wish to provide an imperfect example. In a collaborative project, we published²⁷ a paper on how to construct ultra-low cost (3D printed) nano-dot sensors to detect mercury (Hg) in water, using a smartphone which runs an AI (artificial intelligence) based program. One key is the *ultra-low cost* of the sensors (which are also robust enough for metrics and measurements). This is a tiny drop in the ocean. But, if we could execute our vision of the “seamless systems as a service” then these ultra-low cost sensors and the smartphone detection system may save lives. The system can detect contamination (mercury, Hg) in drinking water and alert the end users.

Embracing the mission to enable science to serve society is fraught with financial challenges. Thousands of life-saving sensors never escape the lab and their potential withers in publications. The description of “World Sensor Organization” in Commentary C is an idea²⁸ which few may grasp in terms of its immense global impact and even fewer may wish to support. Society may need new organizational structures to stitch the vision of connectivity, and service for citizens, in a manner that is economically prudent, sustainable and offers measureable value. Universities, public agencies, government and non-government organizations, are all important part of this ecosystem but none appear to be equipped or eager to lead this important charge.



Fig 5: Bridges are built on pillars: Ponte di Rialto and Ponte Vecchio by Antonietta Brandeis²⁹

3D PRINTING – THE BLESSINGS OF DIMENSIONALITY (THERE IS NO CURSE³⁰ HERE)

In our very small contribution (paper), the tool that enabled us to manufacture the low cost sensor was 3D printing. The technology is 40 years³¹ old, yet, its vast potential seems to be hovering around high end applications³² or facetious³³ consumer toys. In a separate article, I have discussed³⁴ a few thoughts on 3D printing in entrepreneurial innovation (Commentary B).

3D printing may be compared to lenses. The ability to “see” was transformed by lenses³⁵ and in the 17th century³⁶ Anton van Leeuwenhoek (1632-1723) made his “microscope” using a lens. After 400+ years, in the 21st century, we may be going further and forward (?) to a new state of lenslessness³⁷ which promises even more wondrous insights. It is likely to foment a new form of a revolution, for good. 3D printing possess all the ingredients for a revolution, too.

Total knee arthroplasty was first performed nearly 50 years ago³⁸ and knee/hip joint replacements are a part of our modern vernacular. Vast advances in implants, joints, prostheses, are helping people, worldwide, albeit far more in the advanced economies (OECD). The hyper-inflated cost of material combined with ultra-precision manufacturing costs, may make it less affordable to about 80% of the world, who are not a part of the OECD nations.

Can 3D printing bridge this chasm between haves and have-nots, partially? What if 3D printers and materials (alloys, powders) were provided to hospitals or clinics, globally?

The business model may be a portfolio of tools in order to lower the barrier to entry into markets. What if there was a minimal set-up cost, as a down-payment, and then a “pay-per-use” *modus operandi* to charge for each unit of time the 3D printer was used?

The paradigm change is in the business of the product as a service, in this case the product is not only the stent or the hip joint but also the 3D printer. The hospital or clinical may not have to seek capex funds to afford the printer. Micro-payments may transform equipment installations from the capex (capital expenses) column to the opex (operating expenses) domain. The latter may better serve resource-constrained organizations, often held hostage by cash flow.

Are 3D printer manufacturers dictating surgical implants? Not at all. It is the reverse. Surgical implant manufacturers are going to evolve as 3D printer manufacturers, too. The old school investment / sand casting manufacturing of metal products (implants, etc) in a few locations (company manufacturing locations), may be partially replaced by 3D printing, by supplying 3D printers to hundreds of locations, globally distributed, on-demand manufacturing.

In the new business model, for old surgical implant manufacturers, *data will be the salt*.

Precision manufacturing, for material science, is not really precise for physiology or orthopedics or cardiology, it is an approximation to minimize discomfort. In many cases, it is a statistically “average fit” for implants, joints and prostheses. 3D printing may reduce the need for the “one-size-fits-all” approach necessary for mass manufacturing. 3D can deliver precision fit for every individual, when necessary, if feasible. In the new business model (for old surgical implant manufacturers), data from imaging will design the “fit” required for that individual.

The imaging data will be at the location of the patient (assumption - location is equipped with imaging equipment). Imaging data will be transmitted to the company (for example, Bio4D in Cambridge, MA). 3D design experts, orthopedic specialist, neurosurgeons, software experts and engineers can use the imaging data, to create, modify or change, the dimensions of the product (stent, joint, etc). The material specifications (alloys, powders) and the instruction file for the 3D printer, for 3D printing the personalized precision part, will be transmitted to the 3D printer, at the location of the patient. The part will be 3D printed and used by the medical team, attending the patient (assumption – printed part does not need any specialized or rate-limiting pre-processing step or cellular treatment which may be unavailable at the location of surgery).

The surgical parts business of Bio4D (for example), remains the same – still providing implants, joints. But, in this highly distributed manufacturing on-demand model, the company has extended its ecosystem and owns a new line of business which provides 3D printers, and perhaps also inks an IP agreement for the 3D printer alloy powder, with innovation labs in material science, and instrumentation for co-creating the specs for the alloy to be used for parts.

However, the ecosystem for Bio4D does not stop at printers and powders, it also holds the **data** from [1] patient imaging and [2] the algorithms and software necessary to turn that data into a precision fit for the required 3D printed part. The raw data from the patient may still belong to the patient or the hospital of origin. But Bio4D can own, or reserve the right to license, the **processed data** which is created by Bio4D, through convergence of imaging data with software for 3D printing. The **data set** (instruction) for printing the part which is transmitted to the 3D printer (at a remote location), is a part of the business revenue for Bio4D in terms of the digital economy, or knowledge economy or health information (whatever jargon may apply).

The combination of these strands of revenue demands new business models. Traditional pay-for-product and pay-for-service schemes may not be the only tool. Pay-per-use and its variations, may be complementary mechanisms. Micro-payment strategies may stay in place for the life cycle of the user. The latter may be 10-50 years, depending on post-operative longevity.

If the cost of **implant-as-a-service** was priced at \$1 per day, as long as the person is alive, then for a 10 year life cycle, the service³⁹ will earn \$3,650 or if it a bigger part⁴⁰ (for example, knee or hip joint), charging \$10 a day generates \$36,500 as gross earnings, per item, per patient, for a 10 year post-operative use. In addition to per part revenue, there will be revenue from use of 3D printers, per use, over the life cycle of the engagement with the hospital or clinic. By reducing the burden of upfront fees, one increases market penetration for services.

GOING BACK TO THE BLEEDING EDGE

Vilfredo Pareto (1848-1923) published his first work, *Cours d'économie politique* (1896–97), where the 80/20 “rule” (Pareto Principle) was used⁴¹ to represent various distributions of land and wealth, in Italy. We have used this 80/20 rule to claim that untapped economic growth from the 80% of the world’s population, may not need all the accoutrements from bleeding edge R&D, in order to provide a plethora of services to improve the quality of life and living, globally.

The 20% of the affluent world, funds inventions and innovations. Polarization (Fig 6) of wealth is a gigantic problem yet some of these individuals are investors pushing forward the boundaries of science and technology. In our example of 3D printed parts, we discussed what may help 80% of the world. But, *much more* can happen in the context of 3D body parts. But, it will need massive investments, experiments and trials, before an approved development may become a **feasible** part of the future of 3D printed parts, for the less affluent global citizens.

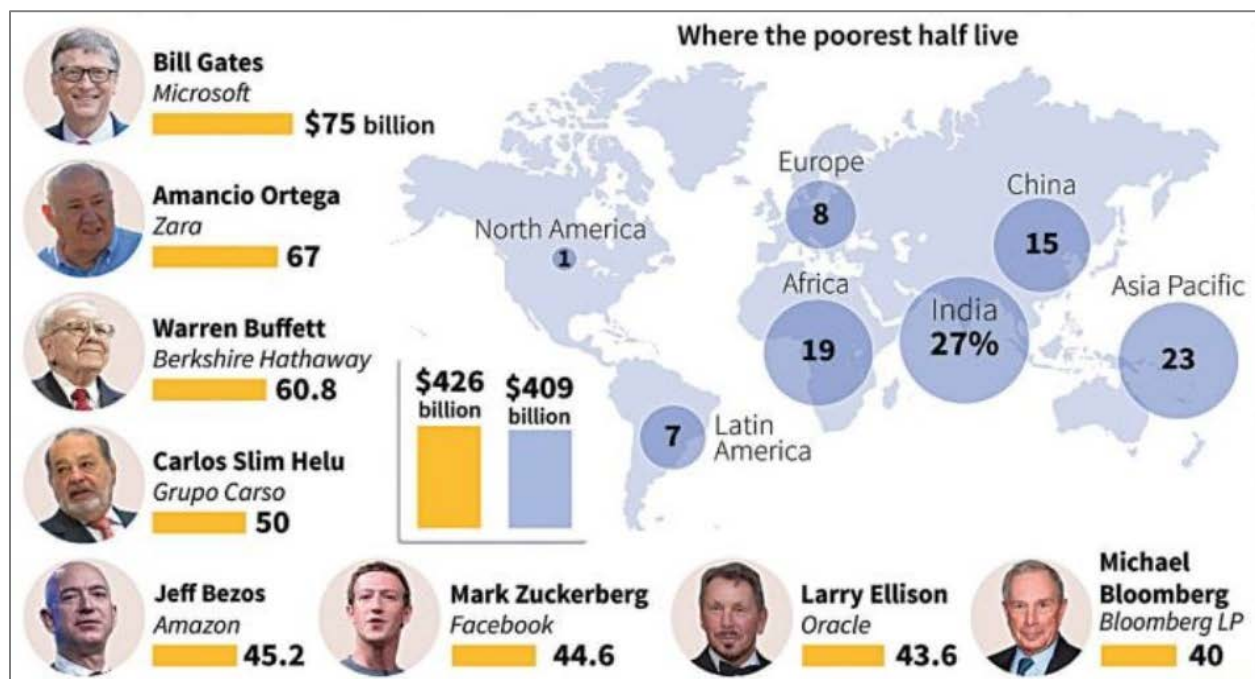


Fig 6: Eight men, own more wealth than the poorest half of the world’s population⁴² according to calculations⁴³ from Oxfam based on a 2017 report⁴⁴ from Credit Suisse. Jeff Bezos cracked \$150 billion on July 16, 2018, but remains shy of \$151.5 billion, the combined Walton family fortune.

Flexibility and precision due to 3D printed body parts may enable the use of 3D printed implants to act as Trojan Horses⁴⁵. For example, stents filled with drugs⁴⁶ or stem cells or joints with internal sensors, printed polymer⁴⁷ electronics, tunable radiofrequency communications⁴⁸ and nanotube radios⁴⁹. Using data from implant-sensors, the delivery service of drugs, cells and analytes, *in vivo*, on demand, may be remotely controlled using RF communications network ***in*** the body, in partnership with analytics, systems and humans-in-the-loop, ***outside*** the body.

A perusal of references 43-46 (above), will reveal that these ideas, and papers, are more than a decade old (in some cases, 20 years old). The self-adjusting hip joint using a smartphone to “sense” gait (provide auto feedback to the hip joint to adjust) is not impossible to deliver, for 20% of the world, who can afford to invest in the R&D and pay for the services. When will that service become feasible for 80% of the world?

The answer depends on the investors (in that 20% group) who must fund the bleeding edge R&D necessary to transform this idea into reality. If adopted by users, in the 20% group, the cost of the service may start to decline, over time. At some point, it may become affordable even for the people in the developing economies.

Hence, the need for individuals in the 20% group, to catalyze certain forms of progress, which may lift the lives of people, referred to as the 80% of the world.

COMMENTS and OPINION

In this example of economic development from the digital economy, I have focused on a tiny sliver, that of, the impact of 3D printing on replacement of body parts. It is not at all a new technology. The suggestion is not about advanced technical R&D, but the ***strategy*** of its use, aimed to offer healthcare ***solutions***, even for the developing economies (80% of the world).

What the 20% of the world can do, to further the R&D related to 3D printing, should not stop us from finding ways to deliver the help, we can, at this time. But, transformation is hard.

Transforming Bio4D, which mass manufactures surgical implants, to view the future of its business as “implant-as-a-service” is the business challenge. The ability to think outside the box, and “connect the dots” essential for the service ecosystem, is not an easy task. It requires vision, leadership and investment. Truth is, it also requires altruism, a dedication to the mission of improving lives, and a sense of the future, where credibility, *égalité* and dignity, are not just buzz words or platitudes but part of the corporate mission, which, of course, must also include profitability.

The global growth of new business offers immense potential for profit, albeit, over time, from micro-revenue. There may not be any instant financial gratification. There is an underlying need for establishing credibility through local and global partnerships. There is a need to serve as global ambassadors for health and healthcare, to lift many lives, bring hope to the hopeless.

Old world “industry” leaders chained to Wall Street may not “see” the future. Perhaps their imagination is out of focus, their vision may suffer from myopia or macular degeneration, and risk-averse strategists may insist that they keep within their well-defined comfort zones.

On the other hand, the “new” world is super-saturated with the high tech buzz, where creating an “app” can apparently escalate one to celebrity status on social media. Once on the pedestal of prosperity, the next step is to surround oneself with ultracrepidarian marketing staff. The reality of the bigger picture, pales, and fades, by comparison with the thrills from virtual reality (VR). High tech seems to be synonymous with high growth (Figure 7).

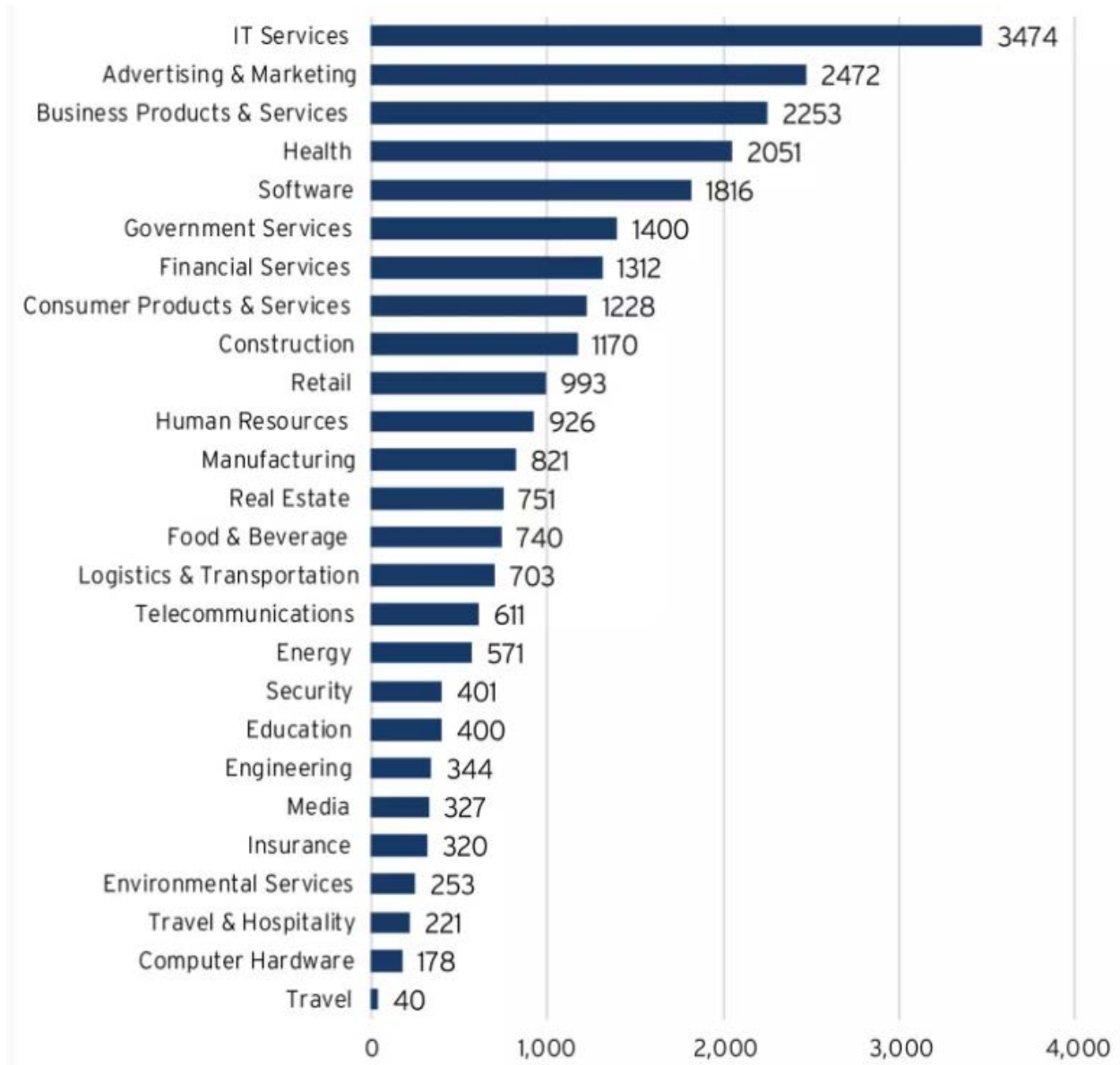


Figure 7: High growth company industries⁵⁰ in the US (2011-2017)

The suggestions in this simplified proposal can lead to global prosperity, albeit incremental in nature. It may be accomplished without any grand invention and vastly differs from the prediction of consulting pundits, according to the sales mantra shown in Figure 8. The need for safe drinking water, sewer systems, and managed sanitation services, does not even register on the “map” yet these are daily challenges⁵¹ for billions of people, in the 80% group.

- **2.1 billion people** lack access to managed drinking water services. (WHO/UNICEF 2017)
- **4.5 billion people** lack safely managed sanitation services. (WHO/UNICEF 2017)
- 340,000 children under five die every year from diarrhoeal diseases. (WHO/UNICEF 2015)
- Water scarcity already affects four out of every 10 people. (WHO)
- 80% of wastewater flows back into the ecosystem without being treated (UNESCO, 2017)

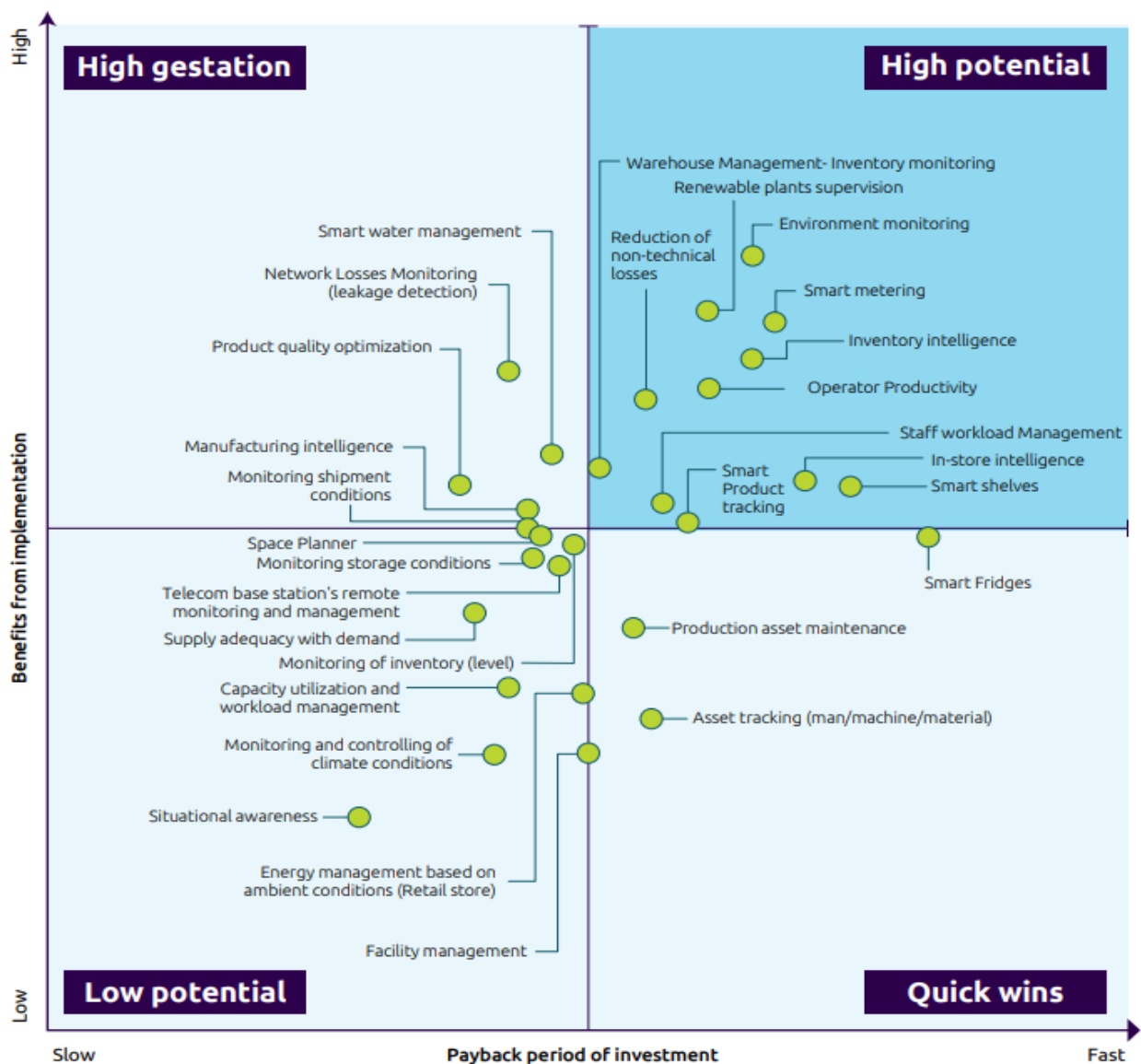


Figure 8: Use cases peddled by US consulting⁵² firms, indicates “smart fridges” as a quick win.

The (delusional?) choice of “smart fridges” by the consulting firm (Figure 8), points to a flawed vision: the failure to recognize efficiency as a function of the ecosystem. The “smartness” of a fridge is linked with identification of inventory in the fridge. The *retail supply chain of food* must offer tools for identification, recognition and communication of items, stored in the fridge. Slapping sensors or cameras inside the appliance is ***not a systemic answer***. The *systems as service* approach to a smart fridge is much more complex. It needs convergence of multi-tiered supply chains. It harks back to incorrect steps made by proponents⁵³ of RFID. The history⁵⁴ of general purpose technologies reveals similar mistakes made during the 1920’s in course of electrification in the US. However, “smart fridges” may be relevant to use⁵⁵ in OECD nations (20% group), but, even then, the business case remains extremely wobbly. The “smart” bubble is luring investments from developing countries (Fig 9). Is it mimicry or competition?

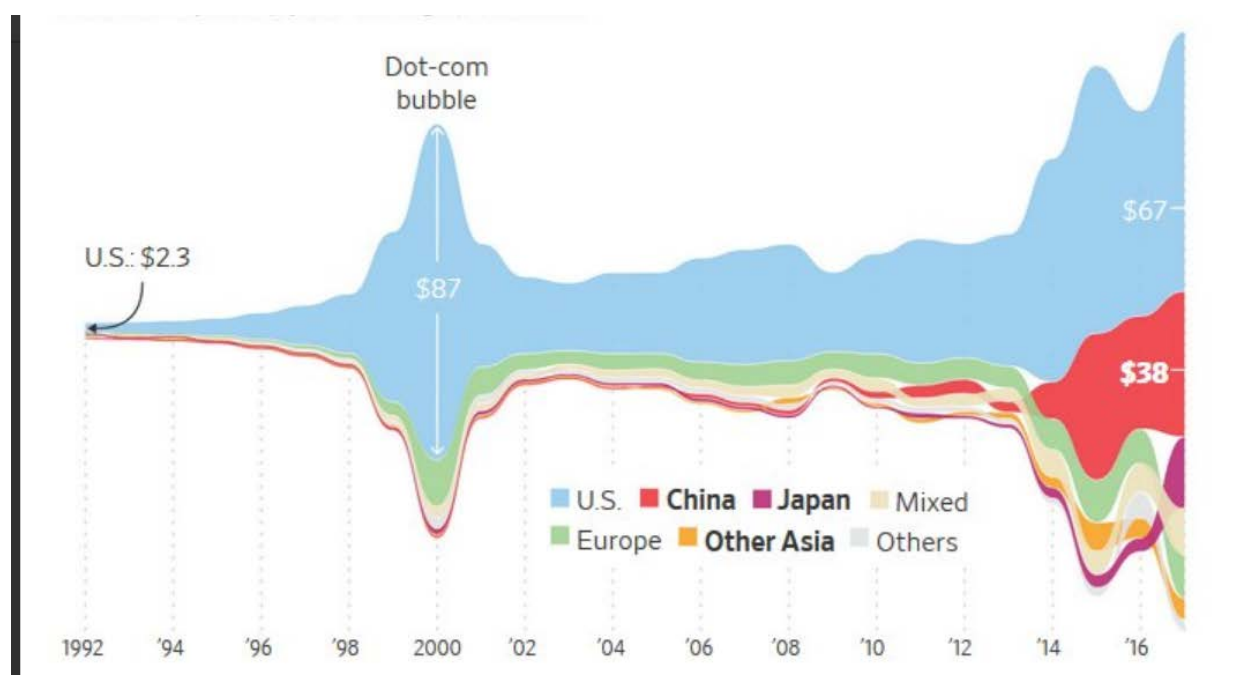


Figure 9: Venture Capital Flow, US\$ Billions. Source: Wall Street Journal Venture Source Data

Entrepreneurial innovation is a word bandied around in business conferences. Here, in this essay, we present examples calling for distributed and global entrepreneurial innovation for the rest of the world. We echo the renewed wake-up call by Jim Kim, President of World Bank, who admits⁵⁶, “*it is imperative we find new paths to prosperity. The traditional route to economic growth and job creation through industrialization is rapidly closing.*”

The convergence of ecosystems outlined in this suggestion is greater than the sum of its parts. The magnitude of its potential cannot be unleashed in little steps, small advances or short term thinking. Long term ROI is inextricably linked to economies of scale, and services, which can penetrate any market. The “heart” of this model is not a lab project or a “small” pilot test bed or an isolated experiment. One may not be able to build an elephant using the mouse as a model.

AFTER-THOUGHT

After reading an earlier draft of my “mindless drivell” (this essay), a teenager from a developing nation in SE Asia (daughter of a friend of a friend), send me a message via WeChat. She wondered if 80% of the world is just a “market” for the “systems as a service” businesses that 20% of the world may wish to develop (because “the 20%” have the R&D resources, human resources, and necessary investment, to stitch together the services and decision systems).

The first response to her question is that I really don’t know the dimensions and dynamics of how and who may create these systems as a service. Because, the **context of demand** must be relevant and specific to each market. Hence, it is my naïve assumption that these “services” must be **partnerships** where part of the R&D, tools and technologies may be from OECD nations but the human resources required for systems integration, deployment, and maintenance, is likely to originate from developing economies. Knowledge transfer, skills training, and workforce development, are central to the “shared” notion. Online education⁵⁷ may be a platform to facilitate dissemination.

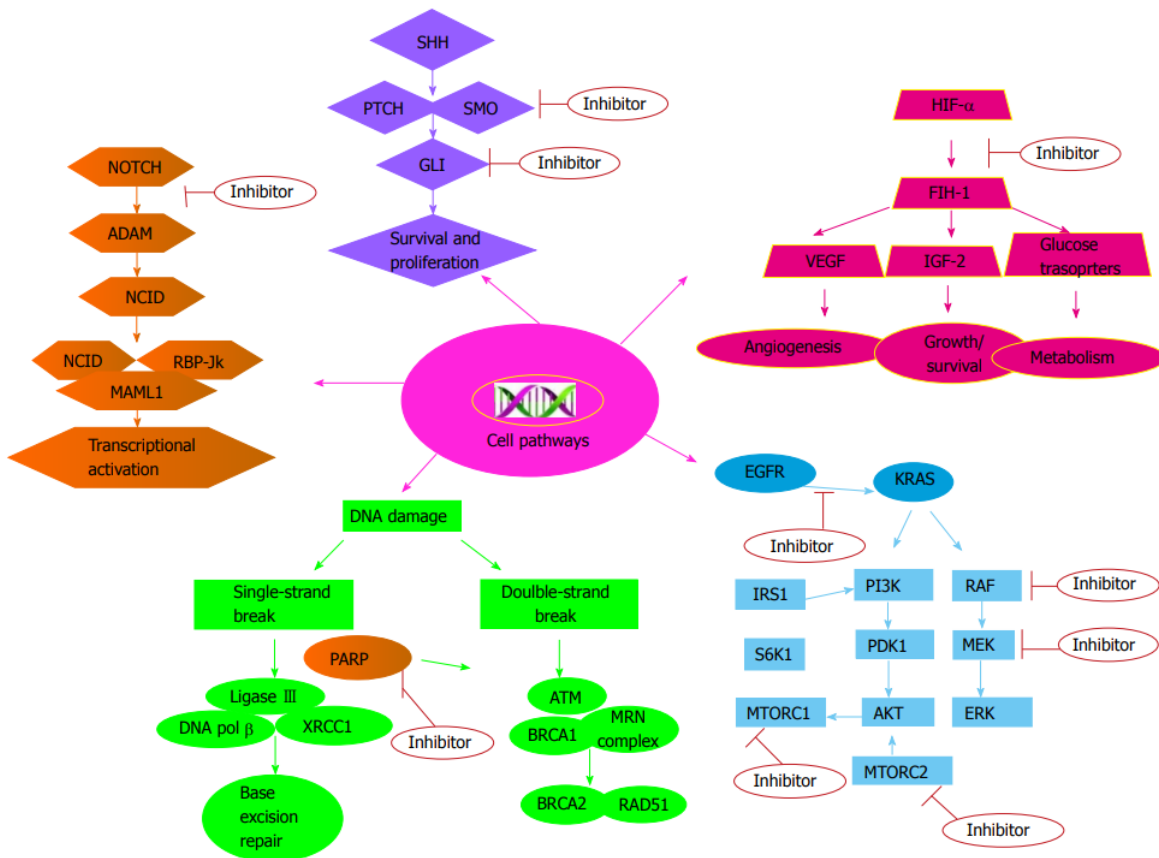


Figure 10: Cell signaling pathways involved in pancreatic ductal adenocarcinoma carcinogenesis and actionable molecular targets⁵⁸. Imagine the research necessary to scratch the surface of one type of cancer **system**. Scientists in developing nations must also ask the hard questions, which require peace of mind, infinite patience, and a sense of purpose, to use science to serve society.

However, there may be a deeper question, which remains unvisited. Where should the developing economies invest in terms of research? I am unequivocally unqualified to answer that question. But, the latter wouldn't stop me from making some suggestions, for example, malaria research (you do not have to agree with any suggestion, we can pre-agree to disagree).

The etiology of malarial diseases (which results in 2 million deaths per year) is a clear example of how parasites evade cellular immunity using antigenic variation⁵⁹ (*Plasmodium falciparum*, is responsible for about 90% of human mortality and morbidity, but over 200 species of *Plasmodium* are known to infect vertebrates). The almost exclusive occurrence of malaria within the 80% of the global population, mostly in non-OECD nations, makes it a target for eradication, by 80% of the world (rather than depending on initiatives from the 20%).

But, the 80% of the world cannot ignore the other afflictions, for example, cancer, diabetes, cardiovascular malfunctions and pulmonary diseases, to name a few. Which means, in the biomedical domain, the rest of the world must find ways to use therapeutic advances, for example, human induced adult pluripotent stem cells, plant based bio-pharmaceuticals, traditional biologics (monoclonal antibody producing autologous cells), metabolomic sensor networks (*in vivo* wireless communication networks monitoring analytes and transmitting data from inside the body), molecular robotics (ingested micro-machines removing intestinal polyps) and nano-machines⁶⁰ to target apoptosis⁶¹, precision cell death⁶² and time-based drug delivery.

Therapeutic **systems** have a long way to travel from the bench to the bedside. Business models focused on profit⁶³ and business school education, may be detrimental to the vision of convergence. Should we demolish⁶⁴ business schools? The business of translational medicine, as outlined in the above paragraph, may need a business model which values R&D partnerships.

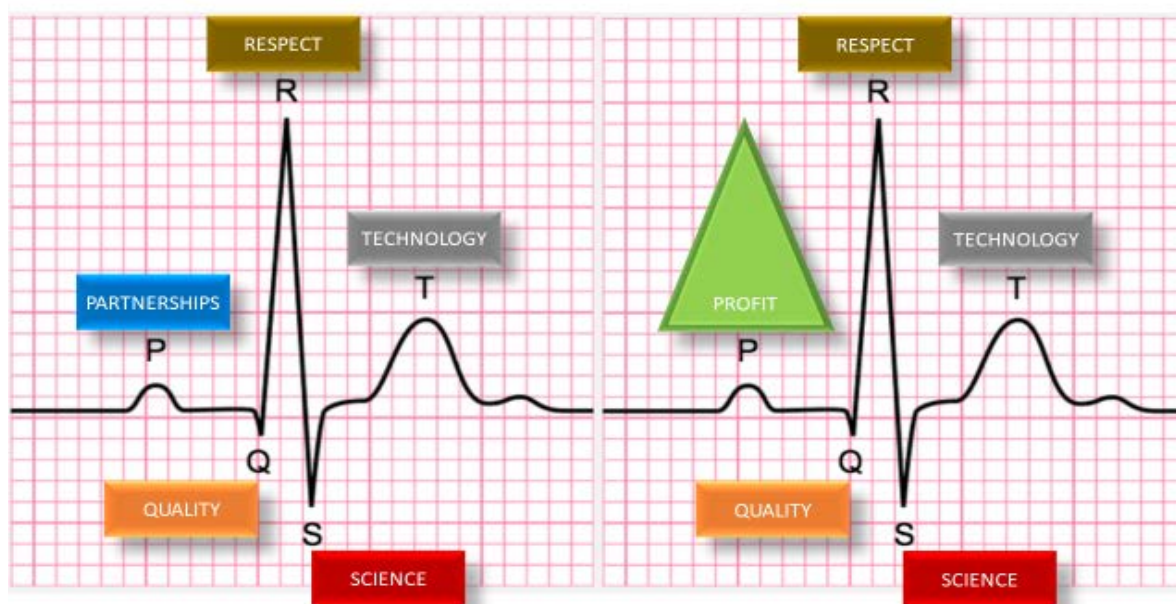


Fig 11: Profit from business value of partnerships may exceed profit from profit-driven business

The heartbeat of business, illustrated in Figure 11, may benefit from a slightly different perspective. Consider the basic PQRST waveform⁶⁵ telemetry, displayed as electrocardiograph, representing electrical impulses generated by the heart (transferred to electrodes on the skin, which in turn displays the waveform on a screen or prints out on a telemetry strip). PQRST may serve as a bio-inspired business guide, to draw attention to the push-pull dynamics between P for Profit (the business school mantra) and P for Partnerships (a sense of the future). The new path does not exclude profit. It maximizes profit. PQRST suggests the need for industry and businesses to structure partnerships, with other industries, academia, government agencies, and global organizations, to co-create, co-invent, co-innovate in order to co-opt markets, grow goodwill and profit from delivering a higher quality of service for society.

These and other suggestions for business and society, aimed at improving the quality of life, and living, shares a common denominator, irrespective of the wealth of the nations. The supply chain of talent may be the underlying primary determinant and the purveyor of progress for civilization.

In this context, one observes that the US has built a Taj Mahal on top of a wobbly base of rickety twigs. One may arrive at this general observation based on the near-abysmal quality of US public education in 80% of K-12 schools vs the rigor, creativity, excellence, and brilliance, in about 20% of US entities of higher education (research universities, institutions). Even a cursory glance at Figure 12 drives home the fact that is far cheaper to be entertained⁶⁶ in US, but very expensive to pursue higher education.

In this essay, one may find ample evidence of “see-saw” between **service as a system** for the 80% of the world and occasional discussions about the bleeding edge of R&D advances. There is no doubt we need **service as a system** but the origin of talent is agnostic of nations. The limited budget in developing nations may be judiciously used to strengthen academic foundations, to contribute to the global supply chain of talent. But, the affinity for STEM must not induce a phobia for funding humanities, languages, arts and music.

In research, developing nations must not be afraid to ask the hard questions, with long term value. Biomedical research is an essential part of FEWSH, as well as materials science, nano-satellites, energy storage and mathematics. These are preferred over programming, networking certifications, and serving as robots, in call centers. However, there is also a place for vocational education and apprenticeships. Fact is, there will never be an optimum one shoe fits all solution. It is always going to be a question of balance and priorities in order to remain competitive in the global economy without sacrificing the plight for decent standards of living, for all, with dignity.

Leaders, to qualify to be referred to as leaders, must possess incisive foresight, vision, and imagination. Business leaders, social pundits, and academic gurus, must all understand that humans need to belong, to be appreciated, and to be valued. Leaders must understand, that at the heart of civilization, at its PQRST core, lies an incontrovertible truth. The education of a boy may change the fate of a man, but, the education of a girl, may change the destiny of a nation.

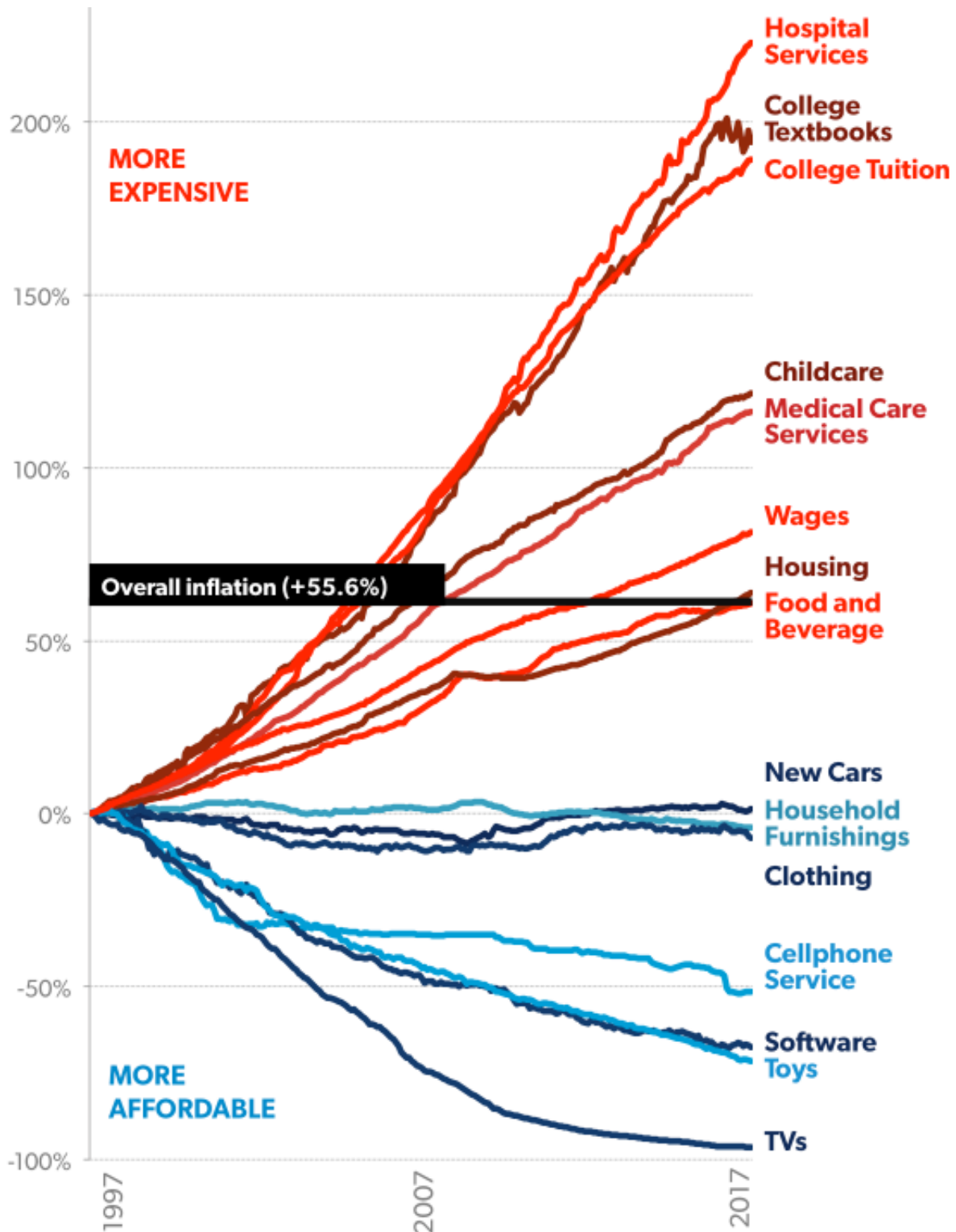


Figure 12: Changes since January 1997 in the prices of selected consumer goods and services. There is no dearth of cheap entertainment even for the minimum wage masses in the US but cost of higher education, and healthcare, may pose insurmountable barriers, or bankruptcy.

EPILOGUE

Progress depends on our ability to ask hard questions, and the correct questions, in context. Solutions from science and engineering must serve society. Hence, numbers, analyses and frameworks, are necessary but the best technology is the one where the outcome offers maximum value to the masses, but the tools used to achieve the outcome are invisible to the user, yet are ubiquitous in the environment of the user.

Herbert Simon, Harvey Sacks and other erudite visionaries⁶⁷ and groups⁶⁸ continue to discuss user engagement models, in one form or the other, perhaps, since the dawn of the so-called information age. But, we are still steeped in quandary amidst the quagmire of data versus the use of information, to address pragmatic issues. An analogous conundrum may be the public perception of teleportation. People assume, albeit erroneously, that we, the physical entity, may be transported from A to B in real time, no matter how far apart the points A and B, may be. In quantum teleportation, matter is NOT teleported. Instead, quantum information **describing matter** is teleported. Which raises the question: Are you the sum of your information?



Fig 13: Common misunderstanding: reflects a conundrum for science, data, service and society.

The most important criteria, in the context of science and engineering, as invisible yet ubiquitous tools, is to improve quality of life. The latter, to a large extent, depends on convergence and evolution of information and knowledge, which is sufficiently agile to adapt to the rate of change of paradoxes to paradigms, driven by design and/or consumer demand.

Consumer demand driven global supply networks are inextricably linked with food, energy, water, sanitation and healthcare, or FEWSH, as pointed out at the beginning of this essay. Science in the service of society must focus on FEWSH. Everything else is a means to achieve the *end*, the *end* being FEWSH.

Yet, the business pursuits are rather myopic or at the abyss of a silo, for example, transport, space and more recently, software. The bulk of businesses are interested in selling their wares to departments of corporations. This essay is a call to impact the dynamics of the direction of civilization. Commercial enterprises are running in circles to stitch products and services to cater to obvious consumer needs. Synthesizing seamless solutions to meet the unseen demand requires incisive foresight, analyses and vision, to view the non-obvious relationships.

Progress of civilization, which is sharply different from the balance sheet of Amazon, depends on our quest to improve outcomes from FEWSH. Scientists, engineers and leaders from industry, academia, societies and governments, may wish to reach into their experiences from yesterday, to guide the experiments we must pursue today, in order to meet our expectations, tomorrow. Alas, most leaders are consumed by their effort to polish the chrome. They are more interested in PR and TV where they perform “tricks with bricks and blocks and chics and clocks” but little time, to tune the engine. Those who are tuning the engine (for example, Maria Klawe) are “knox in box” and rarely allowed “out of the box” or on the news by the *Fox in Socks*.

The trans-disciplinarity of combining bio, info, nano, eco and economics, in the context of FEWSH, may be as fundamental and central as the combination of vowels and consonants. The manifestation we call English language is a combination of vowels and consonants, but, not simply in terms of “systems integration” but synthesis through ***synergistic integration***.

A view of the ***unseen*** and a sense of the future, may be triggered, when we start thinking about and visualizing *systems as a service*, but, in ways which are much more than the canonical systems integration approach. We have to imagine the wave of synergistic integration. The latter may be the long-term view, which is necessary, to feed 10 billion people, circa 2050.

Cross-pollination, buoyed by multi-disciplinary approaches, in the pursuit of untested ideas and inventions, when taken together, in combination, may create platforms to lift many boats, not just a few yachts. Academia, industry and government partnerships (public-private) must embrace the volatility of non-linear frameworks and the irreverent ways that progress may be achieved. The latter often evolves in the form of punctuated equilibria. What do you see with your mind, inside, or ***outside***, the “area under the ROC curve” that none has visualized, yet?

How can science and engineering solve problems, replenish, and sustain inventories, in a manner that is sustainable, for public access to the most basic, global, public goods?

REFERENCES

¹ In the 1300's, the Venetian traders were first to start trading securities from other governments. In 1531, the first 'stock exchange' in Antwerp dealt in promissory notes and bonds. In the 1600's, the Dutch, British, and French governments gave charters to companies with East India in their names. Amsterdam Stock Exchange was established in 1602 by the Dutch East India Company (Verenigde Oostindische Compagnie, VOC) and was the first to formally begin trading in securities. They issued stocks and offered dividends. Many "exchanges" occurred in coffee houses in London, for example, in Lloyd's Coffee House, opened by Edward Lloyd on Tower St in 1686 (which finally gave birth to the eponymous Llyod's of London, the insurance company). The first stock exchange in London (formed 1773), was followed by the Philadelphia Stock Exchange (first US stock exchange) and then the New York Stock Exchange (1792).

² Conceived in 1937, the machine was built by Iowa State College mathematics and physics professor John Vincent Atanasoff and graduate student Clifford Berry. It was tested in 1942.

³ <https://www.weforum.org/agenda/2016/05/4-billion-people-still-don-t-have-internet-access-here-s-how-to-connect-them/>

⁴ <https://www.statista.com/statistics/273018/number-of-internet-users-worldwide/>

⁵ <http://bakercenter.utk.edu/wp-content/uploads/2018/03/Net-Vitality-2.0.pdf>

⁶ <https://www.sandler.com/blog/6-benefits-of-teamwork-in-the-workplace>

⁷ T-H Lee, H White, and C.W.J. Granger (1993) *Testing for neglected nonlinearity in time series models: A comparison of neural network methods and alternative tests*. J of Econometrics **56** 269-290 www.faculty.ucr.edu/~taelee/paper/1993_Journal_of_Econometrics.pdf

⁸ <https://www.cs.cmu.edu/afs/cs/academic/class/15782-f06/slides/timeseries.pdf>

⁹ <https://pdfs.semanticscholar.org/88b4/a255082d91b3c88261976c85a24f2f92c5c3.pdf>

¹⁰ J. E. Siegel, S. Kumar and S. E. Sarma (2017) The Future Internet of Things: Secure, Efficient, and Model-Based. <https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8055694>

¹¹ Datta, S. (2016) *Emergence of Digital Twins* in "IoT is a Metaphor" (Chapter 3) MIT Library <https://dspace.mit.edu/handle/1721.1/111021>

¹² <http://www.dtic.mil/dtic/tr/fulltext/u2/a188848.pdf>

¹³ www.eugdpr.org

¹⁴ <https://www.pcmec.com/article/overview-atx-micro-atx-itx-motherboards/>

¹⁵ <http://www.lau.edu.lb/about/history/>

¹⁶ <http://college.usatoday.com/2015/08/25/study-foreign-universities-unlikely-to-expand-into-the-u-s/>

¹⁷ <https://www.theguardian.com/science/2013/dec/06/peter-higgs-boson-academic-system>

- ¹⁸ <https://hbr.org/2016/04/more-universities-need-to-teach-sales>
- ¹⁹ https://en.wikipedia.org/wiki/Standing_on_the_shoulders_of_giants
- ²⁰ Quote attributed to Winston Churchill in *Twenty One Years (1964)* by Randolph S. Churchill
- ²¹ L. F. Audrieth, O. S. Reading, Herbert Malamud, Don E. Kash, James W. Russell, Nathan M. Becker, Hanna Newcombe & John Barden (2015) *Scientists on Tap or on Top? We Are Missing the Real Issues/Good Science, Good Politics/A Flaw in Pure Science?/On Vietnam*. Bulletin of the Atomic Scientists 21:7, 24-31 DOI: 10.1080/00963402.1965.11454835
- ²² <https://www.theguardian.com/money/2010/jan/09/jobs-of-the-future>
- ²³ https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/391911/15.01.05_UKCES_Career_Brochure_V13_reduced.pdf
- ²⁴ https://www.rec.uk.com/_data/assets/pdf_file/0009/398331/REC-Future-of-Jobs-Report-Web-13.10.17.pdf
- ²⁵ <http://www.businessinsider.com/best-jobs-future-growth/#19-wholesale-and-manufacturing-sales-representatives-except-technical-and-scientific-products-3>
- ²⁶ https://www.bls.gov/emp/ep_table_104.htm
- ²⁷ ULTRA LOW COST WATER SENSOR USING A SMARTPHONE AS A DETECTOR
<http://pubs.rsc.org/en/content/articlelanding/2018/an/c8an00065d>
- ²⁸ Commentary **C** is in the book “*Haphazard Reality – IoT is a Metaphor*” download from the MIT Library (PDF marked “IoT is a Metaphor”) <https://dspace.mit.edu/handle/1721.1/111021>
- ²⁹ <http://www.antonietta-brandeis.org/>
- ³⁰ David L Donoho (2000) High Dimensional Data Analysis: The Curses and Blessings of Dimensionality <http://statweb.stanford.edu/~donoho/Lectures/AMS2000/Curses.pdf>
- ³¹ <http://www.me.utexas.edu/news/news/selective-laser-sintering-birth-of-an-industry>
- ³² See Dr Suman Das – “*laser-based additive manufacturing processes for high-performance aerospace parts*” - <http://www.me.utexas.edu/news/news/selective-laser-sintering-birth-of-an-industry#das2>
- ³³ <https://sci-chic.myshopify.com/pages/about-us>
- ³⁴ Commentary **B** is in the book “*Haphazard Reality – IoT is a Metaphor*” download from the MIT Library (PDF marked “IoT is a Metaphor”) <https://dspace.mit.edu/handle/1721.1/111021>
- ³⁵ http://webs.ucm.es/info/giboucm/index.php?option=com_content&view=article&id=12&Itemid=30
- ³⁶ <https://h2g2.com/entry/A2805725>

-
- ³⁷ J. K. Adams, V. Boominathan, B. W. Avants, D. G. Vercosa, F. Ye, R. G. Baraniuk, J. T. Robinson, A. Veeraraghavan, Single-frame 3D fluorescence microscopy with ultraminiature lensless FlatScope. *Science Advances* 3, e1701548 (2017).
<http://advances.sciencemag.org/content/advances/3/12/e1701548.full.pdf>
- ³⁸ <https://www.ncbi.nlm.nih.gov/pubmed/12597066>
- ³⁹ <https://www.epainassist.com/test-and-procedures/cost-of-stent-placement-procedure>
- ⁴⁰ <https://www.npr.org/sections/health-shots/2014/01/06/260263610/how-much-does-a-new-hip-cost-even-the-surgeon-doesnt-know>
- ⁴¹ Vilfredo Pareto (1909) *Manuel'économie politique*
<http://www.ecn.ulaval.ca/~pgon/hpe/documents/neoclassiques/Pareto.pdf>
- ⁴² <https://www.oxfam.org/en/pressroom/pressreleases/2018-01-22/richest-1-percent-bagged-82-percent-wealth-created-last-year>
- ⁴³ <https://oxfam.app.box.com/s/eosi27xj7nxuyywysr06d734ct1xyuev/folder/45012657669>
- ⁴⁴ <http://publications.credit-suisse.com/tasks/render/file/index.cfm?fileid=12DFFD63-07D1-EC63-A3D5F67356880EF3>
- ⁴⁵ https://en.wikipedia.org/wiki/Trojan_Horse
- ⁴⁶ <https://patentimages.storage.googleapis.com/6a/2a/fa/752d53b675896a/US20170216060A1.pdf>
- ⁴⁷ http://www2.ece.ohio-state.edu/~berger/courses/ee835_02_aut02/1999jun_physworld_friend_review.pdf
- ⁴⁸ Kimberly Hamad-Schifferli, John J. Schwartz, Aaron T. Santos, Shuguang Zhang and Joseph M. Jacobson (2002) *Remote electronic control of DNA hybridization through inductive coupling to an attached metal nanocrystal antenna*. *Nature* **415** 152-155
<https://www2.cs.duke.edu/courses/cps296.4/spring08/papers/HSSZJ02.pdf>
- ⁴⁹ K. Jensen, J. Weldon, H. Garcia, and A. Zettl (2007) Nanotube Radios.
<https://ipo.lbl.gov/wp-content/uploads/sites/8/2014/08/2431.pdf>
- ⁵⁰ <https://www.brookings.edu/research/high-growth-firms-and-cities-in-the-us-an-analysis-of-the-inc-5000/>
- ⁵¹ <http://www.un.org/en/sections/issues-depth/water/>
- ⁵² https://www.capgemini.com/wp-content/uploads/2018/03/dti-research_ iot_web.pdf
- ⁵³ http://money.cnn.com/2004/01/13/news/companies/future_store/

⁵⁴ Paul A. David and Gavin Wright (1999) *General Purpose Technologies and Surges in Productivity: Historical Reflections on the Future of the ICT Revolution*. Presented to the International Symposium on ECONOMIC CHALLENGES OF THE 21ST CENTURY IN HISTORICAL PERSPECTIVE.

<http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.123.2728&rep=rep1&type=pdf>

⁵⁵http://www.bigee.net/media/filer_public/2012/12/04/bigee_doc_2_refrigerators_freezers_worldwide_potential_20121130.pdf

⁵⁶ <https://etradeforall.org/the-world-bank-using-big-data-and-the-internet-of-things-to-help-end-poverty/>

⁵⁷ <http://professional.mit.edu/programs/short-programs/additive-manufacturing>

⁵⁸ <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4714146/pdf/WJGO-8-55.pdf>

⁵⁹ <https://www.annualreviews.org/doi/abs/10.1146/annurev-micro-090816-093841>

⁶⁰ https://www.nobelprize.org/nobel_prizes/chemistry/laureates/2016/

⁶¹ Shigekazu Nagata and Masato Tanaka (2017) Programmed cell death and the immune system. *Nature Reviews Immunology* 17 333–340 DOI:10.1038/nri.2016.153

<https://www.nature.com/articles/nri.2016.153>

⁶² Dart, Anna (2017) “Cell death: A better way to die” *Nature Reviews Cancer* 17(10) DOI: 10.1038/nrc.2017.90

⁶³ <https://www.jamesmartin.center/2016/06/whats-wrong-with-business-schools/>

⁶⁴ <https://www.theguardian.com/news/2018/apr/27/bulldoze-the-business-school>

⁶⁵ <https://www.ncbi.nlm.nih.gov/libproxy.mit.edu/books/NBK2214/figure/A73/?report=objectonly>

⁶⁶ <http://www.aei.org/publication/chart-of-the-day-century-price-changes-1997-to-2017/>

⁶⁷ <http://www.cs.umd.edu/hcil/interliving/chi02/tolmie/tolmie.htm>

⁶⁸

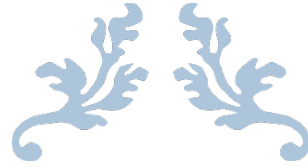
https://cdait.gatech.edu/sites/default/files/georgia_tech_cdait_thought_leadership_working_group_white_paper_july_9_2018_final.pdf

Opinions in this essay are due to the author and do not represent the views of any institution.

Dr Shoumen Palit Austin Datta

Senior Member, MIT Auto-ID Labs, Research Affiliate, Department of Mechanical Engineering, Massachusetts Institute of Technology, 77 Massachusetts Ave, Cambridge, Massachusetts 02139 Senior Scientist, MDPnP Lab, Department of Anesthesiology, Massachusetts General Hospital, Harvard Medical School, Partners MGH Research, 65 Landsdowne St, Cambridge, MA 02139

Email contact ► shoumen@mit.edu ▪ sdatta8@mg.harvard.edu



APPENDIX

UNLEASHING THE NEW WEALTH OF NATIONS

Shoumen Palit Austin Datta



This “appendix” is contained in the book
“Haphazard Reality – IoT is a Metaphor”

Available as a PDF

“IoT is a Metaphor”

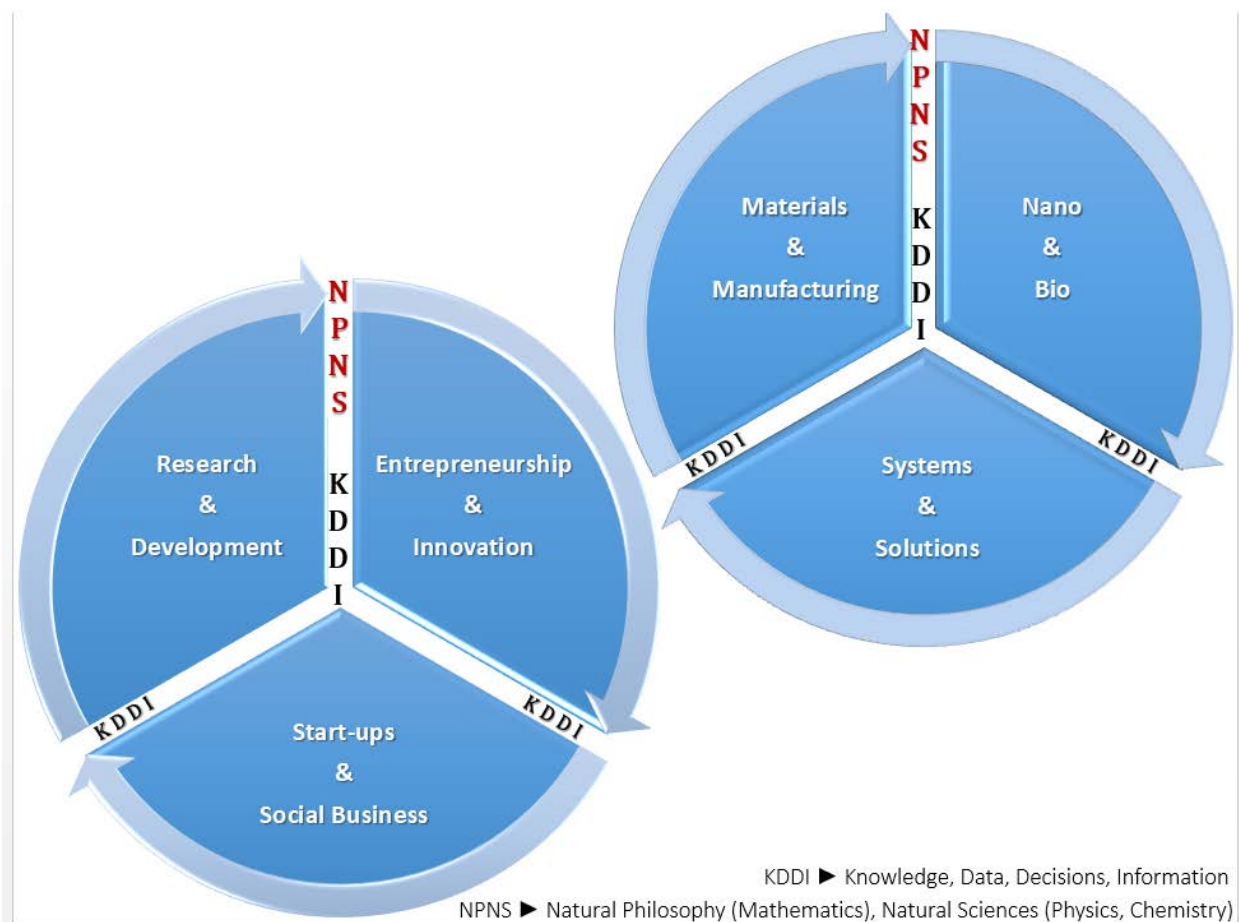
Download PDF from MIT Library

<https://dspace.mit.edu/handle/1721.1/111021>

This “appendix” appears in “Commentary D”

The following material is an edited transcript of a wide ranging interview which included ideas about global economic development and the role of academia. This section is an opinion shared at this meeting by Shoumen Datta. The proposal is not an action plan and it is not under implementation by the author.

¹ Email contact shoumen@mit.edu ▪ Dr Shoumen Palit Austin Datta <https://dspace.mit.edu/handle/1721.1/111021>
This is an excerpt of an interview with academics, Nikkei Sangyo newspaper and Nikkei BP digital media publications (<http://www.nikkeibp.com/>) following a talk on September 9, 2015 at Tokyo University of Science, Tokyo, Japan.
www.youtube.com/watch?v=EILABk5NrnI ► The opinions expressed in the APPENDIX are solely due to the author.



University Research ► Cross-Pollinators are an Organizational Essential

It is a truth, almost universally accepted in democratic societies, that the role of providing research leadership in academic institutions, is a key to catalyze economic *ecosystems*. The latter is necessary for development, economic growth and job creation.

There are few, if any, formulaic approaches. My view, illustrated above and discussed below, may be partially suitable in certain cases and completely wrong in other circumstances. There may not be one answer, because approaches must adapt or respond to the socio-economic *context* of implementation. *Outcomes* ought to differ.

Illustrated above are the 2 of the 3 core layers, in my opinion. Viewed as a tripod, the third layer is that of education and the *educational organization* of the institution. The *credibility* of education, the *freedom to debate doubts*, and tools for dissemination using online *platforms* for digital learning, are a few of the segments, of the third leg.

2 Email contact shoumen@mit.edu • Dr Shoumen Palit Austin Datta <https://dspace.mit.edu/handle/1721.1/111021>
 This is an excerpt of an interview with academics, Nikkei Sangyo newspaper and Nikkei BP digital media publications (<http://www.nikkeibp.com/>) following a talk on September 9, 2015 at Tokyo University of Science, Tokyo, Japan.
www.youtube.com/watch?v=EILABk5NrnI ► The opinions expressed in the APPENDIX are solely due to the author.

In this view, mathematics, science and engineering faculties in universities and institutions may wish to accelerate investment, and human resources, to pursue, among other things, a three pronged approach, broadly categorized (arbitrarily) as follows:

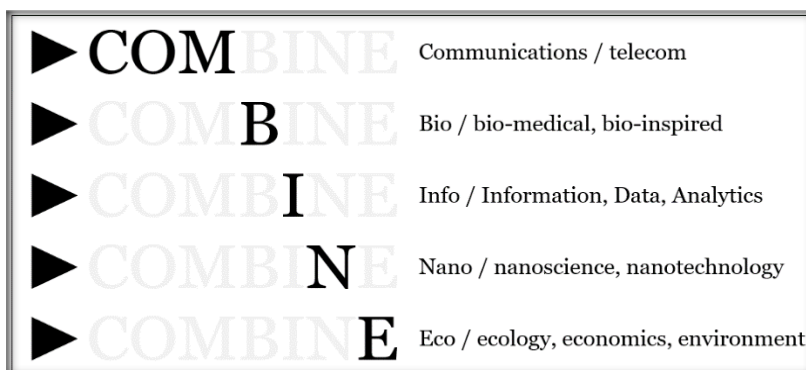
- **Materials and Manufacturing**
- **Nano and Bio**
- **Systems and Solutions**

It is irrelevant to emphasize that these are not domains or buckets or fields. These bullet points are just names, loosely assigned, to multi-disciplinary, cross-pollinating, convergent fields, for the sake of convenience, during this discussion.

Materials and Manufacturing – includes [a] chemistry to material science and everything in between [b] it embraces the advances that one must pursue in classical manufacturing, as well as the future digital foundry. Additive manufacturing of metals, composites, biomaterials (joints, prosthetics), will re-form the supply chain using distributed additive manufacturing on-demand and replenishment (DAMODAR).

Nano and Bio – includes [a] all relevant areas ranging from chemistry to material science for [b] applications ranging from 3D printed graphene nano-dot sensors for biogenic monoamines in perishable grocery to [c] temperature sensors in jet engine turbines to [d] printed polymer sensors inside the intestine of ruminant animals (cow) wirelessly transmitting data which can be analyzed to better estimate the kinetics of small chain (volatile) fatty acids which influences the quality and quantity of milk.

Systems and Solutions – includes almost everything that science and society may use in the progress of civilization on earth, and our pursuit of space. Convergence of systems to create useful and affordable solutions, is the quintessential essence of the concept of **COMBINE**. Products and services, related to food, energy, water, sanitation, public health and healthcare, are transdisciplinary outcomes from basic research, which are branches of STEM, including **nano & bio** and **materials & manufacturing**.



UNEASY WORDS FOR INSTITUTIONAL ORGANIZATIONS DEFINED BY SILOS:
COMPLEMENTARITY, CROSS-POLLINATION, CONVERGENCE, CONNECTIVITY

3 Email contact shoumen@mit.edu • Dr Shoumen Palit Austin Datta <https://dspace.mit.edu/handle/1721.1/111021>
This is an excerpt of an interview with academics, Nikkei Sangyo newspaper and Nikkei BP digital media publications (<http://www.nikkeibp.com/>) following a talk on September 9, 2015 at Tokyo University of Science, Tokyo, Japan.
www.youtube.com/watch?v=EILABk5NrnI ▶ The opinions expressed in the APPENDIX are solely due to the author.

For ***each*** of these ***three*** prongs (and other categories one may choose to create)

- ***Materials and Manufacturing***
- ***Nano and Bio***
- ***Systems and Solutions***

There will be a ***three*** pronged approach converging on each category, as follows:

- ***Research and Development***
- ***Entrepreneurship and Innovation***
- ***Start-ups and Social Business***

For example, material science is inextricably linked and embedded with basic ***research*** in chemistry. The ***development*** of nano-composites (for example, nanomaterials for 3D printed hip joints or ceramic composites for turbine parts), is an outcome based on research. ***Innovation*** in material science (for example, alloys that can withstand temperatures inside turbine combustion chambers) may create opportunities for ***entrepreneurship*** which may lead to ***start-ups***. If ***affordable*** graphene based sensors can detect mercury and arsenic in water, it can lead to ***social business*** opportunities by transferring the technology to regions of the world where these sensor systems may improve quality of life. This general approach repeats for all categories, ie, nano & bio, systems & solutions.

THE CROSS-POLLINATION ROLE OF LEADERSHIP

Engaging 24/7/365 to usher and chaperone this continuum of convergence, across multiple institutional domains organized by disciplines, is the primary task of leadership. Individuals in this role must be able to visualize how the fundamentals of natural philosophy, including mathematics, and natural sciences, through research, can influence, shape, and direct, the ***outcome***, which may be useful for humans and life. For example, mobile phone app alerts a city manager that in block xyz, a sudden flux of non-metabolized recreational drug was detected in the sewer effluent filter. This is a system which requires parts, basic and applied, captured in the cartoon **COMBINE**.

Proselytizing the merits of basic research and the vast potential of **COMBINE**, may fall on deaf ears (eg Board of Trustees) because these are well-worn, old facts. The value of this role may be realized when ***strands can be stitched***, in a manner that the basic sciences and the entrepreneurial innovation opportunities, may converge. The value of this role will be ***delivered*** when strands of such ***synergistic convergence*** can excite donors and patrons (public, private, industry) to ***invest*** in the university to help transform the vision of synergistic convergence of “strands” to reality. The value of this role will ***change the global equation*** when such transformation creates business services which may be used by ***billions***, where each user may pay only ***one penny*** for each use.

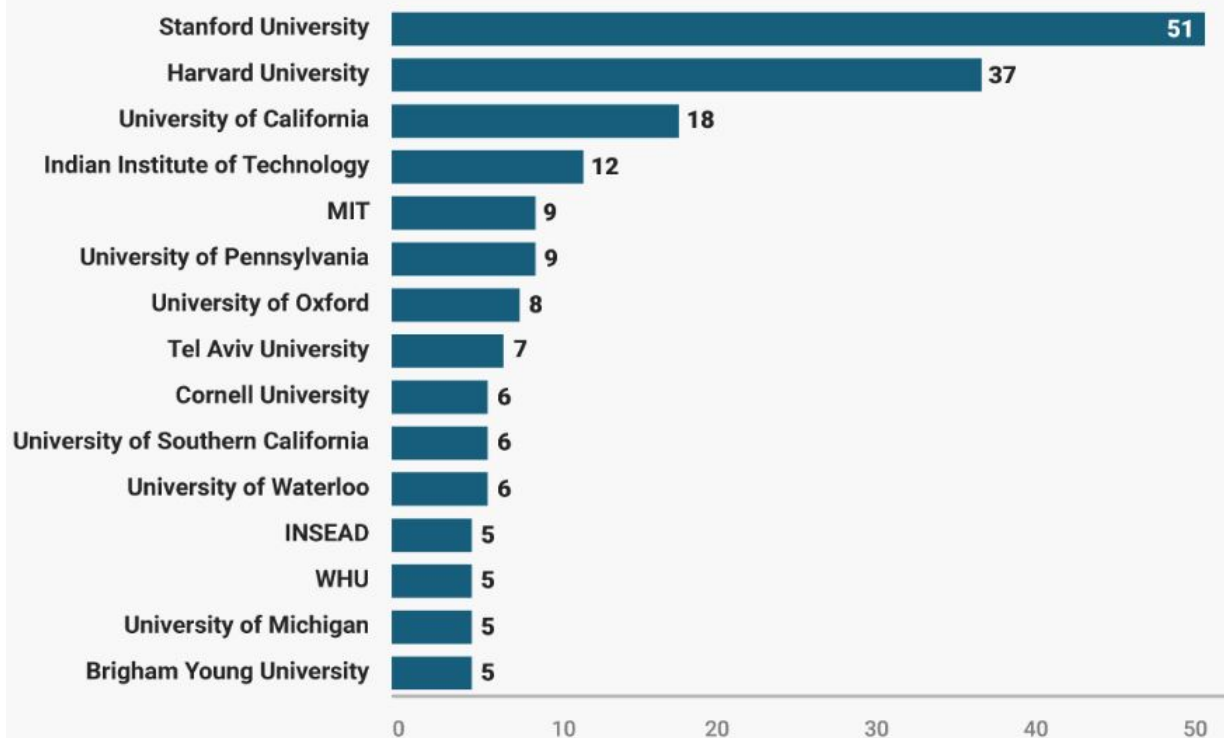
⁴ Email contact shoumen@mit.edu ▪ Dr Shoumen Palit Austin Datta <https://dspace.mit.edu/handle/1721.1/111021>
This is an excerpt of an interview with academics, Nikkei Sangyo newspaper and Nikkei BP digital media publications (<http://www.nikkeibp.com/>) following a talk on September 9, 2015 at Tokyo University of Science, Tokyo, Japan.
www.youtube.com/watch?v=EILABk5NrnI ► The opinions expressed in the APPENDIX are solely due to the author.

I very frequently get the question: “What’s going to change in the next 10 years?” That’s a very interesting question.

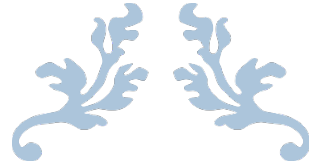
I almost never get the question: “What’s not going to change in the next 10 years?” And I submit to you that that second question is actually the more important of the two.

www.businessinsider.com/colleges-founders-unicorn-startups-1-billion-2017-1

COLLEGES THAT HAVE PRODUCED THE MOST FOUNDERS OF BILLION-DOLLAR STARTUPS



5 Email contact shoumen@mit.edu • Dr Shoumen Palit Austin Datta <https://dspace.mit.edu/handle/1721.1/111021>
This is an excerpt of an interview with academics, Nikkei Sangyo newspaper and Nikkei BP digital media publications (<http://www.nikkeibp.com/>) following a talk on September 9, 2015 at Tokyo University of Science, Tokyo, Japan.
www.youtube.com/watch?v=EILABk5NrnI ▶ The opinions expressed in the APPENDIX are solely due to the author.



Yes, you can help

ESSE QUAM VIDERI

Shoumen Palit Austin Datta



The “appendix” is contained in the book
Haphazard Reality – IoT is a Metaphor

OPEN CALL

Shoumen Palit Austin Datta

Auto ID Lab, Dept of Mech Eng, Massachusetts Institute of Technology

Medical Device Plug & Play Lab, MDPnP, MGH, Harvard Medical School

OPEN CALL ► REITERATING COMMON ISSUES WITH UNCOMMON POTENTIAL

As an academician and scientist, with experience in government and business, albeit, in the affluent Western world, I have arrived at a few key observations. I acknowledge it is neither new nor novel. I may be also wrong in my opinion.

Significant research and research outcomes are languishing in academia, which can help lift lives of people in developing, and impoverished, countries. The knowledge resources may impact food, energy, water, sanitation and health.

What in the process of “translation” appears to pose insurmountable barriers?

Greed.

Greed in two forms – business greed for profit margins and greed inherent in SV (silicon valley) type venture capitalists (and the influence of their ethos on VC's).

In general, scientists are most comfortable in sub-domains of sub-domains where their thinking and outcome may flourish. If slightly stretched, perhaps, they will contribute their intellect and combine it with intellectuals from closely related sub-domains. Even that basic convergence, often, yields results of value, at least, scientific value, perhaps in terms of one or more peer-reviewed journal papers. Most advances of this nature simply stop with the publication of the paper(s).

A small percentage of these scientists may venture out to team with academic engineers and generate an outcome which holds potential in the context of science serving society.

A small segment, of that science and engineering team, may venture outside their comfort zone, to seek funding in order to transform the latent vision into reality. If they survive the VC's, one may expect a component or a product or a service.

In a few instances, such outcomes, when combined, is usable and useful. iPhone.

² Email contact shoumen@mit.edu ▪ Dr Shoumen Palit Austin Datta <https://dspace.mit.edu/handle/1721.1/111021>
This is an excerpt of an interview with academics, Nikkei Sangyo newspaper and Nikkei BP digital media publications (<http://www.nikkeibp.com/>) following a talk on September 9, 2015 at Tokyo University of Science, Tokyo, Japan.
www.youtube.com/watch?v=EILABk5NrnI ► The opinions expressed in the APPENDIX are solely due to the author.

Greed is the rate-limiting factor in the process. If the component, product or service cannot generate a projected **10x** ROI (ten times the return on investment) in 2-5 years, then most SV-esque VC's will treat you as a leper. If the component, product or service, can be adopted or assimilated in the portfolio of a pre-existing business (corporate acquisition), the short-term profit margin will be the key, if the enterprise wants to invest in the component, product, service or related R&D.

Scientists would rather spuddle along academic corridors than face the wrath of the sharks. Political illiteracy of scientists add further woes to global quagmires.

It is a fact that most discoveries and inventions are unsuitable for innovation. The path from invention to innovation may not be impossible but may not be feasible.

It is a fact that a component or a product or a service, as an outcome from a lab, may not be usable in the context of science serving society. Arrhenius equation is a formula for the temperature dependence of reaction rates. It may be applied to estimate shelf-life of perishable items (food) which are likely to be influenced by changes in temperature. The imagination and knowledge of scientists/engineers to use the Arrhenius equation is an outcome from basic science and mathematics.

$$k=A * \exp(-E_a/R * T)$$

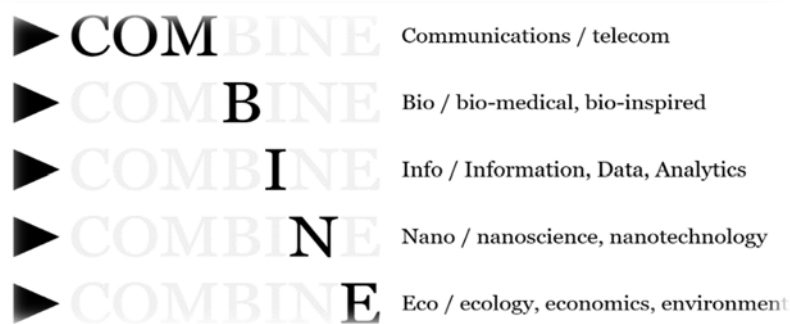
where k is the rate coefficient, A is a constant, E_a is the activation energy, R is the universal gas constant, and T is the temperature (in kelvin).

It is a fact that scientific knowledge is not a **system** that can be used as an user-friendly solution, in the context of science serving society.

Application of the Arrhenius equation in the *data analytics* framework of the food *supply chain* depends on the *acquisition* and *transmission* of data from *sensors* embedded in the perishable goods supply chain *network*. *Information* from sensor data may be invaluable to ensure *food safety* and prevent *public health* outbreaks due to food-borne *pathogens* or other *toxins*. The variety of sensors (temperature, biogenic amines, inorganic metals, chemicals) are crucial to gather relevant data (not only temperature) for comprehensive status. Hyped up blockchain euphoria may find a way to enhance *data security* for food safety.

It is a fact that research-based scientific knowledge is fundamental but certainly not enough, and the outcome from one or more labs, about a component, product or service, is woefully inadequate, unless combined, to serve as a solution in the context of science serving society.

The application of Arrhenius equation and other “**tools**” in the context of the global food supply chain, and food safety, requires us to stitch a **system**, which functionalizes **synergistic integration** of different parts and components on a common **platform** which can be accessible as a **mobile solution** for end-users. Synergistic integration, of products and services, combined, are at the heart of the process behind *systems, which manifests as solutions*, and we may use it daily, for example, automobiles, mobile phones and TOTO Neorest 750H toilets.



⁴ Email contact shoumen@mit.edu ▪ Dr Shoumen Palit Austin Datta <https://dspace.mit.edu/handle/1721.1/111021>
This is an excerpt of an interview with academics, Nikkei Sangyo newspaper and Nikkei BP digital media publications (<http://www.nikkeibp.com/>) following a talk on September 9, 2015 at Tokyo University of Science, Tokyo, Japan.
www.youtube.com/watch?v=EILABk5NrnI ▶ The opinions expressed in the APPENDIX are solely due to the author.

The remainder of this discussion is applicable to everybody who is interested in the progress of civilization. But, it may become an action item or to-do agenda, specifically for you, if you may qualify to check all of the following boxes:

- ☑ You are an ardent well-wisher of the global economy to lift the lives of the down-trodden and the forgotten
- ☑ It pains you that half of the world's population lives without managed water and sanitation services
- ☑ You possess immense wealth or you have access to substantial funding and you have deep pockets of influence as well as connected to network of power brokers
- ☑ You have the intrinsic desire to help improve the dignity and plight of people who can do nothing for you in return
- ☑ You wish to use your influence and political capital in an aggressive pro-active manner to plant some trees under whose shade you may never sit

A \$1 dollar plate of bean stew costs the equivalent of \$321.70 in South Sudan

<https://www.weforum.org/agenda/2017/10/a-plate-of-bean-stew-costs-320-in-this-country/>



Real price of a plate of bean stew is \$321.7 in South Sudan. The result is hunger. REUTERS/Andrew Campese 30 Oct 2017

5 Email contact shoumen@mit.edu ▪ Dr Shoumen Palit Austin Datta <https://dspace.mit.edu/handle/1721.1/111021>
This is an excerpt of an interview with academics, Nikkei Sangyo newspaper and Nikkei BP digital media publications (<http://www.nikkeibp.com/>) following a talk on September 9, 2015 at Tokyo University of Science, Tokyo, Japan.
www.youtube.com/watch?v=EILABk5NrnI ► The opinions expressed in the APPENDIX are solely due to the author.

OPEN CALL ► THE APPEAL

The lengthy preface is intended to serve as a rationale for the appeal, to follow.

The central thesis of the appeal is to seek ***investment*** to execute synergistic integrations of various products and services, to create systems and solutions, with mass appeal for billions of people (who may not be residents of US, EU, JP).

Having said that, I hasten to add that the investment sought is ***not charity***.

The altruistic investment is to create ***for-profit social businesses***, where profit is re-invested to create the *organization necessary* in order to ***sustain*** the operation (financial autonomy) without recurring need for financial assistance.

Investment is sought to **[a]** accomplish the synergistic integration in order to create the desired system and solution **[b]** create proof of concept, large scale pilot and evaluation followed by vast implementation of services expected to engage millions/billions of users **[c]** establish business operational frameworks.

Repayment of the investment may be expected but return on investment (ROI) may be smaller than business as usual and may take longer (10-20 years). The ***for-profit model*** is expected to operate as a ***pay-a-penny-per-use*** strategy, which will ***monetize each instance*** of use or engagement with ***service*** but at a ***nano-cost*** which will enable us to break down the barriers to entry in any market, and penetrate all potential markets, no matter how impoverished. The market size (*economies of scale*) and adoption of services (number of users) are the dominant determinants of the micro-revenue model of public goods business.

The domains of global interest are food, energy, water, sanitation and healthcare. Each vertical may have some common horizontal features (see APPENDIX) but execution may depend on the context of the need, some less technical than others. Solutions and systems with niche appeal may earn additional revenue.

⁶ Email contact shoumen@mit.edu ▪ Dr Shoumen Palit Austin Datta <https://dspace.mit.edu/handle/1721.1/111021>
This is an excerpt of an interview with academics, Nikkei Sangyo newspaper and Nikkei BP digital media publications (<http://www.nikkeibp.com/>) following a talk on September 9, 2015 at Tokyo University of Science, Tokyo, Japan.
www.youtube.com/watch?v=EILABk5NrnI ► The opinions expressed in the APPENDIX are solely due to the author.

In general, the focus will shift on demand, for example, for food, the supply chain of replenishment is far more critical in certain parts of the world. Manufacturing with respect to energy is one way to leapfrog the dead weight of old technology. The latter is far more relevant to the development world to bypass grid based distribution, and it is a perfect fit for renewable energy storage, worldwide.

Bleeding edge technologies, which must be made affordable, are essential for clean water. It is also inextricably linked with sanitation and effluent systems. Impurities and pathogens in water and sewer are ground zero for public health vigilance and prevention. Hence, a “**sense & response**” system may be part of a horizontal “digital thread” of connectivity solution between water, sanitation and healthcare. A plethora of remote sensing tools are surfacing for wellness/health, and advances in nano-bio sensors for molecular diagnostics. Together, these tools may help billions in emerging economies and offer remote access to primary care.

In the vast context of FEWSH (food, energy, water, sanitation, healthcare), a host of options and components may be available from research labs and academic R&D organizations. Investment is necessary to identify the strands, stitch the components, align with platforms, create systems, and then integrate to generate system of systems, which may finally generate user-friendly solutions, in the form of **service, not products**. Even if the outcome is a product, the product must be adapted to be offered as a **pay-per-use service**, in the context of science serving society, for billions of users, who can use it as a **plug and play** service.

It is **this** business, the business of **science serving society**, by creating usable, affordable and useful solutions, for billions, in Asia, Africa and South America, to use science as a catalyst to improve quality of life. *Is this ethos an anathema to SV VC's?* The real world needs investment from investors who are less interested in the Forbes list of billionaires and more interested in the human race. We need investors who can invest with humanity, and humility, to uphold human **dignity**.

⁷ Email contact shoumen@mit.edu ▪ Dr Shoumen Palit Austin Datta <https://dspace.mit.edu/handle/1721.1/111021>
This is an excerpt of an interview with academics, Nikkei Sangyo newspaper and Nikkei BP digital media publications (<http://www.nikkeibp.com/>) following a talk on September 9, 2015 at Tokyo University of Science, Tokyo, Japan.
www.youtube.com/watch?v=EILABk5NrnI ► The opinions expressed in the APPENDIX are solely due to the author.

Unleashing the new Wealth Of Nations

Shoumen Palit Austin Datta

shoumen@mit.edu, sdatta8@mgh.harvard.edu | Senior Member, MIT Auto-ID Labs; Research Affiliate, Department of Mechanical Engineering Massachusetts Institute of Technology, Room 35-203, 77 Massachusetts Ave Cambridge, MA 02139, USA Senior Scientist, Medical Interoperability Program, MDPnP Laboratory Massachusetts General Hospital, Harvard Medical School; Partners MGH Research Building, 65 Landsdowne St, Cambridge, MA 02139, USA Managing Director, NSF Center for Robots and Sensors for Human Well-Being School of Engineering Technology, Purdue Polytechnic, Purdue University 156 Knoy Hall, West Lafayette, IN 47907, USA

Letter from Academia

Abstract. Economic growth and wealth creation was once exclusively a product based operation, through sale of goods (cattle, cars, planes, trains, parts). Today, it is also based on services. Economic growth through services, naturally, started with financial services, circa 1300. In the 20th century, economic value from the use of “data as a service” was made possible by the creation of the Atanasoff-Berry computer in 1942. Geographic limits on the export of knowledge was rendered agnostic, when the internet was publicly released by the NSF, in 1995. In the 21st century, the information economy is still crawling, with 60% of the world not yet connected to the internet. Those who are connected may not have the necessary access. Expert knowledge arbitrage, combined with data as a service, are major economic drivers, which is far from its utilization potential, in the US. Therein, lies vast opportunities. Reasonable weather, low incidences of natural disasters, and basic infrastructure makes certain locations more attractive. Dynamic demographics, academic institutions and cultural liaison to large external markets, are other positive features, for the future of wealth creation.

Keywords. Global Economic Development; Systems as a Service; Supply Chain; Innovations.

Cite paper as: Datta, S., (2018). Unleashing the new Wealth Of Nations - Letter from Academia, *Journal of Innovation Management*, www.open-jim.org, 6(2), 12-36. <http://hdl.handle.net/10216/113222>

1 Introduction

Economic growth and wealth creation was once exclusively a product based operation, through sale of goods (cattle, cars, planes, trains, parts). Today, it is also based on services. Economic growth through services, naturally, started with financial services¹, circa 1300. In the 20th century, economic value from the use of “data as a service” was made possible by the creation of the Atanasoff-Berry computer² in 1942. Geographic limits on the export of knowledge was rendered agnostic, when the internet was publicly released by the NSF, in 1995. In the 21st century, the information economy is still crawling, with 60% of the world not yet connected³ to the internet. Those who are connected⁴ may not have the necessary⁵ access. Expert knowledge arbitrage, combined with data as a service, are major economic drivers, which is far from its utilization potential, in the US. Therein, lies vast opportunities. Reasonable weather, low incidences of natural disasters, and basic infrastructure makes certain locations more attractive. Dynamic demographics, academic institutions and cultural liaison to large external markets, are other positive features, for the future of wealth creation.

2 Information as a service evolves to systems as a service

Enterprise creation using advanced R&D generates jobs and economic growth. In the US and some OECD nations, we are eager to probe the bleeding edge. Hence, we aim to lead in robotics, aeronautics and astronautics, high value healthcare tools and similar high end, high margin, high profit, areas. This is welcome news but there is a lot of room left behind the edge!

Think about complementarity in business and strategy, ventures and entrepreneurship, innovation and necessity, systems and solutions. This suggestion is about massive economies of scale, where services are offered for low end, low margin, low R&D solutions, needed by 80% of the world, with the potential for sustained, long term, cumulative, mega profit, for providers.

This note is also about the evolution, from data and information as a service, suitable for OECD nations, to *systems as a service*, for the rest of the (80%) world. The latter demands answers, not numbers. Advanced tools and technologies are catalysts for advanced nations, where infrastructure and skilled resources exist, to *synthesize* the advances, generate solutions, and profit from outcomes. Developing economies (80% of the world) may lack the ability to deal with bleeding edge resources. Their solutions must be synthesized, seamless and integrated, to serve as functional systems. In other words, *outcomes* are preferred over gadgets, and widgets.

Hence, the advanced R&D paradigm, including data as a service (as a subset), is suitable for developed nations. But, immense business opportunities, revenue and “loads of money are left on the table” unless advanced strategies are complemented by parallel approaches. In this prong, solutions are synthesized to fit the *context of the demand*, economic feasibility and availability of infrastructure.

Systems as a service indicates that “data as a service” is insufficient and must integrate ecosystems, to generate “systems as a service” in order to provide the solution, or the desired outcome. Data and information are a *part* of the solution, and information arbitrage may *still* be a source of profit, but *systems as a service* will be the source of the revenue.

Mobility of information, due to the internet, *where available*, induces unlimited potential for innovation and creativity to shape the “systems as a service” business model, by distributing the tasks, and generating pay-per-use revenue, from *each instance* or event.

There are no 800-lb gorillas (or sharks⁶) as the sole player, in the digital economy. It is a distribution, albeit, often, uneven, skewed and heteroskedastic. Co-creators of systems shall seek to profit from sub-components or sub-sets of the system. Entrepreneurial innovation in systems integration may need access to the ecosystem of R&D, which, in turn, becomes a part of the solution, but, *within* the *systems as a service* paradigm.

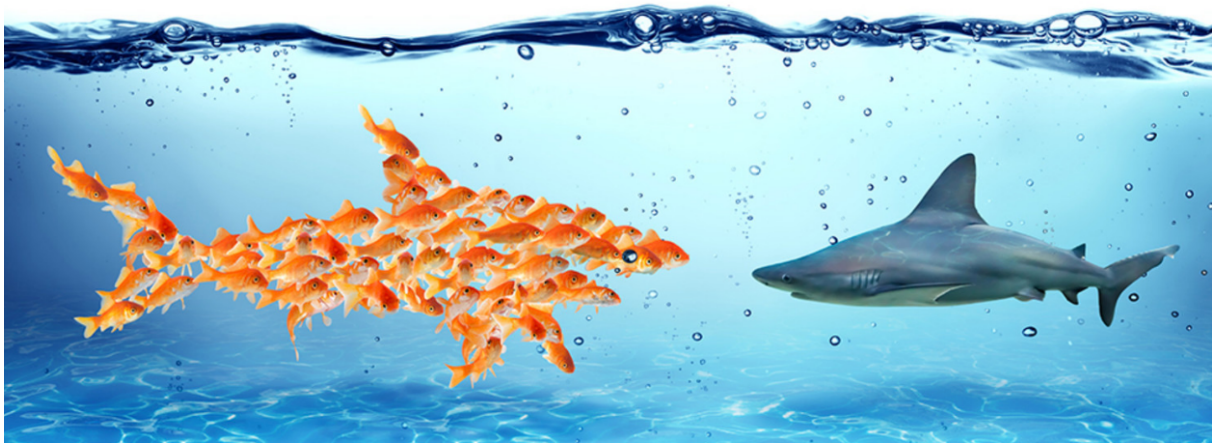


Fig. 1. Service SCM - Systems as a service - whole is greater than the sum of the parts ⁷

Advanced R&D at the bleeding edge may be sequestered by the upper crust of the supply chain. But, pragmatic innovation can re-shape the outcome to serve the rest of the world, where the mega markets exist – excluding US, EU and JP (which represents 10% of the population).

The distributed digital pay-per-use service economy is a virgin territory. The US-EU *entente* balks at low cost services. The digital economy, catalyzed by the global internet, is the mobile medium, where service businesses can profit, slowly, not only for the lifetime of the product, but for the *lifetime of the customer*. Lifecycle management evolves from product lifecycle (1-10 years) to the lifecycle of the consumer (10-50 years). Is it a significant change?

The digital economy makes it possible to transform the paradox of a product-less world to a new paradigm, where products are leased as services related to the products. The product sale is a fee, not a final event. The service is always “on” and each instance of use, of the product, is logged in as a service, which in turn, generates micro-revenue, one event at a **time**. Billions of instances of pay-per-use, per day, generates trillions in earnings, **over time**. To profit from this paradigm, the focus must be on the business need of the billions. Hence, the complete solutions, through convergence, are more useful than high tech advanced R&D at the bleeding edge, alone.

The time-dependency of digital dividends, may suggest that time series econometrics⁸ may be a potential tool for exploring the digital economy using time series (lagged ? values) data as input⁹ for artificial neural networks, illustrated below. The roots of this line of thinking is not new and can be traced back to the seminal contribution by Sir Clive W. J. Granger (reference

7).

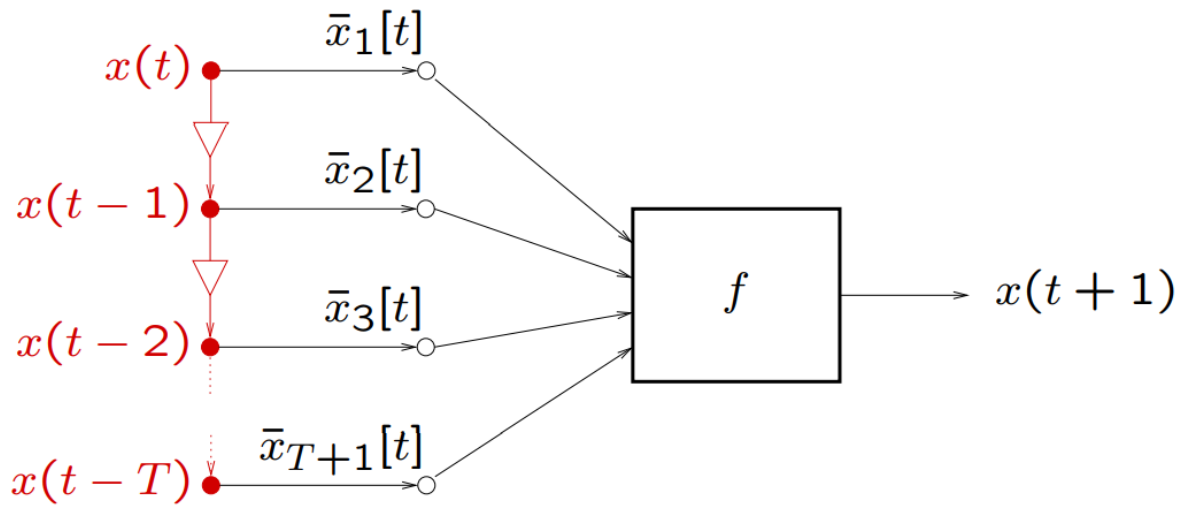


Fig. 2. Artificial neural networks & time series econometrics - digital SCM - convergence of tools⁸

Time dependent profitability, from micro-payments, is not a new business equation. It is the underpinning of the 99 cent hamburger, in the American parlance. The digital economy has introduced a dynamic stream of “push-pull” mix of product and services. In this paradigm shift, we have not removed the product, but we have enabled digital transformation of the **business model related** to the product. We have made the product, and the associated service, a part of the **systems as a service** solution pack, using digital threads to track and trace deliveries.

In this model, earnings must be traceable to its lowest common denominator, which is the *pay per each use of each unit of service*. We aim to replace one time purchase of a product, or a block purchase of service (warranty) or block payment from customer (leads to customer unhappiness, fractured loyalty, lowered credibility, tarnished brand image, poor penetration). The granular reach of pay-per-use model was not feasible prior to the medium of the internet. Digital transparency in the digital enterprise can provide secure tools, to document the process of consumption, and related services, in order to charge for what is used, nothing more.

The systems integration necessary for pay-per-use business model demands tools and infrastructure. The latter may be beyond the capacity of the developing economies. This is where the advanced economies and forward looking states, can sow creativity, to coalesce the *systems as a service* model. Harvesting revenue from each customer touch point, from billions of users, creates immense potential for ethical profitability. These models can also work through public-private partnerships, if the providers are interested in both, profit and service of public goods.

Vision, and the application of internet based business tools, when coupled with R&D for products, and access to global ecosystems, creates the critical mass of synergy, which is the foundation of the *systems as a service* approach. New sources of revenue can be realized through local, and global, public-private partnerships and academic-industry joint ventures.

The solution may *contain products* which may serve in the geography where it is needed, thou-

sands of miles away from its provider. But, the *service* link to the product in use, that is – data and information – will be linked to the business. Hence, local job creation. Businesses will profit each time its products or service is used, as a part of the *systems as a service* solution package, agnostic of its location. The data and information related to the service offers value. The value is embedded in the *systems as a service network*. If shared, this is the source of continuous revenue, for entrepreneurs, businesses, citizens and public-private partnerships.

This is the digital supply chain of data, from network of devices, enabled by connectivity, globally integrated, to provide *systems as a service*, as a *seamless solution* for the customer. Using jargon, unleashed by MIT in 1999, this is a part of the connected world of IoT, **internet of things**. The networked physical world¹⁰ is about making decisions about the state of atoms.

Decisions, the good ones, profitable ones, can make a great difference. The ubiquity of decisions (what to eat, wear, drink) makes us oblivious that data is constantly converged, to make decisions. If the decision is incorrect due to error in data processing, the outcome may be trivial or catastrophic or somewhere in between. If the parameters and volume of data is too many, and too large, then, humans may choose to use data processing tools and technologies. Automation, machine learning, artificial intelligence, optimization, predictive analytics and risk estimation are a part of this process. Our increasing reliance on tools has created opportunities for “time spoofing” or “infecting” our decision tools. Cybersecurity risk mitigation strategies may call for humans to be involved in key decisions, including digital supply chain, for critical commands. Therein lies the importance and need for “cognitive” tools¹¹ to aid in the monitoring, supervision, and validation of *contextual* data, prior to execution of command(s) in a system.

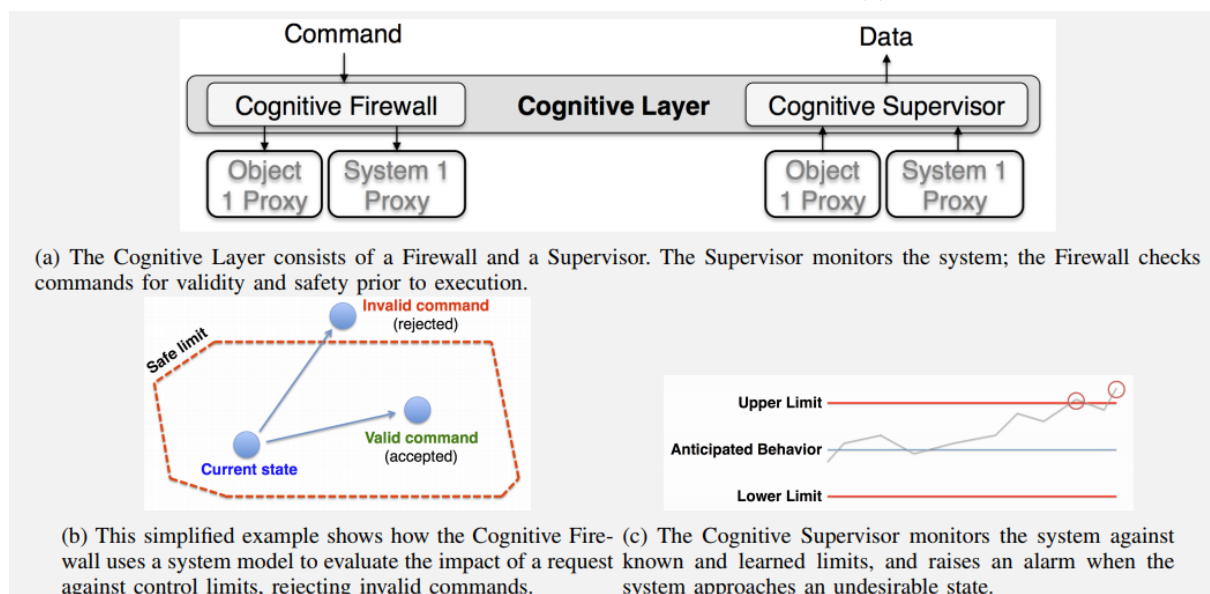


Fig. 3. The ‘cognitive layer’ in the digital copy¹⁰ of the physical world - cognitive digital twins?

The digital copy of the physical world (referred to as digital proxy or digital duplicates or digital twins¹²) may enable real-time visualization of data, metrics and analytics of machines and systems. The sense and response functions in “intelligent” operations may need humans

in the loop for mission critical activities. Introducing “cognition” is a prudent cybersecurity measure and risk mitigation strategy. Cognitive monitoring and supervision ensures the decision system is “behaving as expected” and commands do not cause harm. The Data Proxy model [10] applies context information for monitoring faults and validates incoming commands prior to execution.

In the context of the current discussion to aid in improving 80% of the world, one begs to ask if data analytical tools, such as, machine learning, artificial intelligence, neural networks, and cognitive digital twins, are germane to the effort. The answer depends on what (objects, things, products) is at the “edge” of the networked physical world, what decisions we are trying to improve and who or what is involved in that decision process. 80% of the world is in need of answers, not numbers. But, without numbers one may not be able to deliver the “good” answers.

3 The networked physical world

Data driven decision systems, if supplied with data, information and intelligent analytics, may make better decisions, perhaps more profitable decisions. But, these systems are not trivial, in terms of systems integration. It may need orchestrated performance from various ecosystems.

Whether it is a rice farmer in Saigon about to plant a rice seedling, or

a child about to drink water from a tap in Bogota, or

a house-husband in Dalian preparing to use electric appliances in the kitchen, or

a septuagenarian in Mysore using a sensor to estimate her blood glucose, or

a surgeon in Addis Ababa requesting a 3D-printed stent for coronary angioplasty,

it is all about decisions and data, which, when, and if, connected, is a *system*.

From Santa Clara, we can tell the farmer in Saigon if the conditions are optimum for planting the seedling. From Boston, we can warn the child in Bogota that the tap water contains more than permissible amounts of mercury. From Detroit, we can inform the house-husband in Dalian that it will be cheaper to use the electrical deep-fryer if he could cook the chicken after 630pm but before 8pm. From Miami, we can tell the patient in Mysore that her blood glucose of 140mg/dl is slightly elevated. From Atlanta, we can send the instruction set to the 3D printer in Addis Ababa for the surgeon to print the stent for the percutaneous coronary intervention (PCI).

Data and information from anywhere may serve local needs. Data can be transformed to information or products, globally. Mobility of the medium, the internet, enables *systems as a service* to offer solutions. If one provides a piece of this pie, one may earn a part of the revenue.

However small the profit may be, billions of pennies each day, can lift many boats. It is this piece of the global pie which can be harvested through the social business model. We need the network of tools, technologies, objects, processes and systems, as a part of our symphony.

Using your phone from Shropshire, UK you can call a cab to pick up your Mom from her home in Santiago, Chile. From Mumbai, India, you can order a pizza for a friend in Miami, FL.

This is the digital supply chain, made possible by reduction in *transaction costs*.

This is *systems as a service*. We connect atoms (things) to bits (data, information).

It may require bleeding edge R&D tools from research but must be connected to yield answers, which can penetrate any market, to provide actionable information and real solutions.

What are these systems or solutions most needed by 80% of the people in the world?

This is a business question and central to the global value network and supply chain.

It is not about drone taxi or robots flipping burgers or the pursuit of asteroid mining.

The quest for fundamental solutions needed by 80% of the world is focused and few.

It is a short FEWS:

F Food

E Energy

W Water

S Sanitation

I am inclined to make it FEWSH and add healthcare. FEWS may aid “prevention” and reduce the need for “correction” but, wear and tear of the human system, needs healthcare. This combination, FEWSH, of commodities, if served through the paradigm of *systems as a service*, presents new lines of business and scope of profitability, never imagined before. But, *systems as a service* is **not** a panacea for all solutions. Cumulative profitability from *systems as a service* is vast, one must remain vigilant about the norms of ethical profitability. To transform these ideas into reality, imagination, invention and entrepreneurial innovation must run in parallel with business creativity, to create global liaisons and penetrate markets where FEWSH is in demand.

There is no one clear approach to FEWSH. It will be a complex and dynamic ecosystem, where we must develop solutions in ***collaboration with the markets***¹³ where we intend to sell *systems as a service*. Markets must have some “skin in the game” because we need access, adoption and we must retrieve¹⁴ the data related to *accounting of use*, in order to profit from each granular event, and optimize the economies of scale. This is long term revenue planning.

This is uncharted territory. This is virgin space. This is the digital economy. The classical approach to advanced R&D works well for OECD but it is time to move out of the box. Tools and technologies are parts and components, awaiting integration, to generate a system, which will offer a function. The sum of the parts must be greater than the whole. When you want tea, you actually expect to receive a steaming cup of brewed hot tea. You don’t want an empty cup, a saucer, a spoon, an infuser, Darjeeling tea leaves, electric tea kettle, water, pot of milk, cradle of sugar, malted milk biscuits from Tesco or Fortnum and Mason.

The “whole” in this world, is about systems. Academia, industry and government, plays a critical role as the purveyor of knowledge and tools necessary to install the infrastructure, in order to provide the parts of the system. We profit from components but the ***function*** of the system, the ***outcome***, is a symphony of ***structures***, which is of value, if the product supply chain is seamlessly coordinated with the service supply chain, in a manner that the work flow is friendly for consumers, customers and end users. Hence, a ***seamless systems as a service***.

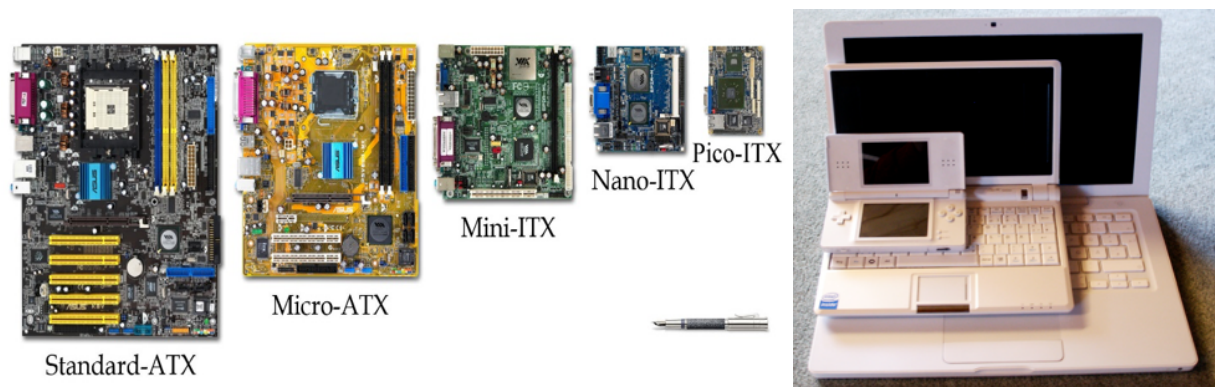


Fig. 4. Advanced R&D products and components (structures¹⁵) are essential but not sufficient to create user friendly solutions (functions). End users may only pay if the “function” offers value.

4 Information arbitrage

United States has exported knowledge at least since 1835, with the establishment¹⁶ of the American School for Girls, which is now the Lebanese American University in Beirut. The list of American Universities abroad has grown significantly.

How many foreign universities do we have in the USA? Very few¹⁷, if at all we can label them as universities. The lack of name recognition and the astronomical cost of creating a campus in the US are probably the main deterrents. Can we attempt to change that equation?

Can we offer “data, information and knowledge” as the catalyst to encourage FDI and foreign universities to establish US campuses? How about King Saud University in Maryland, University of Jordan in Michigan, Cairo University in Boston, Qatar University in Oregon?

Can a similar approach work with China, India, Brazil? An IIT in Tallahassee, FL?

Why am I emphasizing the Middle East and the BRIC nations? Because we want to create and sell services, and the gigantic markets are in the Middle East, Asia and Africa. By co-creating some of the services with campuses in the US, we create a direct sales channel for entrepreneurs, to reach these vast markets. Perhaps we may also hold half the IP rights.

Co-creation, collaboration and cooperation are catalytic to create, open, new markets. Can we change the equation, challenge *status quo*, think global systems. Can we combine?

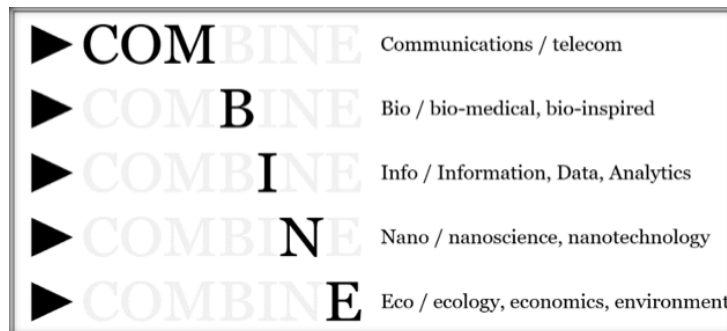


Fig. 5. Combine

5 A few uneasy words for academic departments defined by disciplines? Combine, complementarity, confluence, community, and convergence

Convergence is the inescapable truth for systems and the gospel of *systems as a service*. The mantra of convergence meets with a flourish of *lippenbekenntnis* (lip service) but the vision to practice convergence and complementarity, *at the level of departmental operations*, is quite limited, to a select few elite institutions in the US, and even fewer universities in OECD nations. Perhaps this is at the heart of a disconnect. Perhaps it is a reason why we see so few clusters of entrepreneurial excellence and almost all talent trying to flock to such nodes.

Departmental operations managed by “installed” “tenured” leaders (chairs, search committees) are still drinking the same “cool aid” – chemistry department is for chemists, engineering faculty must have a PhD in engineering, management professors must have a business degree. This rigid attempt to preserve disciplines in departments to pursue “pure” and “credible” research is highly laudable, quintessential to the pursuit of knowledge, and required for excellence in science and engineering. This is **not** the problem. We **must not** dilute rigor.

The problem lies in the failure of departments not to unleash a parallel channel and embrace the view, that, systems and solutions require multi-disciplinary approaches, to solve problems in the real world. Acknowledging this fact requires that departments recruit, at the same ranks, people with non-formal degrees and out-of-the-box experiences as full time faculty members. The pursuit of these faculty members will be unconventional, cannot be subjected to the “publish or perish” dogma¹⁸, they will venture out of the traditional set up, re-define the type of problems to be addressed. These faculty will liaise with other departments, break silos, cross pollinate with industry and reach out to end users, markets and the global ecosystem, at large. These activities may not bode well for departmental “object codes” and create discomfort for the traditionalists who are limited to papers, conferences and grant writing, as performance metrics.

The answer is **not** in this HBR article¹⁹ and certainly not about selling out to industry. The answer is far more complicated. It must balance workforce development and academic complementarity with industrial economic growth as well as the creation of new global markets. Cooperation, collaboration and community must share the grounds with economy, science and engineering. Basic research must be supported and the fruits, when possible, must serve soci-

ety. The erudite faculty dedicated to building “pillars” must find a way to find and accept the need for a breed of people, in traditional departments, who will be building bridges, based on pillars. We must enable some people to see further, even if it is by standing on the shoulders of giants²⁰.

Institutional lethargy to institute change and embrace convergence at the operational level, runs parallel to the resistance for change for local and state governments entrusted with economic and workforce development. City, county and state economic development offices are staffed with public relations and communications people, generally. Occasionally business experts are in the mix with lawyers occupying the leading roles. Academics, scientists and knowledge resources are few, if any. In the management of state and federal economic development, the old adage²¹ may still ring true, *scientists on tap*²² *but not on top*.

Hence, a chasm between knowledge (institutions) and workforce silos (economic development agencies) fails to catalyze the bridges essential for cultivation of symbiosis.

The hype about jobs of the future²³ and the traditional²⁴ view of the future²⁵ are, ultimately, somewhere²⁶ bounded²⁷ by demand, on one hand, and remuneration, on the other.

The task of economic development is to create a supply chain of talent, skills and training, to feed the expected demand for labor. SCM is not only about logistics and returns.

The task of the institutional machinery is to inculcate students, in the pre-college pool, with the foundation that the colleges can build upon, to feed the supply chain of talent necessary for economic growth. Supporting the gifted, identifying the outstanding, and the pursuit of excellence, is also the task of the university-research complex. Departments were created to undertake this task, but not be limited to that task. But, often, they are. Hence, the quagmire.

Building bridges is one solution to support excellence, while maintaining the ability to compete globally. The bridge between institutions and economic development agencies are crucial to our progress.

There must be “people” on both sides who can speak both “languages” and politically adept to navigate the bureaucracy, adroitly. In addition, these “people” must understand the broad spectrum of needs with respect to the community (demographics), economics of the business (industry needs) and disciplines (breadth of knowledge in science and engineering).

These are the “people” who are few and far between. Neither the departments nor the agencies are seeking these people – because they don’t belong in any one box which can be fitted to a “job” description. These people must be dedicated to the “mission” and not a job or a task. These people must do all that is necessary, break barriers, and help to lift many boats. These people must give credit to others, refrain from narcissism and believe in altruism. These people must be able to ‘connect the dots’ and convey their purpose with lucidity, dignity, and *humility*.

It is easy to list ideas, pontificate and hide behind platitudes. It is a difficult task to orchestrate knowledge systems, spur technical innovation, implement tools integration, stitch business models, and offer a “seamless systems as a service” to help people and serve society. I wish to provide an imperfect example. In a collaborative project, we published²⁸ a paper on how to construct ultra-low cost (3D printed) nano-dot sensors to detect mercury (Hg) in water, using a smartphone which runs an AI (artificial intelligence) based program. One key is the *ultra-low cost* of the sensors (which are also robust enough for metrics and measurements). This is a tiny

drop in the ocean. But, if we could execute our vision of the “seamless systems as a service” then these ultra-low cost sensors and the smartphone detection system may save lives. The system can detect contamination (mercury, Hg) in drinking water and alert the end users.

Embracing the mission to enable science to serve society is fraught with financial challenges. Thousands of life-saving sensors never escape the lab and their potential withers in publications. The description of “World Sensor Organization” in Commentary C is an idea²⁹ which few may grasp in terms of its immense global impact and even fewer may wish to support. Society may need new organizational structures to stitch the vision of connectivity, and service for citizens, in a manner that is economically prudent, sustainable and offers measureable value. Universities, public agencies, government and non-government organizations, are all important part of this ecosystem but none appear to be equipped or eager to lead this important charge.



Fig. 6. Bridges are built on pillars: Ponte di Rialto and Ponte Vecchio by Antonietta Brandeis³⁰

6 3D PRINTING – THE BLESSINGS OF DIMENSIONALITY (THERE IS NO CURSE³¹ HERE)

In our very small contribution (paper), the tool that enabled us to manufacture the low cost sensor was 3D printing. The technology is 40 years³² old, yet, its vast potential seems to be hovering around high end applications³³ or facetious³⁴ consumer toys. In a separate article, I have discussed³⁵ a few thoughts on 3D printing in entrepreneurial innovation (Commentary B).

3D printing may be compared to lenses. The ability to “see” was transformed by lenses³⁶ and in the 17th century³⁷ Anton van Leeuwenhoek (1632-1723) made his “microscope” using a lens. After 400+ years, in the 21st century, we may be going further and forward (?) to a new state of lenslessness³⁸ which promises even more wondrous insights. It is likely to foment a new form of a revolution, for good. 3D printing possess all the ingredients for a revolution, too.

Total knee arthroplasty was first performed nearly 50 years ago³⁹ and knee/hip joint replacements are a part of our modern vernacular. Vast advances in implants, joints, prostheses, are helping people, worldwide, albeit far more in the advanced economies (OECD). The hyper-inflated cost of material combined with ultra-precision manufacturing costs, may make it less affordable to about 80% of the world, who are not a part of the OECD nations.

Can 3D printing bridge this chasm between haves and have-nots, partially? What if 3D printers and materials (alloys, powders) were provided to hospitals or clinics, globally?

The business model may be a portfolio of tools in order to lower the barrier to entry into markets. What if there was a minimal set-up cost, as a down-payment, and then a “pay-per-use” *modus operandi* to charge for each unit of time the 3D printer was used?

The paradigm change is in the business of the product as a service, in this case the product is not only the stent or the hip joint but also the 3D printer. The hospital or clinical may not have to seek capex funds to afford the printer. Micro-payments may transform equipment installations from the capex (capital expenses) column to the opex (operating expenses) domain. The latter may better serve resource-constrained organizations, often held hostage by cash flow.

Are 3D printer manufacturers dictating surgical implants? Not at all. It is the reverse. Surgical implant manufacturers are going to evolve as 3D printer manufacturers, too. The old school investment / sand casting manufacturing of metal products (implants, etc) in a few locations (company manufacturing locations), may be partially replaced by 3D printing, by supplying 3D printers to hundreds of locations, globally distributed, on-demand manufacturing.

In the new business model, for old surgical implant manufacturers, *data will be the salt*.

Precision manufacturing, for material science, is not really precise for physiology or orthopedics or cardiology, it is an approximation to minimize discomfort. In many cases, it is a statistically “average fit” for implants, joints and prostheses. 3D printing may reduce the need for the “one-size-fits-all” approach necessary for mass manufacturing. 3D can deliver precision fit for every individual, when necessary, if feasible. In the new business model (for old surgical implant manufacturers), data from imaging will design the “fit” required for that individual.

The imaging data will be at the location of the patient (assumption - location is equipped with imaging equipment). Imaging data will be transmitted to the company (for example, Bio4D in Cambridge, MA). 3D design experts, orthopedic specialist, neurosurgeons, software experts and engineers can use the imaging data, to create, modify or change, the dimensions of the product (stent, joint, etc). The material specifications (alloys, powders) and the instruction file for the 3D printer, for 3D printing the personalized precision part, will be transmitted to the 3D printer, at the location of the patient. The part will be 3D printed and used by the medical team, attending the patient (assumption – printed part does not need any specialized or rate-limiting pre-processing step or cellular treatment which may be unavailable at the location of surgery).

The surgical parts business of Bio4D (for example), remains the same – still providing implants, joints. But, in this highly distributed manufacturing on-demand model, the company has extended its ecosystem and owns a new line of business which provides 3D printers, and perhaps also inks an IP agreement for the 3D printer alloy powder, with innovation labs in material science, and instrumentation for co-creating the specs for the alloy to be used for parts.

However, the ecosystem for Bio4D does not stop at printers and powders, it also holds the *data* from [1] patient imaging and [2] the algorithms and software necessary to turn that data into a precision fit for the required 3D printed part. The raw data from the patient may still belong to the patient or the hospital of origin. But Bio4D can own, or reserve the right to license, the *processed data* which is created by Bio4D, through convergence of imaging data with software

for 3D printing. The *data set* (instruction) for printing the part which is transmitted to the 3D printer (at a remote location), is a part of the business revenue for Bio4D in terms of the digital economy, or knowledge economy or health information (whatever jargon may apply).

The combination of these strands of revenue demands new business models. Traditional pay-for-product and pay-for-service schemes may not be the only tool. Pay-per-use and its variations, may be complementary mechanisms. Micro-payment strategies may stay in place for the life cycle of the user. The latter may be 10-50 years, depending on post-operative longevity.

If the cost of *implant-as-a-service* was priced at \$1 per day, as long as the person is alive, then for a 10 year life cycle, the service⁴⁰ will earn \$3,650 or if it a bigger part⁴¹ (for example, knee or hip joint), charging \$10 a day generates \$36,500 as gross earnings, per item, per patient, for a 10 year post-operative use. In addition to per part revenue, there will be revenue from use of 3D printers, per use, over the life cycle of the engagement with the hospital or clinic. By reducing the burden of upfront fees, one increases market penetration for services.

7 Going back to the bleeding edge

Vilfredo Pareto (1848-1923) published his first work, *Cours d'économie politique* (1896–97), where the 80/20 “rule” (Pareto Principle) was used⁴² to represent various distributions of land and wealth, in Italy. We have used this 80/20 rule to claim that untapped economic growth from the 80% of the world’s population, may not need all the accoutrements from bleeding edge R&D, in order to provide a plethora of services to improve the quality of life and living, globally.

The 20% of the affluent world, funds inventions and innovations. Polarization (Fig 6) of wealth is a gigantic problem yet some of these individuals are investors pushing forward the boundaries of science and technology. In our example of 3D printed parts, we discussed what may help 80% of the world. But, *much more* can happen in the context of 3D body parts. But, it will need massive investments, experiments and trials, before an approved development may become a *feasible* part of the future of 3D printed parts, for the less affluent global citizens.

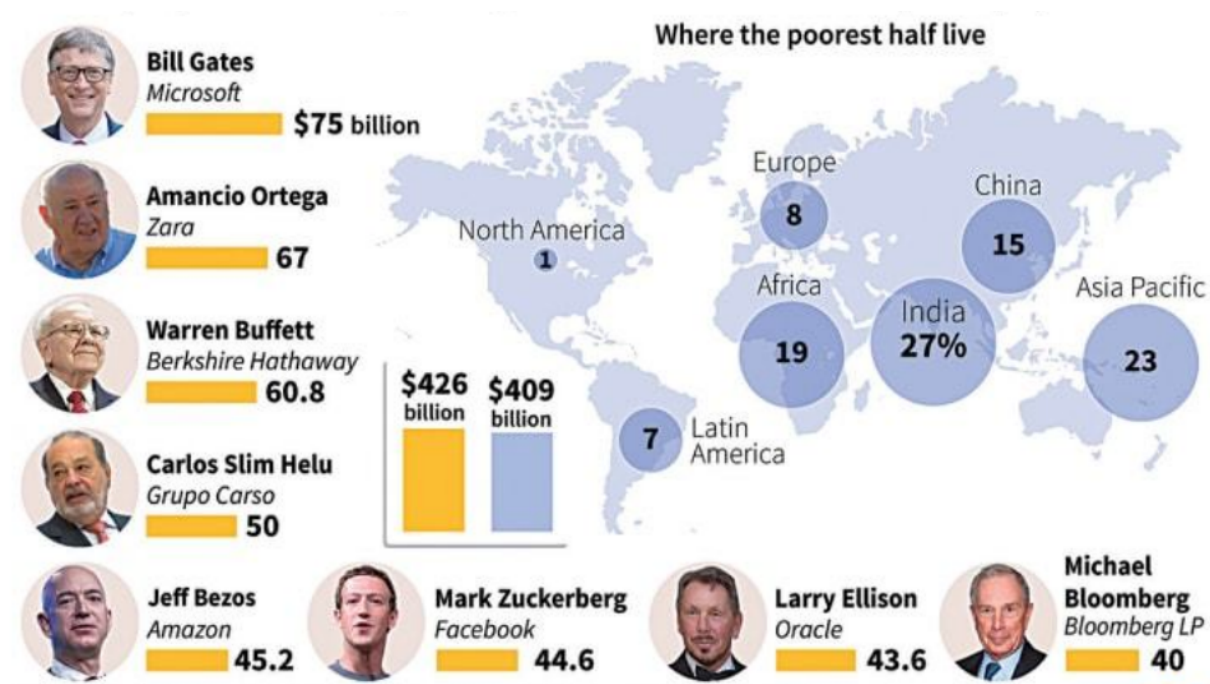


Fig. 7. Eight men, own more wealth than the poorest half of the world's population⁴³ according to (2018) calculations⁴⁴ from Oxfam based on a 2017 report⁴⁵ from Credit Suisse.

Flexibility and precision due to 3D printed body parts may enable the use of 3D printed implants to act as Trojan Horses⁴⁶. For example, stents filled with drugs⁴⁷ or stem cells or joints with internal sensors, printed polymer⁴⁸ electronics, tunable radiofrequency communications⁴⁹ and nanotube radios⁵⁰. Using data from implant-sensors, the delivery service of drugs, cells and analytes, *in vivo*, on demand, may be remotely controlled using RF communications network **in** the body, in partnership with analytics, systems and humans-in-the-loop, **outside** the body.

A perusal of references 43-46 (above), will reveal that these ideas, and papers, are more than a decade old (in some cases, 20 years old). The self-adjusting hip joint using a smartphone to "sense" gait (provide auto feedback to the hip joint to adjust) is not impossible to deliver, for 20% of the world, who can afford to invest in the R&D and pay for the services. When will that service become feasible for 80% of the world?

The answer depends on the investors (in that 20% group) who must fund the bleeding edge R&D necessary to transform this idea into reality. If adopted by users, in the 20% group, the cost of the service may start to decline, over time. At some point, it may become affordable even for the people in the developing economies.

Hence, the need for individuals in the 20% group, to catalyze certain forms of progress, which may lift the lives of people, referred to as the 80% of the world.

8 Comments

In this example of economic development from the digital economy, I have focused on a tiny sliver, that of, the impact of 3D printing on replacement of body parts. It is not at all a new technology. The suggestion is not about advanced technical R&D, but the *strategy* of its use, aimed to offer healthcare *solutions*, even for the developing economies (80% of the world).

What the 20% of the world can do, to further the R&D related to 3D printing, should not stop us from finding ways to deliver the help, we can, at this time. But, transformation is hard.

Transforming Bio4D, which mass manufactures surgical implants, to view the future of its business as “implant-as-a-service” is the business challenge. The ability to think outside the box, and “connect the dots” essential for the service ecosystem, is not an easy task. It requires vision, leadership and investment. Truth is, it also requires altruism, a dedication to the mission of improving lives, and a sense of the future, where credibility, égalité and dignity, are not just buzz words or platitudes but part of the corporate mission, which, of course, must also include profitability.

The global growth of new business offers immense potential for profit, albeit, over time, from micro-revenue. There may not be any instant financial gratification. There is an underlying need for establishing credibility through local and global partnerships. There will be a need to serve as a global ambassador for health and healthcare, to lift many boats, not just a few yachts.

9 Concluding opinion

Old world “industry” leaders chained to Wall Street may not “see” the future. Perhaps their imagination is out of focus, their vision may suffer from myopia or macular degeneration, and risk-averse strategists may insist that they keep within their well-defined comfort zones.

On the other hand, the “new” world is super-saturated with the high tech buzz, where creating an “app” can apparently escalate one to celebrity status on social media. Once on the pedestal of prosperity, the next step is to surround oneself with ultracrepidarian marketing staff. The reality of the bigger picture, pales, and fades, by comparison with the thrills from virtual reality (VR). High tech seems to be synonymous with high growth (Figure 7).

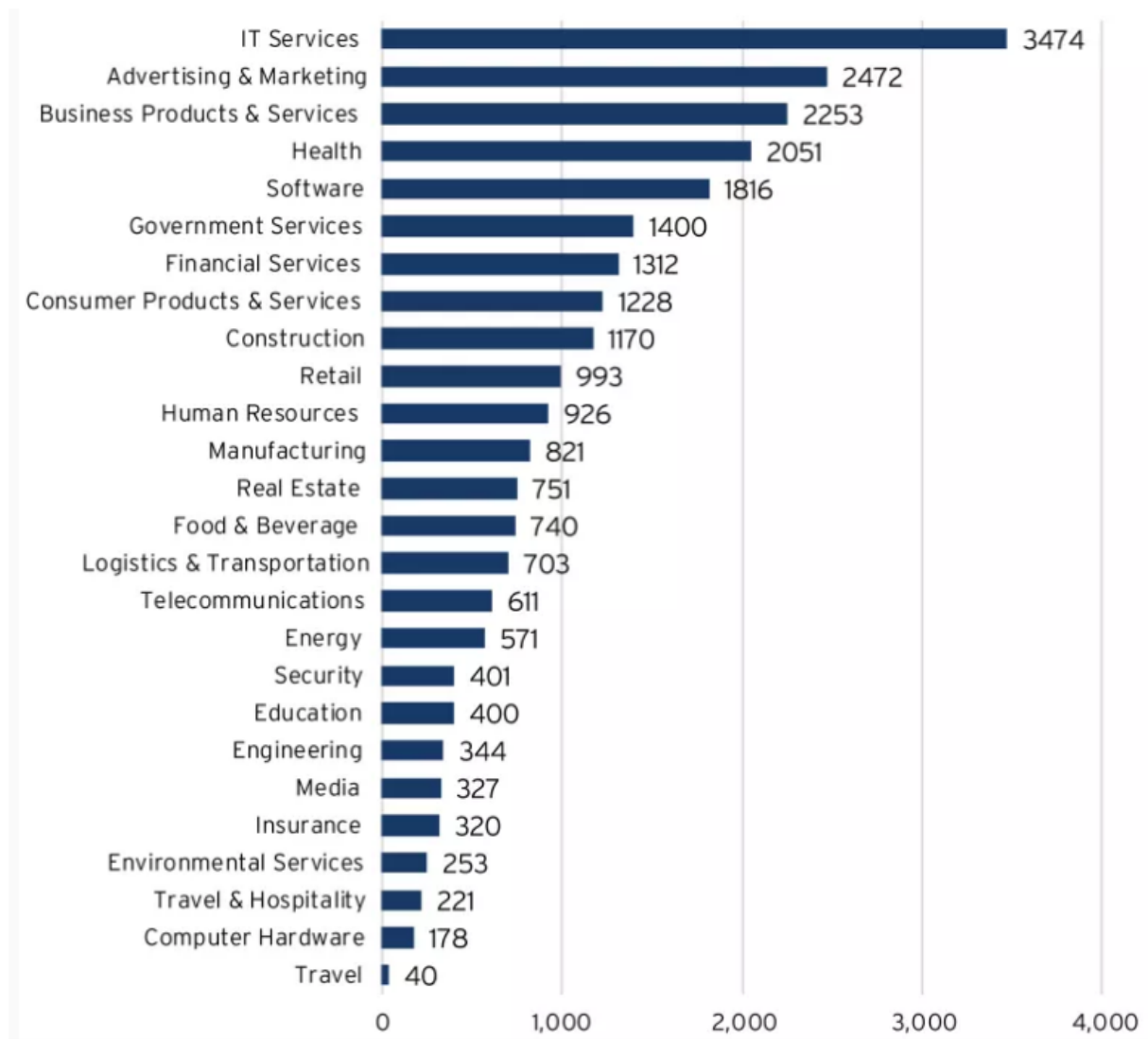


Fig. 8. High growth company industries⁵¹ in the US (2011-2017)

The suggestions in this simplified proposal can lead to global prosperity, albeit incremental in nature. It may be accomplished without any grand invention and vastly differs from the prediction of consulting pundits, according to the sales mantra shown in Figure 8. The need for safe drinking water, sewer systems, and managed sanitation services, does not even register on the “map” yet these are daily challenges⁵² for billions of people, in the 80% group.

- **2.1 billion people** lack access to managed drinking water services. (WHO/UNICEF 2017)
- **4.5 billion people** lack safely managed sanitation services. (WHO/UNICEF 2017)
- 340,000 children under five die every year from diarrhoeal diseases. (WHO/UNICEF 2015)
- Water scarcity already affects four out of every 10 people. (WHO)
- 80% of wastewater flows back into the ecosystem without being treated (UNESCO, 2017)

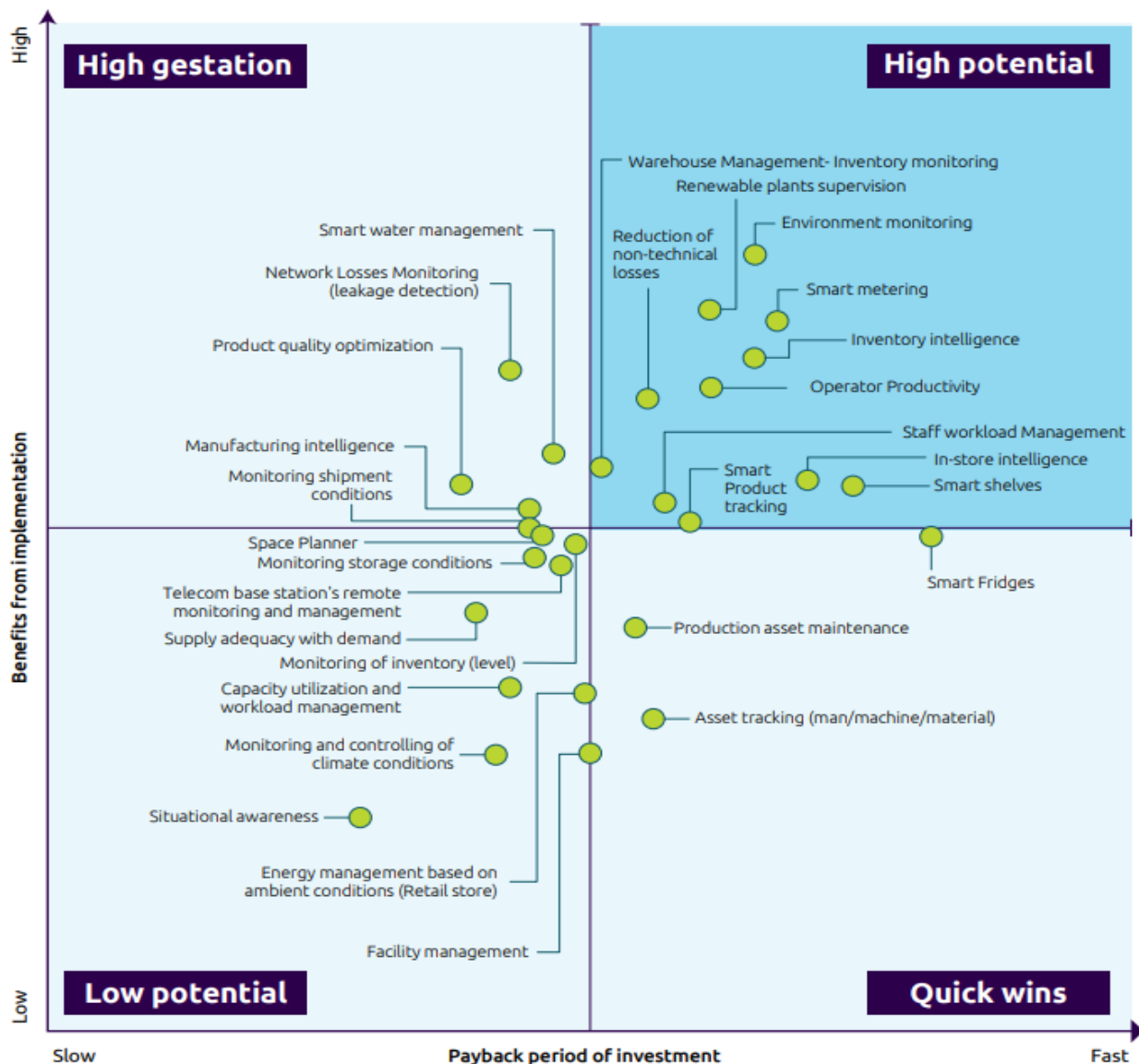


Fig. 9. Use cases peddled by US consulting⁵³ firms, indicates “smart fridges” as a quick win.

The (delusional?) choice of “smart fridges” by the consulting firm (Figure 8), points to a flawed vision: the failure to recognize efficiency as a function of the ecosystem. The “smartness” of a fridge is linked with identification of inventory in the fridge. The *retail supply chain of food* must offer tools for identification, recognition and communication of items, stored in the fridge. Slapping sensors or cameras inside the appliance is **not a systemic answer**. The *systems as service* approach to a smart fridge is much more complex. It needs convergence of multi-tiered supply chains. It harks back to incorrect steps made by proponents⁵⁴ of RFID. The history⁵⁵ of general purpose technologies reveals similar mistakes made during the 1920’s in course of electrification in the US. However, “smart fridges” may be relevant to use⁵⁶ in OECD nations

(20% group), but, even then, the business case remains extremely wobbly. The “smart” bubble is luring investments from developing countries (Fig 9). Is it mimicry or competition?

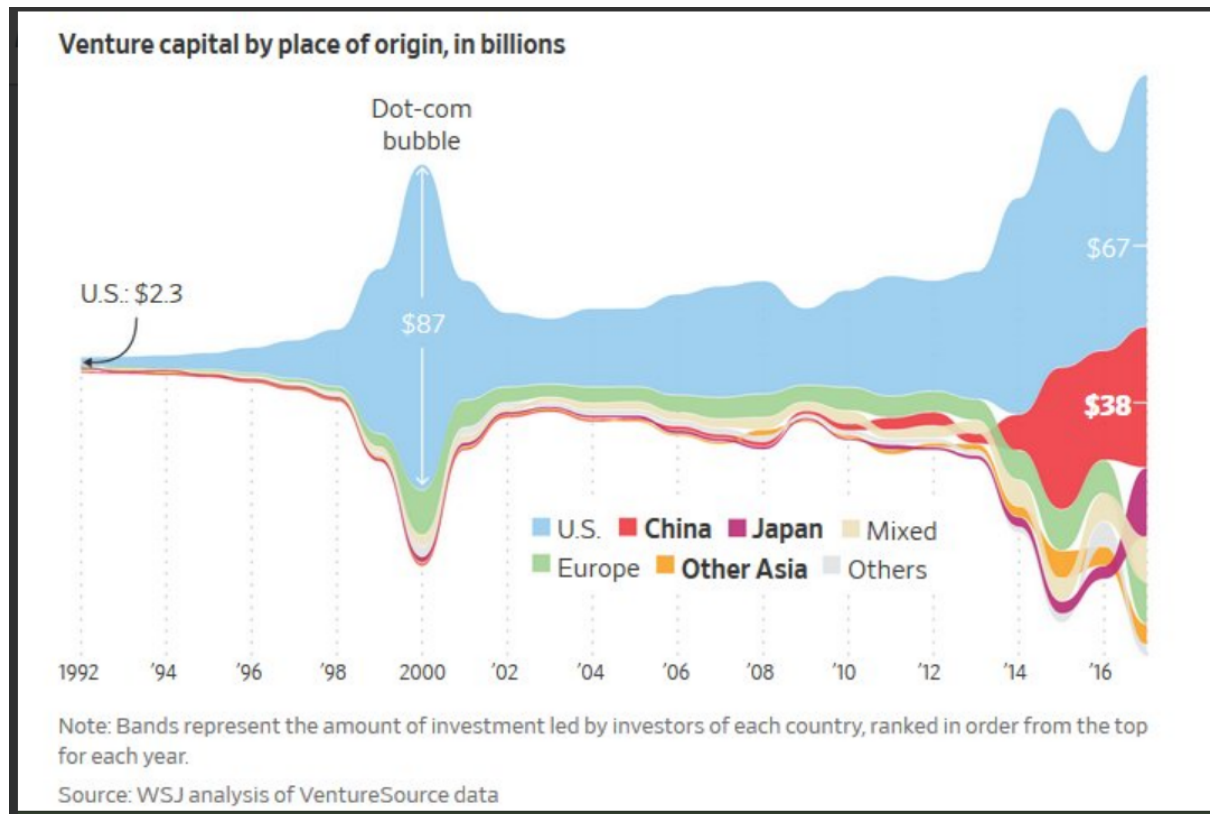


Fig. 10. Venture Capital Flow, US\$ Billions. Source: Wall Street Journal Venture Source Data

Entrepreneurial innovation is a word bandied around in business conferences. Here, in this essay, we present examples calling for distributed and global entrepreneurial innovation for the rest of the world. We echo the renewed wake-up call by Jim Kim, President of World Bank, who admits⁵⁷, *“it is imperative we find new paths to prosperity. The traditional route to economic growth and job creation through industrialization is rapidly closing.”*

The convergence of ecosystems outlined in this suggestion is greater than the sum of its parts. The magnitude of its potential cannot be unleashed in little steps, small advances or short term thinking. Long term ROI is inextricably linked to economies of scale, and services, which can penetrate any market. The “heart” of this model is not a lab project or a “small” pilot test bed or an isolated experiment. One may not be able to build an elephant using the mouse as a model.

10 Epilogue

After reading an earlier draft of my “mindless drivel” (this essay), a teenager from a developing nation in SE Asia (daughter of a friend of a friend), send me a message via WeChat. She wondered

if 80% of the world is just a “market” for the “systems as a service” businesses that 20% of the world may wish to develop (because “the 20%” have the R&D resources, human resources, and necessary investment, to stitch together the services and decision systems).

I have now added this epilogue to respond to her concerns. The first response to her question is that I really don’t know the dimensions and dynamics of how and who may create these systems as a service. Because, the *context of demand* is relevant to each market, hence, it is my naïve assumption that these “services” must be *partnerships* where part of the R&D, tools and technologies may be from OECD nations but the human resources required for systems integration, deployment, and maintenance, is likely to originate from developing economies. Knowledge transfer, skills training, and workforce development, are central to the “shared” notion. Online education⁵⁸ may be a platform to facilitate dissemination.

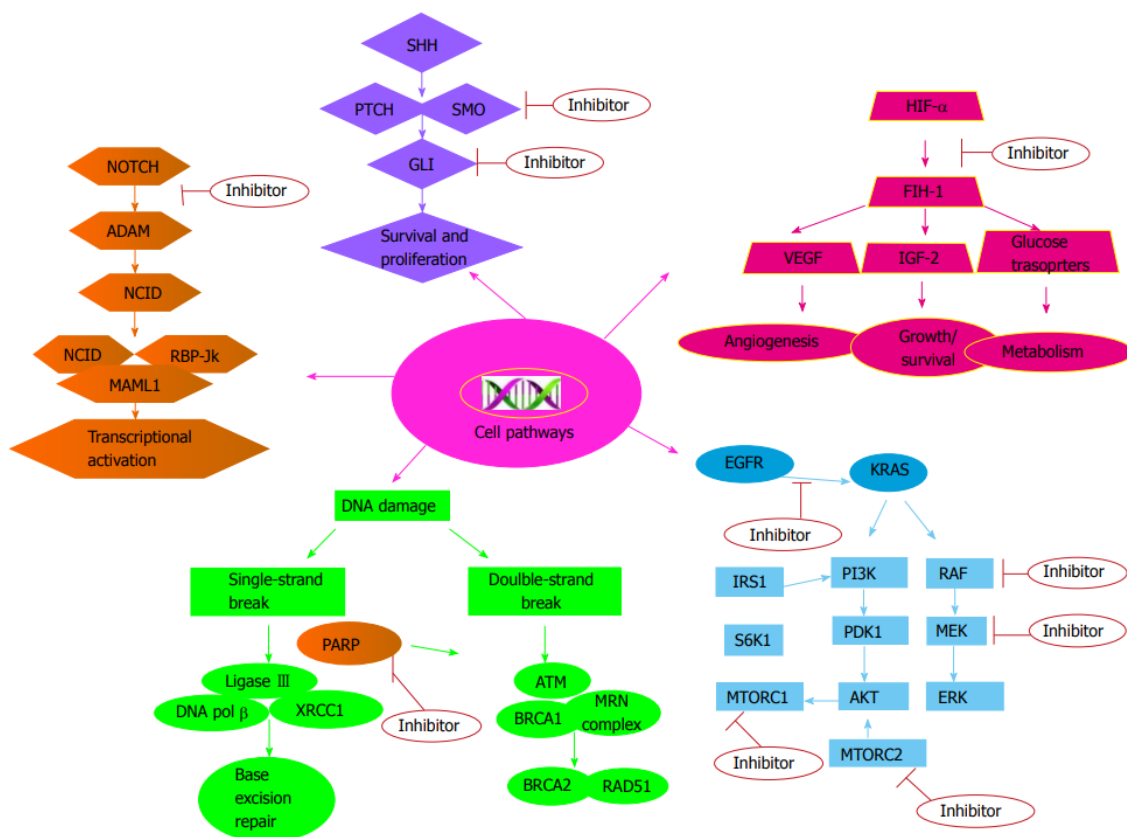


Fig. 11. Cell signaling pathways involved in pancreatic ductal adenocarcinoma carcinogenesis and actionable molecular targets⁵⁹. Imagine the research necessary to scratch the surface of one type of cancer *system*. Scientists in developing nations must also ask the hard questions, which require peace of mind, infinite patience, and a sense of purpose, to use science to serve society.

However, there may be a deeper question, which remains unvisited. Where should the developing economies invest in terms of research? I am unequivocally unqualified to answer that question.

But, the latter wouldn't stop me from making some suggestions, for example, malaria research (you do not have to agree with any suggestion, we can pre-agree to disagree).

The etiology of malarial diseases (which results in 2 million deaths per year) is a clear example of how parasites evade cellular immunity using antigenic variation⁶⁰ (*Plasmodium falciparum*, is responsible for about 90% of human mortality and morbidity, but over 200 species of *Plasmodium* are known to infect vertebrates). The almost exclusive occurrence of malaria within the 80% of the global population, mostly in non-OECD nations, makes it a target for eradication, by 80% of the world (rather than depending on initiatives from the 20%).

But, the 80% of the world cannot ignore the other afflictions, for example, cancer, diabetes, cardiovascular malfunctions and pulmonary diseases, to name a few. Which means, in the biomedical domain, the rest of the world must find ways to use therapeutic advances, for example, human induced adult pluripotent stem cells, plant based bio-pharmaceuticals, traditional biologics (monoclonal antibody producing autologous cells), metabolomic sensor networks (*in vivo* wireless communication networks monitoring analytes and transmitting data from inside the body), molecular robotics (ingested micro-machines removing intestinal polyps) and nano-machines⁶¹ to target apoptosis⁶², precision cell death⁶³ and time-based drug delivery.

Therapeutic *systems* have a long way to travel from the bench to the bedside. Business models focused on profit⁶⁴ and business school education, may be detrimental to the vision of convergence. Should we demolish⁶⁵ business schools? The business of translational medicine, as outlined in the above paragraph, may need a business model which values R&D partnerships.

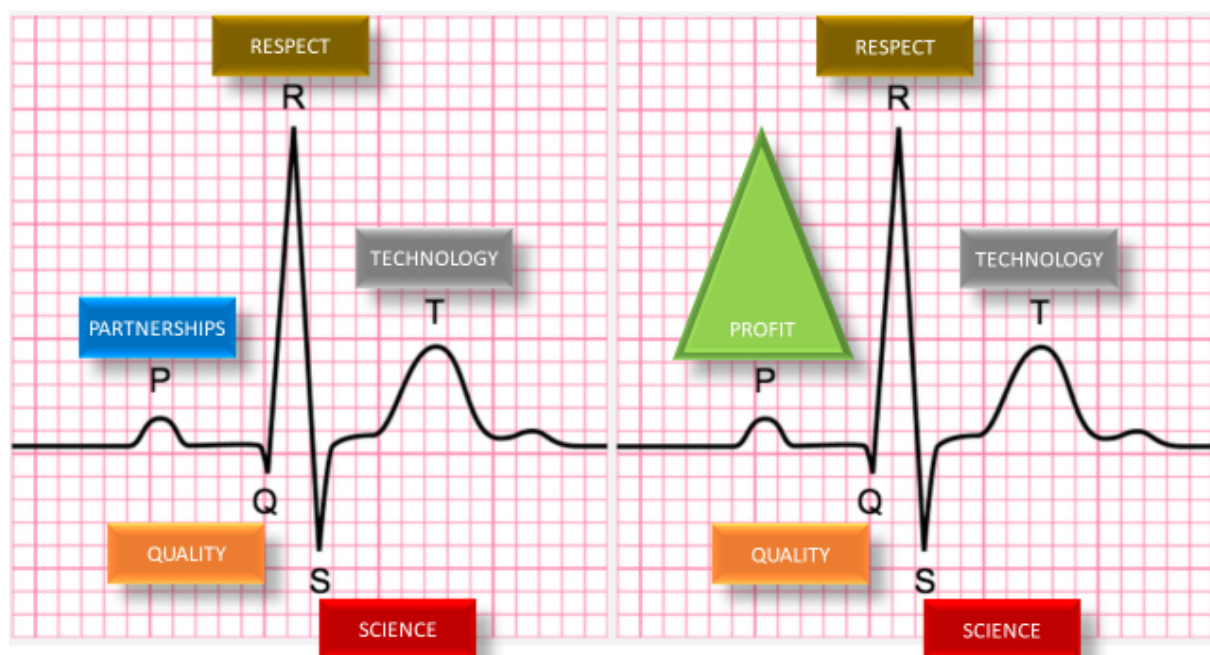


Fig. 12. Profit from business value of partnerships may exceed profit from profit-driven business

The heartbeat of business, illustrated in Figure 11, may benefit from a slightly different perspective. Consider the basic PQRST waveform⁶⁶ telemetry, displayed as electrocardiograph,

representing electrical impulses generated by the heart (transferred to electrodes on the skin, which in turn displays the waveform on a screen or prints out on a telemetry strip). PQRST may serve as a bio-inspired business guide, to draw attention to the push-pull dynamics between P for Profit (the business school mantra) and P for Partnerships (a sense of the future). The new path does not exclude profit. It maximizes profit. PQRST suggests the need for industry and businesses to structure partnerships, with other industries, academia, government agencies, and global organizations, to co-create, co invent, co-innovate in order to co-opt markets, grow goodwill and profit from delivering a higher quality of service for society.

These and other suggestions for business and society, aimed at improving the quality of life, and living, shares a common denominator, irrespective of the wealth of the nations. The supply chain of talent may be the underlying primary determinant and the purveyor of progress for civilization.

In this context, one observes that the US has built a Taj Mahal on top of a wobbly base of rickety twigs. One may arrive at this general observation based on the near-abysmal quality of US public education in 80% of K-12 schools vs the rigor, creativity, excellence, and brilliance, in about 20% of US entities of higher education (research universities, institutions). Even a cursory glance at Figure 12 drives home the fact that is far cheaper to be entertained⁶⁷.

In this essay, one may find ample evidence of “see-saw” between *service as a system* for the 80% of the world and occasional discussions about the bleeding edge of R&D advances. There is no doubt we need *service as a system* but the origin of talent is agnostic of nations. The limited budget in developing nations may be judiciously used to strengthen academic foundations, to contribute to the global supply chain of talent. But, the affinity for STEM must not induce a phobia for funding humanities, languages, arts and music.

In research, developing nations must not be afraid to ask the hard questions, with long term value. Biomedical research is an essential part of FEWSH, as well as materials science, nano-satellites, energy storage and mathematics. These are preferred over programming, networking certifications, and serving as robots, in call centers. However, there is also a place for vocational education and apprenticeships. Fact is, there will never be an optimum one shoe fits all solution. It is always going to be a question of balance and priorities in order to remain competitive in the global economy without sacrificing the plight for decent standards of living, for all, with dignity.

Leaders, to qualify to be referred to as leaders, must possess incisive foresight, vision, and imagination. Business leaders, social pundits, and academic gurus, must all understand that humans need to belong, to be appreciated, and to be valued. Leaders must understand, that at the heart of civilization, at its PQRST core, lies an incontrovertible truth. The education of a boy may change the fate of a man, but, the education of a girl, may change the destiny of a nation.

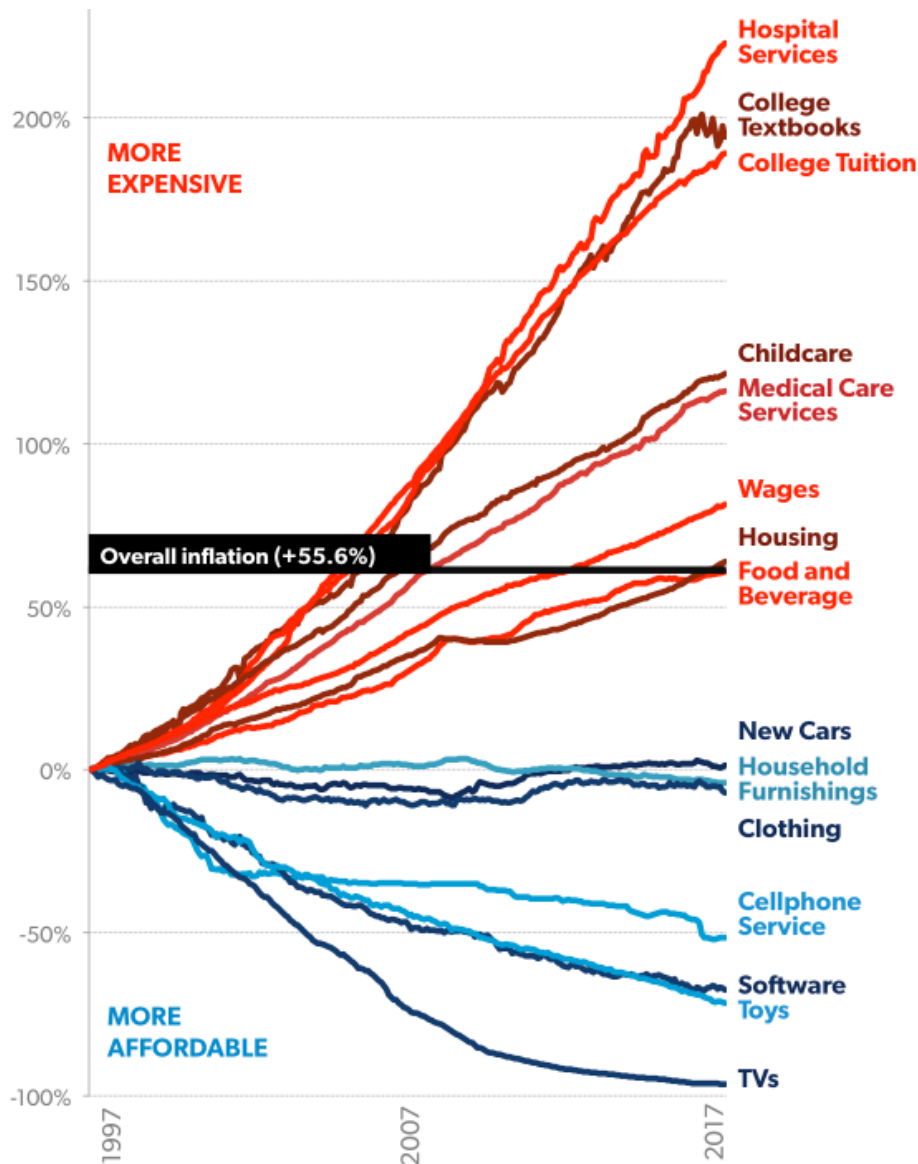


Fig. 13. Changes since January 1997 in the prices of selected consumer goods and services. There is no dearth of cheap entertainment even for the minimum wage masses in the US but cost of higher education, and healthcare, may pose insurmountable barriers, or bankruptcy.

Final Remark: Opinions in this essay are due to the author and do not represent the views of any institution.

Notes

¹In the 1300's, the Venetian traders were first to start trading securities from other governments. In 1531, the first 'stock exchange' in Antwerp dealt in promissory notes and bonds. In the 1600's, the Dutch, British, and French governments gave charters to companies with East India in their names. Amsterdam Stock Exchange was established in 1602 by the Dutch East India Company (Verenigde Oostindische Compagnie, VOC) and was the first to formally begin trading in securities. They issued stocks and offered dividends. Many "exchanges" occurred in coffee houses in London, for example, in Lloyd's Coffee House, opened by Edward Lloyd on Tower St in 1686 (which finally gave birth to the eponymous Lloyd's of London, the insurance company). The first stock exchange in London (formed 1773), was followed by the Philadelphia Stock Exchange (first US stock exchange) and then the New York Stock Exchange (1792).

²Conceived in 1937, the machine was built by Iowa State College mathematics and physics professor John Vincent Atanasoff and graduate student Clifford Berry. It was tested in 1942.

³<https://www.weforum.org/agenda/2016/05/4-billion-people-still-don-t-have-internet-access-here-s-how-to-con>

⁴<https://www.statista.com/statistics/273018/number-of-internet-users-worldwide/>

⁵<http://bakercenter.utk.edu/wp-content/uploads/2018/03/Net-Vitality-2.0.pdf>

⁶<https://www.sandler.com/blog/6-benefits-of-teamwork-in-the-workplace>

⁷<https://www.sandler.com/blog/6-benefits-of-teamwork-in-the-workplace>

⁸T-H Lee, H White, and C.W.J. Granger (1993) *Testing for neglected nonlinearity in time series models: A comparison of neural network methods and alternative tests*. J of Econometrics **56** 269-290 www.faculty.ucr.edu/~taelee/paper/1993_Jou

⁹<https://www.cs.cmu.edu/afs/cs/academic/class/15782-f06/slides/timeseries.pdf>

¹⁰<https://pdfs.semanticscholar.org/88b4/a255082d91b3c88261976c85a24f2f92c5c3.pdf>

¹¹J. E. Siegel, S. Kumar and S. E. Sarma (2017) The Future Internet of Things: Secure, Efficient, and Model-Based. <https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8055694>

¹²Datta, S. (2016) *Emergence of Digital Twins* in "IoT is a Metaphor" (Chapter 3) MIT Library <https://dspace.mit.edu/handle/1721.1/111021>

¹³<http://www.dtic.mil/dtic/tr/fulltext/u2/a188848.pdf>

¹⁴www.eugdpr.org

¹⁵<https://www.pcmec.com/article/overview-atx-micro-atx-itx-motherboards/>

¹⁶<http://www.lau.edu.lb/about/history/>

¹⁷<http://college.usatoday.com/2015/08/25/study-foreign-universities-unlikely-to-expand-into-the-u-s/>

¹⁸<https://www.theguardian.com/science/2013/dec/06/peter-higgs-boson-academic-system>

¹⁹<https://hbr.org/2016/04/more-universities-need-to-teach-sales>

²⁰https://en.wikipedia.org/wiki/Standing_on_the_shoulders_of_giants

²¹Quote attributed to Winston Churchill in *Twenty One Years (1964)* by Randolph S. Churchill

²²L. F. Audrieth, O. S. Reading, Herbert Malamud, Don E. Kash, James W. Russell, Nathan M. Becker, Hanna Newcombe & John Barden (2015) *Scientists on Tap or on Top? We Are Missing the Real Issues/Good Science, Good Politics/A Flaw in Pure Science?/On Vietnam*. Bulletin of the Atomic Scientists 21:7, 24-31 DOI: 10.1080/00963402.1965.11454835

²³<https://www.theguardian.com/money/2010/jan/09/jobs-of-the-future>

²⁴https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/391911/15.01.05._UKCES_Career_Brochure_V13_reduced.pdf

²⁵https://www.rec.uk.com/_data/assets/pdf_file/0009/398331/REC-Future-of-Jobs-Report-Web-13.10.17.pdf

²⁶<http://www.businessinsider.com/best-jobs-future-growth/#19-wholesale-and-manufacturing-sales-representative>

²⁷https://www.bls.gov/emp/ep_table_104.htm

²⁸ULTRA LOW COST WATER SENSOR USING A SMARTPHONE AS A DETECTOR <http://pubs.rsc.org/en/content/articlelanding/2018/an/c8an00065d>

²⁹Commentary *C* is in the book "*Haphazard Reality - IoT is a Metaphor*" download from the MIT Library (PDF marked "IoT is a Metaphor") <https://dspace.mit.edu/handle/1721.1/111021>

³⁰<http://www.antonietta-brandeis.org/>

³¹David L Donoho (2000) High Dimensional Data Analysis: The Curses and Blessings of Dimensionality <http://statweb.stanford.edu/~donoho/Lectures/AMS2000/Curses.pdf>

³²<http://www.me.utexas.edu/news/news/selective-laser-sintering-birth-of-an-industry>

³³See Dr Suman Das – “*laser-based additive manufacturing processes for high-performance aerospace parts*” - <http://www.me.utexas.edu/news/news/selective-laser-sintering-birth-of-an-industry#das2>

³⁴<https://sci-chic.myshopify.com/pages/about-us>

³⁵Commentary *B* is in the book “*Haphazard Reality – IoT is a Metaphor*” download from the MIT Library (PDF marked “IoT is a Metaphor”) <https://dspace.mit.edu/handle/1721.1/111021>

³⁶http://webs.ucm.es/info/giboucm/index.php?option=com_content&view=article&id=12&Itemid=30

³⁷<https://h2g2.com/entry/A2805725>

³⁸J. K. Adams, V. Boominathan, B. W. Avants, D. G. Vercosa, F. Ye, R. G. Baraniuk, J. T. Robinson, A. Veeraraghavan, Single-frame 3D fluorescence microscopy with ultraminiature lensless FlatScope. *Science Advances* 3, e1701548 (2017). <http://advances.sciencemag.org/content/advances/3/12/e1701548.full.pdf>

³⁹<https://www.ncbi.nlm.nih.gov/pubmed/12597066>

⁴⁰<https://www.epainassist.com/test-and-procedures/cost-of-stent-placement-procedure>

⁴¹https://www.npr.org/section*s/health-shots/2014/01/06/260263610/how-much-does-a-new-hip-cost-even-the-surge

⁴²Vilfredo Pareto (1909) *Manuel 'économie politique* <http://www.ecn.ulaval.ca/~pgon/hpe/documents/neoclassiques/>

Pareto.pdf

⁴³<https://www.oxfam.org/en/pressroom/pressreleases/2018-01-22/richest-1-percent-bagged-82-percent-wealth-crea>

⁴⁴<https://oxfam.app.box.com/s/eosi27xj7nxuyywsr06d734ct1xyuev/folder/45012657669>

⁴⁵<http://publications.credit-suisse.com/tasks/render/file/index.cfm?fileid=12DFFD63-07D1-EC63-A3D5F67356880EF3>

⁴⁶https://en.wikipedia.org/wiki/Trojan_Horse

⁴⁷<https://patentimages.storage.googleapis.com/6a/2a/fa/752d53b675896a/US20170216060A1.pdf>

⁴⁸http://www2.ece.ohio-state.edu/~berger/courses/ee835_02_aut02/1999jun_physworld_friend_review.pdf

pdf

⁴⁹Kimberly Hamad-Schifferli, John J. Schwartz, Aaron T. Santos, Shuguang Zhang and Joseph M. Jacobson (2002) *Remote electronic control of DNA hybridization through inductive coupling to an attached metal nanocrystal antenna*. *Nature* 415 152-155 <https://www2.cs.duke.edu/courses/cps296.4/spring08/papers/HSSZJ02.pdf>

pdf

⁵⁰K. Jensen, J. Weldon, H. Garcia, and A. Zettl (2007) Nanotube Radios. <https://ipo.lbl.gov/wp-content/uploads/sites/8/2014/08/2431.pdf>

⁵¹<https://www.brookings.edu/research/high-growth-firms-and-cities-in-the-us-an-analysis-of-the-inc-5000/>

⁵²http://www.un.org/en/section*s/issues-depth/water/

⁵³https://www.capgemini.com/wp-content/uploads/2018/03/dti-research_iot_web.pdf

⁵⁴http://money.cnn.com/2004/01/13/news/companies/future_store/

⁵⁵Paul A. David and Gavin Wright (1999) *General Purpose Technologies and Surges in Productivity: Historical Reflections on the Future of the ICT Revolution*. Presented to the International Symposium on ECONOMIC CHALLENGES OF THE 21ST CENTURY IN HISTORICAL PERSPECTIVE. <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.123.2728&rep=rep1&type=pdf>

⁵⁶http://www.bigee.net/media/filer_public/2012/12/04/bigee_doc_2_refrigerators_freezers_worldwide_potential_20121130.pdf

⁵⁷<https://etradeforall.org/the-world-bank-using-big-data-and-the-internet-of-things-to-help-end-poverty/>

⁵⁸<http://professional.mit.edu/programs/short-programs/additive-manufacturing>

⁵⁹<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4714146/pdf/WJG0-8-55.pdf>

⁶⁰<https://www.annualreviews.org/doi/abs/10.1146/annurev-micro-090816-093841>

⁶¹https://www.nobelprize.org/nobel_prizes/chemistry/laureates/2016/

⁶²Shigekazu Nagata and Masato Tanaka (2017) Programmed cell death and the immune system. *Nature Reviews Immunology* 17 333–340 DOI:10.1038/nri.2016.153 <https://www.nature.com/articles/nri.2016.153>

⁶³Dart, Anna (2017) “Cell death: A better way to die” *Nature Reviews Cancer* 17(10) DOI: 10.1038/nrc.2017.90

⁶⁴<https://www.jamesgmartin.center/2016/06/whats-wrong-with-business-schools/>

⁶⁵<https://www.theguardian.com/news/2018/apr/27/bulldoze-the-business-school>

⁶⁶<https://www.ncbi.nlm.nih.gov.libproxy.mit.edu/books/NBK2214/figure/A73/?report=objectonly>

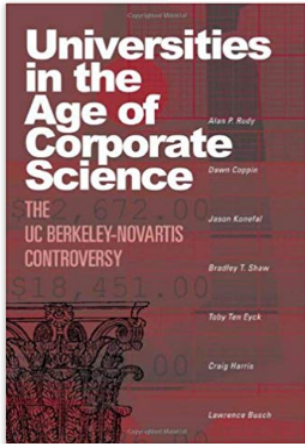
⁶⁷<http://www.aei.org/publication/chart-of-the-day-century-price-changes-1997-to-2017/>

Biographies



Shoumen Palit Austin Datta. Dr Shoumen Palit Austin Datta is a Senior Member of the MIT Auto-ID Labs, Research Affiliate at the Department of Mechanical Engineering, School of Engineering, MIT (<http://autoid.mit.edu/people-2>) and Senior Scientist, MDPnP Lab, at the Massachusetts General Hospital, Harvard Medical School (<http://mdpnp.mgh.harvard.edu>). He is the former Co-Founder and Executive/ Research Director of the MIT Forum for Supply Chain Innovation (2001-2010) at the MIT School of Engineering. A former Member of the Auto ID Center at MIT (1999-2003), MIT Data Center (2004-2006) and MIT Energy Initiative (2008-2009). As a Research Scientist in the Engineering Systems Division, MIT School of Engineering, he explored technology innovation, RFID, IoT, supply chain, data analytics and confluence of solutions.

He has taught Supply Chain, Strategy and Management at the MIT Sloan School of Management. He has offered executive education courses at MIT and several other institutions in US, EU and APAC. He is the former founding Senior Vice President for the Industrial Internet Consortium (IIC) and Senior Vice President at the Object Management Group (OMG). His current engagement with the MDPnP Program at Massachusetts General Hospital, Harvard Medical School is aimed at convergence of medical device interoperability with security and emerging tools from medical CPS and medical IoT. He is interested in IoT/IoT as a design metaphor and promoting the vision of the internet of systems (IoS) which extends ubiquitous connectivity, including the industrial internet, to catalyze economic growth, in different and diverse dimensions, for example, food and robotics. For the latter, he is also affiliated with the University of Florida and Purdue University. He has authored books, papers and articles related to evolution of IoT and the industrial internet (2003), intelligent software agents (2001), framework for predictive analytics, general operations and supply chain management, sensors in public health and healthcare platforms, renewable energy and digital transformation. He has served as advisor for start-ups, corporations and governments including US Department of Defense, United Nations (UNDP), World Customs Organization (WCO), President's Science and Technology Advisory Group (PSTAG) for the President of Taiwan (ROC). Dr Datta attended the University of Pittsburgh and earned his PhD from Rutgers University School of Medicine in collaboration with Department of Molecular Biology at Princeton University. He was a Research Fellow in Medicine (Thyroid Lab, Neuro-Endocrine Lab, Molecular Oncology) at the Massachusetts General Hospital and Instructor in Medicine at Harvard Medical School. He was a Research Associate at the Whitehead Institute at MIT and member of the MIT Human Genome Project. He was a Research Scientist at University of California UCSF School of Medicine, San Francisco, California. Dr Datta has served the public sector to improve education and technology as Special Assistant to the City & County of San Francisco, California; Science Education Partnership at UCSF School of Medicine; Berkeley Pledge initiative at the University of California, Berkeley and Chair of the National Task Force on Education, Workforce and Technology sponsored by ITAA, US Department of Commerce and The White House Council of Economic Advisers. For more info <https://autoid.mit.edu/shoumen-datta> & <http://mdpnp.mgh.harvard.edu> MIT Library <http://bit.ly/MIT-SD> and various articles <https://dspace.mit.edu/handle/1721.1/111021> Also explore: https://scholar.google.com/citations?user=_xAnvDEAAAAAJ&hl=en&oi=ao.

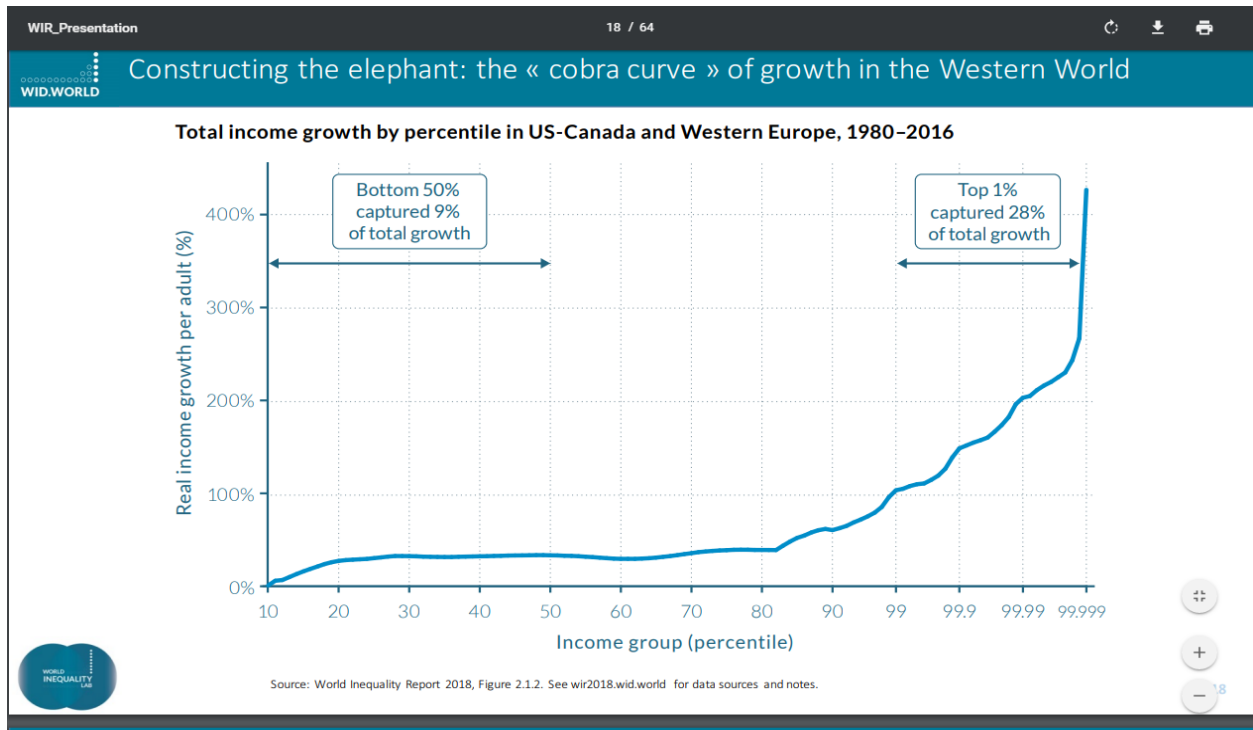


Universities in the Age of Corporate Science: The UC Berkeley-Novartis Controversy^{III}

January 28, 2007

by Alan P. Rudy (Author), & 6 more

As a result of widespread financial pressures, U.S. research universities increasingly stress the pursuit of funding beyond that available from government grants and contracts. Concomitantly, recent legal changes have encouraged universities to develop closer ties to the private business sector. This book represents the most thorough review ever undertaken of a major collaboration between industry and academe. A professional evaluation team obtained authorization for unprecedented access to those associated with the landmark \$25 million contract entered into by the Plant and Microbial Biology Department at the University of California, Berkeley, and the Novartis Agricultural Discovery Institute, a subsidiary of Novartis, an international pharmaceutical and agribusiness conglomerate. This model study presents the inside story of the partnership itself, places it in the context of contemporary university-industry relationships, and provides a larger theoretical framework for evaluating such collaborations in the future.



<https://wir2018.wid.world/files/download/wir2018-full-report-english.pdf>

<https://wir2018.wid.world/files/download/wir-presentation.pdf>

COMMENTARY [E] “ SIGNALS ”

Shoumen Datta

HAPHAZARD REALITY – IOT IS A METAPHOR

<https://dspace.mit.edu/handle/1721.1/111021>

“SIGNALS” contains a series of essays spewing amorphous thoughts:

1. SITS
2. SIP-SAR
3. SARS♠AG
4. ART
5. PEAS

Please download “SIGNALS”

● PDF from MIT Library

<https://dspace.mit.edu/handle/1721.1/111021>

Alternate <http://bit.ly/SIGNALS-SIGNALS>

SIGNALS is part of the collection of essays (book)

“IoT is a Metaphor” (see Commentary E)

Please download “IoT is a Metaphor”

● PDF from MIT Library

<https://dspace.mit.edu/handle/1721.1/111021>

The page numbers in the PDF do not match the document page numbers at the bottom of the pages. This PDF is made up of a few separate documents which were then combined. Hence, the temporary mis-match of page numbers. Apologies.

“SIGNALS” contains a series of essays spewing amorphous thoughts:

1. SITS ----- **You are here**
2. SIP-SAR
3. SARS♠AG
4. ART
5. PEAS

Please review “SIGNALS”

- Download PDF from MIT Library

<https://dspace.mit.edu/handle/1721.1/111021>

Alternate <http://bit.ly/SIGNALS-SIGNALS>

SIGNALS is part of the collection of essays (book)

“IoT is a Metaphor” (see Commentary E)

Please review “IoT is a Metaphor”

- Download PDF from MIT Library

<https://dspace.mit.edu/handle/1721.1/111021>

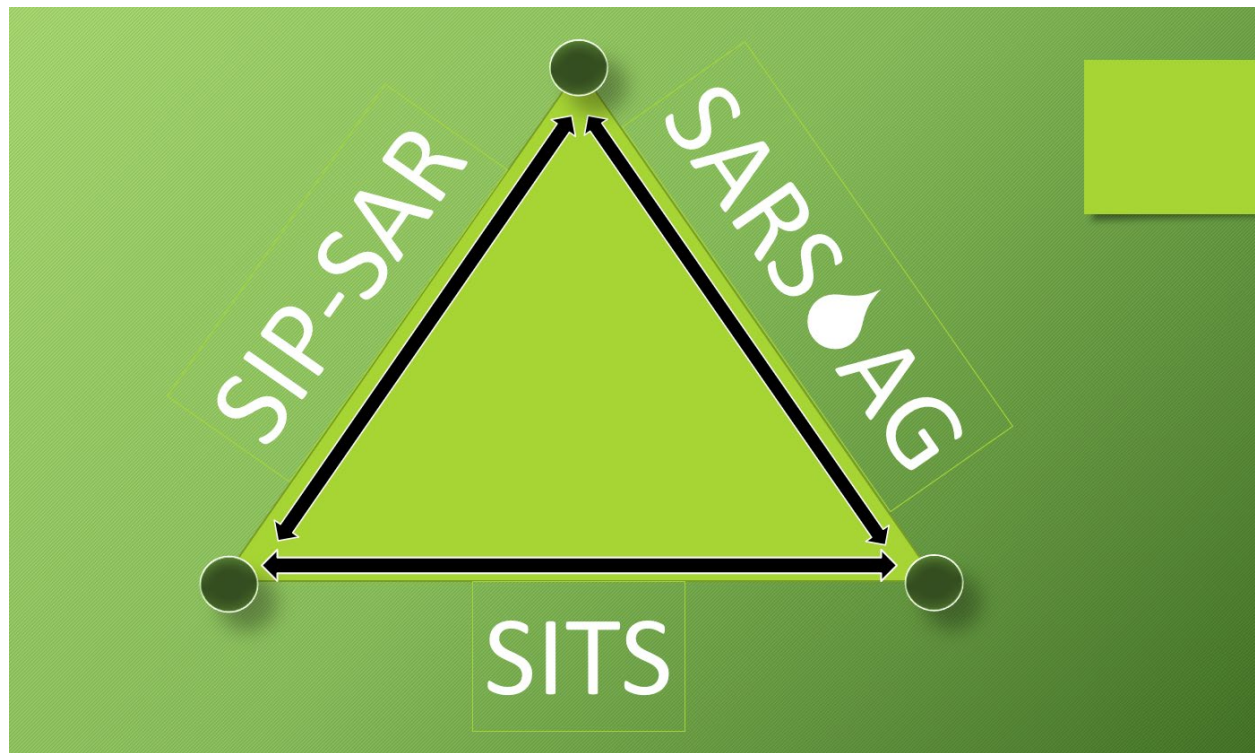
The page numbers in the PDF do not match the document page numbers at the bottom of the pages. This PDF is made up of a few separate documents which were then combined.

Hence, the temporary mis-match of page numbers. Apologies.

THE DISCOMFORT ZONE



SITS – SIGNALS N THE SOIL



SIGNALS IN THE SOIL

The global thrust for macro-climate discussions (UN IPCC, etc.) are increasingly at the center of our collective social conscience. The granularity of the distributed impact is less known, perhaps due its complexity. How many know about NASA SMAP using 102GHz radar for soil moisture mapping?

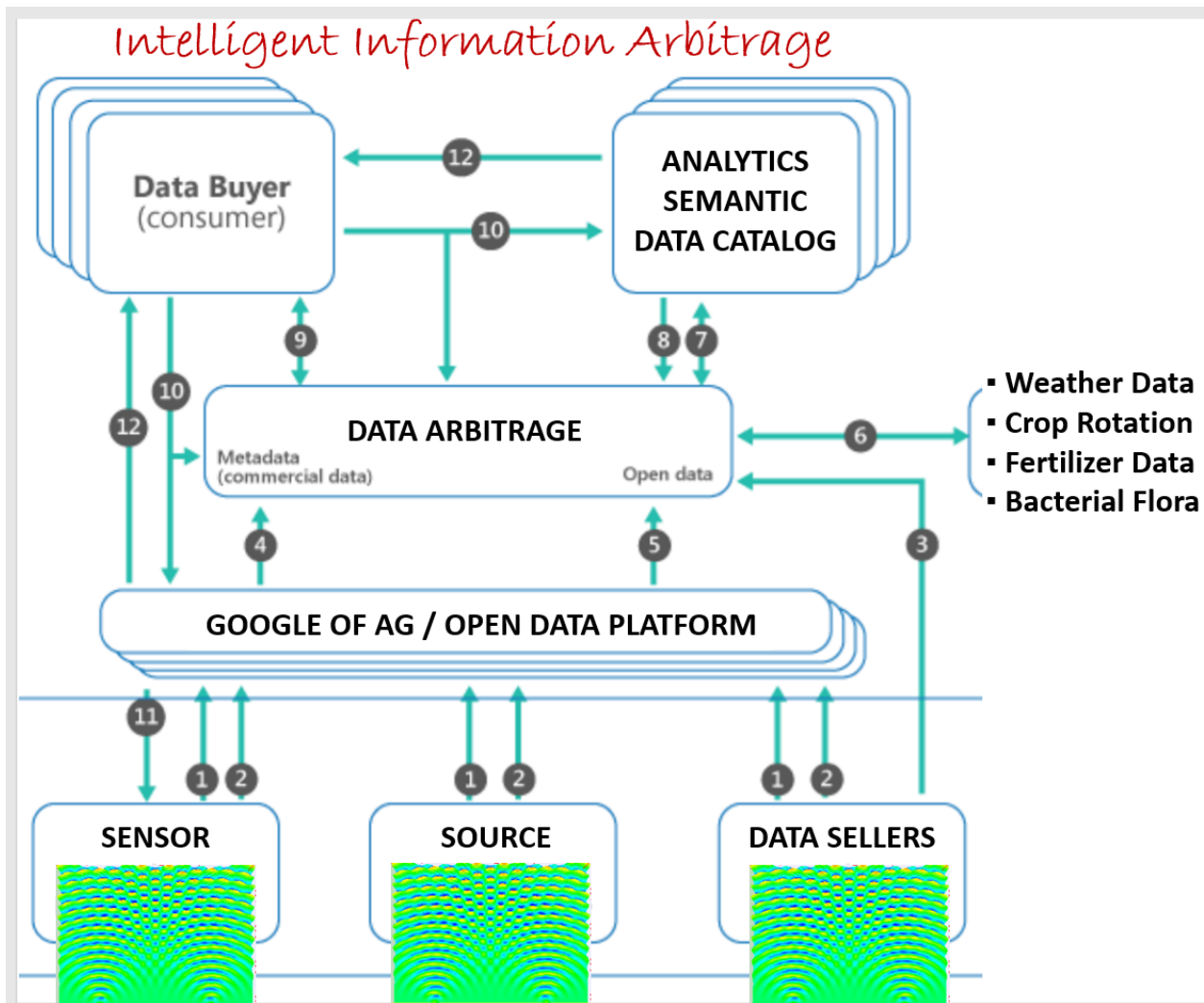
We are approaching an inflection point where it may become feasible to use nano-satellites, on a pay-per-use basis, to download daily or hourly precision micro-climates (by GPS coordinates, zip codes) via apps on smartphones, tablets or portals, connected to (intelligent?) decision support systems.

In the context of using nano-satellites for micro-climates, acquired data, analytics, information and knowledge, may be of limited value without *complementarity* of advances in data granularity, on the ground. If these two resources can converge or if combined, the output may be more valuable.

Haphazard thoughts and a clutter of amorphous ideas about "PEAS" may be found in this lengthy collection of essays '**SIGNALS**' (PDF is here <https://dspace.mit.edu/handle/1721.1/111021>).

“What we know is not much.
What we do not know is immense.”

Mathematician/scientist Pierre-Simon Laplace ▪ March 23, 1749 – March 5, 1827



Can SITS serve as an exploration to usher a confluence of systems?

Essay by Shoumen Datta • Auto-ID Labs, Dept of Mech Eng, MIT • MDPnP Lab, Dept of Anesthesiology, MGH, Harvard Medical School

BACKGROUND

Perhaps from a philosophical or pensive perspective, human health and soil health may share some common grounds. Both are complex examples of convergence shaped by genes, geology and the environment. This essay, triggered by the discussion surrounding “signals in the soil” (SITS), presents a few suggestions about tools to monitor soil health. A few ideas may be practical in the short term and some may seem pragmatic in a few more years. Other thoughts may be found in “PEAS” at the end of this PDF. Still others may take shape a few decades from now. For the latter, *is earlier always better*¹ if one wants to plant a few seeds? Early adopters may fail² but one must *dare, to propose new ideas*³ and admit errors.

ABSTRACT

In the context of a recent request for proposal (NSF 19-556 RFP⁴), signals in the soil (SITS) offers yet another opportunity to re-address, the universal context of how to benefit from data. This essay is not about soil health *per se* and is not focused on soil research⁵ data⁶.

Provided data is sufficiently valid, relatively noise-free and originated from a reliably calibrated instrument, the data may be useful *agnostic of the source*, instrument or sensor. Acquisition of the data from the source, instrument or sensor, is *agnostic of the medium* of the raw data (waves, voltage, chemicals) as long as the signal transduction is reproducible, does not violate laws of physics and its authenticity is uncontaminated by signal processing artefacts⁷ (anomalies often introduced due to digital signal processing, analog to digital converters, digital to analog conversion).

Content, validity and *use* of the data is *agnostic of the subject* of the data (for example, soil, humans, machine) as long as the data is untarnished and the subject of the data has value for our purpose or question (for example, is soil still valuable? Are humans, machines, still valuable?).

Stripped of its source, medium and subject, *data is a vehicle to answer questions*. To move forward, imagine data represented as a vehicle (cartoon of an automobile). Science, engineering and technology sits under the bonnet. Soil, humans and machines are in the boot. Questions hop on the passenger seat, which serves as the *context*. When they reach their destination (question is answered), they hop off. The automobile is a convertible, an open platform. Time to time, elements under the bonnet and boot may be serviced, replaced and upgraded. Semantics and ontology are crowdsourced fuels. The (abstract) journey continues irrespective of incongruities, on the unpaved road, to meet unknown challenges.

For SITS, we may transform the abstract journey into reality, by viewing the infrastructure of the proposal as a scaffold for convergence of systems science and data science with soil science. Other groups may wish to add to this systems approach and install infrastructure for, for example, food science, water science, health science. As a consequence, the systems science module grows to accommodate the dynamics, connections and networks relevant to the systems (food, energy, water, sanitation, health). Data, rising to the top, from these different domains, may begin to reveal deeper patterns⁸ beyond obvious correlations (decreasing levels of blood calcium and increasing instances of osteoporosis). Data science, in this trifecta, delivers the obvious, *yet* poised to address *questions that were not asked*. With advanced tools, we can now pursue *non-obvious* relationship *analytics*.

Non-obvious relationship analysis⁹ (NORA) may move beyond the *awareness*¹⁰ realm to empower a new breed of thinkers to ask the correct questions, and tinker with unknown unknowns, in quest of answers, knowledge and/or breakthroughs. The shrink-wrapped version of existing conventional wisdom¹¹ is void of vision, mundanely obvious and offers tired recipes for incrementalism. The latter may induce one to wonder whether the electric light bulb could have evolved from incremental¹² improvement of candles?

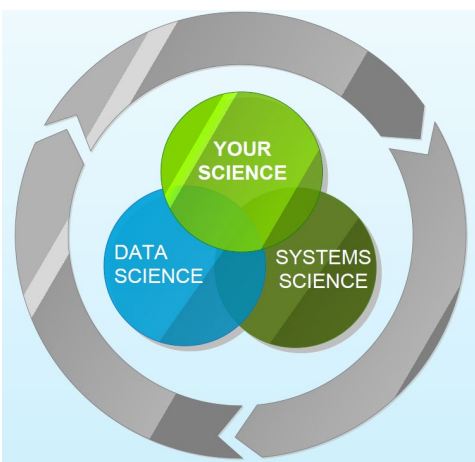
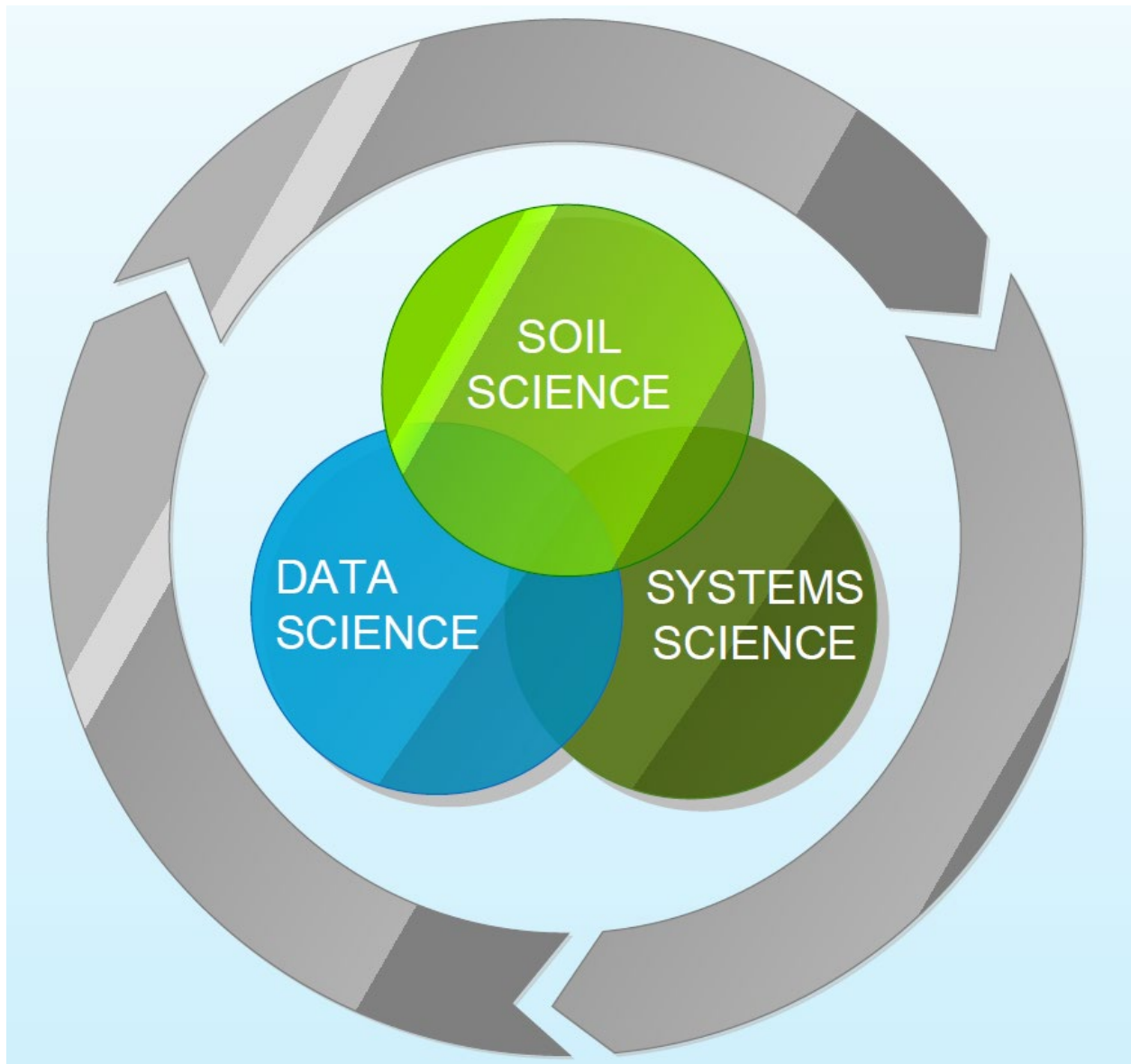


Figure 0 – In the SITS context, the proposal may focus on the trinity of soil science, systems science and data science. Systems science refers to the vast ecosystem accompanying the domain of interest. It must be accounted for in terms of interrelationships relevant to sub-domains [for example, soil science may include microbes, chemicals, water, weather (local, global), geochem/geobiology, vegetation, etc]. However, a very tiny slice of the system may be the focus in any proposal, for research and funding.

OUTCOME

The amorphous idea of NORA is the implicit optimism latent in this triumvirate mode of thought (Figure 0). Non-obvious relationship analysis is strenuously non-linear, difficult to predict, may be uncertain in its meaning or output, if viewed with canonical perspectives (in other words, if the imagination is out of focus). It may provide clues that are undetectable or remain undiagnosed or unrecognized. The latter is the greatest loss of value. NORA-like approaches may hold untold potential for exploring questions that we did not even *know* how to frame or ask.

Non-obvious clues are beginning to emerge from diverse domains, for example, biomimicry¹³ and cross-kingdom tools in plants¹⁴ and humans¹⁵ perhaps structured as evolutionary immune response strategies against viral invaders. However, one must hasten to add that phages and viruses may also provide solutions to our problems. There may be “*million times more virus particles than there are stars in the observable Universe*” but less than 5,000 virus species¹⁶ of the virome are currently documented.

With respect to soil science, whether the outcome of this miniscule slice of the system (SITS) will generate any results, remains to be seen. Developing tools to answer obvious questions generates data. Analytics may reveal cryptic relationships, which may hold clues for molecular interactions (plants, microbiomes, viromes) influenced by macro- and micro-environments (soil, water, pH, gases, air, temperature, chemicals, irradiance, insolation). The central question concerns the ambiguity whether observers can ask the correct questions. It is even more dubious whether we may possess the incisive foresight to decipher and/or recognize that new data and/or information and/or a nugget of *experience* just emerged.

At this time, we cannot answer these questions. Hence, we will focus on outcomes driven by tools to acquire data, to catalog categories, attributes and characteristics. The path to the outcome may have to travel through uncharted territories. From the point of view of scientific research proposal on pedology, perhaps this knowledge is of value. When combined with a thoughtful data management plan, this approach may illuminate the meaning of this data, at the least, with relevance to SITS. This is a journey and the destination is still TBD.

Table 1 – Lists data acquisition with respect to each entity/characteristic (upper). Mapping physico-chemical attributes in the context (environment) of the microbes detected (lower).

Physico-Chemical Properties and Biological Content: Is this pedology still relevant for SITS ?							
Microbe 1	Microbe 2	Microbe 3	Microbe 4	Microbe 5	Microbe 6	Microbe 7	Microbe 8
pH	moisture	salinity	metals	ions	density	particles	color

	Microbe 1	Microbe 2	Microbe 3	Microbe 4	Microbe 5	Microbe 6	Microbe 7	Microbe 8
pH								
Moisture								
Salinity								
Metals								
Ions								
Density								
Particles								
Color								

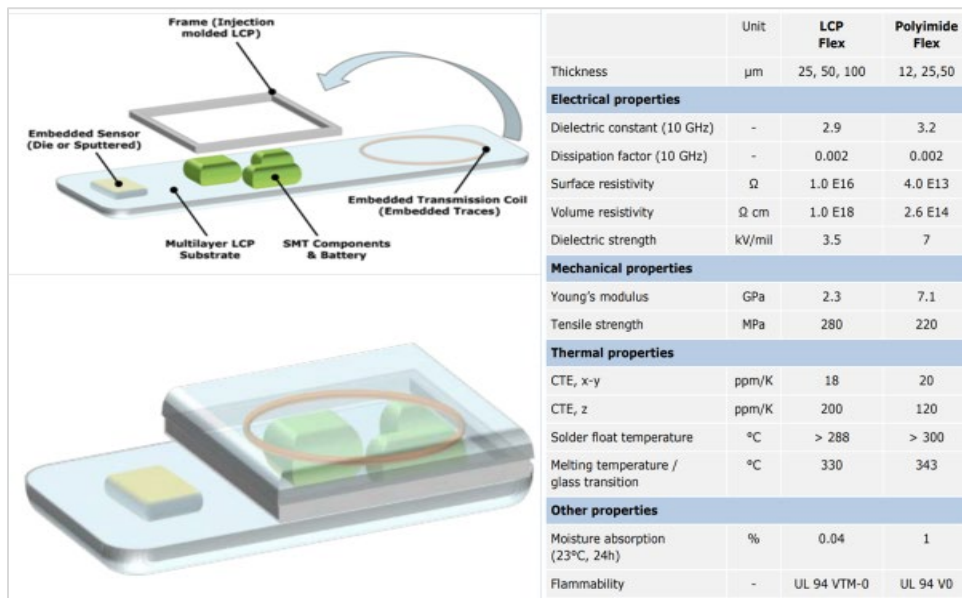


Figure 1 – Sensor engineering¹⁷ combines thin film with flex circuit manufacturing using liquid crystal polymer (LCP) and other thermoplastic polymers. LCP substrate with embedded sensors, communication coil (left top) after folding over frame (left bottom).

SCIENCE – USING PRINCIPLES AND PRACTICE OF PHYSICS (OF REMOTE SENSING)

SITS may reveal its value in terms of the creative convergence¹⁸ of science and engineering to create tools and technology, to detect signals in the soil, faster and cheaper.

The collaboration with physicists and engineers for breakthroughs in remote sensing may be a pivotal part of SITS in *pushing the envelope*. It is encouraging to note that reflected (RF) radiowaves¹⁹ can be used for remote²⁰ applications in humans. Remote sensing in the context of SITS include [a] concepts²¹ for moisture detection by satellites²² and data²³ from 102GHz frequency, as well as [b] use of 2.45GHz (WiFi) to estimate soil moisture²⁴ using drones²⁵ rather than WSN²⁶ to acquire data from immobile tethered sensors, which pollutes the soil, yet, often promoted by laissez-faire titles and published²⁷ by august/elite journals.

Moving from gigahertz (GHz) to terahertz (THz) improves the spatial resolution of the signal (difficult to obtain with WiFi). The interest in THz have waxed and waned over the past half century. THz (0.3 to 3.0) may be useful frequency cluster for detection of radio signals from bio-molecules²⁸ (protein electro-dynamics views proteins as radios, with distinct signatures, but too “noisy” to decipher the data, for example, differentiate between wild-type and mutant protein signatures, which could be of immense value in biomedical diagnostics).

Therefore, advances from the convergence of terahertz integrated electronic and hybrid electronic-photonic systems, may lend itself to new applications²⁹ in sensing. Sengupta *et al* mentions *waveguides emulating artificial dielectric medium*, which, for SITS may translate to better soil moisture sensor using THz. The role of physics and engineering experts is to [a] help us understand the continuing interest³⁰ in (artificial) dielectrics³¹ and [b] guide SITS in *combining* that knowledge with improved spatial resolution (THz or sub-millimeter wavelengths), for breakthroughs in remote sensing and future instrumentation.

Dielectrics seem to appear from several dimensions³² and for many³³ uses. It may hold clues for remote sensing tools to measure pH, salts and enzymes³⁴ in the soil, as previously³⁵ suggested. Static dielectric constant of water³⁶ drops with addition of salts, but the reverse is true, if the complexity of permittivity of water is explored with THz transmission spectroscopy³⁷ (the value increases, Debye relaxation, with salt concentration).

For SITS, is it possible to exploit any correlation³⁸ between dielectric permittivity, ionic charge, charge density (phosphates) and chemical structure? Dielectric permittivity³⁹ is the primary diagnostic physical property⁴⁰ for GPR⁴¹ (ground penetrating radar)? Creative use of ISAR⁴² (inverse synthetic aperture radar) in the development of WiVi (Katabi *et al*) emerged from radar technologies. Dielectric permittivity is one of many tools from radar technology which may be quite pragmatic in terms of applications for the ag/food industry.

The use of dielectric medium as a “marker” to extrapolate data relevant to SITS (pH, salts) may gain momentum from prior research which indicates that it is possible to model⁴³ dielectric medium with electric *and* magnetic reservoirs. The latter unleashes electromagnetic field quantization, which may serve as another principle for remote sensing. We need to delve deeper into dielectrics⁴⁴ as well as investigate other ion-based detection systems (GC/MS⁴⁵).

The importance of “markers” cannot be overemphasized. Glucose oxidase was the first enzymatic marker⁴⁶ (coupled to an amperometric electrode for monitoring oxygen in blood) followed by various forms of spectroscopy. Raman spectroscopy⁴⁷ and bio-impedance spectroscopy⁴⁸ are emerging as principles of choice for non-invasive remote applications.

Impedance spectrum, or dielectric spectrum, is measured in the range 0.1-100MHz. To measure variations in plasma glucose concentrations⁴⁹ (critical for diabetes patients), the primary “marker” is the detection of *the change in red blood cells due to the variation of plasma glucose concentration*.

The variation changes the membrane potential of red blood cells (RBC) due to decrease in [Na⁺] and increase in [K⁺] concentrations. The changes in the membrane potential is estimated by determining the permittivity and conductivity of the cell membrane through the dielectric spectrum. This data is used to *extrapolate* plasma glucose concentration.

SITS is in quest of such markers. The key is to extract the rigor of basic science, and use the principles, in applications, to identify “markers” to serve as quantitative standards, or indices, for remote sensing, with respect to the characteristics of soil we wish to measure.

SITS, therefore, is seeking ground-breaking scientific principles and affordable engineering tools, which will further enable mobile data collection technologies. Half a century ago, the concept of projection reconstruction⁵⁰ changed the field of medical imaging. By analogy, it is tempting to speculate that nanoscale vector magnetometry⁵¹ from the domain of magnetic field sensing, may be one such tool, to detect signals in the soil (SITS) using vector sensing of static fields to reveal properties of soil (moisture, pH, chemicals, etc.). The authors claim far-reaching consequences⁵² for nanoscale NV-NMR (nitrogen-vacancy nuclear magnetic resonance) to map spin arrangements of single proteins with increasing spatial resolution. The ability to *control* nanoscale quantum sensors may unleash new paradigms in precision metrology (measuring atomic-scale magnetic fields with great precision, not only up and down, but sideways, as well). One branch of this development, hopefully, may create new low-cost⁵³ mobile tools to decipher signals from the soil. Applying super-resolution quantum spectroscopy for agriculture may seem obtuse, now, in the same manner that applying NMR/MRI (nuclear magnetic resonance/magnetic resonance imaging) for monitoring growth of roots⁵⁴ may have appeared as far-fetched “pie-in-the-sky” idea.

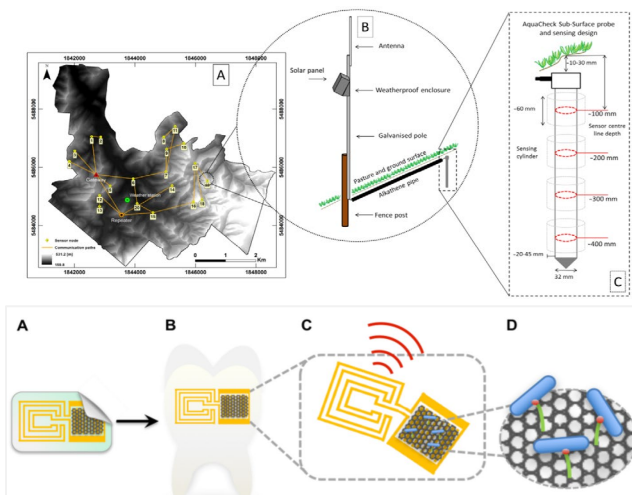


Figure 2: Top - The “bucket brigade” for data collection. Sensors in the soil²⁶ vs modern wearables⁵⁵. Bottom - Glucose sensor⁵⁶. (A) Graphene printed on bio-resorbable silk with wireless coil. (B) Bio-transfer of sensor on tooth. (C) Non-invasive wireless glucose sensing (D) Self-assembly of pathogenic bacteria bound by peptides on nano-transducer surface. SITS seeks nanoscale quantum sensors and super-resolution quantum spectroscopy tools.

The next open question in our scientific exploration of SITS may address whether we can use bio-inspired principles from dolphins and bats, in addition to electromagnetic radiation (radiowaves, radar) and quantum tools, to help us create tools for remote sensing.

Reflected sound waves coupled with timing devices are echo-signal transduction medium for sonar and ultrasound tools. More than a quarter century ago, ultrasound chips⁵⁷ were fabricated. Capacitive micromachined ultrasonic transducers⁵⁸ (CMUT) recently reached the summit of the hype curve⁵⁹ with respect to medical imaging. However, in this instance (for SITS) air-borne applications⁶⁰ may be more relevant. Use of a multi-frequency CMUT device for ultrasound capnography⁶¹ suggests that soil gas analysis using ultrasound⁶² may be possible. Advances in precision ultrasound chips⁶³ treats gas as an interference, to be damped. What if we perhaps reverse the experiment and *measure* the gas (multi-frequency ultrasound device for multiple gases to be measured) in the soil? Can we use gas⁶⁴ as markers? Gas-as-a-marker may be suitable for determining soil characteristics? In the final category of waves, lidar's laser pulses may be useful for measurements of density and particles in, the soil. Lidar tools on a chip may be the future of pressure sensors⁶⁵.

I digress to point out that advances in (any) systems on a chip (radar, sonar, lidar) are creative tools which suffer from a common chronic problem - noise. The ubiquity of "noise" infects and introduces errors in almost all systems (waves, sensors, data). Hence, error detection, error correction codes, and error mitigation tools, are in great demand and hold immense significance to assure performance levels below the fault-tolerance threshold, because of noise associated with signals. Key milestones in error correction are due to Shannon (1948⁶⁶), Kalman (1960⁶⁷), Granger (1969⁶⁸), Engle (1982⁶⁹) and Granger and Engle (1987⁷⁰). A recent paper (2019⁷¹) may be interesting, too. Noise in any communication introduces transmission errors. Source coding may remove redundancy from source data. Channel coding may make noisy channels appear "noiseless" by controlled addition of redundancy. One (of many) unsolved problems in error correction may concern protein dynamics⁷² and implied by Martin Karplus⁷³ and suggested⁷⁴ by others. It appears that proteins are radios. Could we use THz waves to explore⁷⁵ protein signatures? The signal will be contaminated by noise from vibration of water molecules (think van der Waals radii).

SCIENCE – PRINCIPLES AND PRACTICE OF CHEMISTRY (OF MOLECULAR ANALYTES)

Soil microbiology has deep roots. Circa 1904 witnessed the germination of the concept of rhizosphere⁷⁶ and soil flora⁷⁷ has been studied intensely since the turn of the last century. Our task is simpler in the context of SITS. We are not focused on biological function of phyto-microbiomes⁷⁸ or viromes⁷⁹ associated with soil, crop, or plants. We wish to detect individual microbes in soil samples (reflect on the content of Figure 1 and Figure 11).

We are searching for *bio-available* extra-cellular molecules on bacterial cell walls and/or membranes which we can use as molecular targets (analytes). We prefer to select molecular targets with sufficient degree of *species specificity* and limit the identification to species. We may exclude subspecies, biovars⁸⁰ and serovars, as well as analysis involving genes, genomics⁸¹ and metagenomics. The latter takes weeks to months to obtain data. Our detection time range aspires to remain in the seconds to minutes, or hours, if necessary.

Therefore, rather than choosing a microbiome (set of bacteria, fungi or algae specific for a habitat, for example, citrus grove), we are in quest of *accessible microbial molecular targets* (Figure 3) which can serve (bind), as an analyte, with a complementary molecule on a sensor. The binding may or may not be reversible, but the binding must elicit a detectable signal (impedance spectroscopy, plasmon resonance, photonics, electrochemical, SERS). Signal transduction, analog to digital conversion, data analysis and data visualization⁸² in seconds to minutes, is the expectation. Access to data via open platforms and visualization via any mobile platform⁸³ (for example, using an app on a smartphone, tablet, or laptop) is key to mass consumption of data, to reduce transaction cost⁸⁴ based on economies of scale.

Identifying available molecular targets for microbes in the soil will enable us, initially, to select a few microbes, to be detected with new tools (see Table 1 & Figure 1). For growers, the most abundant forms of soil bacteria⁸⁵ may be less useful compared to the microbiome specific for their plant or crop. The context of crop-specific microbiomes/viromes are key to understanding potential molecular and cellular interactions. But, we cannot reach such goals without these tools of detection and the advances in science and engineering fundamentals.

Detection using plant lectin-based bio-sensors⁸⁶ are one of the widely used sensing tools (in addition to other uses⁸⁷ and biological role of lectins⁸⁸). Recent advances⁸⁹ using fluorescent emission spectra⁹⁰ are improving the quality and intensity of the signal from lectin agglutination assays. Our goal is to use a variety of tools, combined, as appropriate, to **identify microbes using sensors in the soil**. From the published literature, we hope to determine specific accessible molecular targets, for example, in, *Rhizobium leguminosarum*⁹¹, *Bacillus subtilis*⁹², *Pseudomonas fluorescens*⁹³, *Nitrosomonas europaea*⁹⁴, and Cyanobacteria⁹⁵ (*Synechococcus sp* and if there is/are soil equivalent of *Prochlorococcus*⁹⁶). We will select other microbes if we can identify specific extracellular molecules (Figure 3). An example of the **use of molecular targets for detection** is illustrated in Figure 4.

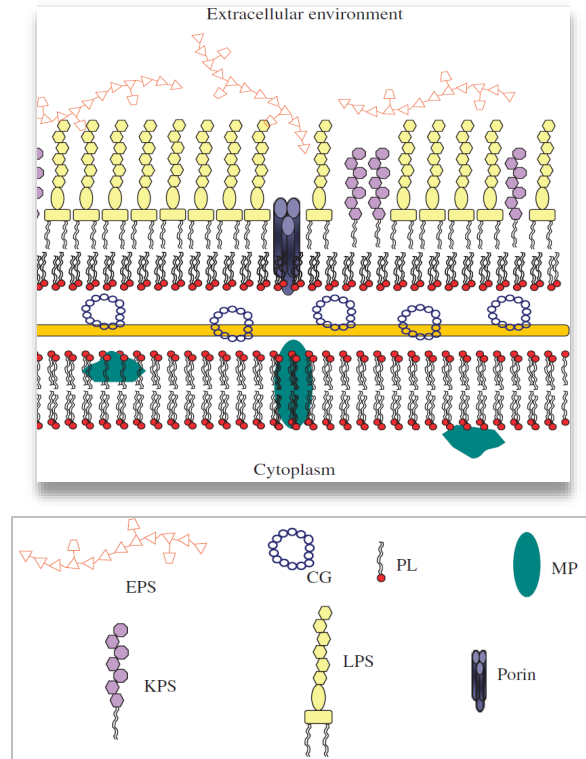


Figure 3 – Rhizobial cell surface⁹⁷ cartoon, illustrated with polysaccharides involved in rhizobial attachment to roots. The “accessible” nature of EPS and KPS suggests its potential as molecular targets for binding to sensors. OM-outer membrane; PS-periplasmic space; PG-peptidoglycan layer; PM-cytoplasmic membrane; EPS-exopolysaccharide; CG-cyclic glucan; PL-phospholipid; MP-membrane protein; KPS-capsular polysaccharide (K-antigens); LPS-lipopolysaccharide.

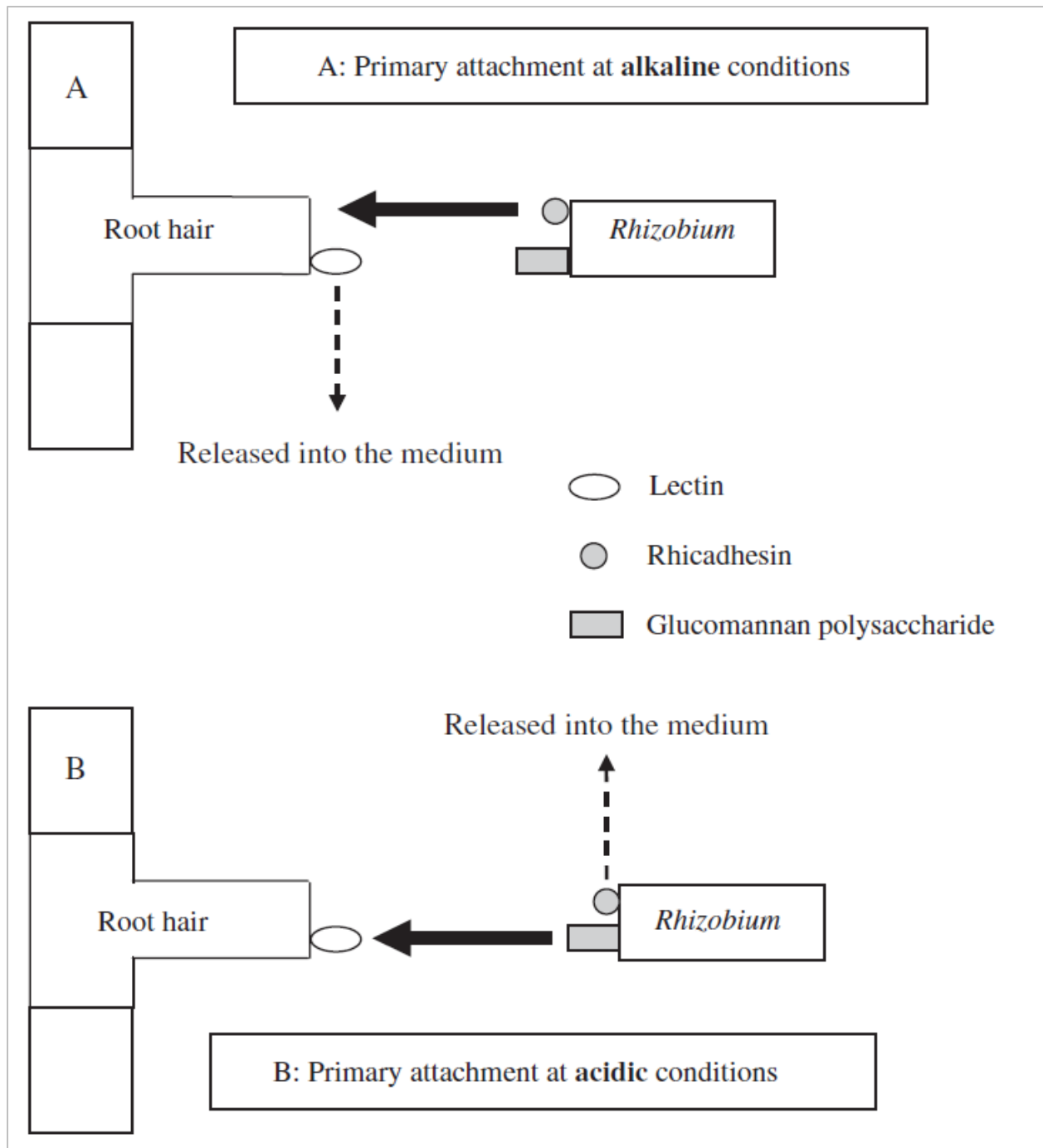


Figure 4 - Attachment of *Rhizobium leguminosarum* to lectin released from pea and vetch root hairs is pH dependent⁹⁸. (Top) Alkaline: Lectin released from root-hair tips. Rhizobial Rhicadhesin mediating attachment. (Bottom) Acidic: Lectin remain anchored. Rhicadhesin released from bacterial surface. Plant lectin and bacterial glucomannan involved in bacterial attachment to plant root hairs.

Lectins, also referred to as phytohemagglutinins, are proteins with at least one non-catalytic domain that can reversibly bind specific carbohydrate moieties. Figure 4 illustrates research results indicating that lectin from roots of the pea (*Pisum sativum*) and vetch (*Vicia sativa*) plants interact with a specific glucomannan polysaccharide from strain RBL5523 of *Rhizobium leguminosarum*.

The interest of SITS is in identifying, for example, *Rhizobium leguminosarum* using a *sensor*. There are probably several ways to accomplish this task but a published⁹⁹ research paper seems to be a good example, except that we must perform the task in reverse. In the paper, carbohydrate moieties were functionalized noncovalently on the surface of CCG-FET and SWNT-FET devices (field-effect transistor devices comprised of chemically converted graphene or single-walled carbon nanotubes). These devices were tested for nano-electronic detection of lectins from *Canavalia ensiformis* (concanavalin A from beans) and *Pseudomonas aeruginosa* (12kDa and 13kDa, two separate proteins).

For SITS, the nano-bio sensor surface will display the lectin from pea or vetch plant (attached via spacer, linker, innovative 3D¹⁰⁰ printing). If the soil sample contains *Rhizobium leguminosarum*, the attachment of the bacteria to the lectin on the sensor surface will trigger a (net positive) signal. Hence, in principle, the binding of an analyte (in this case, microbes) to the immobilized substrate with a complementary molecule (may be a lectin), is the *modus operandi*, which is quite common, in general.

From a pragmatic perspective, “dipping a sensor” in the soil to estimate any microbe may suffer from a variety of problems, the foremost of which is “wetness” or the ability of the signal to attach to the sensor in a preferred medium. How the “medium” may affect the signal strength is a question for experts in energetics and thermodynamics. The involvement of thermodynamics in the energetics of evolution¹⁰¹ and natural selection¹⁰² may be unexplored but the role of thermodynamics in chemical reactions and molecular interactions¹⁰³ are central to future discoveries.

Amplification of the signal strength, mentioned above, may probe the potential to create/introduce a *cascade effect* to augment the signal when microbes bind the sensor. In this context the role of nanozymes¹⁰⁴ in sensing¹⁰⁵ devices¹⁰⁶ may be an important topic¹⁰⁷ for SITS. **Dissociation** of the target molecule from the sensor substrate (to create multi-use

sensors) may be a “cleaning” task which may be engineered by co-locating nanozymes as cleaning agents¹⁰⁸ (perhaps mimic how enzymes are used in the laundry¹⁰⁹ industry).

We will continue to identify molecules sensitive as a detector for sensor development, suitable for signal transduction, amenable to generating⁴³ rapid results and provide specificity in identification. The ability to create a reversible reaction (sensor) for continuous monitoring (for example, using pH as a switch or trigger) which can *re-calibrated* in the field, may be immensely valuable and a worthy sign post for SITS 2.0 proposal of the future.

Sensors based on binding of an analyte follow the “lock-key” model¹¹⁰ which may be the most widely used analogy¹¹¹ in biology. The actual biological mechanism, the induced fit¹¹² hypothesis, may be relatively unknown. The proposal of induced fit was a *déjà vu* moment if we recall that the Periodic Table¹¹³ is not¹¹⁴ what it used to be¹¹⁵ at the turn of the 20th century¹¹⁶, a fact which is rapidly receding from general knowledge, judging from a recent title¹¹⁷ of at least one global publication, regarded to be “adequately” informed.

The reason for this preface (digression) is the unexplored sense, that sensors, which bind analytes in an irreversible manner (single use), wishes we re-visit old ideas¹¹⁸ to find new room for basic science research. Can we deploy nanozymes to break the lock-key and perform a direct cleaning action? If the direct approach is not feasible, can we engineer indirect use of nanozymes (or cations/anions) to trigger allosteric¹¹⁹ transitions? The critical role of allosteric ligands¹²⁰ and the value of allostery¹²¹ remains under-appreciated. The observation of long-range allosteric effect in hemoglobin¹²² is now relegated only to the hidden pages of history.

The chemical identification of an analyte by a sensor (eg sensor microarray¹²³ on a chip using nanoplasmonics and fluorescence assay¹²⁴) may provide evidence for the presence of a biological species. The conundrum, for ag, is that soil levels of microbes and nutrients, and changes, are *non-linear* in terms of crop growth (plant tissue). The *value for growers is that data* which synthesizes signals not only from a single species as an indicator but provides *real-time information* about the “jigsaw” of the fauna and the functions¹²⁵ of soil biota “guild”¹²⁶ which is a confluence of soil biology and chemistry (Table 1). Data about functional guilds and the ecosystem must be combined. The physics and chemistry of sensing as well as the design of sensors for agro-ecosystem management demands a *mix of signals from the breadth of responses* from guilds. These guilds may be crop-specific.

DATA SCIENCE – UNDERSTANDING DATA IN THE CONTEXT OF SYSTEMS SCIENCE

*Those who cannot remember the past are condemned to repeat it*¹²⁷ is an apt quote applicable to the history of our approach to making sense of data. In 1954, Texas Instruments touted transistors as bringing “electronic ‘brains’ approaching the human brain in scope and reliability” closer to reality¹²⁸. In 2015, IBM’s Modha¹²⁹ made the idiotic claim to have “*the brain in a box by 2020*” and corporate lunacy¹³⁰ followed. In 2000, President Bill Clinton¹³¹ declared that the Human Genome Project¹³² would lead to a world in which “our children’s children will know the term cancer only as a constellation of stars.” And now with quantum computing, a complex tool¹³³ with potential¹³⁴ but far from panacea. The hoax¹³⁵ and hubris from snake oil salesmen¹³⁶ resonates on the Minsky¹³⁷ scale¹³⁸, “*within a generation the problem of creating 'artificial intelligence' will substantially be solved.*”

A tsunami of data handling tools and software have flooded the market. But few, if any, can make *sense of the data* and extract *contextual information*. The claim¹³⁹ of the semantic web¹⁴⁰ as a tool for “understanding” was, albeit, temporarily¹⁴¹ crushed, a decade ago. Since *Nature abhors a vacuum*¹⁴², hysteria¹⁴³ and deadly¹⁴⁴ sins¹⁴⁵ of AI¹⁴⁶ raced to fill¹⁴⁷ the void. Media frenzy and AI stupidity¹⁴⁸ overshadowed¹⁴⁹ the importance of machine learning¹⁵⁰ (ML) and even experts used *the cover of AI*¹⁵¹ to sell books, rather than inculcating the *society of mind*¹⁵² paradigm. The paradigm has shifted in favour of news cycles as catalysts for polishing the chrome, rather than the ardor for tuning the engine¹⁵³.

From the dawn of computing, the role of context¹⁵⁴ in understanding the meaning of data was not a part of the process, for example, the difference engine¹⁵⁵ and what followed thereafter. Yet there is little need to overemphasize that information arbitrage tools¹⁵⁶ can make a difference between life and death. AI, ML are important in this respect as long as we do not dwell on the terms and admit that these are manufactured labels. The hype of AI/ML is due to smug and glib marketing by folks unaware of the vast field of data driven methods. Labels to build classifiers is referred to as “supervised ML” but for over a century it is also called regression. So-called “unsupervised learning” includes clustering, dimensionality reduction, principal component analysis (PCA), support vector machines (SVM), and a long list of statistical modeling techniques that do not require labels (response variables).

Data anomalies¹⁵⁷ and lack of data interoperability¹⁵⁸ is the third leading cause of death in the US¹⁵⁹ (actual number may exceed quarter of a million deaths per year). Deaths due to medical errors is analogous to more than one 747 jumbo jet, with >500 passengers in each plane, crashing every day, with all lives lost in each plane crash, daily. Shocking?

Lack of understanding is not an *irremediable injustice*¹⁶⁰ perpetrated by the binary system. Proof of concept¹⁶¹ and examples¹⁶² from late 20th century reveals that we may know¹⁶³ how¹⁶⁴ to make computers *understand*. Fundamental principles of these tools remain in relative obscurity except perhaps one¹⁶⁵ application which was “dumbed down” to serve as a weather¹⁶⁶ “app” for select smartphones. The basic problems are not so difficult, at least in principle, as illustrated in Figure 5.

The solutions and so-called standards (Figure 6) are good attempts but was not designed to promote understanding and context, of data and information. The herculean task of understanding and the failed approach from the last century is outlined in Figure 7. The global wave of digital transformation¹⁶⁷ calls for digital semantics based on ontology schema with URN (see Figure 8, introducing the digital concept of universal resource numbers).

The very limited scope of SITS may not be the platform for the global revolution necessary to usher in digital semantics. But, SITS may move beyond traditional data architectures discussed¹⁶⁸ elsewhere and attempt to embrace data, context, and connectivity, combined. The latter implies that tools from the semantic web standards (OWL/RDF) shall creep into the SITS data architecture. The hope is that the expert teams involved in this key segment of SITS may find ways to bring creativity and innovation (knowledge graphs) in using semantics rather than remain handicapped by the dead weight of old technology.

Context and understanding are inextricably linked with value. Making sense of data is crucial for adoption. Trust in the value of information increases when it is based on curated (noise-free?) data which can be shared between system of systems using open standards¹⁶⁹ (for example, DDS¹⁷⁰ or data distribution service¹⁷¹). However, in attempting to free data from noise, it is possible that we might eliminate “signature” signals about the ecosystem (environment which is generating the noise). Should we be as interested in the associated noise as we are in the signal itself? It will be a mordant irony if the brilliance of science and signals is rejected due to ignorance, if we fail to view noise and errors¹⁷² with new¹⁷³ eyes¹⁷⁴.

Hence, data by design *might separate but include “noise”* in the context of error correction (correct obvious errors but provide errors in a separate container for analysis by qualified users). Enabling the interpretation of errors, by a host (crowd) of users, can breathe new life into *signals latent in the noise* and new ideas about the concept of flux (data versus fluctuations of noise-types associated with data). The latter may contribute to the design of solutions, because multiple points of correlation could be helpful to provide a better picture of the guild, where the type of noise may be a potent signal for changes in the agroecosystem.

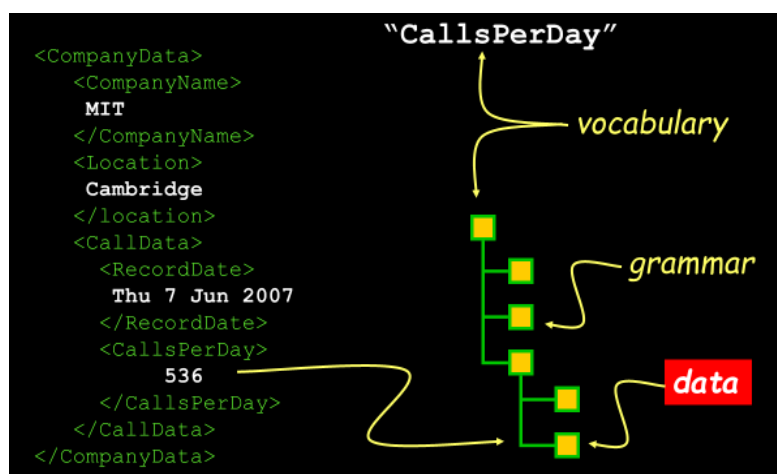


Figure 5 – Problems that can be solved¹⁷⁵ still fuels lack of interoperability even between intra-company databases. The syntax “callsperday” hard-coded in this software lacks any attribute which can be included in any semantic data dictionary because “callsperday” is void of key linguistic structure¹⁷⁶ (grammar). In another instance, another programmer, in another country, with another type of education, with another natural language proficiency (but not English) may choose to hard-code the syntax “callseachday” or “callsper24hour” or “callseveryday” which are linguistic heresies but semantically equivalent. In the absence of (infrastructure) ontological schema¹⁷⁷ and domain knowledge¹⁷⁸ the semantics of the syntax is lost in translation. Data cannot merge if the syntax differs between databases. Call records in two branch offices may use data loggers sourced from different vendors, which may use different or proprietary programming languages (for example, ABAP used by SAP). DDS may offer solutions but vendor-specific implementation of DDS are similar but not identical.

4ML	ARML	BiblioML	CIDX	eBIS-XML	HTTP-DRP	MaTML	ODRL	PrintTalk	SHOE	UML	XML F
AML	ARML	BCKXML	xCIL	ECML	HumanML	MathML	DeBPS	ProductionML	SIF	UBL	XML Key
AML	ASML	BEFP	CLT	eCo	HyTime	MBAM	OFX	PSL	SMML	UCLP	XMLife
AML	ASML	BGML	CHRP	EcoKnow	IML	MTSML	OIL	PST	SMBXML	UDDI	XML MP
AML	ASTM	BHTML	ComicsML	edaXML	ICML	MCJ	OTM	QML	SMDL	UDEF	XML News
AML	ATHL	BIBLIDTML	Covad xLink	EMSA	IDF	MODL	OLIFE	QAML	SDML	UIML	XML RPC
AML	ATHL	BIOML	CPL	eosML	IDML	MOSt-XML	OML	QuickData	SMIL	ULF	XML Schema
ABML	ATHL	BIPS	CP eXchange	ESML	IDWIG	Metanale	OND DTD	RBAC	SOAP	UMLS	XML Sign
ABML	ATHL	BizCodes	CSS	ETD-ML	IEEE DTD	MFOJ	OOPML	RDOI	SDDL	UPnP	XML Query
ACML	AWML	BLM XML	CVML	FieldML	IFX	MIX	OPML	RDF	SOX	URI/URL	XML P7C
ACML	AXML	BPML	CWMI	FBML	BMPP	MMML	OpenMath	RDL	SPML	UXF	XML TP
ACAP	AXML	BRML	CyML	FTS	IAS Global	NML	Office XML	RecipeML	SpeechML	VML	XMLVoc
ACS X12	AXML	BSML	DYML	FXML	InTML	NML	OPML	RELAX	SSML	vCalendar	XML XCI
ADML	AXML	CML	DAML	FLBC	IOTP	NML	OPX	RELAX NG	STML	vCard	XAML
AECM	BML	xCML	DoiML	FLOWML	IRML	ModL	OSD	REXML	STEP	VCMIL	XACML
AFML	BML	CoXML	DoqXML	FPML	DXML	MOS	OTA	REPML	STEPML	VHG	XBL
AGML	BML	CaseXML	DAS	FSML	DXRetail	MPML	PML	ResumeXML	SVG	VBML	XSBEI
AHML	BML	xCIL	DASL	GML	JabberXML	MPXML	PML	RETML	SWAP	VISA XML	XBN
AJML	BML	CBML	DCMI	GML	IDF	MRML	PML	RFML	SWMS	VNML	XBRL
AJML	BML	CDA	DOI	GML	IDox	MSAML	PML	RightsLang	SynchML	VocML	XCOF
AIF	BannerML	COF	DeltaV	GOML	JECMM	MTML	PML	RDXML	TML	VoiceXML	XCES
AL3	BCKXML	COISC	DIG35	GAME	JLife	TMML	PML	RoadmOPS	TML	VRML	Xchart
AIML	BEFP	CELLML	DJML	GBXML	JSMIL	MusixXML	PML	RosettaNet PIP	TML	WAP	Xdelta
AIWTEA	BGML	ChessGML	DMML	GDML	JSHML	NAAML	PML	RSS	TaBML	WDDX	XDF
AIWTEA	BHTML	ChordML	DocBook	GEML	JScoreML	xNAL	P3P	RuleML	TaxML	WebML	xForms
APML	BIBLIDTML	ChordQL	DocScope	GEDML	KBML	NAA Ads	PDMML	SML	TDL	WebDAV	XGF
APPMML	BIOML	CIM	DoD XML	GEN	LACITO	Navy DTD	PDX	SML	TDML	WebML	XGL
AQL	BIPS	CIML	DPRL	GenLang	LandXML	NewsML	PEF XML	SML	TEI	WakingXML	XGML
APPEL	BizCodes	CIDS	DRI	GBML	LEDES	INML	PetroML	SML	ThML	WT-XML	XHTML
ARML	BLM XML	CIDX	DSML	GXD	LegalXML	NISO DTR	PGML	SAML	TBM	WIDL	XIDP
ARML	BPML	xCIL	DSO	GXL	Life Data	HTF	PhysicsML	SABIE	TBM	WTISML	XLF
ASML	BRML	CLT	DXS	Hy XM	LithML	NUMXML	PICS	SAE J2008	TMMML	Work808	XLIFF
ASML	BSML	CHRP	EML	HITS	LMML	IVML	PHML	SBML	TMX	WSML	XLIW
ASTM	BCKML	ComicsML	EML	HR-XML	LogML	OAGIS	PIHML	Schemtron	TP	WSIA	XMI
ARML	BEFP	CIM	DJML	HRMML	LogML	ORI	PHML	SDML	TPAML	XML	XMSG
ARML	BGML	CIML	EAD	HTML	LTSC XML	OCF	PIG	SearchDM-XML	TREX	XML Court	XMTIP
ASML	BHTML	CIDS	ebXML	HTTPL	MAML	ODF	PrintML	SGML	TxLife	XML EDI	XNS

Figure 6 – One answer to the dilemma (above, Figure 5) is the use of a standard. Illustration displays multiple forms of a “*standard*” (HTML). Each application modified the standard to serve its niche! Why? English, with its vocabulary of a million words, can’t express every thought unambiguously, so with ~100 words we can use in HTML, there are many situations when the *standard* element may be unsuitable for a piece of the content, in the *context* of the application (for example, 6 different types of PML¹⁷⁹ are highlighted in red, used by object naming service, ONS, a conceptual cousin of domain name system, DNS). It is not far fetched to imagine that the umbrella of tools and techniques referred to as “AI/ML” can address and even solve some of these problems, in *select domains*, in certain sub-categories and *specific contexts*. But, one success or one solution does not imply that “AI/ML” can now be generalized to solve all problems, *even if the problems appear to be similar or related*. The dictionary of context and the labyrinth of connections are far deeper than meets the eye.

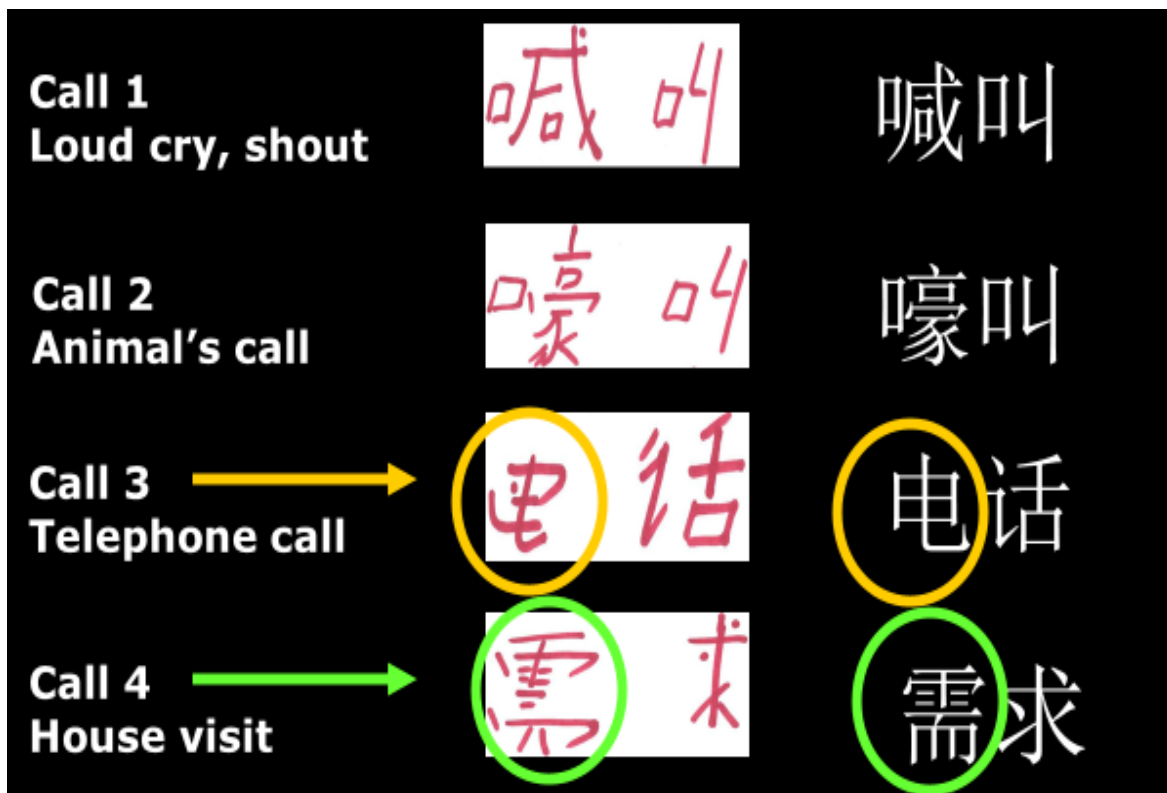


Figure 7 – The task of understanding is far more difficult than perceived by the Anglo-Saxon world. For a binary system agnostic of natural language, the difficulty in understanding the meaning of the word “call” in the context of its use and *user*, may be difficult (impossible?) to accomplish using traditional¹⁸⁰ semantic web ideas, which lack binary translation features in its toolkit. RDF¹⁸¹ (resource description framework) is the key to data interchange and relationships between things (triples) which leads to directed graphs (edges of relationships). Other tools, for example, OWL (ontology working language) which builds on RDF, fine tunes *the descriptive structure* with the (misguided?) notion that it helps interoperability of data between dissimilar communities. The illustration above points out the semantic variability of the word “call” in only 2 languages. The *descriptive structure* without a binary translation holds the entire system hostage to words and syntax. Digital transformation¹⁸² of the *descriptive structure* with binary translation for *context* (call.1, call.2, call.3, call.4) may exceed *machine readable*, it may be *machine understandable*¹⁸³.

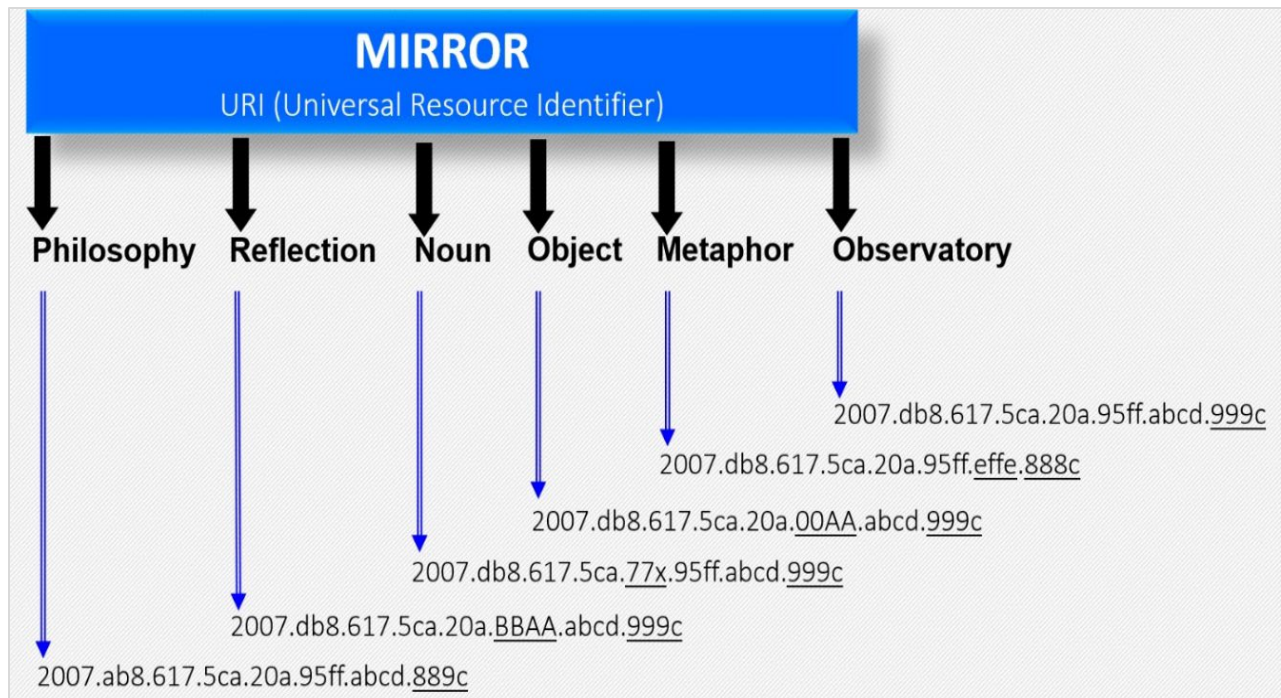


Figure 8 – Digital Semantics – URN – Universal Resource Numbers for ontological frameworks? *Each context* has a unique id [numerical (knowledge) representation]. The list can grow (number spaces similar to EPC¹⁸⁴ or UPC¹⁸⁵ barcode) as communities/countries crowdsource and contribute to the “context list” the *descriptive structures* relevant to *their language and cultural context*. Mapping between a numeric system and categorization (taxonomy¹⁸⁶) with relevance to specific ontologies, that is, by associating a number with the context of use, the context can now be translated to binary. “Mireille bought a mirror” indicates the meaning of mirror (URI) in the context of an “object” (URN). The statement, “it mirrors my life” conveys the meaning that Mireille is choosing to be “philosophical” about her life¹⁸⁷. The failure to promote URN as a global standard and enabler of the digital semantic web may be linked to its complexity. The latter may be one reason why ‘marketing’ departments have failed to create a value proposition for the diffusion of URN. Irrespective of how great a technology may be in the context of advancing the knowledge society¹⁸⁸, its adoption, especially in business and industry, is solely a matter of economics. Exploring corn¹⁸⁹, dynamo¹⁹⁰ and electricity¹⁹¹ have demonstrated that the economics of technology is catalyzed by proof of profitability.

DATA SCIENCE – DATA FROM THE EDGE CONNECTS WITH SYSTEM OF SYSTEMS

The most important outcome from, and use of, any system, is its data. SITS may provide crucial information about the characteristics of soil and its microbial flora. This information may help decision support systems to feed 10+ billion¹⁹² people on the Earth, at the dawn of the 22nd Century. Data may be inert if divorced from its relationships. The effect of data and information on interconnected resources may be viewed through the lens of decision nodes. A node is where other paths may branch, meet, start or finish. Each node is a resource which connects to other nodes (may have weighted relationships with other nodes). The relationships between nodes, and sum of the attributes, are collectively referred to as a graph¹⁹³. Each edge of a graph (the line connecting the circles, the nodes), is a relationship. The internet¹⁹⁴ is an example of a directed graph¹⁹⁵. In computing, a graph database is a database that uses graph structures for semantic queries with nodes, edges and properties to represent and store data¹⁹⁶ which users can access, analyze and interpret, to derive value.

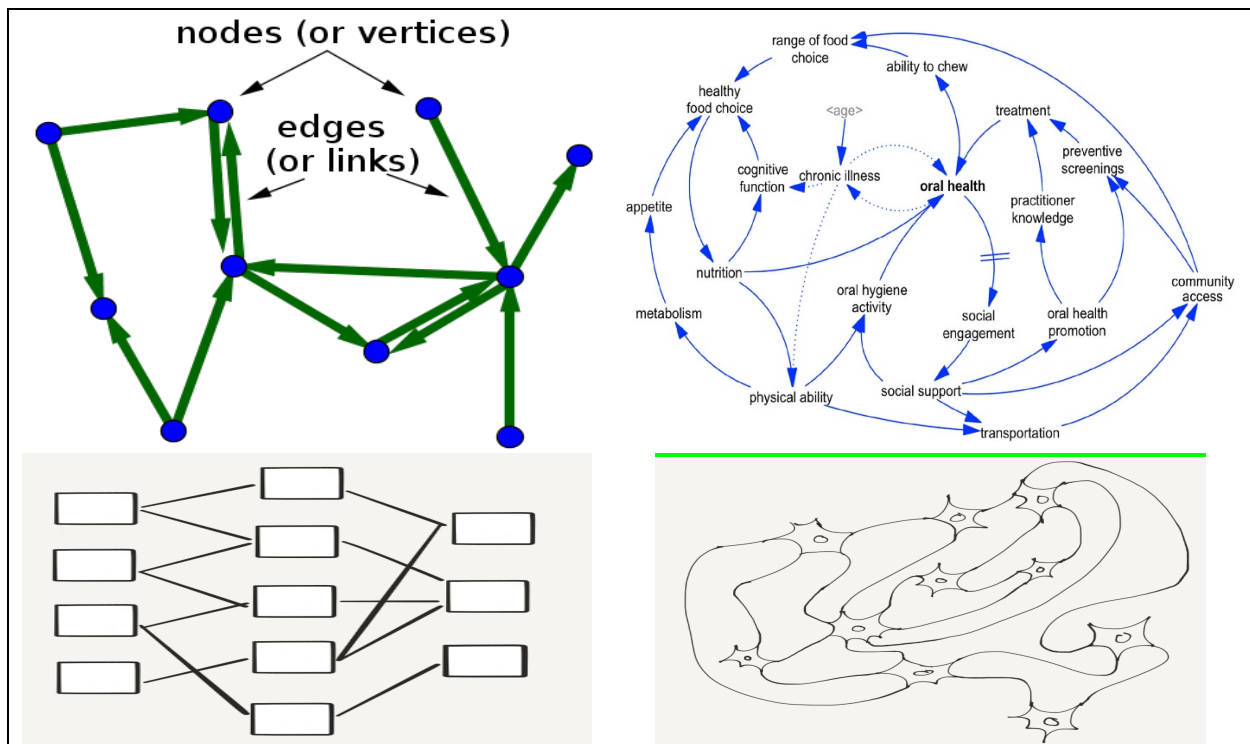


Figure 9 – Example of a graph (top, L), a system dynamics model¹⁹⁷ (top, R), cartoon of an artificial neural network (b, Left) and sketch of a biological network of neurons (b, Right).

With decreasing cost of computation, memory and storage, graph databases are rapidly emerging, catalyzed by GPU servers (graphics processing units). A central processing unit (CPU) consists of four to eight CPU cores, while the GPU consists of hundreds of smaller cores, which is used for the graphics card, necessary for 3D gaming applications. CPU and GPU, together, operate to crunch through the data in applications. This parallel architecture is what gives the GPU its high compute performance. Graph databases demand high end computation because they hold edges, connectivity and relationships, in the form of graphs. The most interesting queries on graph data structures tend to have computational (requiring traversal), not analytical (closed-form), answers.

Because relationships are central to SITS, graph databases may be a key component of the SITS information architecture. Experts¹⁹⁸ may point out that graph databases are still developing, which has implications for the ecosystem of connectors to write data *to* them, clients to read data *from* them and security/ops tools which are necessary for maintenance. In addition, certain forms of graphs (DAG, Directed Acyclic Graph) can be represented¹⁹⁹ and traversed²⁰⁰ in relational databases, hence, the question, do we need graph databases?

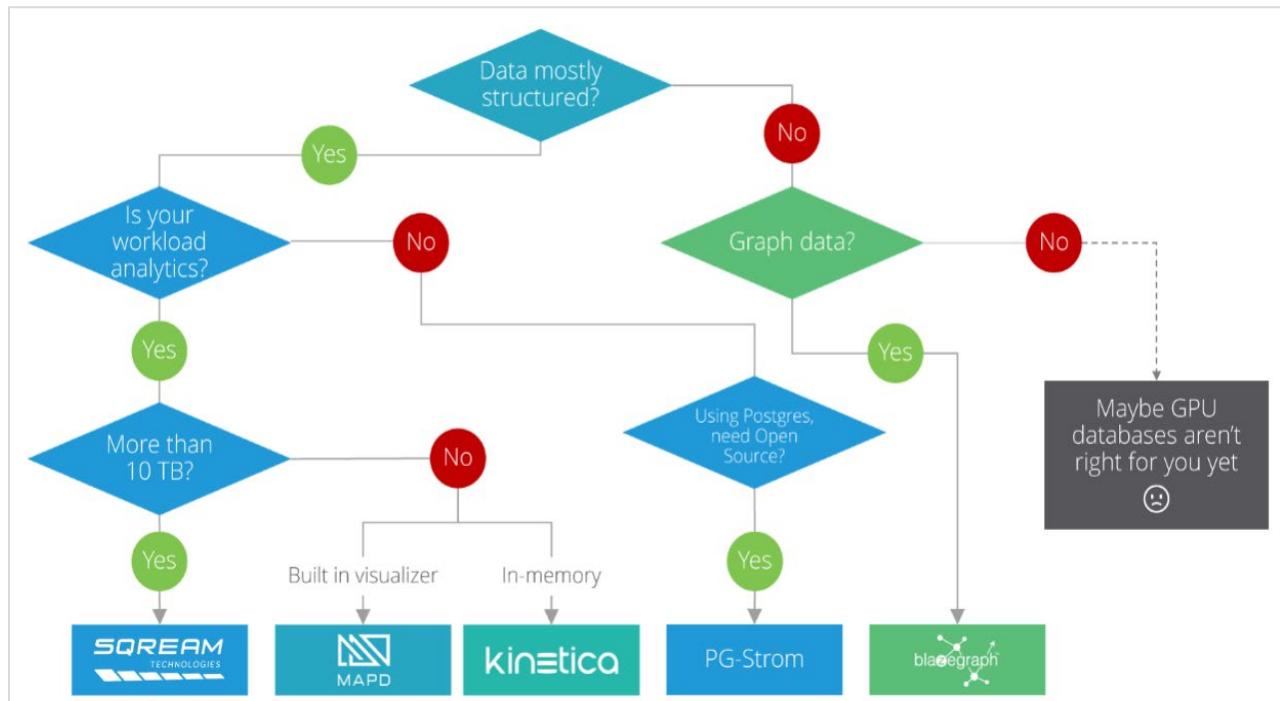


Figure 10 – Graph DB: a future forward strategy? Is graph database²⁰¹ right for SITS?

The primary interaction between SITS and SUGs (SITS user groups) may focus on the use of SITS as a repertoire for users to query relevant information. Compatibility with different query languages, for example, SQL, SPARQL, NoSQL DSLs (domain-specific languages²⁰²), is mandatory. Graph databases are likely to handle multiple query languages. Can this be an opportunity for more research and innovation in semantic query languages?

In the context of the data, context determines the users focus on the data and *that* focus, hence, the context, could vary. In other words, users may view the same data from different contexts (in software jargon, need multiple cursors). Depending on the application, the user is going to define the context (externally). Therefore, by separating data and context (application), the information architecture may provide users the flexibility to view the data from all possible perspectives (rather than fixed schema or set of relationships, typical in a relational database). Graph databases (semantic databases) enables creation of context-free data systems. For example, < soil pH 8 > may be important to one grower in the context of planting seeds, for another grower the context may be nitrogen fixation and still another user may ask whether upstream leaching of salts may be influencing the pH of downstream soil. The relationship between pH and planting seeds, pH and soil nitrogen fixation, pH and water management, is an enormous task, perhaps better captured in knowledge graphs.

This task cannot be “complete” on day one. Graph databases may crowdsource this information and grow the repertoire from information curated/contributed from vast number of users. Can users “drag and drop” this information in the database? Open interfaces (API) to import sensor data (local, global) in the knowledge graph database, agnostic of file format (CSV, JSON, XML), is the expectation from smart data hubs (semantic data warehouse).

For context-agnostic data ingestion, the characteristics of *ingestor logic* gains prominence. Smart hubs facilitate direct ingestion of data (think, time series data from sensors) from external databases. One segment for creativity and innovation is how to embed metadata during this ingestion process, when the incoming data is converted to the form which is useful for the recipient database. How can we be creative in seeding metadata and improve this step continuously to better support [a] search [b] navigation [c] data identity keys [d] provenance information and [e] data governance?

To amplify the value of the SITS information architecture, can we use SITS graph database to serve as a (local, state, national, global) repertoire for different types of sensor data? The value of the future forward data and information architecture of SITS may not be limited by the sensors in Table 1. For example, if a laboratory offers sensor data²⁰³ unrelated to Table 1, how do we incorporate the sensor types in the SITS graph database? It will be necessary to create open interfaces (APIs) as “feeder tubes” to ingest data (from anywhere) relevant to the sensors already occupying the database.

One obvious approach may involve creation of an automated feature²⁰⁴ selection tool. It may be downloaded by labs interested to share sensor data. Feature²⁰⁵ engineering and selection, will enhance compatibility of data uploaded to the SITS repository. Labs may export their data using open APIs from the SITS portal. If feature selection criteria are similar, then feeding data directly to SITS database may be easier or a less arduous task.

However, it is desirable for feature engineering to be independent of data *persistence*, so that raw data can be replayed through new feature engineering ideas. In this respect the design of IoT (internet of things) in applications²⁰⁶ (such as Farm²⁰⁷ IoT) is a detail worth pursuing because in many IoT applications raw data has a narrow window to be persisted, since the attached storage, at the source of sensing, is typically limited (less storage may mean less cost). Therefore, if the data at the source is lost (historical data deleted from storage to make room for new data), then “replaying” the raw data (if there is a new feature engineering idea) is only possible if the transmitted raw data from the source was stored in the parent (graph) database (for example, linked to an open source time series database²⁰⁸).

Importing raw sensor data and populating structured data fields may be sufficient in relational databases but in SITS graph database, setting up the graphs (relationships), are equally critical. Replaying raw data in the context of a new feature(s) may create new graphs and other relationships may emerge, which could lead to questions not yet asked. Hence, these attributes (independence of data persistence, context-free data) allows data to remain accessible to multiple levels of queries. It enables questions to be asked by other users using “new eyes” to see old problems, which could lead to new approaches to trigger new solutions.

Knowledge graphs, at this time, are a human-driven endeavor to install semantic architecture (metadata, data, may have to be curated). Furthermore, building ontological schema is required to perform Google-like searches. Management of metadata in case of overlapping ontological schema (from different sources) may be ripe for automation²⁰⁹ to avoid human-centric curation as the rate limiting step, especially in the management of mapping from one ontology to another. The erroneous assumption is that the sensor data, in question, has associated metadata, semantics or any ontological schema.

Perhaps the fallacy, in this context, is the organizational ambition to create a single conceptual model for the expression of information between organizations. It means that everyone should use the same model, if they wish to communicate information, for example, RDF. It requires that the data in question is in RDF and the external content contains enough of the metadata model used by the source system to successfully execute the query.

But, SITS and its ecosystem (distributed databases that may contain sensor data and other information relevant to relationships between data, models and their context, from global organizations), are likely to be highly heterogenous, non-RDF based databases. In this context, knowledge graphs are better suited to handle heterogenous data. Multiple structured and unstructured data silos, connecting their data sets in a meaningful way and contextual manner (things and related data of things) makes this possible through knowledge graphs.

Rather than spreadsheets and folders, data in knowledge graphs are connected with respect to context and relations, which are critical for almost all users and industries (finance, manufacturing, banking, utilities, healthcare, retail, logistics, and agriculture). To extract value (use and re-use) from the immense volume of data in distributed data silos, users turn to algorithms (statistical, machine learning) to improve their search. Knowledge graph models, of knowledge domains, are created by subject-matter experts who weave the foundation of how the domains are connected. Therefore, the strength and value of the knowledge graph model is as good as, or limited by, the knowledge and bias, of the expert. We need tools to increase the breadth of knowledge and reduce the spread of bias. By creating structures, standards and common interfaces, the knowledge graph model may be improved by crowdsourcing the “knowledge” rather than reliance on a few experts.

Tools to create “low-bias, universal models” are few and far between. The dynamic breadth and incisive insight of knowledge graph models will be quintessential to generate not only the obvious outcomes but also the *non-obvious relationships*. Because knowledge graphs overlay existing databases or data sets (structured or unstructured), agility increases when new data is added or new data sources are linked. Standard outcomes and performance of NORA improves with increasing relationships in context of data. The ability of knowledge graphs to establish relationships is determined by (hence, restricted to) the knowledge of the knowledge domain expert(s) establishing rules, including vocabulary, ontology, taxonomy, related to the data. Thus, these rules cannot be governed by specific groups or remain limited within certain geographies (introduces cultural bias). The crowd-sourced *modus operandi* is key for knowledge graphs to learn, *un-learn*, and grow to embrace the rules stemming from different vocabularies (global users and their social bias) as well as ontologies from different bodies and plethora of tools (statistical techniques, ML, algorithms). This may not happen on *day 1* but must be a salient feature for knowledge platforms of the future (KIDS in PEAS).

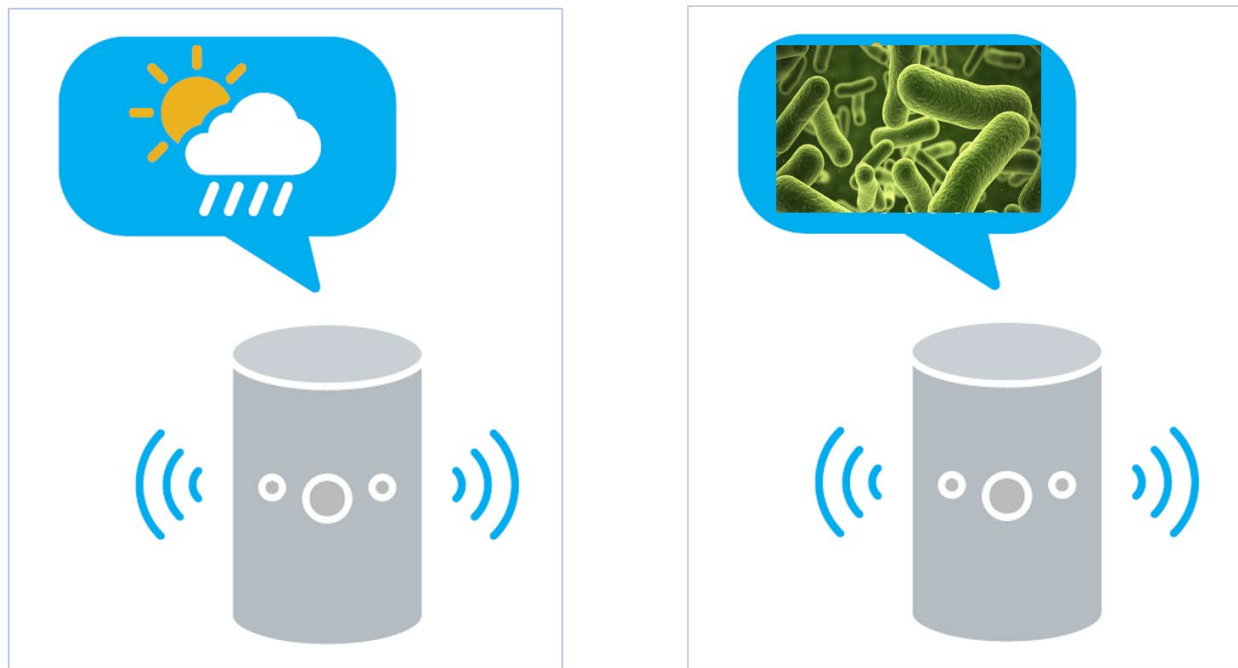


Figure 11 – Knowledge graphs come alive when we query “Alexa” what is the weather? (Left box). What we propose to achieve is the SITS version for ag. We may ask “Hypatia - which types of bacteria are in the soil sample from Alexandria?” (Right box). Note: re-visit Figure 1

TEMPORARY CONCLUSION

The suggestions here are amorphous but enabling mass adoption²¹⁰ of these tools remains the Holy Grail. Adoption of these tools are a pre-requisite if we view SITS as the future anchor and resource for “Google of ag” which may be an “one-stop shopping mall” for scientists/researchers to upload their data and users/growers to access that data to answer questions. The emphasis on open platforms and open APIs in the information architecture is key to engage with diverse sources of information, ingest big data, if relevant, and invite non-compete alliances to enable industry to contribute and benefit (profit) from this digital initiative through data analytics and intelligent information arbitrage. SITS may be ag’s answer to the “geological Google” (Deep-time Digital Earth Initiative²¹¹) which is one reason for suggesting open source²¹² GPU²¹³ database in the design of SITS.



Figure 12 – Viewing the ancient library card catalog with “*new eyes*” in the Semantic Data Catalog. SDC contains links (URL, URI, URN) to resource and information/connections to other SDCs, to navigate across information spaces. It does not actually include the resources, only their addresses and metadata, to identify a particular representation of that resource, in a traditional database. It²¹⁴ appears to be, in principle, similar to the transition when actual data on the RFID tag was replaced with an unique 64-bit EPC, which used PML and ONS to indicate, where to find (link to an URL) the information relevant to the unique ID (EPC), that was read by the RFID reader from the RFID tag. IoT systems²¹⁵ are increasingly using semantic graphs to keep up with the edge²¹⁶ of connectivity (explore ART and PEAS).

Significant breakthroughs may be necessary. Part of the scientific content in this haphazard essay is almost pure speculation (quantum spectroscopy). The data science section is a regurgitation of common knowledge. Creating the edge connectivity (SITS graphs) may be a mammoth undertaking, which may mature over years, or decades. An example²¹⁷ of a related task for oncology may be just the tip of the iceberg. It will be foolish to assume that the primary repertoire for the future “Google of ag” may be an easy undertaking.

In attempting to provide my two cents on this *threepenny opera*²¹⁸ I attempted a task much too great for my abilities, the extent of which I didn’t perceive when I started²¹⁹. We choose to pursue these ideas “*not because they are easy, but because they are hard*”²²⁰.

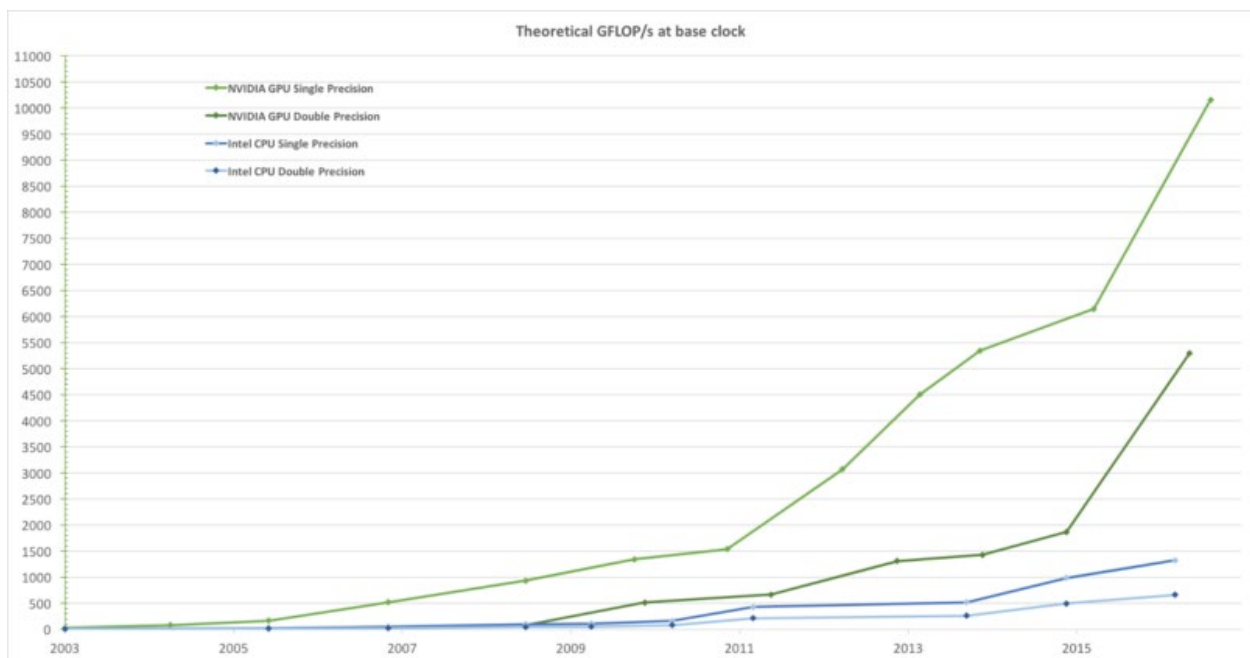


Figure 13 – Signals²²¹ in the soil databases will not only provide access to the data but also display GIS maps to show source of the signal (and environment, for example, tomato growers in Florida or rice paddy on terrain in Yunnan Province, China). To render realistic views of images at a high frame rate, GPUs process massive amount of geometries and pixels in parallel, at high speed. The clock-rate increase for processing units has plateaued but the number of transistors on a chip is increasing. GPU computation speeds, (gigaflops per sec, GFLOP/second), are increasing. Graph²²² compares GPU vs CPU trends.

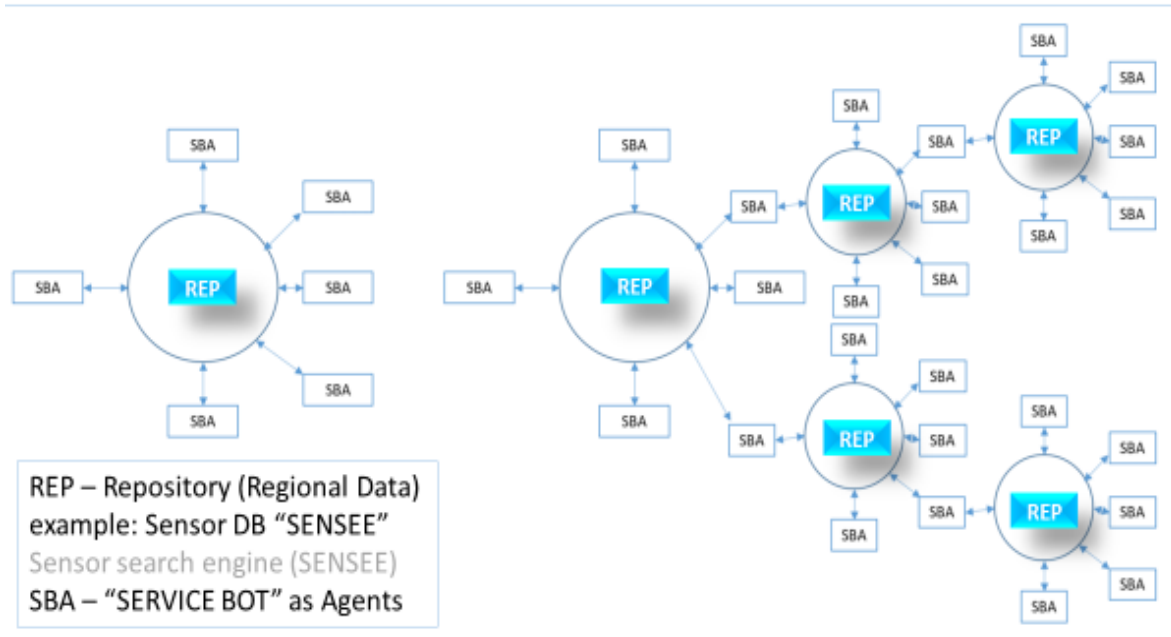


Figure 14 – Locally distributed repositories [SENSEE] containing data and questions (relevant to users and growers by crop or environment) can be globally connected by Agent-based communication (top panel) and consumed by any system, in near-real time, due to interoperability of open source mobile platforms (bottom panel). Explore ART and PEAS.

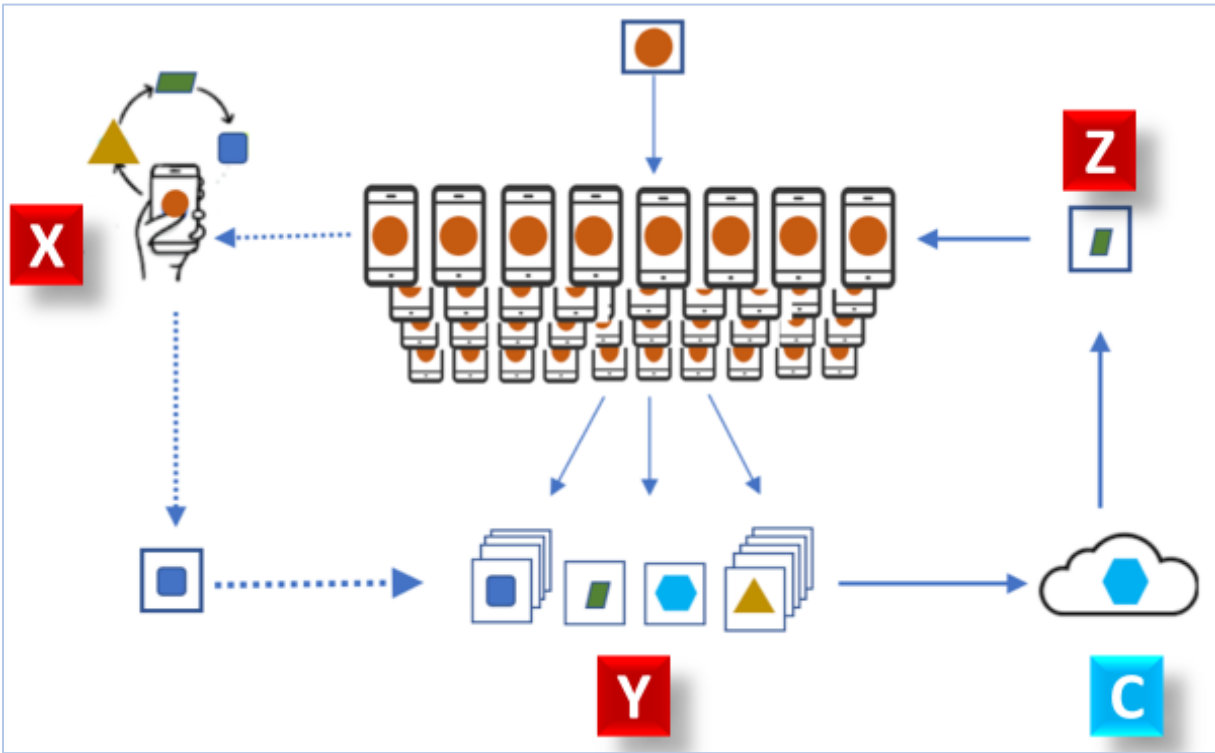


Figure 15 – The value of the REP concept (SENSEE) may be enhanced by coupling publish-subscribe modes with crowd-sourced data adoption/dissemination. User “X” (edge) may update data, recommend tools or techniques or share outcomes/outputs (for example, growers can share photographs of infected produce or sinfully delicious tomatoes). Thus, local user personalization (point X, in the crowd - edge) is sent/stored to the analytical platform (engine Y). An emerging consensus from contributed data (for example, improved technique or data with incorrect units or better use of a tool) is sent to cloud C for expert evaluation and critical analysis. Verified change Z is communicated to all subscribers, globally. This process repeats, to enhance open models and enrich common goals for public goods, using distributed data from crowdsourcing (experts, users, farmers, growers, scientists, engineers, academics, politicians) but deploying a neutral/trusted analytical evaluator (cloud C) to deconstruct/reconstruct, aggregate/disaggregate data and models, to serve the best interest of the system. It may prevent data pollution, act to neutralize cyberthreats and stop, if at all possible, attacks perpetrated by GAN (general adversarial network) as infectious agents.

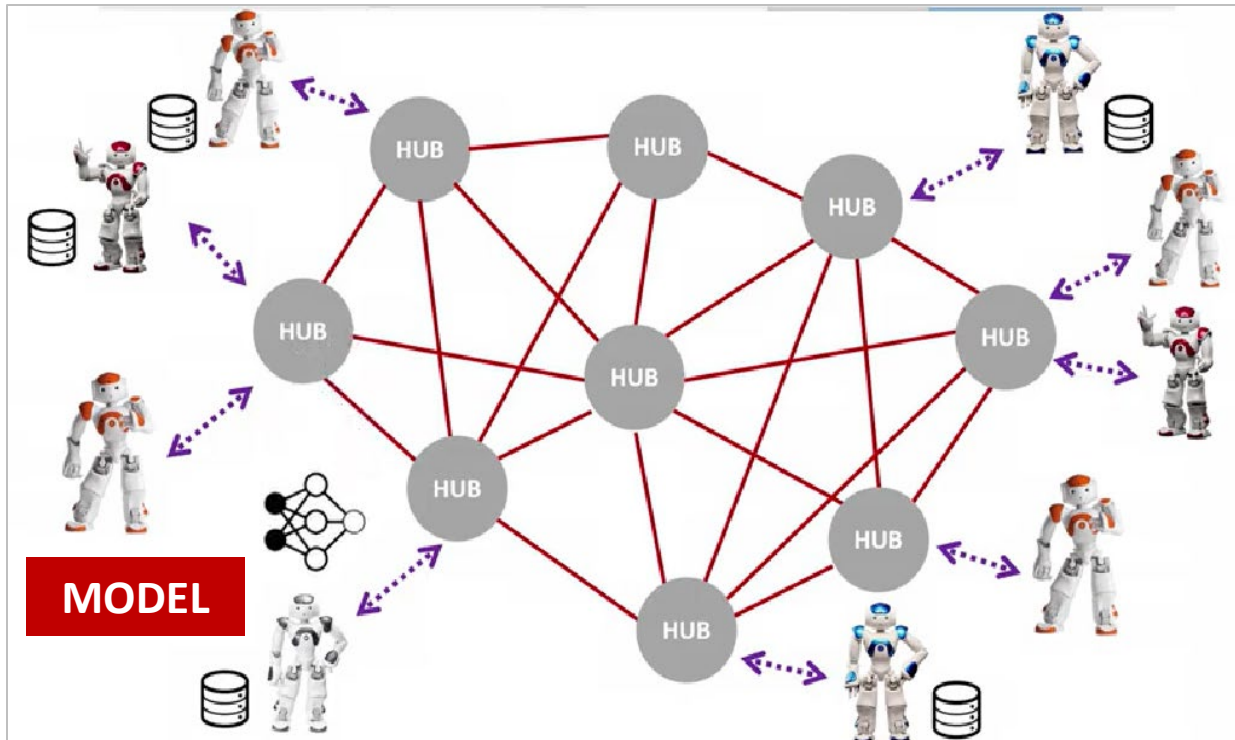


Figure 16 – The SENSEE suggestion increasingly *reverses* the paradigm where the edge (the user X in Figure 15) becomes the point of information, analysis, feedback and actuation, because it is the user at the edge (grower, farmer) who must benefit from data arbitrage. In this approach, we envision that the “model” (see cartoon, lower left corner) which is created at the edge, locally, by one or more (crowd) of users, is of value to that user or user group. But the learning from this edge (the cartoon) may be applicable in educating other users (other edges in the illustration). Imagine the cartoon “model” to travel over the “network tracks” (hubs and spokes in the illustration) and serve other users. They may use “as is” or modify or reject the model. ***In other words, we deliver the analytical engines, models and algorithms to the data, rather than the classical concept of sending the data to a hub or cloud for analysis and analytics.*** These ideas as based on “federated learning models” commonly used by financial institutions and banks to train fraud detection models without sharing their sensitive customer data. Popular frameworks now include TensorFlow Federated, an open source framework for experimenting on decentralized data. PySyft is a open source library built on top of PyTorch for encrypted, privacy preserving deep learning.

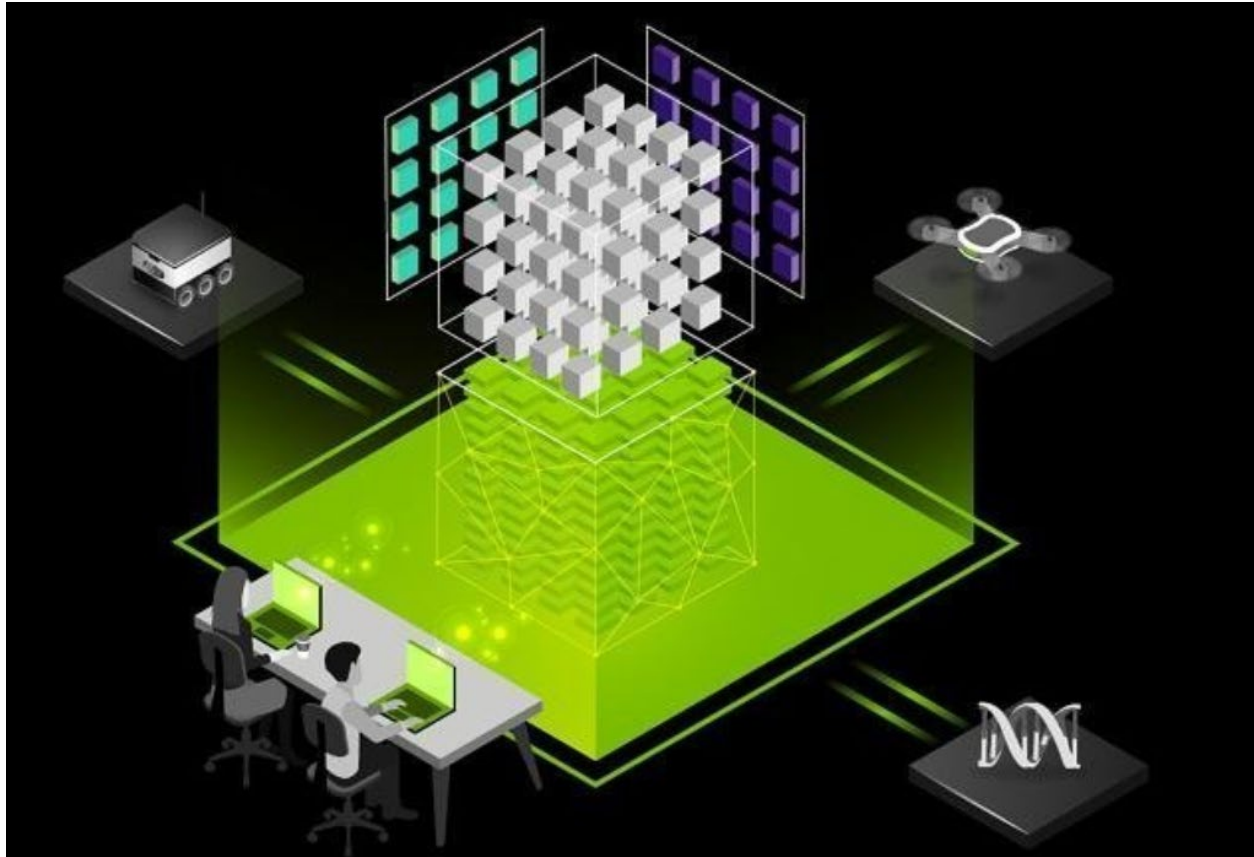
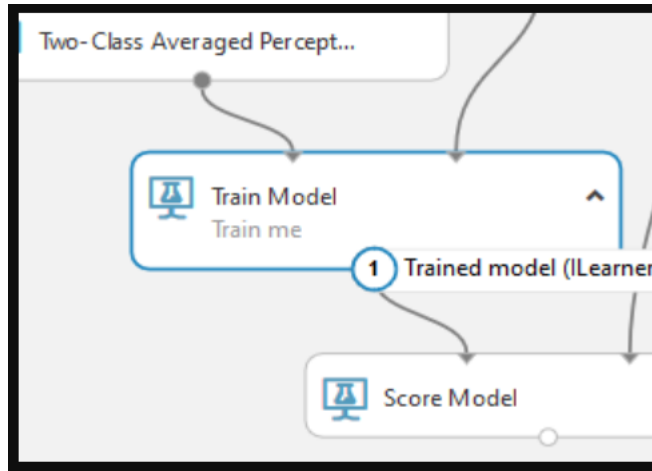
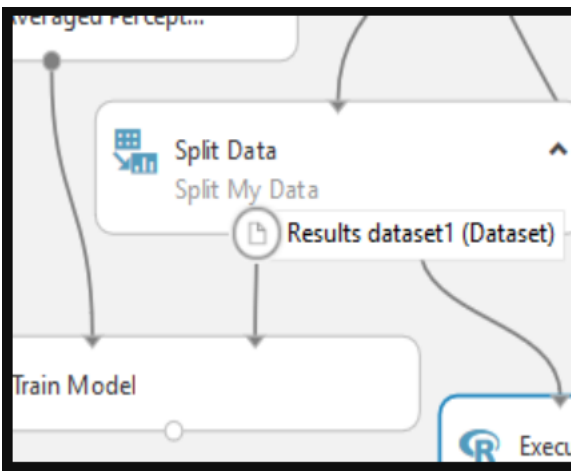
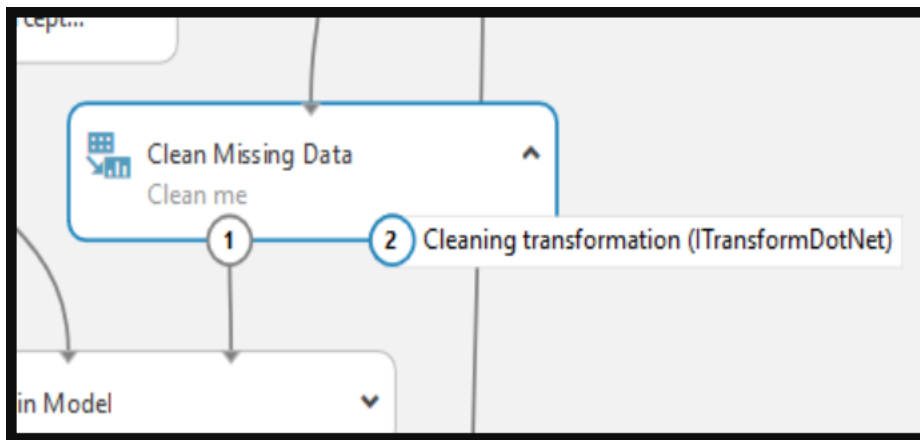
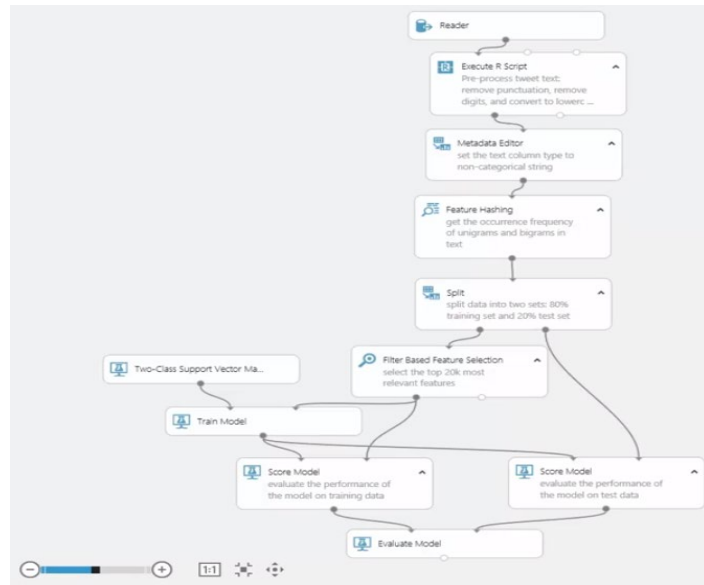


Figure 17 - Federated AI Technology Enabler (FATE) is an open-source project initiated by Webank's AI group to provide a secure computing framework to support the Federated AI ecosystem. Despite the hype whipped up by the glib, snake oil salesmen of AI, there is value in this approach, if and when rationally analyzed, for specific purposes, using bonafide tools, which may be customized for specific applications and are based on rigorous mathematics and statistics. It may be useful for SITS and its ecosystem to explore these advanced tools of the future and adapt enterprise solutions around federated learning for the agro-ecosystem. At present, the primary deployment challenge may be the computational constraint of edge devices (smartphone, tablet) to perform local training, cloud consultations and inferencing. However, smartphones and IoT devices are increasingly equipped with GPUs or sufficient computing hardware to run CNN/RNN and other ANN/AI models at the edge to augment near-real time "intelligent" decision support systems, at the point of use. In Figure 14 the idea of REP/SENSEE may be the SITS "smart path" approach to harvest these ideas and convert them into actionable transactions to help the ag industry in the pursuit of food.

Figure 18 – Sense of the future – “DRAG AND DROP” interfaces of partially automated processes which will be agnostic of the user’s knowledge of programming (akin to the next generation of Lego Mindstorms). Cartoon source <https://github.com/hning86/azuremlps>



REFERENCES

¹ <http://news.mit.edu/2019/securing-internet-things-in-quantum-age-0301>

²

https://www.researchgate.net/publication/228136384_First_to_Market_First_to_Fail_Real_Causes_of_Enduring_Market_Leadership

³ <https://www.nobelprize.org/prizes/physics/1991/summary/>

⁴ <https://www.nsf.gov/pubs/2019/nsf19556/nsf19556.pdf>

⁵ <http://www.soilhealthinstituteresearch.org/Home/Search>

⁶ <http://www.soilhealthinstituteresearch.org/Content/DataDictionaryv2.pdf>

⁷ <http://bit.ly/DATA-AA>

⁸

https://canvas.harvard.edu/files/3486763/download?download_frd=1&verifier=qRAG5jUIbng83WzE18BnQQop9GgeXfw0hCkeMYiJ

⁹ <http://www.cs.utsa.edu/~bylander/cs1023/SRD-IBM-Entity-Analytics-9-15-05.ppt>

¹⁰ https://jeffjonas.typepad.com/jeff_jonas/2010/07/hell-with-rules.html

¹¹ <https://www.nap.edu/download/25059>

¹² <http://www.matshore.com/849-2/>

¹³ <https://onlinelibrary.wiley.com/doi/full/10.1111/cei.13195>

¹⁴ <http://science.sciencemag.org/content/360/6393/1126>

¹⁵ <https://www.nature.com/articles/s41586-018-0238-4>

¹⁶ <https://www.nature.com/articles/d41586-019-00599-8>

¹⁷ <https://www.techbriefs.com/dl/2019.php?i=34095&eid=376590803&bid=2405616&d=1>

¹⁸ <https://arxiv.org/pdf/1805.04011.pdf>

¹⁹ <https://people.csail.mit.edu/fadel/papers/wivi-paper.pdf>

²⁰ <http://equadro.csail.mit.edu/files/equadro-paper.pdf>

²¹ https://smap.jpl.nasa.gov/files/smap2/c1_Njoku_Entekhabi.pdf

²² http://smap.jpl.nasa.gov/files/smap2/SMAP_Apps_Plan_120706.pdf

²³

https://smap.jpl.nasa.gov/system/internal_resources/details/original/484_L2_SM_P_ATBD_rev_D_Jun2018.pdf

²⁴ https://www.microsoft.com/en-us/research/uploads/prod/2018/10/SMURF_TR-1.pdf

²⁵ <https://www.youtube.com/watch?v=BCIohEJYxdY>

²⁶ <http://bit.ly/WSN-MASSEY>

²⁷ <http://robotics.sciencemag.org/content/4/27/eaaw1875>

²⁸ <http://bit.ly/SIN-BTH>

²⁹ <https://www.nature.com/articles/s41928-018-0173-2>

³⁰ <http://www.wave-scattering.com/pbgheadlines.html>

³¹ <https://apps.dtic.mil/dtic/tr/fulltext/u2/601325.pdf>

³² <https://polymerscience.physik.hu-berlin.de/docs/manuals/dielectric.pdf>

³³ <https://arxiv.org/ftp/cond-mat/papers/0612/0612570.pdf>

³⁴ <http://jgp.rupress.org/content/jgp/44/1/19.full.pdf>

³⁵ <http://bit.ly/SARS-AG>

³⁶ <https://pdfs.semanticscholar.org/f363/6deed27227fa5a52603ccf16a5127f48f085.pdf>

³⁷ <https://pdfs.semanticscholar.org/839b/dbc3ce47df32b04b9722aa492d51b3921268.pdf>

³⁸ <https://core.ac.uk/download/pdf/61188787.pdf>

³⁹ https://www.lehigh.edu/imi/teched/JapanWS/WS11AB_Lanagan.pdf

⁴⁰ <https://www.mdpi.com/2072-4292/6/10/9712/pdf>

⁴¹ <http://onlinepubs.trb.org/Onlinepubs/trr/1992/1355/1355-012.pdf>

42 <https://www.mdpi.com/1424-8220/18/10/3333>
43 <https://arxiv.org/pdf/quant-ph/0411002.pdf>
44 <https://arxiv.org/pdf/hep-ph/0406008.pdf>
45 <https://dspace.mit.edu/openaccess-disseminate/1721.1/69931>
46 <https://www.ncbi.nlm.nih.gov/pubmed/14021529>
47 <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5896772/pdf/nihms955832.pdf>
48 <https://www.ncbi.nlm.nih.gov/pubmed/17644693>
49 [https://www.amjmed.com/article/S0002-9343\(99\)00055-8/fulltext](https://www.amjmed.com/article/S0002-9343(99)00055-8/fulltext)
50 <https://www.ias.ac.in/article/fulltext/reso/021/08/0741-0747>
51 <https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.122.100501>
52 <https://arxiv.org/pdf/1604.01677.pdf>
53 <http://web.mit.edu/ashokaj/www/>
54 <https://arpa-e.energy.gov/?q=slick-sheet-project/magnetic-resonance-imaging-root-growth>
55 <https://pubs.rsc.org/en/content/articlelanding/2017/lc/c7lc00192d#!divAbstract>
56 <https://www.mdpi.com/1424-8220/17/8/1866>
57 http://stanford.edu/group/khuri-yakub/publications/94_Haller_01.pdf
58 <https://iopscience.iop.org/article/10.1088/0960-1317/21/5/054004/meta>
59 <https://www.technologyreview.com/s/532166/with-100-million-entrepreneur-sees-path-to-disrupt-medical-imaging/>
60 <http://repository.bilkent.edu.tr/bitstream/handle/11693/27202/bilkent-research-paper.pdf?sequence=1&isAllowed=y>
61 https://erj.ersjournals.com/content/46/suppl_59/OA301
62 <https://patentimages.storage.googleapis.com/7c/77/4e/867b47a5072065/US8689606.pdf>
63 <https://www.nature.com/articles/s41467-018-08038-4>
64 <https://www.mdpi.com/2079-6374/6/4/60>
65 <https://www.nist.gov/news-events/news/2019/02/floc-takes-flight-first-portable-prototype-photonic-pressure-sensor>
66 <http://math.harvard.edu/~ctm/home/text/others/shannon/entropy/entropy.pdf>
67 <https://www.cs.unc.edu/~welch/kalman/media/pdf/Kalman1960.pdf>
68 <https://www.jstor.org/stable/1912791>
69 <http://www.econ.uiuc.edu/~econ536/Papers/engle82.pdf>
70 <https://www.jstor.org/stable/1913236>
71 <https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.122.080504>
72 <https://www.nature.com/articles/267585a0>
73 <https://www.nobelprize.org/prizes/chemistry/2013/karplus/facts/>
74 <http://orca.cf.ac.uk/58996/>
75 <https://www.nature.com/articles/415152a>
76 <https://link.springer.com/article/10.1007/s11104-007-9514-z>
77 <https://jb.asm.org/content/jb/2/1/35.full.pdf>
78 https://link.springer.com/chapter/10.1007/978-981-10-5708-3_7
79 <https://www.nature.com/articles/s41598-018-20256-w.pdf>
80 <https://jcm.asm.org/content/39/5/1840>
81 <https://aem.asm.org/content/aem/72/3/1719.full.pdf>
82 <http://bit.ly/EDWARD-TUFTE>
83 <https://pubs.rsc.org/en/content/articlelanding/2018/an/c8an00065d#!divAbstract>
84 <https://www.law.uchicago.edu/files/file/coase-nature.pdf>
85 <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC440936/pdf/bactrev00182-0090.pdf>
86 <http://docsdrive.com/pdfs/ansinet/biotech/2010/428-443.pdf>
87 https://smartechnology.gatech.edu/bitstream/handle/1853/55276/g-32-629_399496.pdf

- 88 <https://pubs.acs.org/doi/abs/10.1021/jf025660x>
- 89 <https://doi.org/10.3390/ma8125478>
- 90 <https://link.springer.com/content/pdf/10.1186%2Fs11671-018-2772-2.pdf>
- 91 <https://jb.asm.org/content/jb/190/13/4706.full.pdf>
- 92 <https://www.jstor.org/stable/3625499>
- 93 <https://naldc.nal.usda.gov/download/IND43966191/PDF>
- 94 <https://royalsocietypublishing.org/doi/pdf/10.1098/rstb.1890.0005>
- 95 <https://www.frontiersin.org/articles/10.3389/fmicb.2016.00529/full>
- 96 <https://www.nature.com/articles/334340a0>
- 97 <https://academic.oup.com/femsle/article/272/2/127/637339>
- 98 <https://onlinelibrary.wiley.com/doi/epdf/10.1111/j.1365-2958.2006.05057.x>
- 99 <https://pubs.acs.org/doi/10.1021/nn2042384>
- 100 <https://smartech.gatech.edu/handle/1853/45965>
- 101 <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1085052/pdf/pnas01891-0031.pdf>
- 102 <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1085053/pdf/pnas01891-0035.pdf>
- 103 <https://core.ac.uk/download/pdf/55640662.pdf>
- 104 <https://www.springer.com/us/book/9783662530665>
- 105 <https://pubs.rsc.org/en/content/articlelanding/2016/qi/c5qi00240k>
- 106 https://www.mdpi.com/journal/chemosensors/special_issues/nanozyme-based-sensors
- 107 <https://doi.org/10.1016/B978-0-323-50878-0.00007-0>
- 108 <https://doi.org/10.1016/j.yrtph.2012.06.016>
- 109 <https://www.statnews.com/sponsor/2018/02/22/clean-laundry-enzyme-science/>
- 110 <https://onlinelibrary.wiley.com/doi/abs/10.1002/cber.18940270364>
- 111 <https://www.medschool.lsuhs.edu/biochemistry/docs/Lichtenthaler.pdf>
- 112 <https://www.nature.com/articles/432447a>
- 113 <http://www.sussexvt.k12.de.us/science/The%20Periodic%20Table/Seaborg.htm>
- 114 <https://arxiv.org/ftp/physics/papers/0411/0411080.pdf>
- 115 <https://link.springer.com/article/10.1023/A:1025673206850>
- 116 <https://pdfs.semanticscholar.org/0379/02a15832359ff6527db3e949ceadb8d2dd16.pdf>
- 117 <https://www.economist.com/science-and-technology/2019/02/28/the-periodic-table-is-150-years-old-this-week>
- 118 <https://doi.org/10.1073/pnas.0604452103>
- 119 [https://doi.org/10.1016/S0022-2836\(63\)80091-1](https://doi.org/10.1016/S0022-2836(63)80091-1)
- 120 <http://www.unige.ch/sciences/biochimie/Edelstein/Monod%20Wyman%20Changeux%201965.pdf>
- 121 <https://doi.org/10.1016/j.jmb.2013.02.033>
- 122 <https://www.physiology.org/doi/pdf/10.1152/ajplung.00527.2018>
- 123 <https://pubs.acs.org/doi/abs/10.1021/acsphotonics.8b00440>
- 124 <https://www.osapublishing.org/boe/abstract.cfm?uri=boe-9-11-5735>
- 125 <https://www.frontiersin.org/articles/10.3389/fenvs.2014.00007/full>
- 126
- www.researchgate.net/publication/222791698_Soil_fauna_guilds_functional_groups_and_ecosystem_processes
- 127 https://www.wikipremed.com/reading/philosophy/The_Life_of_Reason.pdf
- 128 <https://www.electronicdesign.com/defense/1950s-transistors-fill-vacuum-digital-age-begins>
- 129 <http://www.research.ibm.com/articles/brain-chip.shtml>
- 130 <https://www.nextgov.com/emerging-tech/2015/02/ibm-tries-sell-government-brain-box-technology/105975/>
- 131 <https://clintonwhitehouse3.archives.gov/WH/New/html/20000626.html>
- 132 <https://biology.mit.edu/profile/eric-s-lander/>

133 <https://eccc.weizmann.ac.il/report/2018/107/>
134 <https://www.pnas.org/content/114/29/7555>
135 <https://www.nature.com/articles/s41598-019-40765-6>
136 <https://www.consulting.us/news/1485/accnture-wins-quantum-computing-related-patent>
137 <https://www.jstor.org/stable/e24931041>
138 <https://www.siliconrepublic.com/machines/marvin-minsky-ai-predictions>
139 https://www-sop.inria.fr/acacia/cours/essi2006/Scientific%20American_%20Feature%20Article_%20The%20Semantic%20Web_%20May%202001.pdf
140 <https://www.w3.org/>
141
https://www.researchgate.net/publication/237288554_Knowledge_Web_Technology_Roadmap_The_Technology_Roadmap_of_the_Semantic_Web
142 www.newscientist.com/article/mg21228390-800-nothingness-the-turbulent-life-of-empty-space/
143 <https://rodnebrooks.com/the-seven-deadly-sins-of-predicting-the-future-of-ai/>
144 <https://www.technologyreview.com/s/609048/the-seven-deadly-sins-of-ai-predictions/>
145 <https://www.telegraph.co.uk/technology/2018/07/27/ibm-watson-ai-criticised-giving-unsafe-cancer-treatment-advice/>
146 <https://www.healthnewsreview.org/2017/02/md-anderson-cancer-centers-ibm-watson-project-fails-journalism-related/>
147 http://www.cs.virginia.edu/~robins/The_Rise_of_AI.pdf
148 <https://www.advisorperspectives.com/commentaries/2019/02/23/ai-will-add-15-trillion-to-the-world-economy-by-2030>
149 <http://sprott.physics.wisc.edu/Chaos-Complexity/allard17.pdf>
150 <https://www.deeplearningbook.org/>
151 <http://aima.cs.berkeley.edu/>
152 <http://www.acad.bg/ebook/ml/Society%20of%20Mind.pdf>
153 <https://arxiv.org/ftp/arxiv/papers/1610/1610.07862.pdf>
154 <https://www.nature.com/news/when-google-got-flu-wrong-1.12413>
155 <https://cs.stanford.edu/people/eroberts/courses/soco/projects/1998-99/babbage/diff.htm>
156 <https://www.gao.gov/assets/680/677454.pdf>
157 <https://www.chistlukeshhealth.org/sites/default/files/CMS%20Survey.pdf>
158 <https://www.govinfo.gov/content/pkg/FR-2019-02-15/pdf/2019-02519.pdf>
159 <https://www.bmj.com/content/353/bmj.i2139>
160 <https://dutraeconomicus.files.wordpress.com/2014/02/amartya-sen-the-idea-of-justice-2009.pdf>
161 <http://www.ai.mit.edu/projects/oxygen/oxygen-book2001/oxygenbook2001.pdf>
162 <http://oxygen.csail.mit.edu/videosketching.html>
163 <http://oxygen.csail.mit.edu/Overview.html>
164 <http://www.ai.mit.edu/projects/oxygen/oxygen-jan02-slides/>
165 <http://oxygen.csail.mit.edu/videomultilingual.html>
166 <https://www.siriuserguide.com/article/how-to-check-the-weather-forecast-with-siri>
167 <http://bit.ly/IOT-METAPHOR>
168 <http://bit.ly/SARS-AG>
169 <https://www.dre.vanderbilt.edu/~schmidt/PDF/dds-sos.pdf>
170 <https://www.omg.org/spec/DDS/About-DDS/>
171 http://www.laas.fr/files/SLides-A_Corsaro.pdf
172 <https://www.sciencedirect.com/science/article/pii/0304407681900798>
173 <https://www.jstor.org/stable/1913236>

-
- 174 <http://www-stat.wharton.upenn.edu/~steele/Courses/434/434Context/Co-integration/GrangerNobelAddress.pdf>
- 175 <http://unitsofmeasure.org/ucum.html>
- 176 <https://chomsky.info/wp-content/uploads/195609-.pdf>
- 177 <https://www.w3.org/standards/semanticweb/ontology>
- 178 https://protege.stanford.edu/publications/ontology_development/ontology101-noy-mcguinness.html
- 179 <http://xml.coverpages.org/pml-ons.html>
- 180 <https://www.w3.org/RDF/Metalog/docs/sw-easy>
- 181 <https://www.w3.org/RDF/>
- 182 <https://dspace.mit.edu/handle/1721.1/111021>
- 183 <https://dspace.mit.edu/handle/1721.1/41902>
- 184 <https://www.gs1.org/standards/epc-rfid>
- 185 <https://www.gs1.org/standards/barcodes/ean-upc>
- 186 <https://www.forbes.com/sites/cognitiveworld/2019/03/12/taxonomies-ontologies-and-machine-learning-the-future-of-knowledge-management>
- 187 <https://www.tandfonline.com/doi/abs/10.1080/2287108X.2012.11006070>
- 188 https://www.economics.ox.ac.uk/materials/working_papers/paper084.pdf
- 189 <https://pdfs.semanticscholar.org/02be/4bd7dc9f91a20fc522edd041ac6708889dc7.pdf>
- 190 <https://warwick.ac.uk/fac/soc/economics/research/workingpapers/1989-1994/twerp339.pdf>
- 191 <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.123.2728&rep=rep1&type=pdf>
- 192 <https://www.tandfonline.com/doi/pdf/10.1080/13102818.1997.10818934>
- 193 <https://www.cs.le.ac.uk/people/terlebach/talks/haifa06internet.pdf>
- 194 https://www.mdh.se/polopoly_fs/1.34346!/Menu/general/column-content/attachment/MAA507_L1_vt13.pdf
- 195 <http://snap.stanford.edu/class/cs224w-readings/broder00bowtie.pdf>
- 196 <https://neo4j.com/developer/graph-database/>
- 197 <http://dx.doi.org/10.4135/9781526410993>
- 198 https://www.youtube.com/watch?v=6Z_XVbECJzw
- 199 <https://www.fusionbox.com/blog/detail/graph-algorithms-in-a-database-recursive-ctes-and-topological-sort-with-postgres/620/>
- 200 http://people.apache.org/~dongsheng/horak/100309_dag_structures_sql.pdf
- 201 <https://hackernoon.com/which-gpu-database-is-right-for-me-6ceef6a17505>
- 202 <https://www.elastic.co/guide/en/elasticsearch/reference/current/query-dsl.html>
- 203 <http://bit.ly/SENSOR-LIBRARY-ERIC-MCLAMORE>
- 204 http://www.jmaxkanter.com/static/papers/DSAA_DSM_2015.pdf
- 205 <http://bit.ly/BOOKS-FEATURES>
- 206 <https://aioti.eu/wp-content/uploads/2017/03/AIOTIWG06Report2015-Farming-and-Food-Safety.pdf>
- 207 <https://ieeexplore.ieee.org/document/8081906>
- 208 <https://outlyer.com/blog/top10-open-source-time-series-databases/>
- 209 <https://aip.scitation.org/doi/full/10.1063/1.4999209>
- 210 <http://science.sciencemag.org/content/363/6430/912>
- 211 <http://science.sciencemag.org/content/363/6430/917>
- 212 <https://eng.uber.com/aresdb/>
- 213
- https://developer.download.nvidia.com/compute/DevZone/docs/html/C/doc/CUDA_C_Programming_Guide.pdf
- 214 http://cocoa.ethz.ch/downloads/2014/06/None_MIT-AUTOID-WH-001.pdf

²¹⁵ www.technologyreview.com/s/601013/the-internet-of-things-roadmap-to-a-connected-world/

²¹⁶ <http://eyeriss.mit.edu/>

²¹⁷ <https://www.nature.com/articles/s41598-018-36973-1>

²¹⁸ http://ciml.250x.com/archive/communists/brecht/english/brecht_the_threepenny_opera.pdf

²¹⁹ https://www.earlyprintedbooks.com/ames_typographical-antiquities_1749_alr/

²²⁰ <https://er.jsc.nasa.gov/seh/ricetalk.htm>

²²¹ <http://www.css.cornell.edu/extension/soil-health/manual.pdf>

²²² <https://eng.uber.com>

²²³ <http://www1.cs.columbia.edu/~ji/F02/ir02/p44-perlman.pdf>

²²⁴ <https://www.bloomberg.com/graphics/2018-us-land-use/>

RADIA PERLMAN²²³

Algorhyme

I think that I shall never see
A graph more lovely than a tree

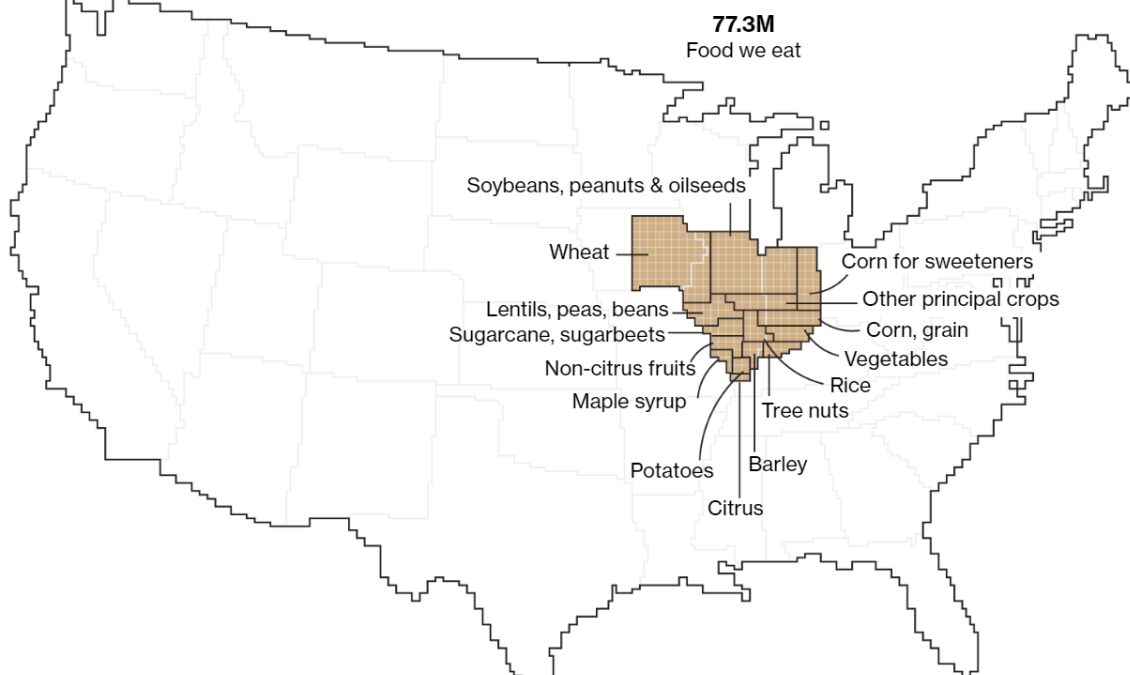
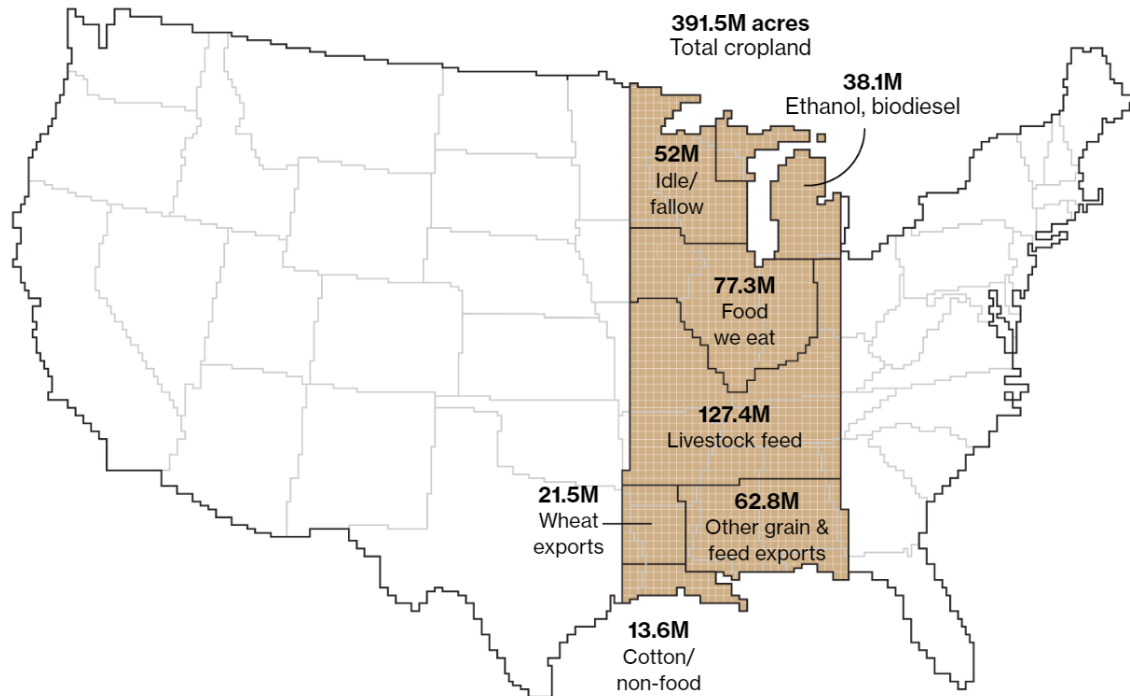
A tree whose crucial property
Is loop-free connectivity.

A tree which must be sure to span
So packets can reach every LAN.

First the Root must be selected
By ID it is elected.

Least cost paths from Root are traced.
In the tree these paths are placed

A mesh is made by folks like me
Then bridges find a spanning tree.



While the U.S. benefits from an overall agricultural trade surplus, Americans imported 15 percent of their food and beverage products in 2016. More than 30 percent of the fresh fruits and vegetables Americans consume come from other countries, predominantly Mexico and Canada. The amount of U.S. land used to produce citrus fruits alone is larger than Rhode Island.

“SIGNALS” contains a series of essays spewing amorphous thoughts:

1. SITS
2. SIP-SAR ----- **You are here**
3. SARS♠AG
4. ART
5. PEAS

Please review “SIGNALS”

- Download PDF from MIT Library

<https://dspace.mit.edu/handle/1721.1/111021>

Alternate <http://bit.ly/SIGNALS-SIGNALS>

SIGNALS is part of the collection of essays (book)

“IoT is a Metaphor” (see Commentary E)

Please review “IoT is a Metaphor”

- Download PDF from MIT Library

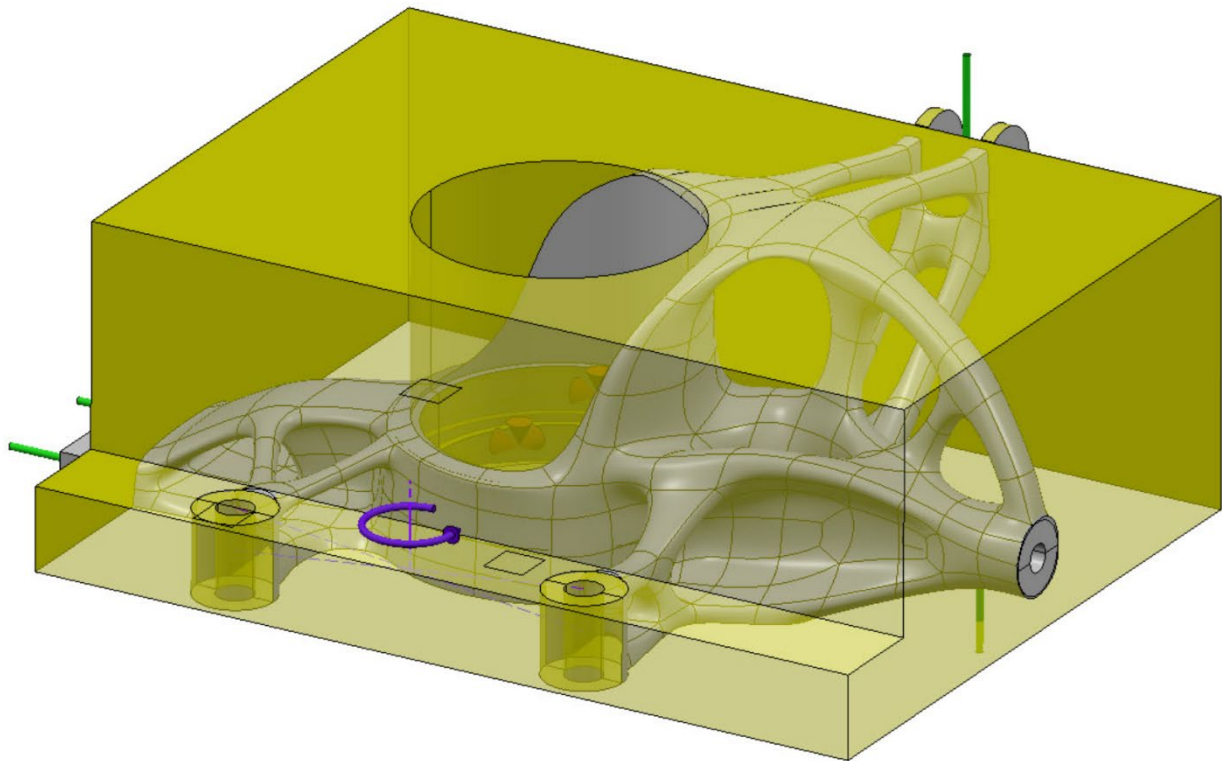
<https://dspace.mit.edu/handle/1721.1/111021>

The page numbers in the PDF do not match the document page numbers at the bottom of the pages. This PDF is made up of a few separate documents which were then combined.

Hence, the temporary mis-match of page numbers. Apologies.

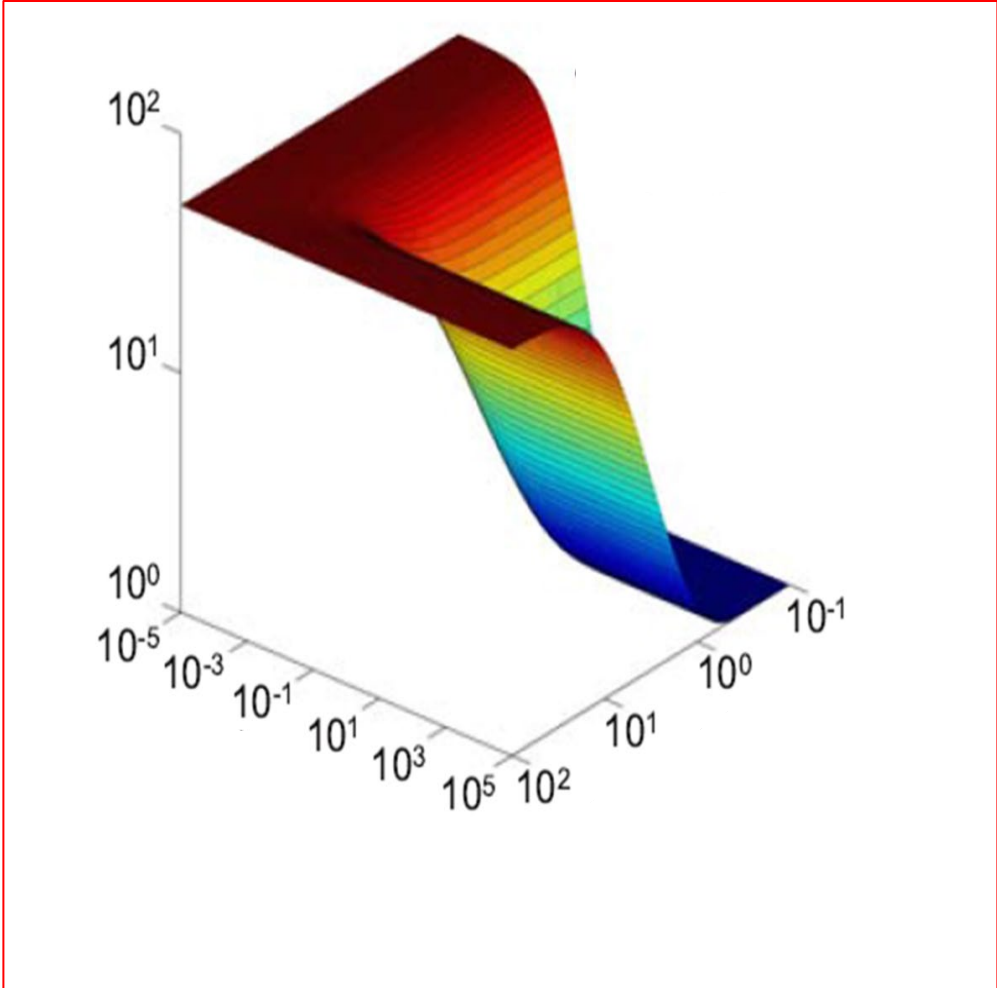
RELEVANCE OF SIP-SAR IN CONTEXT OF “SIGNALS”

The unexpected interjection of product lifecycle management (PLM) related to machines in “SIGNALS” is based on the fact that machine tools play a critical role in the agro-ecosystem. Data from machines, devices and tools (which are not sensors in soil or water) must be combined in decision support systems, to extract the full picture. In addition, sensors in machines, devices and tools are also generating data, which are valuable for the operation of the system.



SIPSAR

Shoumen Palit Austin Datta
Email - shoumen@mit.edu



Platform for Synergistic Integration of Predictive Maintenance of Machines with Maintenance and Repair Supply Networks: Virtual Mobile Dashboard for Near Real-Time Transparency and Operations Management Optimization

Shoumen Datta, Auto ID Labs, Massachusetts Institute of Technology and MDPnP Lab, Massachusetts General Hospital, Harvard Medical School

PREFACE

In the US, a quarter million patients die each year due¹ to preventable medical errors. One leading cause is the lack of medical device interoperability² and the lack of data integration platforms. The latter is quintessential to treat the patient, as a whole. The widespread practice of viewing stand-alone data from multiple medical devices, attached to the patient, manufactured by different medical device equipment companies, increases the risk of fatal errors, due to the reliance on medical professionals, who must integrate all the data, in order to actuate treatment.

The human heart, as an example of a machine, may be deconstructed into parts and components. Hence, a bill of materials (BOM) may be prepared and various parts/components may lend itself to monitoring using signals and sensors. Reconstructing the signals on a common “heart health platform” may reveal the state of heart health. The knowledge, dependencies and case logic, embedded in the platform, may remain cryptic to the point-of-care end-user. But, the *combined* outcome, based on analytics of the data, from signals and system of sensors, from various medical devices, may aid in the precision and accuracy of the decision support system (DSS). Humans in the loop may use the outcome to design preventive measures, recommend maintenance (for example, valvuloplasty) or prescribe medication (for example, statins, a class of lipid-lowering drug which is a HMG-CoA reductase inhibitor).

The thrust of this position paper is to recommend that we pursue an analogous approach for all machines and devices, to maintain the **health of machines**. We advocate an open source approach to **synergistic integration** of data, using “plug-n-play” modular platforms, running analytical engines to extract information, from system of sensors. Promoting interoperability between platforms may unleash the potential for diagnostics using real-time data. Taken together, it may mitigate mechanical risks due to usage, reduce uncertainty of operational downtime, prevent energy waste, optimize output efficiency, catalyze savings from economies of scale and use of big data.

The application of this *modus operandi* is scalable for manufacturing, through integration with legacy manufacturing execution systems (MES), product lifecycle management (PLM) systems and advanced planning and optimization (APO) routines, commonly found in classical enterprise resource planning (ERP) systems. Shop floors with a few or a few hundred machines, are equally capable of harvesting the value from synergistic integration. We can extend this approach to [1] a collection of diverse machines, for example, farm equipment, [2] different devices, for example, home health monitoring, wearable body sensors for wellness and healthcare, [3] transportation network of vehicles, combined with traffic data, [4] optimize load balancing in energy distribution using smart grids.

These suggestions are neither unique nor novel. The strength of this note is grounded in an *open-source, modular* approach, which supports scalability, interoperability and real-time communications for transparency, with suitable data protection (cybersecurity, privacy, identity and authorization). Proprietary platforms often retard productivity by reducing economies of scale, may exclude outlier events which could influence performance and increases TCO or total cost of ownership (for example, capital expenses, cost to operate) for global operations, if multiple types of platforms, which may lack interoperability, give rise to local silos or cannot “talk” between regions. Open-source optimization for customer-centric value is not synonymous with corporate profit-centricity. Hence, transforming this vision into reality, albeit in parts, requires PPP (public-private partnership) framework with pre-competitive collaborators from industry and users (customers), along with academia and government agencies, to fund this initiative, and enable large scale implementations. Monetization of open source platforms, and the service supply chain of data acquisition tools (sensors, communications), are quite common. To accelerate global diffusion, a pay-per-use, micro-revenue business model, may lubricate market entry, and amplify, long term, ethical profit.

¹ <https://doi.org/10.1136/bmj.i2139>

² <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5052027/>

FRAMEWORK

The concept of **synergistic integration platform**, may be illustrated by the old telephone switchboard (Fig 1) as well as **PEAS** (last item in this PDF). The “plug-n-play” input resembles the potential to aggregate data streams from sensors, actuators, RFID tags and other tools. In the “logic tools” background, the nature or type of data may trigger *data-dependent selection* of one or more tools, for example, analytical engines, “containers” with algorithms for data-driven micro-services³ and other virtual machines, which may be on-site or sourced, *ad hoc*, from clouds, fog, or mist computing repertoires. Automated programming⁴ and feature engineering⁵ may be included with ML.



Fig 1: Old telephone switchboard – conceptually analogous to future ‘plug-n-play’ synergistic integration platforms.

The analytical output may feed decision support systems, and/or actuators, and/or executable software programs, to act/modify physical systems (for example, cyberphysical systemic control of valves based on rate/flow). The visualization of the data on a mobile device (smartphone) may resemble the cartoon in Fig 2. The illustration is adapted from an agent-based inventory monitoring⁶ example which used RFID data. For our current discussion, each component from the BOM which can be sensed, may be attached with a sensor (vibration, temperature, pressure). The sensor data will be transmitted to an Agent system where one dedicated software agent will be responsible for acquiring the sensor data and feeding it to an ‘agency’ which will converge inputs to trigger alerts or execute action.



Fig 2: Monitoring mean time between failure (MTBF) from sensor data on a mobile smartphone (L). With decreasing residual lifecycle (upper panel) the probability of failure (broken part may precipitate unplanned downtime) increases (lower panel). Just in time spare parts supply chain coordination with maintenance, using MTBF data, prevents potential machine failure. Probability of failure drops to “zero” (lower panel) when the part at risk is

³ <https://ieeexplore.ieee.org/document/7506647/>

⁴ <https://arxiv.org/pdf/1807.02816.pdf>

⁵ https://www.featurelabs.com/wp-content/uploads/2017/12/DSAA_DSM_2015.pdf

⁶ <http://dSPACE.mit.edu/handle/1721.1/111021>

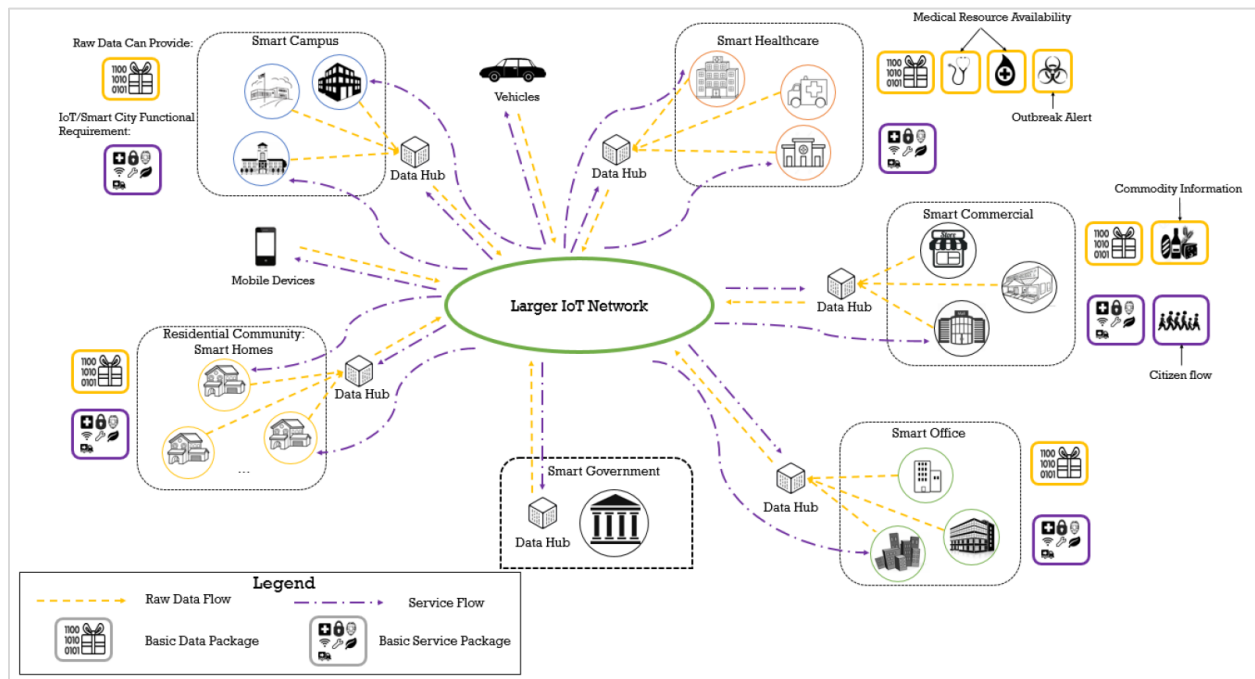
replaced. This example of an agent-based system uses MTBF metrics and ML to guide preventive maintenance. (Right) Cartoon of a partially automated irrigation system (see last PDF - PEAS Platform for the Agro-Ecosystem).

IMMENSE SCOPE – SENSE & RESPONSE

Data from sensors integrated into⁷ sensing-compatible components of machines (eg belts, hoses, seals, pumps) can transmit data about operating conditions (temperature, pressure) as well as micro- and macro-system wear, as a measure of system health. In principle the ‘sense & response’ paradigm may not be restricted to devices, machines, and energy. The scope of *sense & response* can embrace much more than manufacturing (eg Wabash), farm operations (eg Fair Oaks Farms) and robotics (eg Automotive Robotics). The scope may extend to system of systems including machines, buildings, irrigation and emergency response systems. In other words, synergistic integration platform (**SIP**) can distribute the sense & response (**SAR**) paradigm to gauge the real-time “health” of the university campus, community, city, county, state and a bird’s eye view of the networked society (cartoon⁸ below).

SIP-SAR is driven by the mantra of connectivity, the primary barrier preventing the implementation of the scope. Lack of communication between systems, loss of data due to absence of interoperability, and the chasm between manufacturing processes and products, are all remediable injustices, yet they are still holding back global productivity. However, tracking money and financial transactions⁹ are making better use of connectivity.

One purpose of this note is to identify gaps which may be addressed through research to improve the connectivity and, in turn, productivity. In parallel, if formed, PPP may deliver very large scale implementations of SAR (sense & response paradigm), which has been popularized by the metaphor of internet of things (IoT). IoT is a digital by design approach, which encapsulates the connectivity of the networked physical world¹⁰ where the duality of the physical, and digital, converges into a fluidic continuum, at least theoretically, in power-point presentations.



⁷ <https://dl.acm.org/citation.cfm?doid=3131672.3131702>

⁸ <http://bit.ly/CDAIT-IoT>

⁹ <https://newsroom.mastercard.com/press-releases/mastercard-introduces-mastercard-track-to-make-the-business-of-doing-business-easier/>

¹⁰ http://cocoa.ethz.ch/downloads/2014/06/None_MIT-AUTOID-WH-001.pdf

Fig 3: IoT is a metaphor without borders. It represents⁸ a continuum made up of discrete objects, decisions, processes and outcomes, each of which, in turn, impacts and influences, man, woman and machines, life and living.

CYBERMANUFACTURING

Connectivity and chemistry, in combination, presents the next emerging challenge to the *status quo* of manufacturing. The quantum leap for material science is a rags¹¹ to riches story¹² which has the potential to change almost everything in classical manufacturing and usher in cyber-manufacturing, as well as the future digital foundry.

Additive manufacturing of metals, composites, biomaterials (joints, prosthetics), will re-form the supply chain using distributed additive manufacturing on-demand and replenishment (**DAMODAR**). The inclusion of “replenishment” signifies the profound supply chain disruptions, and business discussions, that distributed on-demand direct digital manufacturing (cyberphysical) systems, is poised to usher. The “distributed” local physical presence, will benefit from the confluence of ideas from global digital connectivity (*metaphor of IoT-by-design*). Digital design tools (cyber component) may harvest “best of breed” outcomes from experts and benefit from location-agnostic convergence of deep knowledge. The best parts can be printed in Mongolia and Mogadishu (as well as, on Mars or on a military¹³ aircraft carrier). In combination, it may influence the context, quality, metrology, and performance, of local physical manufacturing (3D printed additive manufacturing products (**DAM**) as a service).

3D printed objects with integrated sensors¹⁴ presents the next opportunity for precision in detection, diagnostics and advanced analytics. Imagine a 3D printed hip joint using metal-ceramic composites or other metal alloys¹⁵ that may be a partially hollow mesh integrated with sensors (gyroscopic sensor, glucose sensor, CTx-1 collagen sensor¹⁶ for bone loss) and room for cancellous bone (spongy bone) containing hematopoietic precursors (forms blood cells). Therefore, direct digital manufacturing brings us back to where we started. Cyber-manufacturing can work as a catalyst to democratize healthcare. Using distributed additive manufacturing, the advanced hip joint may be printed on-site for fortunate folks in Austin, TX as well as the less fortunate people in Addis Ababa, Ethiopia.

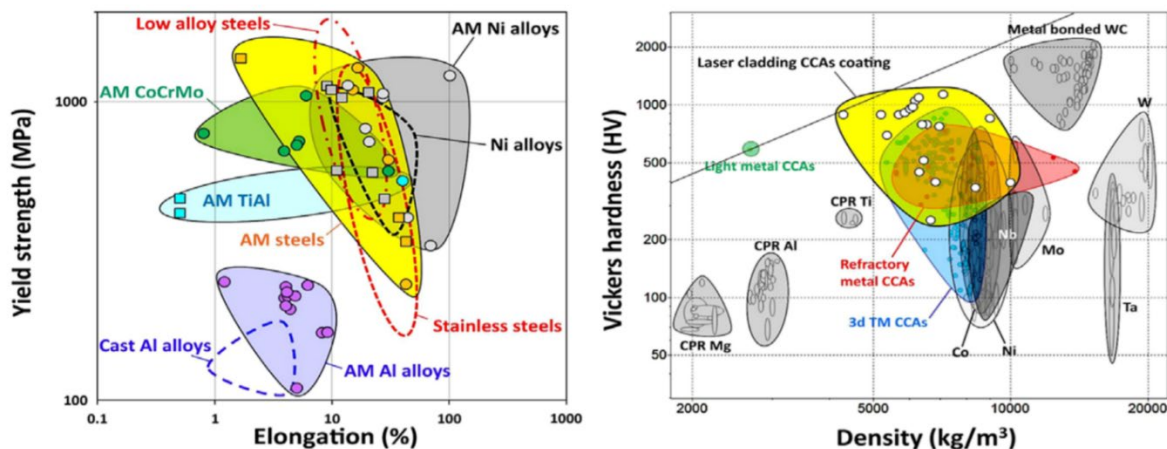


Fig 4: Mechanical properties of additive manufactured alloys¹⁵ compared to conventionally processed counterparts.

¹¹ <https://bases-brevets.inpi.fr/fr/document/FR2567668/publications.html>

¹² <https://patents.google.com/patent/US4575330>

¹³ https://www.darpa.mil/attachments/DARAPA60_publication-no-ads.pdf

¹⁴ <https://pubs.acs.org/doi/10.1021/acsami.8b06903>

¹⁵ <https://www.tandfonline.com/doi/full/10.1080/14686996.2017.1361305>

¹⁶ <http://www.mdpi.com/2224-2708/7/1/10>

SIPSAR is Appendix II in Chapter 5 of the book 'Haphazard Reality - IoT is a Metaphor' available from the MIT Library.

<http://dspace.mit.edu/handle/1721.1/111021>

TRANSCENDENTAL CONNECTIVITY



Chadwick (the discoverer of the neutron) was a student of Rutherford (discoverer of the proton) who was the student of Thomson (the discoverer of the electron).

“SIGNALS” contains a series of essays spewing amorphous thoughts:

1. SITS
2. SIP-SAR
3. SARS♠AG ----- **You are here**
4. ART
5. PEAS

Please review “SIGNALS”

- Download PDF from MIT Library

<https://dspace.mit.edu/handle/1721.1/111021>

Alternate <http://bit.ly/SIGNALS-SIGNALS>

SIGNALS is part of the collection of essays (book)

“IoT is a Metaphor” (see Commentary E)

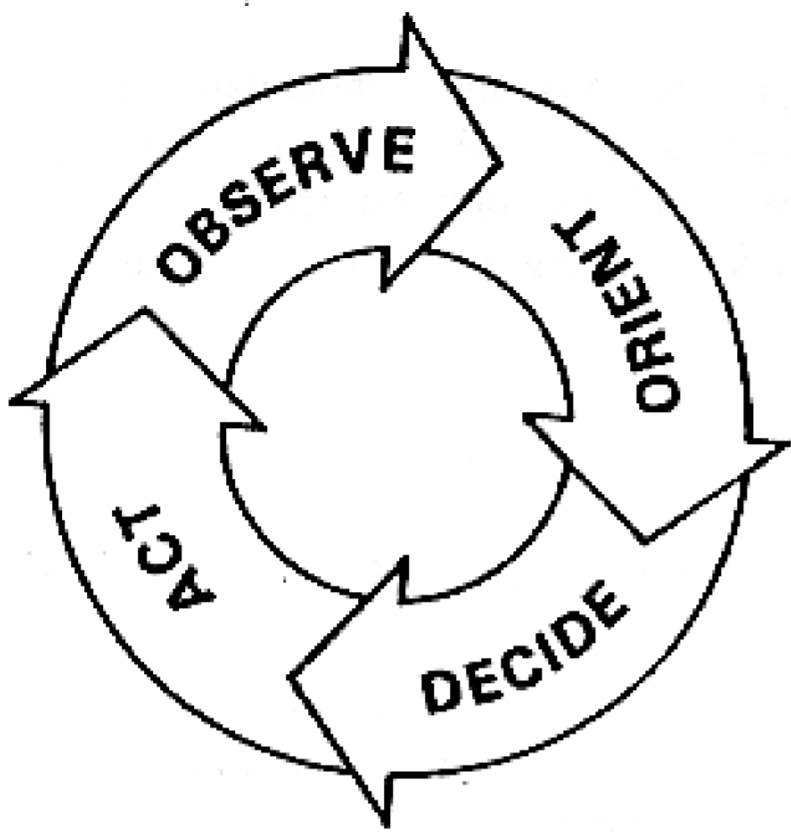
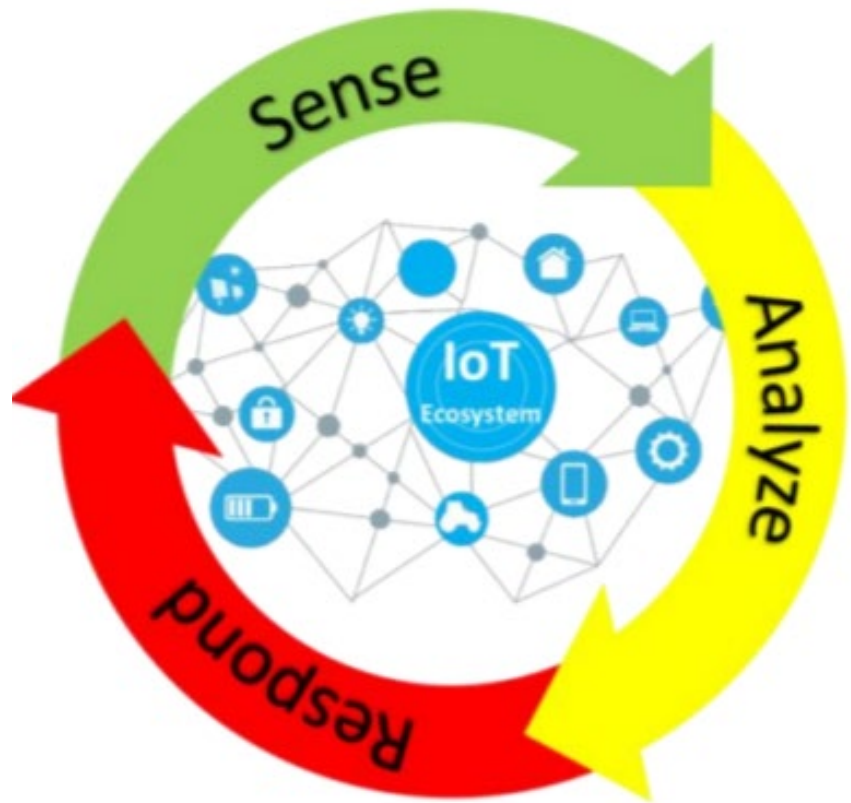
Please review “IoT is a Metaphor”

- Download PDF from MIT Library

<https://dspace.mit.edu/handle/1721.1/111021>

The page numbers in the PDF do not match the document page numbers at the bottom of the pages. This PDF is made up of a few separate documents which were then combined.

Hence, the temporary mis-match of page numbers. Apologies.



SARS ♦ AG

Preface to the PEAS Platform for the Agro-Ecosystem • Essay by Shoumen Palit Austin Datta (shoumen@mit.edu)

SARS – A DESIGN METAPHOR CATALYZED BY UBIQUITOUS CONNECTIVITY

Unless adopted and consumed, products and services are sterile and impotent. R&D exercises, and experiments, may serve socio-economic needs if user-centric design delivers value for users. However, often people do not know what they need. Hence, user-centricity is a suggestion, not a doctrine. SARS for ag (agriculture) advocates ideas with the end user in mind.

The SARS paradigm is an example of synergistic systems integration, an open platform approach to deliver outcomes, decision support or suggest solutions, often quantitative, using defined concepts (sense, analyze, response, systems). It is applicable to almost any domain.

SARS is **not** a paradigm shift. It is an intrinsic concept which is feasible due to decreasing cost of computation, storage, telecommunications and systems. The principle of SARS existed in parallel with human thought, procedural sequencing and the organization of logic. Feeling the water temperature of the sea water by dipping a finger is a form of sensing. The “sense” of the temperature (analysis), influences the response (decision to swim or not). The data, analysis (based on stored data, past experiences) and response, was transmitted by the sensory system (skin¹), neural system (signal transduction) and the musculoskeletal system (use of arms and legs), using a platform to aggregate data, coordinate signals and actuate motor neuron activity, that is, the brain.

This bio-inspired paradigm is SARS and we have replaced the human functions (for example, feeling with fingers) with engineering tools (temperature sensor). Tools help us to sense vast number of parameters and analyze vast volumes of data. Depending on complexity, the tool-based outcome feeds decision support systems. Humans in the loop, generally, execute necessary steps or trigger processes. Examples of SARS may include the “low fuel” gauge in an automobile, the home blood glucose test which may prompt you to visit to your physician or the smoke alarm in your home. SARS in the context of internet of things (IoT²) may be machine maintenance³ as a part of Digital Twins⁴, another emerging trend. In every case, **connectivity**, between different components, is key for data fusion and data analytics, to determine and extract (hopefully) actionable information in the data, **before** the value of the data perishes.

¹ 10.1016/j.protcy.2014.09.015

² <https://dspace.mit.edu/handle/1721.1/111021>

³ <http://bit.ly/SIP-SAR> is now a part of <http://bit.ly/SARS-AG>

⁴ <https://arxiv.org/abs/1610.06467>

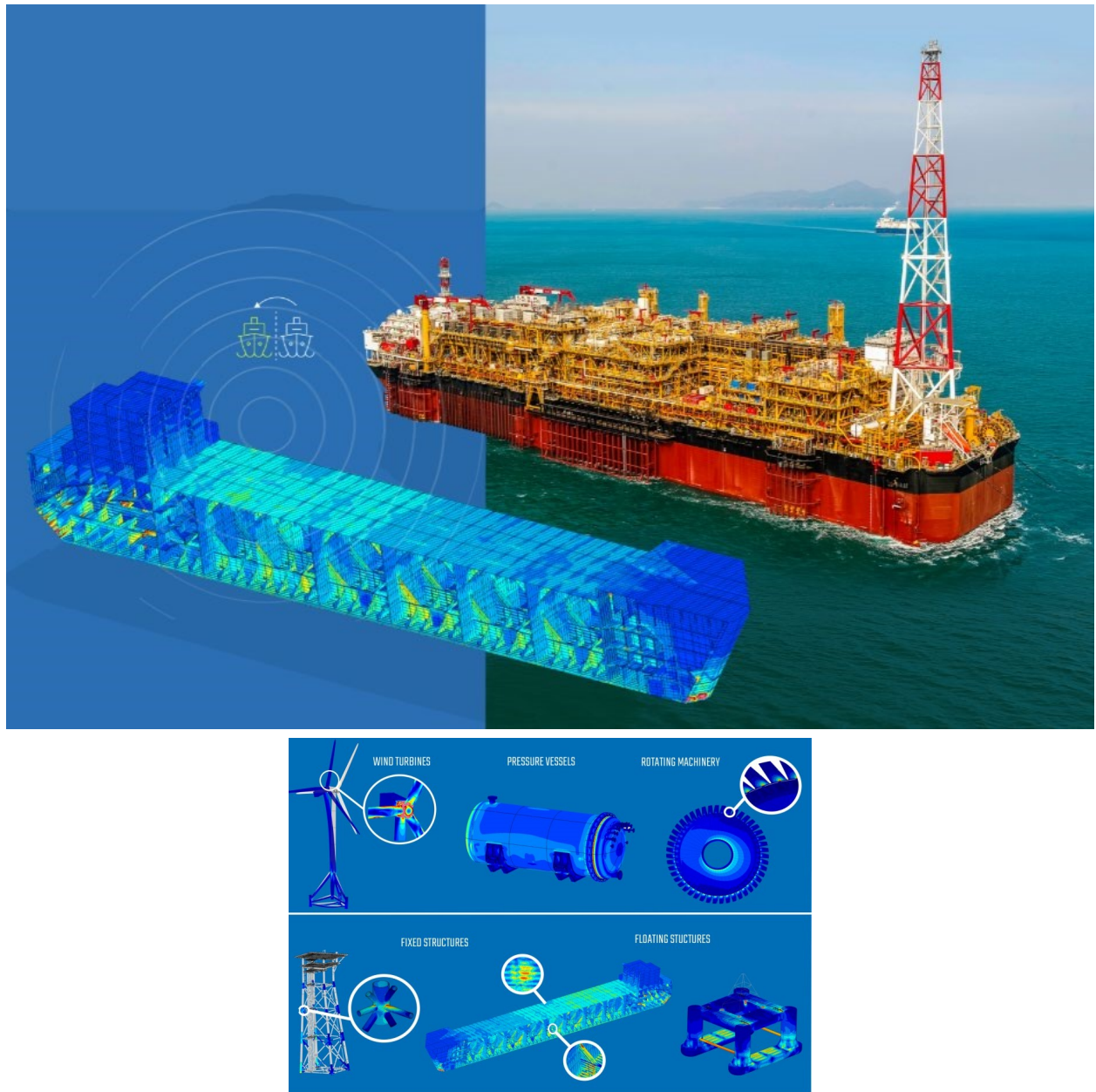


Figure 0: The concept of SARS is embedded in the metaphor of Digital Twins. Shell’s Floating Production Storage Offloading unit (Bonga FPSO, top, has a storage capacity of 2 million barrels of crude oil). It is a digital twin project (left cartoon, top panel) executed by Akselos, a MIT spinout, a high-tech start-up with advanced mathematics at its core. Akselos helped Shell create “digital twins” or computational models of physical structures (bottom panel). Digital Twins mirror the exact characteristics and operating performance data (of assets). It offers decision support for operators (abnormal stress, strain, temperature), allowing information to assist maintenance decision systems, and insights on asset life cycle management and supply chain.

SARS♦AG – SARS FOR AG (AGRICULTURE)

This essay addresses SARS for agricultural end-users (water, soil, air, crops, animals). Due to a vast array of potential scenarios, this essay refers to a proof of concept (PoC), which may be achieved using a sub-set of data (for example, see **SENSEE**, sensor data repository). The limited scope of the PoC is discussed in **ART** and the bigger picture is in **PEAS** (in this collection).

At the **architecture** level (for example, data lake⁵), the **scaffold** of the PoC will be highly modular, to facilitate “plug-n-play” operation with structured and unstructured datastreams, from a variety of sources (including, environmental data, and, pursuit of open⁶ standards, for example, for publish/subscribe data distribution services). The PoC, may limit itself to use only a few sources of data: (a) water quality [water sensors] and (b) soil components [soil sensors], before and after, using specific protocols (for example, waste water treatment). The “skeleton” of the SARS “**logic tool**” for agriculture must be an open **platform**. Other groups and consortia can add to this data platform, leading to growth of the tool for specific or general purposes.

SARS PLATFORM – TOOL DESIGN AND PROOF OF CONCEPT TASK

The PEAS platform (PoC sub-set SENSEE) is expected to connect different components, subsystems and domains⁷ to add value to the outcome (pragmatic solution). For example, the sensor must successfully transduce the signal to (preferably) a mobile device to upload, and/or analyze, the data. The outcome (value of data, meaning of data) may be visualized on a device (smartphone), in a manner that a non-expert may extract actionable information from data, and *know, how to*, benefit from suggestions or instruction. The description of the outcome starts with the end user. The outcome, the end user anticipates, is the “deliverable” scenario.

The design of the SARS logic tool starts from the end, that is, the outcome in the context of the user’s question. By sequential deconstruction of the “outcome” we arrive at sub-systems, components and sub-components (analogous to BOM or bill of materials, in manufacturing). These “parts” when re-assembled, synthesized and harmonized, creates a functional system or a solution which may involve system of systems. The functional and **synergistic** integration between parts, flow of data and analytics, capable of extracting information (if there is any), will generate the outcome, expected by the end user. The user interface (GUI or app on mobile device) is the conduit to initiate the cascade and return the outcome to the GUI or visualized as another app on the device. The user needs to know how to **ask the correct question**, which in turn, will trigger the cascade and how to utilize or benefit from the outcome.

⁵ <https://aws.amazon.com/big-data/datalakes-and-analytics/what-is-a-data-lake/>

⁶ <http://opendds.org/>

⁷ <https://pubs.rsc.org/en/content/articlelanding/2018/an/c8an00065d>

SARS PLATFORM – SCENARIO, SUB-COMPONENTS, SYSTEMS

General SARS is a “google of ag” approach where humans (“user push”) input query, for example: [a] “blood glucose = 157mg/dl” “what does it mean?” [b] “mercury in water = 85 micrograms per liter” “suggest water treatment” for decontamination.

In future, we may move forward by going back, almost a hundred years. SARS proactive system push (“Hello Rebecca – I have new soil spectroscopic⁸ sensor data, click on this link”). Bioinspired “cybernetics⁹ of ag” is bidirectional, discussed by Wiener¹⁰ in the context of sensors at the edge of the eye, which vie for the attention of the analytical core in the *fovea centralis*. SARS PoC may focus on [a] water/soil sensors and [b] water treatment¹¹. In that context the platform rests on two key sources of data (data issues are discussed in SENSEE 2.0 in ART).

In Figure 1, the SARS “platform” (table top in the illustration, below) is a multi-layered application design environment, which connects to the user interface (smartphone, Fig 1). The application logic, decision support tools, machine learning¹² algorithms, feature¹³ engineering, cybersecurity and others, including APIs to facilitate data interoperability, and re-distribution, essential to the function of SARS, connects to this design environment.



Figure 1: Over simplification of the PEAS PLATFORM metaphor and potential connectivity to data (graph databases or datastores may be real or virtual, that is, sourced from cloud, fog or mist). Platform “aggregation” on an open platform architecture where data sources may continuously feed in or drop out (dynamic composition / decomposition). The visualization tool for the platform may be a mobile device, eg, smartphone. The dialog with the platform is executed via an app on the smartphone, which is the user-controlled interface. The red “strings” illustrate link to data resources (eg sensor data, wastewater treatment data). The architecture provides for multi-directional communication (user push, system push, push-pull).

⁸ <https://www.nature.com/articles/s41467-018-06773-2.pdf>

⁹ https://uberty.org/wp-content/uploads/2015/07/Norbert_Wiener_Cybernetics.pdf

¹⁰ <https://libraries.mit.edu/archives/research/collections/collections-mc/mc22.html>

¹¹ <https://oaspub.epa.gov/tdb/pages/general/home.do>

¹² <https://arxiv.org/pdf/1807.00401.pdf>

¹³ <https://dai.lids.mit.edu/wp-content/uploads/2017/10/1407.5238v1.pdf>

The view of the PLATFORM with two “red strings” or two data resources (Figure 2) illustrates the hypothetical PoC linked to limited data [a] water/soil sensors and [b] wastewater treatment protocol. The “user push” query in natural language may be in this form “what is the waste water treatment protocol when the mercury sensor reads mercury in water is equal to 85 micrograms per liter?” The dependencies and inter-relationships between sensor data and treatment protocols are defined in the application logic layer. The data and query triggered by the user generates a response, in another dialog box, which pops-up on the smartphone.



Figure 2: Proof of concept for a platform tool may be created and delivered with only two sources of data, illustrated by two red strings (illustration source¹⁴).

The software architecture of the open platform, its connectivity to data and access to cloud storage, may be designed to embody the broad-spectrum vision of the platform, which can serve a **plethora of purposes**, and is not limited to digital connectivity of atoms to bits. This platform may also serve as a “news and views” clearinghouse for information storage and “analog” information arbitrage by humans, for example, the successful CPS-VO¹⁵ model.

Open architectures may enhance or catalyze “plug and play” operation when integrating other data sources (for example, weather, crop, fertilizers) from different clouds, to feed the platform. The PoC, at hand, may functionalize the tool with an app that can receive (input) and send (output) data and suggestion related to a very limited types of questions in narrow domains, for example, [a] water/soil sensor data and [b] wastewater treatment protocols.

The **potential** for dynamic composability needs an open architecture which can act as a **scalable scaffold**. The nature of data, dependencies between data, and application logic, that is suitable to connect / mine / combine, to generate useful information, are software functions which can be added/subtracted to the application design environment. Modularity and fluidity demands the use of agent-based systems (ABS) and agent-based architectures¹⁶ in the platform.

¹⁴ <https://www.miliashop.com/es/mesas/4187-org-mesa-rectangular-cappellini.html>

¹⁵ <https://phys.org/news/2011-04-global-portal-cyber-physical.html>

¹⁶ <https://dl.acm.org/citation.cfm?id=122367>

User adoption may be directly proportional to the functional strength of the logic tool in delivering the **value of the output**. The strength of recommendations, decision support and predictive suggestions, may be proportional to [a] depth of the noise-free curated data and [b] foresight embedded in the logic layer, which must correlate and synthesize data dependencies **between** domains. The latter is a difficult task with increasing number of variables (explosion of state space). SARS will evolve from ART to DIDA’S to KIDS to PEAS platform (see other PDFs). Knowledge as a key performance indicator (KPI) for the PEAS platform may benefit from old¹⁷ ideas and new developments¹⁸ in data and analytics. The latter are widely practiced¹⁹ in several fields²⁰ based on statistical (ML) machine learning techniques (neural nets, deep learning²¹) and attempts to automate²² data science (and attempt to approach knowledge-informed decisions).

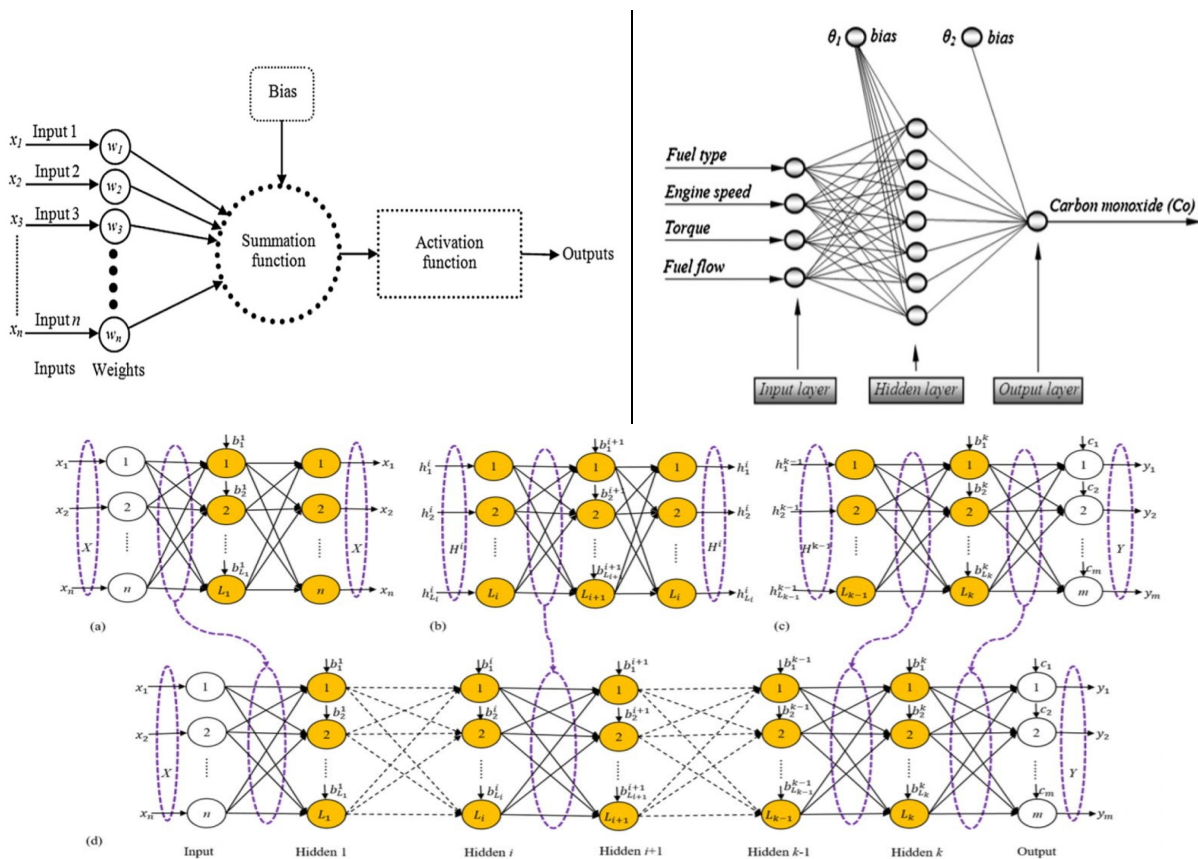


Fig 3: Neural nets optimize outputs²⁰ (above) and deep **bidirectional** learning machines²¹

¹⁷ <https://www.nytimes.com/2013/05/21/science/mit-scholars-1949-essay-on-machine-age-is-found.html>

¹⁸ <https://patents.google.com/patent/US20180170575A1/en>

¹⁹ <http://dx.doi.org/10.1016/j.energy.2012.10.052>

²⁰ 10.1021/acs.energyfuels.7b01415

²¹ <https://arxiv.org/pdf/1404.7828.pdf>

²² http://www.jmaxkanter.com/static/papers/DSAA_DSM_2015.pdf

SARS PLATFORM – PHYSICAL COMPONENTS AND RELEVANCE TO CYBERPHYSICAL SYSTEMS

SARS may be viewed as a subset²³ of cyberphysical systems (CPS²⁴). The physical “things” in the context of SARS, must be connected to deliver value, for example, sensors (sensor data). Therefore, SARS is also a part of the internet of things (IoT) metaphor. The platform may benefit from CPS²⁵ and IoT²⁶ architectures, and generic²⁷ framework. Sensors and “things” are located in the physical layer (bottom of Figure 4). Data from the physical layer is uploaded to the cyber layer where connectivity, between systems, is key. The top layer is IoT connectivity between systems of systems (internet of systems). The SARS platform may immensely benefit from the CPS cybersecurity guidelines. The risk due to food safety and security may be reduced if SARS for agriculture may follow NIST recommendations²⁸ for security and threat assessment.

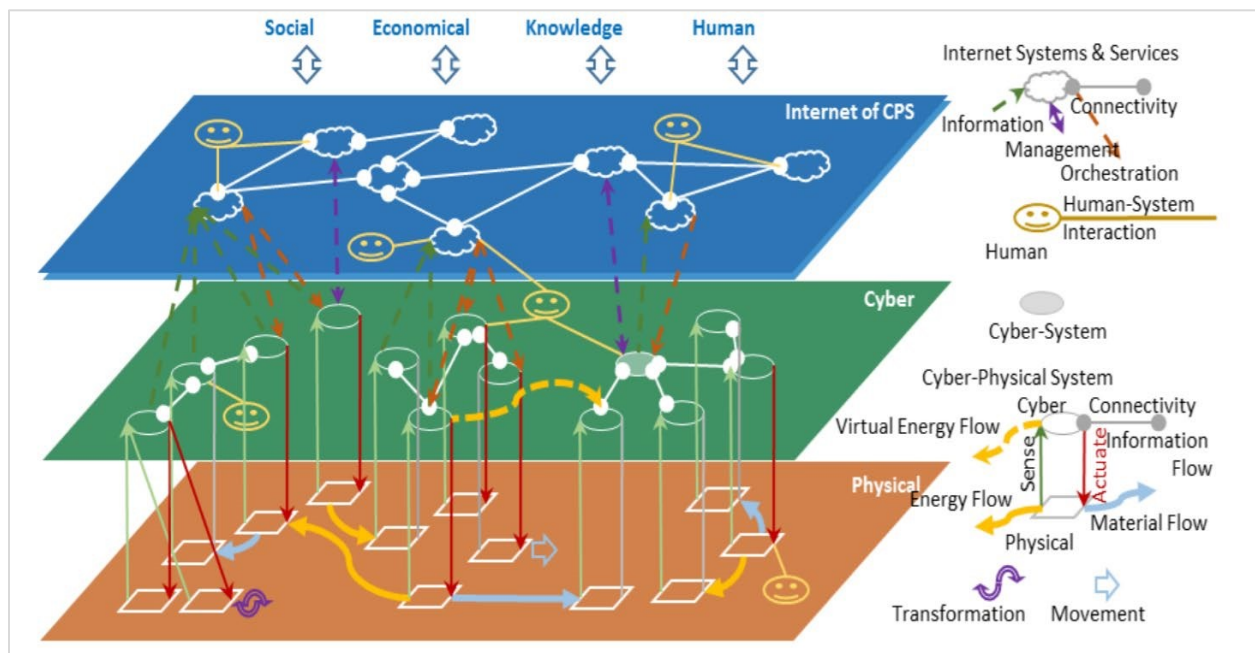


Figure 4: Architectural framework²⁵ for cyberphysical systems proposed by NIST. Most platform paradigms (for example, digital twins, SARS) may be a subset²⁹ of CPS (cyberphysical systems).

²³ <https://doi.org/10.1007/s10845-018-1433-8>

²⁴ <https://cps-vo.org/>

²⁵ https://s3.amazonaws.com/nist-sgcps/cpspwg/files/pwgglobal/CPS_PWG_Framework_for_Cyber_Physical_Systems_Release_1_0Final.pdf

²⁶ <https://iotforum.org/wp-content/uploads/2014/09/D1.5-20130715-VERYFINAL.pdf>

²⁷ <https://arxiv.org/ftp/arxiv/papers/1708/1708.04560.pdf>

²⁸ <https://www.nccoe.nist.gov/>

²⁹ <https://ptolemy.berkeley.edu/projects/cps/>

PLATFORMS DEPEND ON DATA

A cursory survey³⁰ of types of sensors (bundled by loose similarity³¹) is overwhelming, simply due to volume³² and variability. The inordinate complexity of sensor types in agriculture (weather, water, soil, pathogens, chemicals) presents a curse of dimensionality³³ with respect to signals. The latter presents an almost insurmountable barrier to make **collective** sense of data, from different sensors and network of sensors.

One approach to streamline the quagmire is a call for protocols³⁴ and standards³⁵ which offers economic³⁶ incentive. Agnostic of verticals, standards accelerate³⁷ adoption if industry values such non-competitive agreements. This effort may not possess the resources to organize the sensor industry³⁸ to begin any discussion on standards. Even the FDA had to resort to legislation³⁹ just to *define* what is a medical device. These issues are detrimental to **collective** sense of data, unless **all** data sources were transmitting data with common characteristics and handled by a **single** analytical engine. That would be a sole source, proprietary product, closed to open innovation and an anathema for distributed systems (for example, agriculture).

Making **collective** sense of data is crucial, even without sensor standards for specific analytes (eg manufacturers may not pre-agree to specifications for sensors). Therefore, we must think about attempts to “standardize” the **data** rather than the sensor. The signal (data) must be **characterized**, then, grouped, collected and analyzed, as a *data set* with *specific* characteristics. In other words, **feature selection**⁴⁰ and tools⁴¹ for **feature engineering**⁴² are emerging as vital tools to identify selected characteristics. Sensor-agnostic data must feed these features. Without shared features, data cannot be joined (merged, combined). This is a strength and may be a weakness, too. What if, the data with shared features was joined (merged) but the process eliminated outliers or data with uncommon features? Outlier events and unique data may offer clues to non-obvious relationship analysis and determining unknown unknowns. Foresight is key to aggregate, curate and extract value from structured and unstructured data.

³⁰ <http://bit.ly/PLASMONICS>

³¹ <http://bit.ly/GAS-SENSORS-01>

³² <http://www-analytik.chemie.uni-regensburg.de/wolfbeis/P2-www.pdf>

³³ <https://doi.org/10.1155/2018/7467418>

³⁴ <http://www.ieee802.org/>

³⁵ <https://www.gsl.org/standards/epc-rfid>

³⁶ http://www.econ.yale.edu/growth_pdf/cdp984.pdf

³⁷ <https://www.futuremedicine.com/doi/10.2217/pgs-2018-0028>

³⁸ <http://www.sens2b-sensors.com/directory>

³⁹ www.fda.gov/downloads/MedicalDevices/DeviceRegulationandGuidance/GuidanceDocuments/UCM401996.pdf

⁴⁰ <http://dx.doi.org/10.1016/j.compeleceng.2013.11.024>

⁴¹ <https://people.eecs.berkeley.edu/~dawnsong/papers/icdm-2016.pdf>

⁴² <https://www.kdnuggets.com/2018/02/deep-feature-synthesis-automated-feature-engineering.html>

The management of structured data, based on defined syntax and semantics, in data dictionaries, is helpful for maintaining homogeneous institutional data. Its value in information arbitrage is declining. Therefore, we must seek dynamic strategies and agile architectures⁴³ with built-in change control⁴⁴ to mine unstructured data, which is emerging as the norm, rather than the exception. The value of the PoC in the context of IoT⁴⁵ for farming⁴⁶ must address data granularity and how each piece of data may be made to reveal its information, *if there is any information in the data and if the information is actionable*.

The management of unstructured data, therefore, is central to the proposed platform. Structured data is a subset of unstructured data. Management of structured data can only deal with structured data. Strategies to address platform requirements (and PoC) using structured data management, may be a nail on the coffin of data driven decision support systems (DSS). The gradual diffusion of the ideas related to precision agriculture⁴⁷ is directly related to the ability of the farming community to rapidly adopt tools and technologies. The exchange of data and information may not be limited to apps on smartphones or tablets, provided as a part of the service pack by service providers (companies, agencies, organizations). To mine and use the social media data, in this context, unstructured data handling architecture must be at the core of the platform infrastructure. We plan to embrace unstructured data and build capacity for change control⁴⁸ to deal with big data (bad word), because most forms of data, under the “big data” category, may be strenuously unstructured.

However, just because we have acquired data, does ***not*** guarantee it ***will*** contain any information, irrespective of the data acquisition tool, and no matter how sophisticated the analytics may be or the perceived power of algorithms in an engine. Data devoid of information may be natural or an artifact, if the value of the data perishes before information retrieval.

In any effort, to manage⁴⁹ data and to make sense of data in real-time (*before* the value of the data perishes), it is vital to use a *diverse portfolio* of mathematical and statistical tools, solvers and analytical engines, to *curate* and *extract ***actionable**** information, by unpacking and unleashing value⁵⁰ from data, and then *using* the information, in near real-time, to actuate *response* (sense, analyze, *response* system ⇒ SARS). The latter is a segue to a new paradigm, which extends “sense, analyze, response” to include sense, analyze, response, ***actuate*** (SARA).

⁴³ <https://ieeexplore.ieee.org/document/7868325?part=1>

⁴⁴ <https://rmas.fad.harvard.edu/pages/change-control>

⁴⁵ <https://ieeexplore.ieee.org/document/8126169>

⁴⁶ <http://blogs.worldbank.org/ic4d/agriculture-20-how-internet-things-can-revolutionize-farming-sector>

⁴⁷ [http://www.europarl.europa.eu/RegData/etudes/STUD/2016/581892/EPRS_STU\(2016\)581892_EN.pdf](http://www.europarl.europa.eu/RegData/etudes/STUD/2016/581892/EPRS_STU(2016)581892_EN.pdf)

⁴⁸ http://vcaf.berkeley.edu/sites/default/files/change_control_process_aa.pdf

⁴⁹ <https://journals.aom.org/doi/10.5465/amj.2014.4002>

⁵⁰ <http://tarjomefa.com/wp-content/uploads/2017/08/7446-English-TarjomeFa.pdf>

STRUCTURE OF THE INFRASTRUCTURE – ARCHITECTURE, DATA HANDLING, OPEN TOOLS

In the short term, it may be difficult to substantiate convergence of deep⁵¹ systems⁵² thinking⁵³ and system dynamics⁵⁴ with lightweight but agile IoT **connectivity** services, IFTTT⁵⁵. To catalyze the diffusion of these ideas, convergence may benefit from a simulation⁵⁶ to display its potential value⁵⁷ for users and/or socialize parts of the platform concept via extension⁵⁸ and education⁵⁹ programs for dissemination⁶⁰. In reality, the tool may be a limited sandbox option for [a] water/soil sensor data and [b] wastewater treatment, from an “user push” approach.

Open system architectures and modularity, are crucial, to enable the system to grow on demand, amplify in any dimension, and scale to handle large number of variables, diverse data structures, and **unstructured** data. Structure/schema rigor must co-exist with *ad hoc* event driven architectures, eg, using containers for portability on multi-cloud platforms *as well as* serverless functions (nano-services). For example, architect to create a serverless function, which triggers a task, which, in turn, spawns a container and runs a longer-term process, like a complex time series data from a sensor network (which may require hours to complete). At present, we focus on 2 issues: [1] feature selection, and [2] software tools for data.

Feature Selection

To establish a common plane of reference and a calibrated baseline, the performance of the sensor and the sensor data (value derived from the measurement of the specific analyte) are equally important. Agnostic of the use case, without robust performance evaluation, any measurement data will lack credibility and the (sensor) measurement (data, output) may not be trusted to drive decision⁶¹ support (for example, operations or supply chain⁶² decision support).

For the PoC, if we focus on two types of data ([a] water/soil sensor data repository and [b] waste water treatment repository), we can address the various characteristics of the data in these repositories (for example, SENSEE) and explore how to select key features.

⁵¹ https://www.thinkmind.org/download.php?articleid=bustech_2015_1_30_90048

⁵² <http://jasss.soc.surrey.ac.uk/17/4/2.html>

⁵³ <http://www.sfu.ca/~vdabbagh/Forrester68.pdf>

⁵⁴ https://en.wikipedia.org/wiki/System_dynamics

⁵⁵ <https://doi.org/10.1080/01639269.2014.964593>

⁵⁶ <http://web.mit.edu/jsterman/www/SDG/MFS/simplebeer.html>

⁵⁷ <https://ctl.mit.edu/sites/ctl.mit.edu/files/attachments/Josue%20-%20Beer%20Game%20Run%20%20Ex%20Ed%20January%202017%20sub.pdf>

⁵⁸ <https://beergameapp.firebaseio.com/>

⁵⁹ <http://web.mit.edu/jsterman/www/SDG/beergame.html>

⁶⁰ <http://www.beergame.org/>

⁶¹ https://www.theseus.fi/bitstream/handle/10024/132787/Thesis_Bohne_DM%20and%20IoT.pdf?sequence=1

⁶² <https://www2.deloitte.com/content/dam/Deloitte/us/Documents/process-and-operations/us-cons-smart-sensors.pdf>

⇒ For performance characteristics of sensors, the features (dimensions) germane to SARS are:

- Sensitivity (output per input)
- Selectivity (accuracy, discrimination in complex matrix)
- Limit of detection (minimum number of detectable targets)
- Response time (time to 95% pulse input per IUPAC)
- Hysteresis/reusability

⇒ Features for wastewater treatment data repository may include the following characteristics:

- Conversion rate (output per input)
- Selectivity (related to inactivation)
- Loading rate (max number targets inactivated / volume of water)
- Kinetics⁶³ of inactivation (k_d , μ_{max} and K_s)
- Hysteresis/reusability

The characteristics of the 2 types of data, are likely to be a small sub-set. The number of dimensions (from which we will extract contextually relevant features) may be reasonable. There may be more dimensions (more important features) related to the actual measurement data. In future versions of the logic tools, when the number of dimensions increase with the number of different types of sensor data, an initial reduction of dimension may be performed (filter). The value of data is contextual. Context of data is paramount during feature selection. Relevancy and redundancy of the variables/dimensions, which makes it suitable or unsuitable, to create combinations of features, may be sorted using a portfolio of algorithms⁶⁴. The ability to create combinations, enhances the potential to **meaningfully** merge⁶⁵ data.

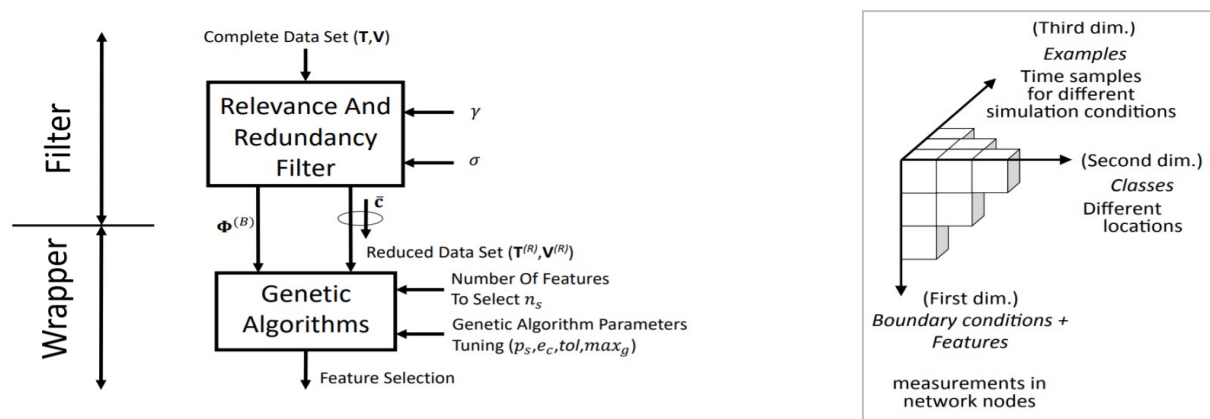


Figure 5: Feature selection (left panel) helps to generate data format (right panel). From ref 64.

⁶³ <http://www.bioline.org.br/pdf?se11003>

⁶⁴ <http://www.iri.upc.edu/files/scidoc/2071-Sensor-Placement-for-Classifer-Based-Leak-Localization-in-Water-Distribution-Networks-using-Hybrid-Feature-Selection.pdf>

⁶⁵ <https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19870013024.pdf>

Feature selection is central to data handling (a short list of selected features will be required for the PoC). Using these features, simulation under different conditions is expected to generate data, organized in a particular data format (Fig 5, right). If data from other sources, repositories and projects, are to be merged, to create the **collective** view, then external data must be able to work with the data format of the tool. Semantics⁶⁶ may play a substantial role in data merger between classes of sensor networks⁶⁷.

Because we may not standardize sensor manufacturing, we use feature selection to extract the data. It does not matter who made the sensor. As long as the data output from the sensors can fit the relevant features, the logic tools (ART, SENSEE) can use diverse sources of data, generated by a plethora of different sensors. In each instance, we are seeking selected types of data, which can **feed the features** that are selected by the tool, or any other future tool. However, data types and data schemas can vary widely even between data from similar types of sensors. For example, waveforms and time stamps. In the 3rd dimension of the data format illustration (Figure 5, right), the time samples may differ in the time elapsed, between measurements. If data sampling is set to every 10 seconds, 1 min or 10 min, the time series⁶⁸ representation of data may prevent merger or data fusion⁶⁹, unless the units are adjusted.

Software Tools for Data

Data level granularity, even for **what if scenario planning** must proceed with clarity about the **question** we are asking, or user-centric queries. The quality, specificity and value of any answer, depends on the data, design, dependencies between data and the influence of external or outlier events. The scenario outlined below is an example, to provide clues, with respect to the architecture necessary for tools and open platforms. The imagination about the “big picture” must be in focus to anticipate future design needs.

Scenario

A plot of land is instrumented with multiple different sensors (water, temperature, air pressure, soil chemistry). Similar instrumentation is replicated on other plots of land. Sensors sourced from different manufacturers (multiple manufacturers make soil, temperature and mercury sensors). Metadata about plots of land (crop type, acreage, soil composition) is available. Rainfall/drought data is available. Logic tool to build infrastructure to store select (disparate) data and answer *ad hoc* user directed queries using a mobile app: Can heavy rainfall explain elevated levels of mercury in the water?

⁶⁶ https://www.w3.org/2005/Incubator/ssn/wiki/Agriculture_Meteorology_Sensor_Network

⁶⁷ <https://www.w3.org/2005/Incubator/ssn/XGR-ssn-20110628/>

⁶⁸ <http://pages.di.unipi.it/bacciu/wp-content/uploads/sites/12/2016/04/nca2015.pdf> ⁶⁹ <https://www.mdpi.com/1424-8220/9/10/7771>

The following is an incomplete list of concerns, software suggestions, architecture notes and data issues, to be considered when designing open PEAS Platform for the Agro-Ecosystem:

- [a] Time assurance of sensor data (variable). Limited bandwidth or transmission cost are reasons to compress⁶⁹ data⁷⁰ or skip (repeat/flatline data) values or aggregate at the edge.
- [b] Geotagging - explicit (observation offers lat/lon) vs implicit (insert coordinates)
- [c] On-chip memory to store data or “one shot” upload? fault tolerance? speed?
- [d] Data upload interfaces (802.X protocols, LPWAN, LTE), gateways, cloud storage
- [e] Time Series DB: Storage of ingested sensor data in TSDB is increasingly⁷¹ popular (InfluxDB⁷² or Prometheus, open⁷³ source). Optimization for time-ordered data reduces storage footprint (sensors often flatline, transmit the same value for some period). Non-TSDB stores each data point but TSDB only stores the *change*. Anomaly detection must be a routine operation.
- [f] Specialized Databases: Applications must deal with variety of data, including data embedded in text (environmental inspection notes). Open⁷⁴ Elasticsearch⁷⁵ with support for search primitives (topic modeling, synonym resolution, fuzzy search) and associated open services⁷⁶ are recommended. RDBMS may not answer "How often after heavy rainfall are mercury concentrations elevated?" or geospatial⁷⁷ queries⁷⁸ "Are there mercury levels above 100ppb within a 10km radius of “this” plot of land?" NoSQL⁷⁹ databases (MongoDB⁸⁰ or Elasticsearch) offer flexible and expressive query languages, do not require defined schemas.
- [g] RDBMS: Schemas must be defined before adding data. SQL needs to know what you are storing in advance. Schema guarantee offers advantage (compared to flexibility of NoSQL) when the query is complicated ("sensor readings from corn or soybean plots within 5 hours after a lightning strike that is within 3 kilometers of the center of the plot") and RDBMS SQL⁸¹ offers flexibility⁸² for unknown query patterns. PostgreSQL⁸³ is a credible⁸⁴ and robust option.

⁶⁹ <https://www.itworldcanada.com/article/canadian-telematics-firm-geotab-doubles-down-on-data-services-as-itfinds-u-s-growth/408647>

⁷⁰ <https://www.nrel.gov/docs/fy18osti/70223.pdf>

⁷¹ https://db-engines.com/en/ranking_categories

⁷² <https://www.influxdata.com/time-series-database/>

⁷³ <http://opentsdb.net/>

⁷⁴ <https://qbox.io/blog/what-is-elasticsearch>

⁷⁵ <https://www.elastic.co/>

⁷⁶ <https://aws.amazon.com/elasticsearch-service/>

⁷⁷ <http://toblerity.org/shapely/manual.html>

⁷⁸ <https://www.omnisci.com/>

⁷⁹ <http://nosql-database.org/>

⁸⁰ <https://www.mongodb.com/nosql-explained>

⁸¹ <https://blog.timescale.com/why-sql-beating-nosql-what-this-means-for-future-of-data-time-series-database348b777b847a>

⁸² <https://pdfs.semanticscholar.org/3635/12f3dc6659d05eba4b6f07339f8542bd2737.pdf>

⁸³ <https://www.postgresql.org/>

⁸⁴ <https://www.csail.mit.edu/person/michael-stonebraker>

Data and Other Issues:

To enhance performance and automate queries, data curation may be necessary. At a simpler level, pre-computing combinable representations of the data in the system may help: [i] converting units of measure, [ii] aligning time series data to same resolution (standardizing on n-hour means, percentiles of all observations), [iii] enriching ingested data⁸⁵ with additional metadata describing its content⁸⁶ (eg, Einstein AutoML system⁸⁷) [iv] aligning geospatial data to one or more known grids (eg, Uber's H3⁸⁸).

At the architecture level, separating the data persistence (store) and retrieval⁸⁹ (query) functions of databases are recommended. Common data stores include open source distributed file systems - HDFS⁹⁰, GlusterFS⁹¹ and Amazon S3⁹² (but life of HDFS is in question). These can be paired with open analytics/query layers for which the underlying storage is swappable (Apache Spark⁹³, Apache Drill⁹⁴, Impala⁹⁵ and Presto⁹⁶). This “divide and conquer” approach is based on the observation that far fewer professionals understand statistics *and* database technology. But analytical code is portable across environments. Due to surge in data science, more human resources may become available in this area (for example, statistical machine learning tools).

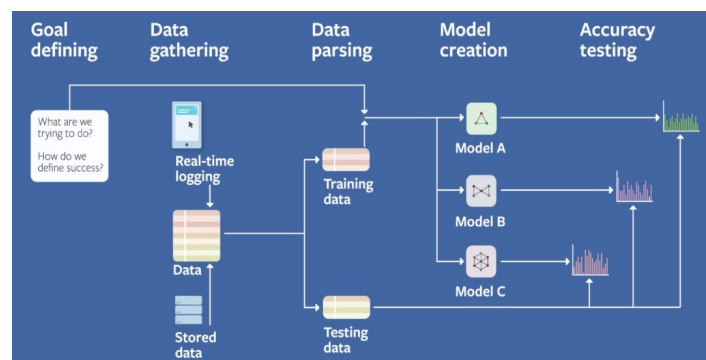


Figure 6: Asking correct questions may better define our goals⁹⁷ and extract value from data.

⁸⁵ <https://github.com/salesforce/TransmogriAI>

⁸⁶ <https://engineering.salesforce.com/open-sourcing-transmogriai-4e5d0e098da2>

⁸⁷ <https://www.salesforce.com/video/1770953/>

⁸⁸ <https://github.com/uber/h3>

⁸⁹ https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4528360/pdf/13321_2015_Article_81.pdf

⁹⁰ https://hadoop.apache.org/docs/r1.2.1/hdfs_design.html

⁹¹ <https://docs.gluster.org/en/latest/>

⁹² <https://aws.amazon.com/s3/>

⁹³ <https://spark.apache.org/>

⁹⁴ <https://drill.apache.org/>

⁹⁵ <https://impala.apache.org/>

⁹⁶ <https://prestodb.io/>

⁹⁷ <https://research.fb.com/category/machine-learning/>

TRANSFORMATION OF SARS TO SARA - PARADIGM SHIFTS

Basic research⁹⁸ in advanced⁹⁹ material¹⁰⁰ science may be the catalyst for forthcoming paradigm shift from SARS to SARA by using materials that not only sense but actuate¹⁰¹ and communicate. SARS may evolve to include and necessitate, for select applications, bidirectional communication, where the response, post-analysis, results in actuation, which may involve modifying the sensor for selectivity or sensitivity (**SARA** ⇔ sense, analyze, response, actuate). Using radio frequency signals to modulate molecules, such as DNA¹⁰², may be used in emerging sensing tools which uses aptamers. The structure-function¹⁰³ relationship of DNA can be tuned by remote RF signals. With the emergence of the IoT¹⁰⁴ concept formalized by Sanjay Sarma¹⁰⁵ (marketing¹⁰⁶ term IoT was coined by Kevin Ashton, the concept of IoT has a rich¹⁰⁷ history¹⁰⁸), the radio frequency identification tool, the RFID tag, evolved as a target for disenfranchised individuals. Functional modification of RFID tags frequently used parasitic backscatter¹⁰⁹ attack, a tool used by cryptanalysts (power analysis attacks). The EPC standard¹¹⁰ utilizes the remote mechanism to “kill” RFID tags using modulated backscatter. Sensing, actuation, transmission and communication has now converged with material science. Convergence of material science, radio frequency, mobile communications, nanobiotech, molecules, biochemistry of infectious disease, and device systems, may enable us to actuate¹¹¹ functions and modify sensors using smartphones.

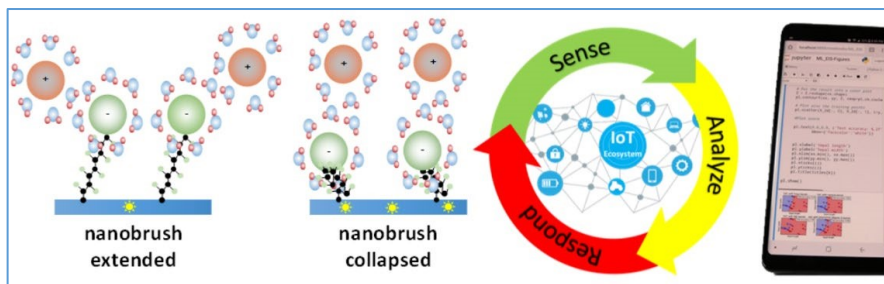


Figure 7: Smart materials can be monitored and actuated with a smart phone (ref 112).

⁹⁸ <https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.120.044302>

⁹⁹ <http://science.sciencemag.org/content/354/6317/1257>

¹⁰⁰ <http://advances.sciencemag.org/content/4/8/eaat4634>

¹⁰¹ <http://science.sciencemag.org/content/347/6228/1261689>

¹⁰² <https://www.nature.com/articles/415152a>

¹⁰³ <https://patentimages.storage.googleapis.com/18/41/67/64c9c21a955380/US20020061588A1.pdf>

¹⁰⁴ http://cocoa.ethz.ch/downloads/2014/06/None_MIT-AUTOID-WH-001.pdf

¹⁰⁵ <https://openlearning.mit.edu/about/our-team/sanjay-sarma>

¹⁰⁶ <https://www.postscapes.com/internet-of-things-history/>

¹⁰⁷ <http://digitalcollections.library.cmu.edu/awweb/awarchive?type=file&item=34057>

¹⁰⁸ <https://www.fantasticfiction.com/a/isaac-asimov/sally.htm>

¹⁰⁹ <https://iss.oy.ne.ro/RemotePasswordExtractionFromRFIDTags.pdf>

¹¹⁰ https://www.gs1.org/sites/default/files/docs/epc/uhfc1g2_1_0_9-standard-20050126.pdf

¹¹¹ https://docs.wixstatic.com/ugd/6a9318_408ad8c2617847708e64cc3ba50d903a.pdf

The SARS platform tool and the future paradigm shift from SARS to SARA, depends on our ability to express our incisive foresight by asking and framing the **correct questions**. Success depends on defining our goals, validation of analytics, and the pragmatic drive to promote end-user adoption. The outcome will be shaped by the questions we ask and the evidence-based responses. Development of a “sense, analyze, response” system (SARS) as a platform and data tool for application in agriculture (water, soil, etc) is an important task at the nexus of food, energy, water, and sanitation (FEWS). The move from SARS to SARA may be a milestone, but SARA is not limited to any vertical. For this discussion, agriculture is an use-case (SARS♦AG).

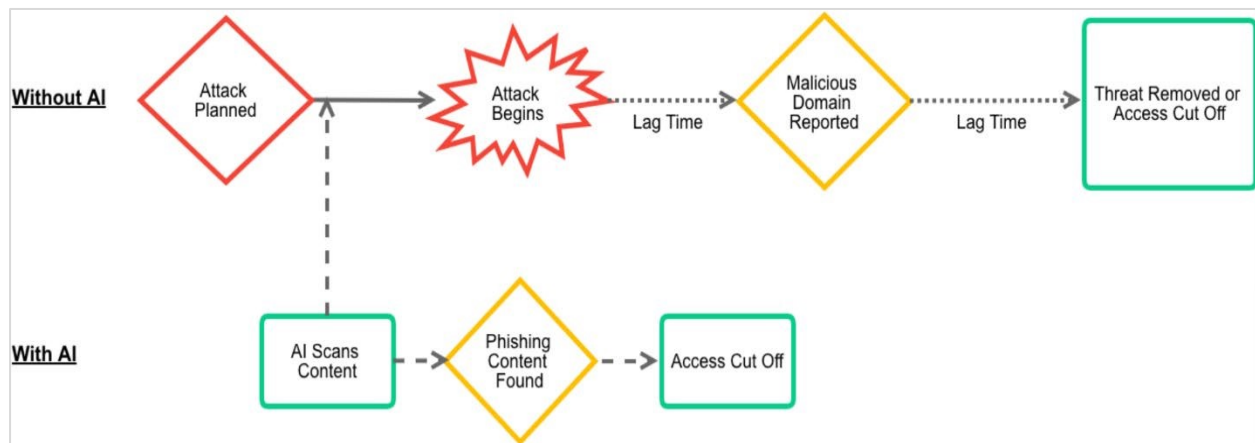


Figure 8: Paradigm of SARA illustrated in cybersecurity (phishing). Agents¹¹² may sense content, find evidence of potential phishing fraud upon analysis, responds by actuating termination.

To substantiate ideas latent in SARS/SARA we need a compass to continuously map need-based innovation. Future-ready architecture must overlay all computation and complexity with simple forms of knowledge representation, such as “drag & drop” icons¹¹⁴ and “traffic light” guidance (red, yellow, green) as the outcome. The complexity of this simplicity is a test of our collective erudition. It may stretch beyond the horizon of our collective imagination.

¹¹² <https://www.technologyreview.com/s/608036/we-need-to-talk-about-the-power-of-ai-to-manipulate-humans/>

¹¹⁴ <http://bit.ly/TOPOLOGY-OPTIMIZATION>

IMAGINATION – WHAT IF YOU ALLOWED IT TO WANDER

The discussion here, and elsewhere, about sensors, centers on the classical *binding* of an analyte. The pragmatism about reversible binding, in order to *re-use* the sensor, is a distant laggard. Even if re-usability was a possibility, concomitant calibration of the sensor, in the field, may be challenging, especially for low-cost sensors. Decreasing efficacy (sensitivity, selectivity) may tarnish data acquired from re-usable sensors, unless robust re-calibration was verifiable. What if we pursued sensors that *do not bind* to an analyte? One alternative medium may be waves, in particular, radio waves, all around us. Can we use RF waves as sensors?

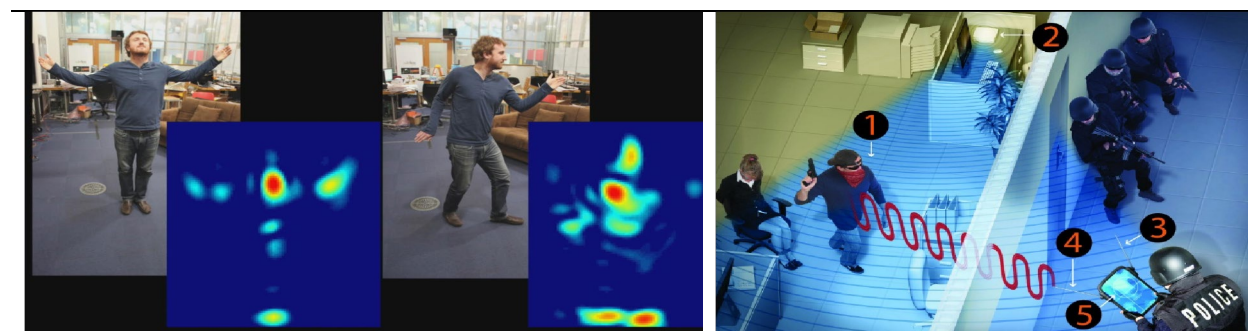


Figure 9: Dina Katabi¹¹³ and Fadel Adib¹¹⁴ and others have demonstrated how reflection of RF waves¹¹⁵ may be used to detect objects behind opaque barriers. Using the ability of frequency modulated carrier waves (FMCW, a radar technique) to separate reflections from different objects, it is possible to detect¹¹⁶ with accuracy, respiration and heartbeat from individuals. Applications¹¹⁷ of this principle (reflection of RF waves) is only limited by our imagination. Panel (right) shows how WiFi passive radar (#2) may assist real-time decision support¹¹⁸ for workers.

Detecting chemical and biological agents in water and soil presents grave challenges. Foremost, attenuation of RF signals and perhaps in second place, the damping or disturbance due to other “similar” molecules which may add significant noise to the reflected wave/signal. Molecular detection using IR/NMR/GCMS may inform this exploration, in terms of the features which may be extracted from signals (reflected waves?). Feature-related data may train new¹¹⁹ algorithms, and use machine learning¹²² techniques to detect “needles” from many haystacks!

¹¹³ <http://people.csail.mit.edu/dina/>

¹¹⁴ <http://www.mit.edu/~fadel/>

¹¹⁵ <https://people.csail.mit.edu/fadel/papers/wivi-paper.pdf>

¹¹⁶ <http://www.mit.edu/~fadel/papers/vitalradio-paper.pdf>

¹¹⁷ http://openaccess.thecvf.com/content_cvpr_2018/CameraReady/2406.pdf

¹¹⁸ <https://pure.coventry.ac.uk/ws/portalfiles/portal/7646003/tancomb.pdf>

¹¹⁹ <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.673.888&rep=rep1&type=pdf>

¹²² <http://bit.ly/BOOKS-ML>

It is interesting to note that we can identify between Coke and Pepsi using RF¹²⁰ signals. Using UWB (ultrawideband) radios, we differentiate between liquids using permittivity¹²¹ of liquids. RF waves travel slower in soil with higher permittivity. By measuring¹²² soil permittivity, we can extrapolate soil moisture and soil conductivity, to aid data-driven smart farming (IoT).

What about molecules? Consider non-destructive testing (NDT) techniques used for sophisticated aerospace components¹²³ as well as simple construction material¹²⁴ (Fig 10L). Now imagine the combination of NDT with ISAR (inverse synthetic aperture radar, Fig 10R). The sensor “housing” may find inspiration from the NDT illustration (Fig 10L) if we imagine that the “substance” (soil, water) sits in the ‘sample holder’ (Fig 10L, illustrates material under testing, as a flat cartoon, located on the ‘sample holder’ platform). The sensor “detection” mechanism may find inspiration from the use of ISAR (Fig 10R). In a conventional approach, an antenna array may be required to locate an object by steering its beam spatially (see (a) in Fig 10R). The authors inverted this concept and used the motion of the object (top part, (b), Fig 10R) to emulate an antenna array. Hence, the creative application of inverse synthetic aperture (ISAR). Wi-Vi¹¹⁶ leverages this principle to beamform the received signal in time (rather than in space) and locate the moving object. For water and soil sensors, is it rational to form a hypothesis, that this “moving object” in the context of Wi-Vi, may be analogous to the “moving analyte” in soil, water, or air? Can we even extrapolate the concept of “motion” (Fig 10R) at the molecular level, necessary for detection of analytes? The assumption is that the intrinsic motion of molecules (random, Brownian) can be used (substituted?) in the context of the “motion” in the Wi-Vi paper (ref 116). The kinetics of molecular motion must be accounted in the design of detector, but are these motions (motion of object vs molecules) comparable?



Figure 10: Rational basis for convergence of ideas? Can we combine NDT¹²⁷ and ISAR¹¹⁷ types of tools & techniques to create sensors, based on differential reflection of waves (RF, EM, sound)?

¹²⁰ https://ink.library.smu.edu.sg/cgi/viewcontent.cgi?article=4878&context=sis_research

¹²¹ https://synrg.csl.illinois.edu/papers/liquid_mobisys2018.pdf

¹²² https://www.microsoft.com/en-us/research/uploads/prod/2018/10/SMURF_TR-1.pdf

¹²³ <https://www.mdpi.com/1424-8220/18/2/609>

¹²⁴ <https://www.sciencedirect.com/science/article/pii/S1876610217321689>

UNPLUGGED, UNBOUND, UNTETHERED

The value and flexibility of “wireless” sensor networks (WSN) partially (often rapidly) evaporates, when the hardware (sensor) is tethered or is made immobile (Figure 11). Isn't it almost oxymoronic to picture immobile RF sensors?

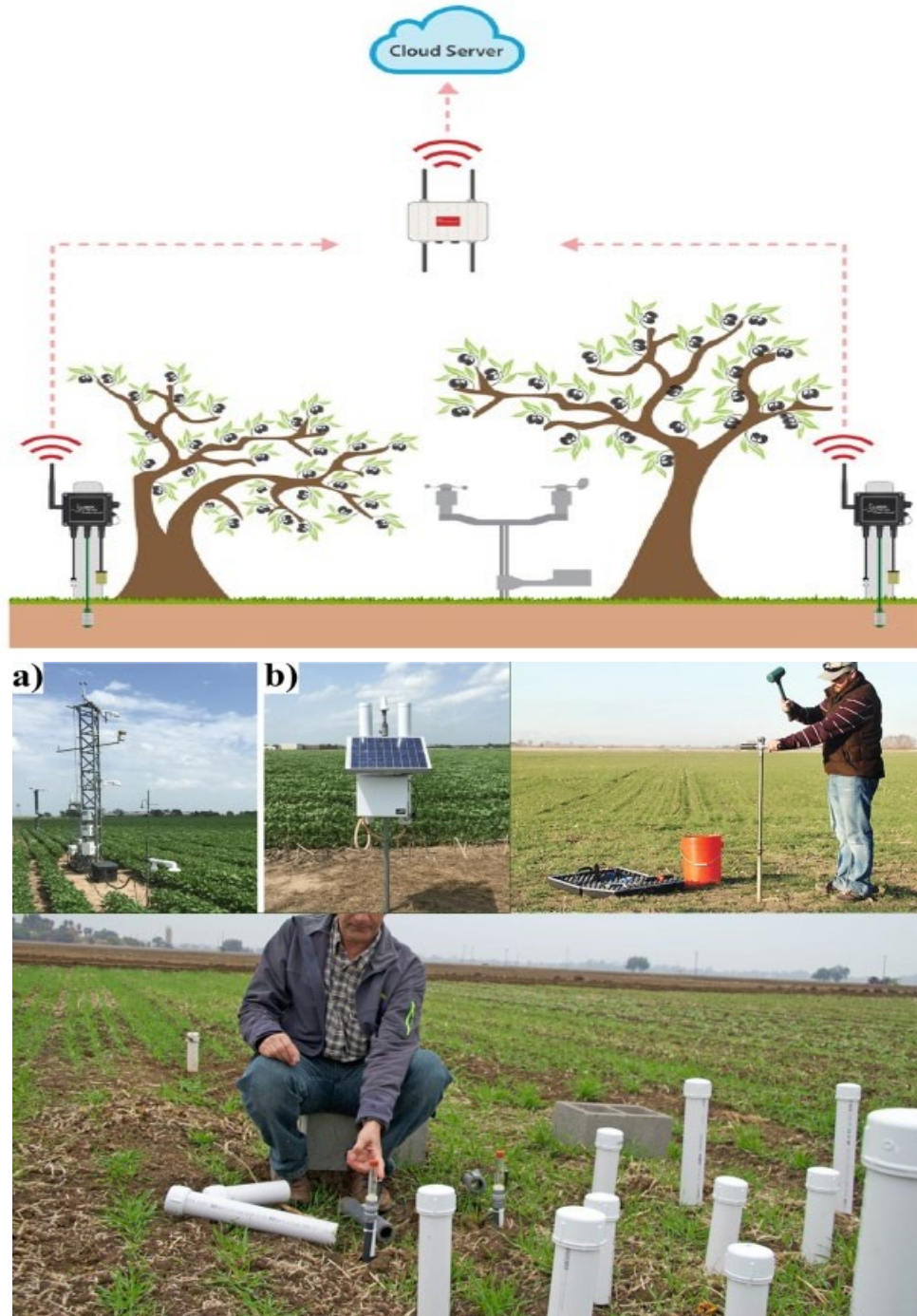


Fig 11: The conventional practice of immobilizing sensors may restrict their dynamic potential. It adds enormous burden of pollution when sensors are non-functional and not biodegradable.

With advances in RF sensing, the use of drones as a gateway¹²⁵ for mobile sensing will increasingly rise in prominence, in the portfolio of data acquisition tools. Mobile sensing is certainly not a panacea, but it may help reduce pollution due to non-biodegradable sensor hardware. But, these advantages are at the mercy of energy systems and advances in portable energy must be feasible for large scale deployments.



Fig 12: The many advantages of UAVs as mobile sensor platforms and data acquisition tools may remain unrealized due to on-board energy limitations. Food, water, soil, sanitation and the economy, globally, may be traced to a single scientific/engineering bottleneck – energy.

Convergence of concepts, manifested through confluence of computation, will make itself useful, *if* we can harvest and invest in data and data analytics. The infectious inclination to claim advances by power-point (Fig 13), which are in abundance (including this essay), is in sharp contrast to the actual/real availability of the real-time tools for simple decision support (Fig 14). It is easy to illustrate what “should/could be” (this essay) and “simulate” what it looks like (Fig 14) but it is a herculean task to transform the vision into reality.

Transformation cannot **stop** at decision support. Detecting harmful pathogens or metals in a sample, calls for treatment. **Suggesting** treatment without **implementation**, does not remedy the problem. Decision support is not a solution.

¹²⁵ <https://www.mdpi.com/1424-8220/18/2/624>

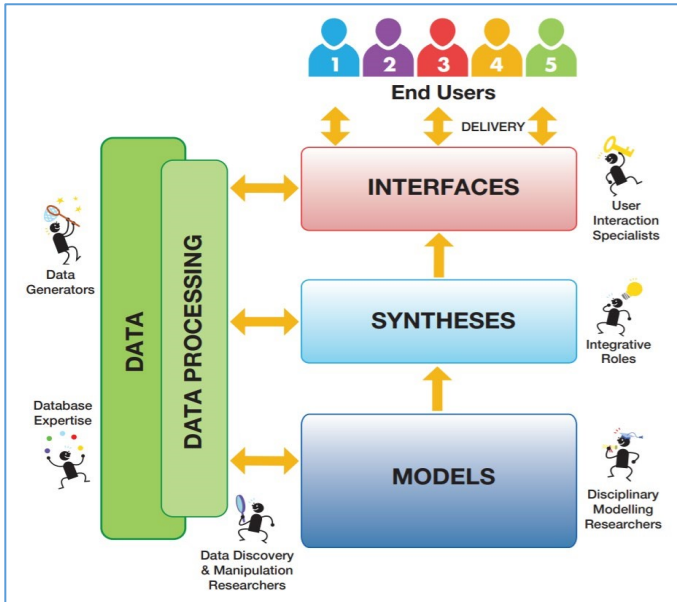


Fig 13: Data-driven intelligent information arbitrage has advanced by power-point¹²⁶ but the real task of driving the data, and merging it to make sense, is the task of feature engineering¹²⁷ which few can accomplish (and rarely seem to surface in august monographs, reference 129). The illustration (on the left) may take into consideration “discovery” processes¹²⁸, include principles of dynamic model-based enterprise¹²⁹ concepts and assume most data to be fuzzy, incomplete, unstructured, and punctuated. This data, devoid of

schemas or structure, must be incorporated, in system dynamics models using agent systems¹³⁰ which can update values (state, parameter), as and when, new data arrives.



Fig 14: Sensors¹³¹ to detect pathogens and transmit data to smartphones¹³² are initial steps to remedial action. All “ideas by power-point” must translate to mobile systems (right) but we still need to “move the needle” by implementing solutions. Knowledge of contaminants must not generate complacency. The task to equip users with solutions and remedies is not an academic role. Hence, the importance of public-private partnerships between academia and industry.

¹²⁶ www.agmip.org/wp-content/uploads/2015/04/Towards-a-New-Generation-of-Ag-Systems-Complete.pdf

¹²⁷ <http://bit.ly/BOOKS-FEATURES>

¹²⁸ <https://dl.acm.org/citation.cfm?doi=2836075.2822529>

¹²⁹ https://www.nist.gov/sites/default/files/documents/2018/11/05/programsummary_mbe.pdf

¹³⁰ <https://bmcinfectdis.biomedcentral.com/articles/10.1186/s12879-017-2726-9>

¹³¹ <https://doi.org/10.1016/j.ebiom.2018.11.031>

¹³² <https://doi.org/10.1016/j.ebiom.2018.09.001>

The mobility of display (Fig 14) is not necessarily mobility of measurement or the sensor. Data from immobile sensors (Fig 11) on smartphones is *mobile access*. For mobility by design, remote sensing using reflected RF (Fig 10), is one solution. SMURF¹³³ soil moisture sensor uses 2.4GHz WiFi band (Fig 16). NASA’s SMAP¹³⁴ radar and radiometer observe the Earth’s surface at 1.2GHz and extrapolates soil moisture. If we probe the versatility of RF and its unlimited¹³⁵ potential, we may find an embarrassment of riches. If we move beyond tools for soil moisture, we can shift our exploration from microwaves to sub-millimeter frequencies, terahertz. Higher frequencies may improve spatial resolution. Can remote sensing measure salts in the soil?

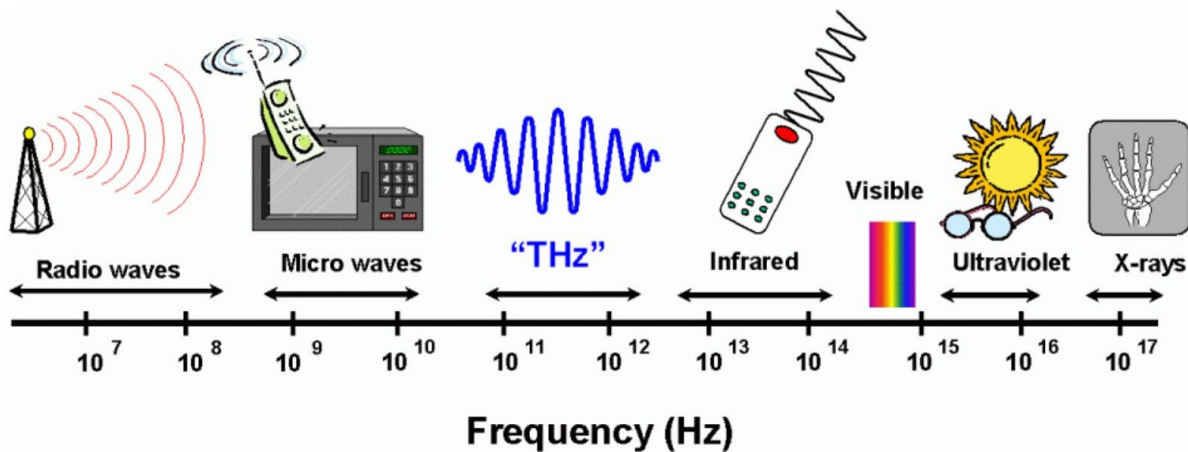


Fig 15: Sign posts of our spectrum: MHz (megahertz, 10^6 Hz), GHz (microwaves are in gigahertz, 10^9 Hz) and THz (sub-millimeter waves are in terahertz, 10^{12} Hz).

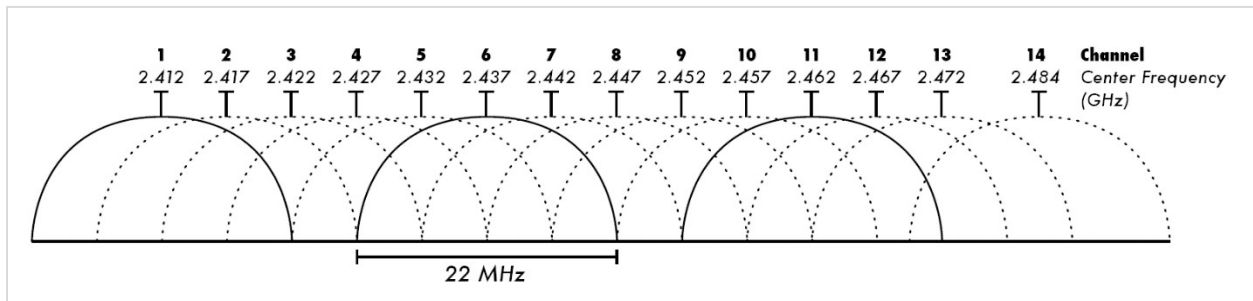


Fig 16: IEEE 802.11 standard protocol provides several distinct radio frequency ranges for use in WiFi communications: 900 MHz, 2.4 GHz, 3.6 GHz, 4.9 GHz, 5 GHz, 5.9 GHz, 60 GHz bands. Each range is divided into a multitude of channels¹³⁶ (illustrated here for the 2.4GHz band).

¹³³ https://www.microsoft.com/en-us/research/uploads/prod/2018/10/SMURF_TR-1.pdf

¹³⁴ <https://smap.jpl.nasa.gov/faq/>

¹³⁵ <https://doi.org/10.1038/s41928-018-0186-x>

¹³⁶

https://upload.wikimedia.org/wikipedia/commons/8/8c/2.4_GHz_WiFi_channels_%28802.11b%2Cg_WLAN%29.svg

Terahertz (THz) sensing and advances in terahertz integrated hybrid electronic-photonic systems¹³⁷ may lead to new dimensions in remote sensing, including, potentially, reflected RF at THz frequencies. It is merely speculation at this point, but the prominent question is whether algorithms can be trained by machine learning techniques, to differentiate between different soil compositions based on data from reflected RF waves. It is encouraging that this approach works for microwaves (WiFi, Fig 9) to differentiate between heart rate and respiratory rate in humans from reflected RF signals. Will it work reliably for terahertz, sub-millimeter waves?

The sensor housing, and acquisition of the signal, may be made mobile-by-design using UAV mounted sensors with tiny TSDB (time series database) embedded in SDR (software¹³⁸ defined radio) transceivers for collecting reflected RF data (ultrawideband transceivers). Algorithms and ML techniques in data analytics may differentiate the signals and extract actionable data and/or information. Due to damping of THz frequencies, error correction routines will be required to improve signal to noise ratio (for example, Kalman filter, Shannon noisy channel). Deploying a swarm of UAVs will require collision avoidance, path optimization, energy minimization and intrusion detection (cybersecurity). Application of swarm intelligence and the principles of collaborative mobile robotics are expected to be integral to this process.

Continuing the speculation to ask even more from remote sensing, the discussion about sensors in the soil may progress from soil moisture to chemical ingredients in the soil (nitrogen, phosphorous) and then to the biological activity in the soil due to nitrogen-fixing bacteria. One idea is to explore whether we can take advantage of the paramagnetic vs diamagnetic nature of the key elements, oxygen and nitrogen. Measuring biological nitrogen fixation using remote sensors may serve as an index or indicator of root health, plant physiology and food production.

¹³⁷ <https://www.nature.com/articles/s41928-018-0173-2>

¹³⁸ <https://dspace.mit.edu/handle/1721.1/9134>

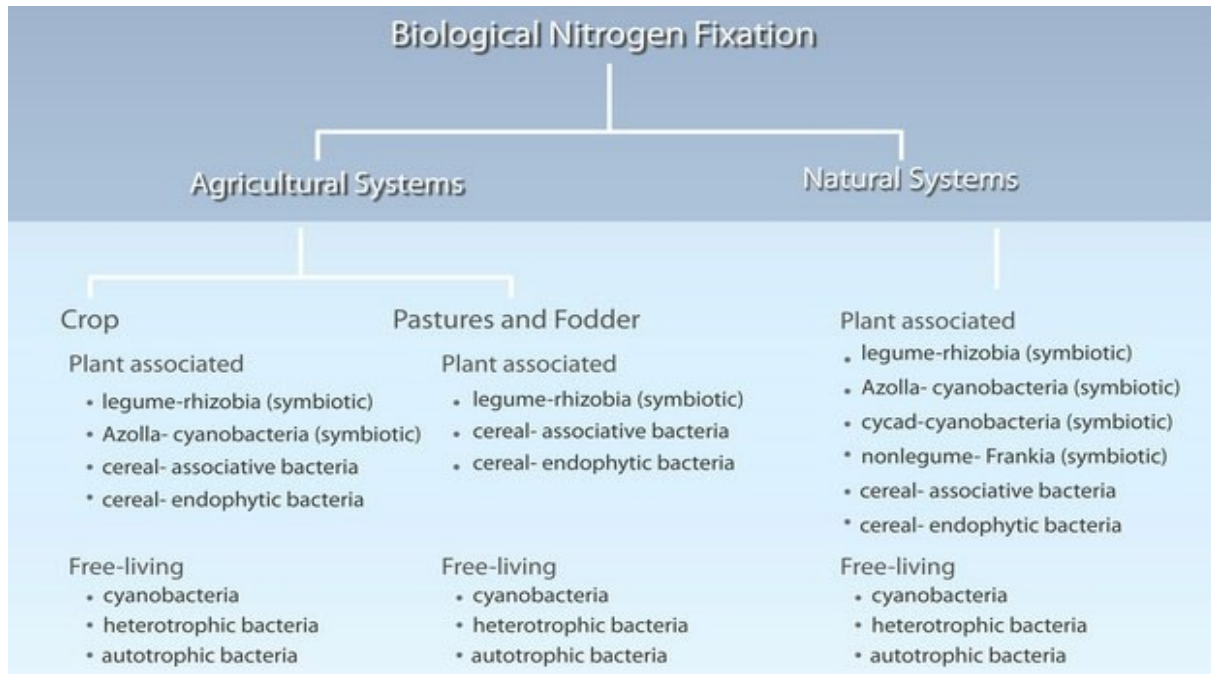


Fig 17: Nitrogen fixation (Beijerinck, 1901), is carried out by a special group of prokaryotes.¹³⁹ The central metalloenzyme¹⁴⁰ for nitrogen fixation is a dimeric protein, nitrogenase, with a moiety of Molybdenum (Mo) and Iron (Fe), one for each of its monomers, but with minor exceptions¹⁴¹ where Vanadium (V) is the metal of choice.¹⁴²

The suggestion here is to exploit the differential between the rapid inactivation of nitrogenase by atmospheric concentrations of oxygen (even an oxygen concentration as low as 57nM within a soybean nodule can reduce nitrogenase activity¹⁴³) versus the demand for oxygen for ATP synthesis which is essential to energize the nitrogenase. These competing needs are met by modulating oxygen concentration via an oxygen diffusion barrier in the nodule, by use of leghemoglobin¹⁴⁴ to buffer oxygen concentration and by a class of bacteroid cytochrome c oxidases¹⁴⁵ with a high affinity for oxygen (in a classic¹⁴⁶ feedback loop, low oxygen signals the transcriptional activation of *nif*¹⁴⁷ and *fix*¹⁴⁸ genes in nitrogen fixing bacteria, eg, *Rhizobium sp.*)

¹³⁹ <https://www.nature.com/scitable/knowledge/library/biological-nitrogen-fixation-23570419>

¹⁴⁰ <https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/nitrogenase>

¹⁴¹ <https://www.cell.com/action/showPdf?pii=0968-0004%2889%2990271-5>

¹⁴² <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1135386/pdf/biochemj00219-0188.pdf>

¹⁴³ <https://www.ncbi.nlm.nih.gov/pubmed/22633062>

¹⁴⁴ <https://www.ebi.ac.uk/chebi/searchId.do?chebiId=35144>

¹⁴⁵ <https://www.pnas.org/content/113/45/12815>

¹⁴⁶ http://www.gs.washington.edu/academics/courses/braun/55106/readings/jacob_and_monod.pdf

¹⁴⁷ <https://journals.plos.org/plosgenetics/article/file?id=10.1371/journal.pgen.1007629&type=printable>

¹⁴⁸ <https://www.frontiersin.org/articles/10.3389/fmicb.2016.01343/full>

The recent focus¹⁴⁹ on leghemoglobin may increase the inclination to develop tools to determine its concentration using the principles of spectroscopy (absorption spectra of human hemoglobin) which were worked out¹⁵⁰ almost half century¹⁵¹ ago and patented¹⁵² a quarter century ago. Modifying non-invasive hemoglobin measurement¹⁵³ tools may be useful but some of the tools available may not be reliable¹⁵⁷ or suitable for leghemoglobin measurements. Since the differential in this scenario is an understanding of the oxygen concentration (or its gradient) and its modulator, leghemoglobin, it is imperative that we measure oxygen or oxygenated compounds. In addition to the potential use of terahertz signaling, paramagnetic property of oxygen makes it possible to use robust tools, such as, electron spin resonance¹⁵⁴ which is increasingly popular as electron paramagnetic resonance (EPR) spectroscopy¹⁵⁵ and used¹⁵⁶ for a variety of purposes. I don't know if EPR spectroscopy can function in a form factor to be an oxygen sensor and transported via UAVs. Understanding which questions to ask about the type of data necessary, remains the most important issue in this complex scenario.

FUTURE SENSE

In one segment of this meandering collection, I discussed SIP-SAR, a synergistic integration platform for machine intelligence, which can better support decision systems, the response part of the SARS paradigm (sense, analyze, response systems).

By now, any astute reader will have made the connection between SARS and PEAS¹⁵⁷ which is an easy to remember mnemonic describing Agent action (Performance metric, Environment, Actuators, Sensors). SARS is a partial inverse of PEAS where we start with the data to drive toward a data-driven decision system rather than a goal driven system where we optimize to reach the performance metric. In the real world, SARS and PEAS are not conceptual compartments, they are dynamic push-pull elements, which may be used in any combination.

PEAS Platform for the Agro-Ecosystem (in this collection) outlines the journey from data to knowledge, in stages, using artificial reasoning tools (ART) to help users, followed by data-informed decision as a service (DIDA'S) and knowledge-informed decision as a service (KIDS).

¹⁴⁹ <https://www.fda.gov/downloads/Food/IngredientsPackagingLabeling/GRAS/NoticeInventory/UCM620362.pdf>

¹⁵⁰ <http://www.jbc.org/content/148/1/173.full.pdf>

¹⁵¹ <https://academic.oup.com/ajcp/article-abstract/29/5/403/1768152?redirectedFrom=PDF>

¹⁵² <https://patentimages.storage.googleapis.com/87/df/6e/daf7dfd6227ac8/WO1993012712A1.pdf>

¹⁵³ <https://doi.org/10.1016/j.ijsu.2015.11.048>

¹⁵⁷ https://journals.lww.com/anesthesia-analgesia/fulltext/2016/02000/Continuous_Noninvasive_Hemoglobin_Monitoring_A.37.aspx

¹⁵⁴ <http://www.its.caltech.edu/~derose/labs/exp6.html>

¹⁵⁵ <https://doi.org/10.1016/B978-0-444-63776-5.00003-6>

¹⁵⁶ <https://www.ias.ac.in/article/fulltext/reso/020/11/1017-1032>

¹⁵⁷ Russell S and Norvig P (2009) *Artificial Intelligence: A Modern Approach* (3rd ed) <http://aima.cs.berkeley.edu/>

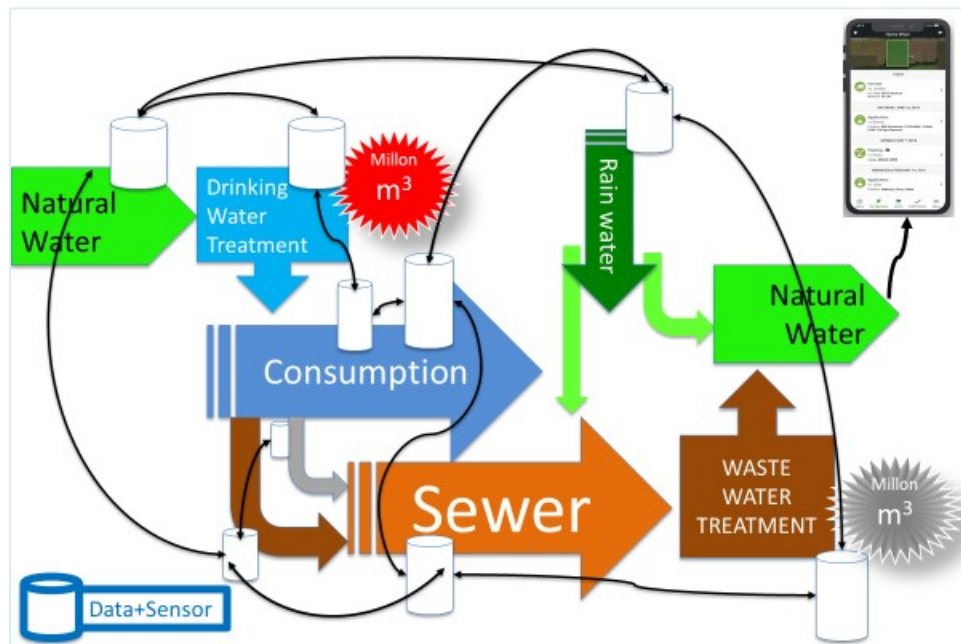


Fig 18: Start with data (SARS) or commence with a goal (PEAS) – The world (of water IoT) needs both. Balance shifts depending on factors determined by the user and/or the user environment.

The reference to digital twin is supposed to be a generalizing approach, because a “twin” can be made of anything, a machine, a sensor, a greenhouse, an orchard, a capnometer. In this respect, SIP-SARS is not about machine intelligence but about the *data of objects*. The objects may be real, with a virtual representation, hence, the *digital twin* concept. All the data elements from Figure 18 may be synthesized in a digital twin for urban water management or the illustration may be modified to make it relevant to water for irrigation or farm use. The system data may be accessible in real-time on smartphones for users and city managers.

The familiarity of internet of things (IoT) makes it easier to understand the meaning of *internet of objects* and the ideas related to “digital objects” which are at least 25 years old. If data about objects are in this repository¹⁵⁸ then the *internet of objects* may be also referred to as the *internet of data*.

In the second part of this essay, SARS-AG, the *digital thread* continues as *data thread*. The suggestion that SARS may evolve to SARA is based on data-driven actuation of function. These paradigms, and their shifts, may be traced back to data, and the connectivity between data sources and sinks.

¹⁵⁸ https://www.doi.org/topics/2006_05_02_Kahn_Framework.pdf

Conceptually, the SIP-SARS-SARA thinking seeks to merge with the conceptual OODA¹⁵⁹ framework and tangles with the six (0-5) levels of autonomy¹⁶⁰ highlighted in automotive automation, and occasionally used as a management tool¹⁶¹ in decision making. The common denominator in all these acronyms and frameworks is data.

Data acquisition tools (hardware, telecommunications, software, services, sensors) and data analytics (machine learning, AI, statistical techniques) enables us to extract information from data (if there is information in the data). This information may be of value to the end user, if it is delivered, at the point of contact or point of use, perhaps in near real-time, before its value perishes. The role of mobility in this process is central, with respect to distributed data acquisition and data driven decision support at the edge (the latter is also a distributed system).

Therefore, any application, of real value, must engage with diverse industry groups, to synthesize the end-to-end components of the outcome, the user/customer/farmer demands.

The industry-academia partnership suggested in Figure 14 is not only between like-minded companies in the same business segment but must involve the value chain partners. In the context of machine tools (SIP-SAR) and applications related to food (SARS-AG), we must engage with behemoths and SMEs, including telecommunications, hardware, software, sensor manufacturers, services, and tool developers. The portfolio of solutions for FEWS (food, energy, water, soil) needs data, convergence of ideas, and implementations which are of value to users.

The last section of this essay are suggestions which may be partially or even completely incorrect because of my lack of relevant depth of knowledge. My thinking involves a quantum leap where one leg is based on the knowledge that in neonatal intensive care units (NICU's), pre-mature babies are sensitive to oxygen concentration. NICU's continuously monitor oxygen using the paramagnetic vs diamagnetic differential (between oxygen and nitrogen in air). I have jumped from that knowledge to connect with other dots. It remains to be seen whether parts of that principle can be applied to remotely sense the nitrogen fixation status of soil microbes.

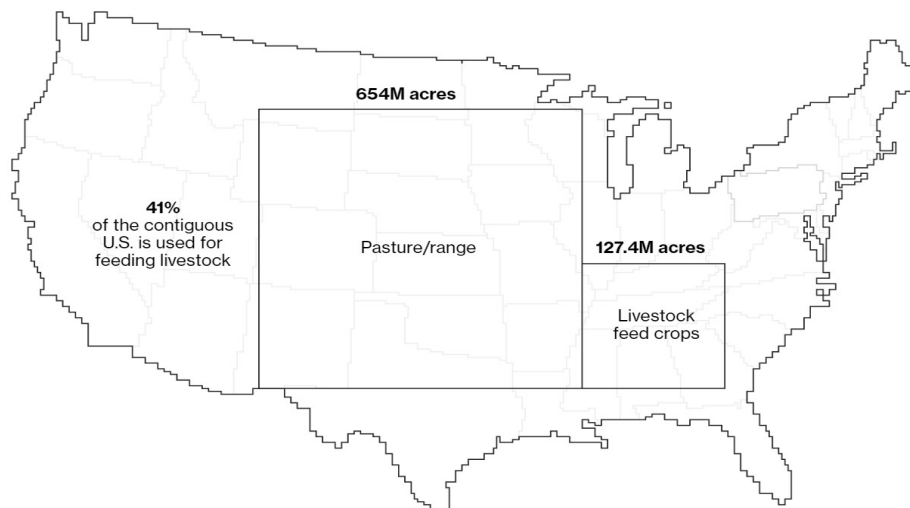
Classical molecular orbital theory (but not VSEPR) indicates oxygen will fill the orbitals following Pauli's Exclusion Principle (σ_{2s} , σ_{2s}^* , σ_{2p} , σ_{2p}^*). Two electrons in $2p^*$ will partially fill this orbital and possess parallel spins. Since the rest of the electrons are paired, the remaining two electrons in $2p^*$ orbital gives the diatomic molecule a net total spin (it does not matter if they are $+1/2$ or $-1/2$ spins, they will both be the *same*). Since there is a net spin, oxygen is paramagnetic. I have assumed laws of physics governing the spin of oxygen and relevant properties of nitrogen, cannot change in the NICU or in the plant root nodule.

¹⁵⁹ <https://apps.dtic.mil/dtic/tr/fulltext/u2/a590672.pdf>

¹⁶⁰ <https://journals.sagepub.com/doi/abs/10.1177/1555343417726476>

¹⁶¹ <https://www.maths.tcd.ie/~nora/FT351-3/DSS.pdf>

The desire to usher mobile tools for continuous remote sensing is the basis for the purely speculative suggestion about combining ultrasound sensing on a chip¹⁶² with terahertz sensing¹⁶³ with hybrid photonic-electronic systems which can take advantage of RF reflection¹⁶⁴ to create new applications. The use of WiFi¹⁶⁵ and NASA SMAP¹⁶⁶ for soil sensing may suggest that a potential convergence, at least in principle, is in progress. The latter may be useful in remote sensing for diverse applications (human blood hemoglobin, plant leg hemoglobin, soil composition, security, metabolites, electromyography). If adapted for use with cows, internally and externally, remote sensing may offer robust return on investment, in the US (Figure 19).



There's a single, major occupant on all this land: cows. Between pastures and cropland used to produce feed, 41 percent of U.S. land in the contiguous states revolves around livestock.

Fig 19: US - the land of cows¹⁷¹ - may need remote sensing tools for external and *in vivo* use.

Remote sensing principles are agnostic of applications. Specific tools may evolve as scaffolds for digital by design metaphor (IoT) by advancing the principles and practice of connectivity. When added to mobile carriers (eg swarms of micro-drones), these may evolve to become tools for mobile sensing, useful for sense, analysis and response systems (SARS) in wide area applications (eg animal farming, agriculture, water, energy, sanitation and public health).

¹⁶² <https://www.nature.com/articles/s41467-018-08038-4.pdf>

¹⁶³ <https://www.nature.com/articles/s41928-018-0173-2>

¹⁶⁴ <http://people.csail.mit.edu/fadel/wivi/>

¹⁶⁵ https://www.microsoft.com/en-us/research/uploads/prod/2018/10/SMURF_TR-1.pdf

¹⁶⁶ https://smap.jpl.nasa.gov/files/smap2/SMAP_Handbook_FINAL_1_JULY_2014_Web.pdf

¹⁷¹ <https://www.bloomberg.com/graphics/2018-us-land-use>

SARS♦AG - ANIMAL♦AG CASE STUDY

DYNAMIC FEED FORMULATION, REAL-TIME NUTRITION, DIGESTIVE ANALYTICS, PRODUCTIVITY

INFLUENCE OF FEED ON FOOD - BIOCHEMISTRY AND METABOLOMICS OF THE BOLUS

This case starts with the adage that *we are what we eat*¹⁶⁷ and the vast plethora of efforts¹⁶⁸ to bring home¹⁶⁹ this message. In this section, we attempt to capture a few ideas and suggestions embedded in SARS♦AG to propose an application for the animal ag industry, relative to the influence of feed on food production.

We start with the bolus, that is, the chewed food, at the moment of swallowing the feed¹⁷⁰ mixture, the animal is eating (think about ruminants, cows). The biochemistry¹⁷¹ of processing this bolus and the kinetics of that process, defines the efficacy of the feed mix with respect to its nutritional content, digestion, excretion and contribution to food production from the animal, for example, quality and quantity of milk production.

Where do we start? Biochemistry of nutrition is very well investigated¹⁷² and needs little introduction or justification of its importance. We may address this case, as follows:

[1] Identify Indicators	[3] Sensing for Measurement
[2] Engineering to Sense	[4] Measurement to Applications

In the biochemical lifecycle of a bolus, can we list [1] the key molecules/pathways which may serve, *in sequence*, as molecular indicators (sugars, fats, acids) of progress (*time series*), from ingestion of the feed to digested products, *in vivo*, ready for absorption in the lumen.

In [2] we explore which molecules may serve as key performance indicators (KPI) in the context of engineering specific sensors. In other words, create sensor(s) to sense the rate of change (in real time?) of the indicator(s), with respect to the identified *sequence* of steps.

In part [3] we focus on closed loop¹⁷³ sensing, sensor engineering and sensor form and factor. The potential for use of soft robots¹⁷⁴ and closed-loop sensing is key to wireless signal acquisition from *in vivo* measurements. Calibration and *in vivo re-calibration* of sensors are

¹⁶⁷ <https://link.springer.com/content/pdf/10.3758%2Fs13423-015-0908-2.pdf>

¹⁶⁸ <https://www.nap.edu/read/1365/chapter/4>

¹⁶⁹ <https://www.cdc.gov/scienceambassador/documents/we-are-what-we-eat.pdf>

¹⁷⁰ [https://cdn2.hubspot.net/hubfs/745395/2017%20Global%20Feed%20Survey%20\(WEB\)%20EDITED%20EM.pdf](https://cdn2.hubspot.net/hubfs/745395/2017%20Global%20Feed%20Survey%20(WEB)%20EDITED%20EM.pdf)

¹⁷¹ <http://bit.ly/BOLUS-BIOCHEM>

¹⁷² <https://www.springer.com/us/book/9781475713510>

¹⁷³ <https://www.ncbi.nlm.nih.gov/pubmed/30503617>

¹⁷⁴ https://www.nsf.gov/awardsearch/showAward?AWD_ID=0938047

central to data reliability. Calibration and mechanism of sensing (binding, signal, reusability, saturation, sensitivity, mobility, degradation, excretion) are key areas for innovative R&D.

In part [4], data capture, data analytics and data visualization on smartphones, are core elements. However, the most important issue in this vein is analytics. The meaning of the data is the single most critical outcome which generates value for the end-user.

Parameters in [2] are the bedrock of digestive dynamics and metabolomics. This is the most exhaustive segment which requires knowledge, wisdom and on-farm working experience to identify targets. without getting lost in the myriad of molecules. The ability to ask correct questions (in the *context* of this specific scenario) may reveal molecular signatures and/or clues to *in vivo* manifestations, due to viromes and microbiomes (phenotypes).

Predictive analytics [4] must deliver value for the user. If this data is aggregated and coupled with information from other farms (animals and species, anywhere), it may begin to reveal patterns or genetic footprints (genotypes), with respect to the food/feed ingested and *in vivo* signals. Information sharing in the “big data” context could be useful, too.

Using data and evidence, optimizing or re-formulating genotype-phenotype balanced bolus may be transformative for the future of the feed industry. The convergence of real-time data with the principles of nutrigenomics may influence the future of food productivity. Data and analytics [4] may aid future metabolic engineering of high methane animals. Different feed formulations may be less expensive than CRISPR-ization¹⁷⁵ to reduce methane emissions.

CREATING A “PLUG AND PLAY” TOOL FOR THE ANIMAL AG INDUSTRY

Visualization of *in vivo* nutritional kinetics data and analytics on smartphones is only information. The preferred **outcome** for the end-user is to *use this information* in near real-time to **address** the problem. For example, re-formulate the feed mix to lower the concentration of some of the volatile (short chain) fatty acids. **When** this re-formulated feed mix generates the required/expected result, **then**, this effort may be labeled as a success. The end user can count the outcome as a positive return on the investment (ROI) and may **pay** for such services. A tool is necessary to deliver parts of this service, based on the data and information. To create this model (where input data will output instructions to change the feed mix), we need to understand the kinetics, in the lifecycle of a bolus, using metabolites as markers (sense) and metabolomic sign-posts. For each metabolite, we may identify (one or more) substrate/product and at least one attribute, which can be measured (sense) to determine the status (rate of formation) of the substrate or product.

¹⁷⁵ <https://www.technologyreview.com/s/612458/exclusive-chinese-scientists-are-creating-crispr-babies/>

¹⁸¹ <http://www.acad.bg/ebook/ml/Society%20of%20Mind.pdf>

Envision the “model” to be a lego-like modular software version of a fusion between a Rubik's Cube, a multi-dimensional matrix, and the cube-on-cube concept¹⁸¹ proposed by Marvin Minsky to demonstrate agent-based connectivity. Modularity of the software enables the user to access/buy only the necessary or affordable modules (Nissan Datsun vs Rolls-Royce Cullinan).

The modular "blocks" in this model may represent ingredients of the bolus. The pathway from ingestion to digestion, that is, sequence of molecular intermediaries, will be ‘weighted’ according to [a] biochemical significance of the ingredient and [b] ease with which it can be measured or serve as a KPI for the process (think “weights” as in artificial neural networks).

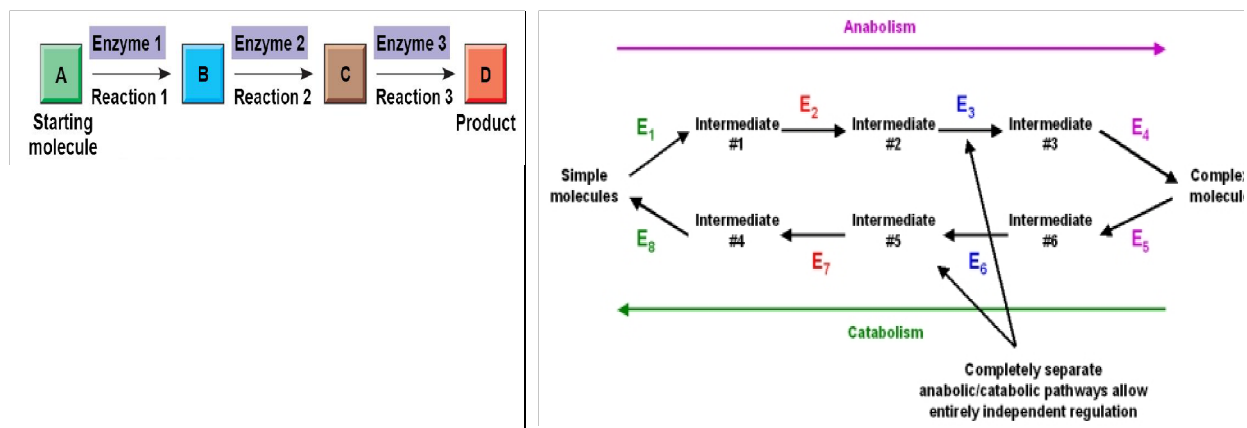


Fig 20: The feed (bolus) is made up of several complex materials which must be digested in a series of biochemical steps to extract nutritional value for the animal. Time series data from measurement of intermediates, or activity of enzymes, are indicative of the progress of these reactions. In the segment [1] we explored these metabolic pathways and identified which molecules (intermediates, enzymes, co-factors) were suitable/amenable for sensing, and acquisition of the sensor data, to map the dynamics of the progress of events *in vivo*.

Clicking on the “blocks” signifying ingredients, may reveal the next visual layer of the drill-down (using the software) as a chain (left panel, Figure 20) on a graphic user interface (smartphone, tablet, laptop). The intermediates will “light” up if the molecule can be sensed. These “feed” blocks and certain combinations (depends on pre-formulated mix) may indicate pre-set outcomes, for example, feed mix A generates X cubic meter of methane and Y gallons of milk. How closely the **factory-suggested** outcome parallels the **observed** results for your cows? The combination and proportion of ingredients may be guided by data from digestive analytics. This “feed mix” may no longer be the same for all cattle. Using this system, the user can mix and match feed ingredients and optimize for milk production or reduction of methane or tackle both, at any level of priority, the user chooses.

The user is not required to “know” the kinetics of digestive process or the metabolic interrelationships that determine the nutritional absorption of molecules from the lumen and the specific/desired outcome, for example, the quality and quantity of milk produced. The user will choose “blocks” or use “auto-select” feature to “drag and drop” the blocks (signifying ingredients). The user can simulate the outcome based on her/his choices and ask the system what will happen to methane and milk production given these set of combinations.

Based on the data embedded in the knowledge and logic segment of the analytical engine, the combination chosen by the user will generate simulated results. The user can use this “tool” to map every animal or groups of animals. User can “tweak” parameters/ingredients to optimize desired outcomes. The system can crowd source independent data modules and aggregate on the open source platform of this tool, to increase number of ingredient options or any other function or knowledge enhancement, related to nutrition and/or nutrigenomics.¹⁷⁶

The presentation “tool” may resemble a mobile application which may draw on some of the ideas in Lego MindStorm¹⁷⁷ (where players may cooperate¹⁷⁸ to mix and match codes, bits and functions, to create their desired outcome). The data, analytics and logic, is embedded in the icons, buttons and levels, with respect to the independent variables (eg ingredients) and dependent variables (eg milk production). Relationships between the scientific and nutritional parameters versus the social and economic operators, can be modeled using agent-based models¹⁷⁹ which are dynamic¹⁸⁰ compared¹⁸¹ to the Jay Forrester¹⁸² school of system dynamics. The logic matrices, knowledge convergence and information arbitrage, perhaps operating on remote open source cloud platforms, will be imported/exported (event-triggered software defined networking) but “invisible” to the user, yet, subject to user exits to control access, authorization, privacy, and cybersecurity.

¹⁷⁶ <https://www.nature.com/subjects/nutrigenomics>

¹⁷⁷ <https://www.lego.com/en-us/mindstorms>

¹⁷⁸ <https://dam-prod.media.mit.edu/x/files/thesis/2008/sylvan-phd.pdf>

¹⁷⁹ https://preventioncentre.org.au/wp-content/uploads/2018/08/080818_Diabetes_FactSheet.pdf

¹⁸⁰ <https://peerj.com/articles/5012.pdf>

¹⁸¹ <https://pdfs.semanticscholar.org/286e/6e25a244d715cf697cc0a1c0c8f81ec88fbc.pdf>

¹⁸² <https://executive.mit.edu/faculty/profile/11-jay-forrester>

SUMMARY

This case is focused on feed and its influence on productivity. The kinetics of digestion and the combined analytics of feed vs food production (milk) is an oversimplification. The real world scenario must account for microbiomes and viromes, which can alter¹⁸³ metabolic rates and outcomes. Implementation of this mobile tool is viewed as a software app. Users choose “lego blocks” to create or choose from a “menu” of feed, to drive their preferred outcomes, with respect to a temporary optimized state, and hopefully, maximize production of food.

CONCLUDING COMMENTS

If one wonders why we should invest in science, the simple answer is that of necessity. We do not know what effort will result in what outcome. We cannot leave any stone unturned. By the end of this century, the Earth may have to feed about 11 billion people. We need food.

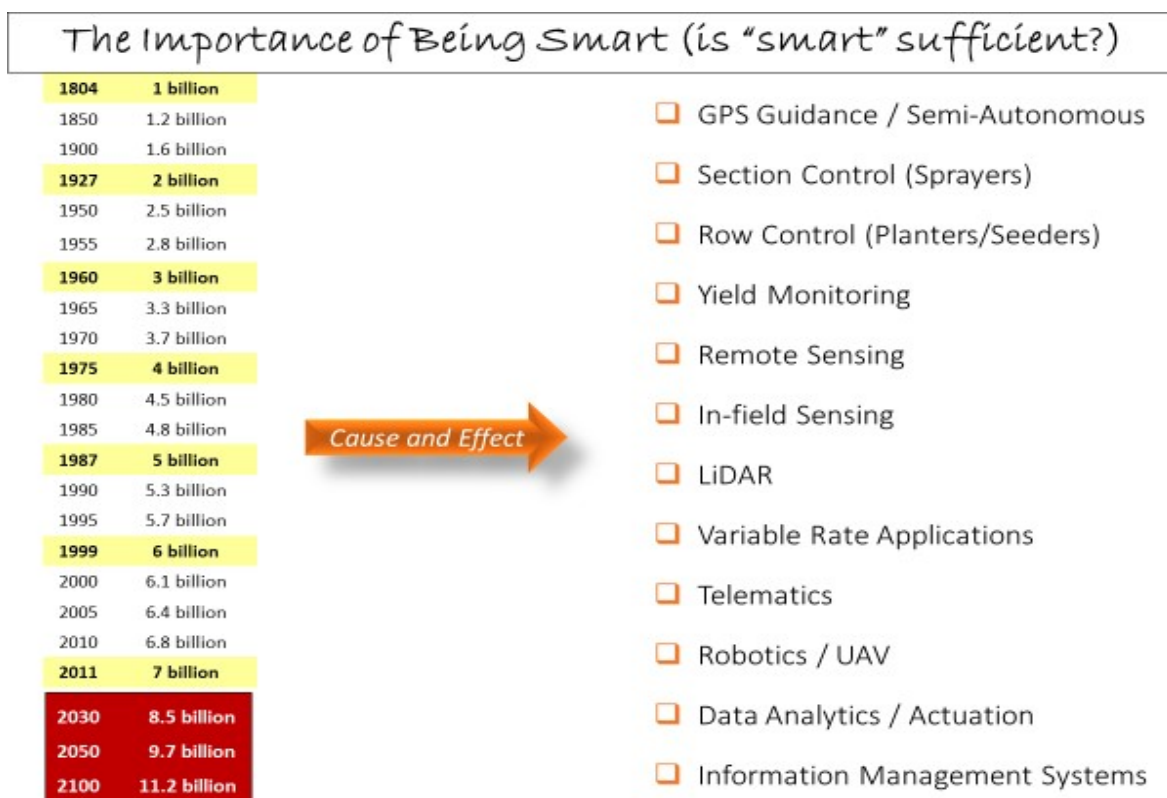


Fig 21: Necessity is the mother of invention. The demand for food and economic development makes it imperative that we search deep within ourselves, and science, to better serve society.

¹⁸³ <https://jci.org/articles/view/94601/pdf>

Causation – Correlation

Shoumen Palit Austin Datta, Massachusetts Institute of Technology and Massachusetts General Hospital, Harvard Medical School, Cambridge, Massachusetts 02139

If simulated¹, system dynamics² and³ agent based⁴ models⁵ may allow us to explore⁶ a range of impact⁷ of different variables⁸ on specific⁹ outcomes¹⁰. By altering parameters and metrics which can shape the outcome from these simulations¹¹, we may identify to what degree the variables may influence the outcome, independently and/or collectively. The co-dependencies¹² and inter-relationships¹³ between variables are central, and may become obvious, if models attempt to isolate and test the impact of variables, which cannot be isolated, in reality, due to functional inter-relationships (for example, what if sales and supply¹⁴ were separated). The latter is also applicable to human behavior¹⁵ related scenarios. To transform the output of these tools¹⁶ to deliver meaning, resilience¹⁷ and relevance¹⁸ in the real world, the simulated data (use of agents¹⁹) from pareto-optimal outcomes, may be targets which development economics must aspire to attain. For example, to reduce morbidity from diarrhoea by 10% we must increase availability of water by 20% and supply of cooking gas by 5%. On one hand, these numbers (outcome) may guide local municipalities or NGOs or development teams, to catalyze this change through capacity building and/or assess the risk²⁰ of economic²¹ loss if the situation is unattended. On the other hand, data-driven²² outcomes driving decision support²³ tools may guide policy²⁴ and loan managers, in global financial²⁵ institutions, to enable²⁶ financial structures necessary to deliver global²⁷ public goods. Convergence of concepts in physical and digital connectivity²⁸, classical operations research²⁹ with educational use³⁰ of simulation tools may promote systems thinking³¹, which is essential for science³² to better serve³³ society³⁴. Understanding causation³⁵ and true correlation is necessary to avoid hype³⁶. Our ability to use these tools are limited, yet necessary for medicine, farming and optimizing milk production.

¹ <https://ncase.me/loopy/>

² https://www.systemdynamics.org/assets/conferences/2004/SDS_2004/PAPERS/381BORSH.pdf

³ <https://www.tandfonline.com/doi/abs/10.1080/01441647.2012.745632>

⁴ <https://arxiv.org/ftp/arxiv/papers/1108/1108.3235.pdf>

⁵ <http://www.thwink.org/sustain/glossary/SystemDynamics.htm>

⁶ <https://www.techrepublic.com/article/systems-thinking-with-a-chromebook/>

⁷ <https://tangible.media.mit.edu/project/airportsim/>

⁸ <http://vensim.com/vensim-software/>

⁹ <https://doi.org/10.1016/j.phpro.2012.03.263>

¹⁰ https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NERL&dirEntryId=310977

¹¹ <https://www.systemdynamics.org/tools>

¹² https://link.springer.com/content/pdf/10.1007%2F978-0-387-74157-4_45.pdf

¹³ <https://thesystemsthinker.com/from-spreadsheets-to-system-dynamics-models/>

¹⁴ <https://tangible.media.mit.edu/project/tangible-business-process-analyzer/>

¹⁵ <http://dx.doi.org/10.1016/j.jenvman.2017.04.036>

¹⁶ <http://sysdyn.simantics.org/>

¹⁷ http://web.mit.edu/scresponse/repository/Rice_SCRsp_Article_SCMR.pdf

¹⁸ <https://rmas.fad.harvard.edu/pages/change-control>

¹⁹ <https://dspace.mit.edu/handle/1721.1/41914>

²⁰ <https://link.springer.com/content/pdf/10.1007%2Fs13753-017-0154-5.pdf>

²¹ <https://doi.org/10.1007/s13753-018-0190-9>

²² <http://science.sciencemag.org/content/359/6373/325>

²³ <https://www.researchgate.net/publication/267635903>

²⁴ <https://issues.org/esty-2/>

²⁵ <https://www.brettonwoodsproject.org/2005/08/art-320747/>

²⁶ <https://www.ebrd.com/downloads/research/guides/finance.pdf>

²⁷ <https://nautilus.org/gps/applied-gps/global-public-goods/what-are-global-public-goods/>

²⁸ <http://dx.doi.org/10.1109/JIOT.2017.2755620>

²⁹ <http://www.bookmetrix.com/detail/book/7153d069-09a3-4211-a6cf-34588ef367e9#reviews>

³⁰ <http://supplychain.mit.edu/supply-chain-games/beer-game/>

³¹ <http://www.sfu.ca/~vdabbagh/Forrester68.pdf>

³² <https://theconversation.com/marie-curie-and-her-x-ray-vehicles-contribution-to-world-war-i-battlefield-medicine-83941>

³³ <http://science.sciencemag.org/content/295/5557/929>

³⁴ https://preventioncentre.org.au/wp-content/uploads/2018/08/080818_Diabetes_FactSheet.pdf

³⁵ <http://links.jstor.org/sici?sici=0012-9682%28196908%2937%3A3%3C424%3AICRBEM%3E2.0.CO%3B2-L>

³⁶ <https://www.amazon.com/Freakonomics-Economist-Explores-Hidden-Everything/dp/0060731338>

“SIGNALS” contains a series of essays spewing amorphous thoughts:

1. SITS
2. SIP-SAR
3. SARS♠AG
4. ART ----- **You are here**
5. PEAS

Please review “SIGNALS”

- Download PDF from MIT Library

<https://dspace.mit.edu/handle/1721.1/111021>

Alternate <http://bit.ly/SIGNALS-SIGNALS>

SIGNALS is part of the collection of essays (book)

“IoT is a Metaphor” (see Commentary E)

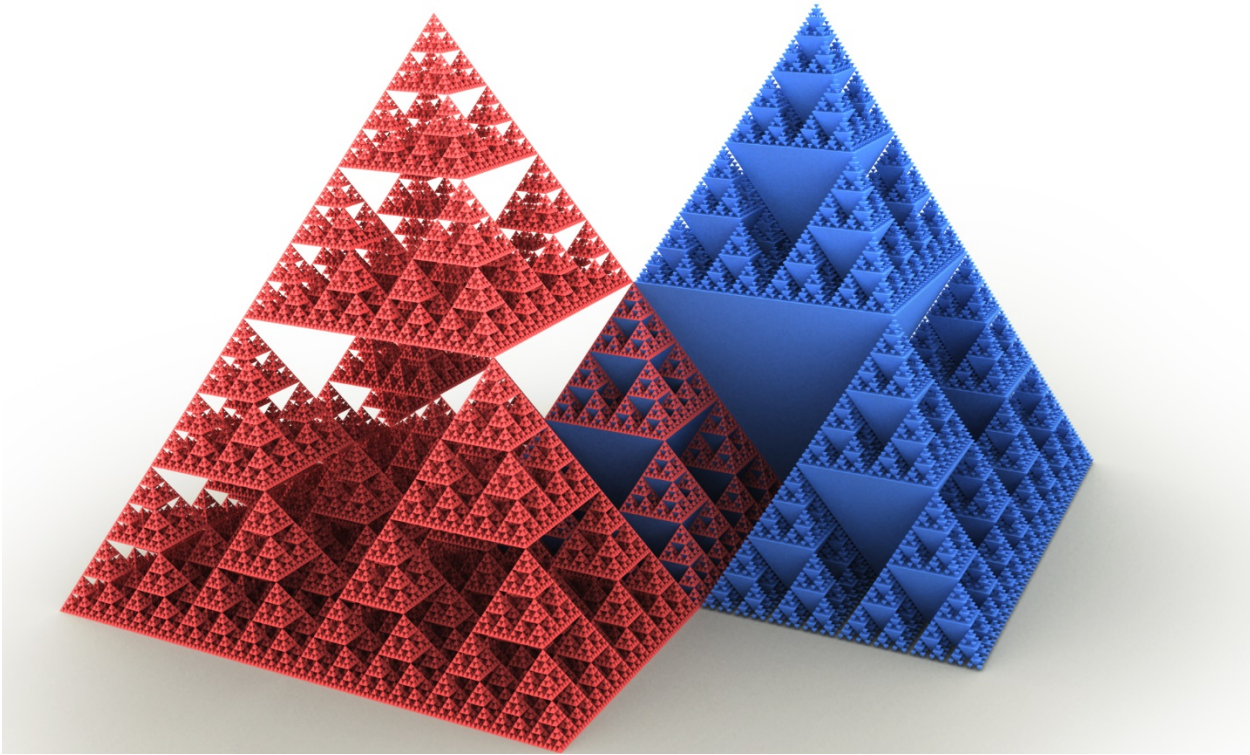
Please review “IoT is a Metaphor”

- Download PDF from MIT Library

<https://dspace.mit.edu/handle/1721.1/111021>

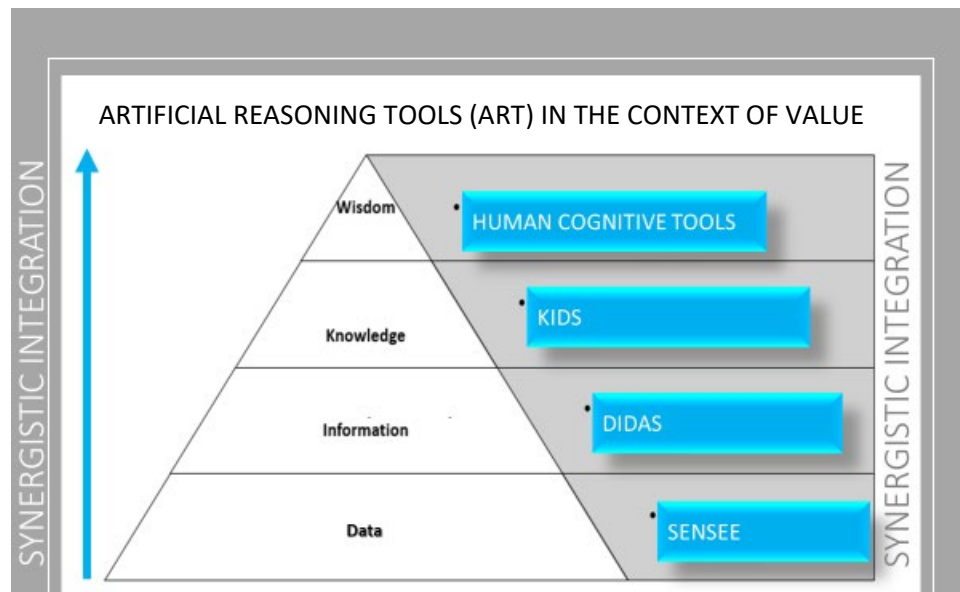
The page numbers in the PDF do not match the document page numbers at the bottom of the pages. This PDF is made up of a few separate documents which were then combined.

Hence, the temporary mis-match of page numbers. Apologies.



The **ART** of transforming these ideas into reality?

Shoumen Datta, MIT



SIGNALS

For the context of this discussion, please download “SIGNALS”

- PDF from <https://dspace.mit.edu/handle/1721.1/111021>
- Alternate <http://bit.ly/SIGNALS-SIGNALS>

The hypothetical ideas in this document outlines data related processes, **not** under implementation, yet. It suggests how we may start phase one (1.0): to create a proof of concept for SENSEE (**SEN**sor **SE**arch **E**ngine).

Draft will be frequently updated and may be downloaded from AWS using this short URL <http://bit.ly/SENSEE-PoC>



This project is a mini proof of concept (PoC) for “SENSEE 1.0” (excludes DIDA’S KIDS). See “PEAS Platform for the Agro-Ecosystem” and essays <http://bit.ly/SIGNALS-SIGNALS>

What do we want for SENSEE 1.0 demonstration purposes?

A short URL, which enables an app equivalent (web-service) on a smartphone. This app, when it opens on the phone, will reveal a dialog box. Users will type questions in the dialog box.

What is the purpose of the app for SENSEE 1.0 demonstration purposes?

Reply to queries related to the questions the user types in the dialog box. The questions will be of the type suggested (below and elsewhere). The answers will be sourced from the xl spread sheet, indicated below as “source” (please download xl from URL provided below). Decisions about sensor types is the expected outcome (at this phase, SENSEE 1.0 may only help sensor experts).

Type of questions that users may wish to ask using the dialog box (on a mobile device):

Deliverable for the mini proof of concept (PoC): answer natural language questions, for example:

[a] what is the LOD score for ionic mercury / mercury ?

[b] can I use graphene paper to detect E. coli ?

[c] is the ammonium ionophore liquid or solid ?

[d] what type of recognition tool do you have at hand for detecting imidacloprid ?

[e] what is the response time for superoxide dismutase ?

[f] what is the phase of the nitrate ionophore ? *Where semantics will come in (not now, in future).*

A detailed data dictionary (semantics) is not required. Query language will be restricted, for PoC.

Answers are in this spread sheet. The “raw data” pertains to sensor categories, attributes.

SOURCE - download xl from - <http://bit.ly/SENSOR-LIBRARY-ERIC-MCLAMORE>

FAQ - What is considered the primary key for the dataset?

This is NOT a data set. This is a reference for type of “tools for detection of molecules” that we refer to as sensors. Therefore, in database terms, the entire set of columns uniquely identifies rows in the table (but we can drop a few less populated columns, in the initial response. It is going to be useful when we move to knowledge graphs). At this time we are not presenting any data for the type of sensors in the xl sheet. When we have a “data set” which represents logged data from a specific sensor (SENSEE 2.0), then the *time stamp* on that data logger may be one of the primary keys to create a unique identifier. As this point we have a set of columns which are *all* key attributes for a sensor (perhaps think column headings as “features” for future phases.)

FAQ - Is there a codebook for column name headings (definitions / standards understood by non-expert users)?

No. This is not the vernacular that farm-users are likely to know or use. For the deliverable proof of concept, ignore the semantics of the column headings (it is a future task when we begin to use graph databases / semantic data catalogs - Fig 12 on page 29 <http://bit.ly/SIGNALS-SIGNALS>).

FAQ - Is there a specific metadata standard for this community of practice (e.g. common naming for data elements)?

[a] Explore SensorML and StarFL – review – <https://pubag.nal.usda.gov/catalog/1229146>

[b] Early XML implementations

<https://www.isprs.org/proceedings/xxxv/congress/comm4/papers/516.pdf>

https://www.iitk.ac.in/nicee/wcee/article/13_956.pdf

[c] STANDARDS

https://geo-ide.noaa.gov/wiki/index.php?title=SensorML_and_ISO_Metadata

<https://www.w3.org/TR/vocab-ssn/>

[d] REVIEW

<http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.562.8057&rep=rep1&type=pdf>

https://publik.tuwien.ac.at/files/PubDat_208567.pdf

<https://www.tandfonline.com/doi/pdf/10.1080/17538940902866195?needAccess=true>

<https://pdfs.semanticscholar.org/0999/630530af38c85f31ef2a6e2bb3f701da582b.pdf>

[e] THE ROAD AHEAD – FUTURE CONSIDERATIONS

<https://www.w3.org/2018/03/wot-f2f/slides/Mdata-WoT-2018-03-26MM.pdf>

<https://www.usgs.gov/land-resources/nli/landsat/science>

FAQ - How to document missing data/null values in columns MW [Da], LOD [M], Max range [M], etc. (e.g. “9999” or N/A)?

When SENSEE 1.0 is a working platform, these values may be contributed. The “open platform” and “open port” approach necessary in the SENSEE information architecture, in order that data can be ingested when we have raw data. SENSEE 1.0 is a database *for sensor device* reference, at this time. In SENSEE 2.0, we will offer a library of interfaces (APIs) that a 3rd party can download to upload *sensor-specific data*. SENSEE 2.0 expects to ingest *case-specific* sensor data (not there yet). In the context of SENSEE 2.0, feature engineering and feature selection (“selecting a few things that are most important, given that only a few can be sustained”) will guide selectivity of data ingestion depending on compatibility between SENSEE 2.0 metadata vs external sources. Publishing “libraries of tools to enable interoperability between databases and data formats” as downloadable tools from the SENSEE portal may help to ensure that we are providing users the *ability to collaborate* even if [a] they are in Cairo, Cardiff, Cali or Calcutta and [b] their data schema, style sheets and data holders may not match SENSEE. Open APIs, open platforms and interoperability must be an integral part of the data management plan. Open information architecture may catalyze distributed data collection to strengthen SENSEE, ART and build toward a “Google of ag” approach, as we move beyond SENSEE (1.0, 2.0) and ART to meet the challenges of DIDA’S KIDS (please see “PEAS Platform for the Agro-Ecosystem”).

Additional information to address potential question - What are the common data elements for column standardization [e.g. Is the LOD [M] the same as Range (LOD)?]

The value is a concentration expressed in the standard form. Range (xl sheet) should be bounded or display the lowest detectable. Limit of detection (LOD) is defined as the lowest concentration (hence, value in nanomoles, micromoles, millimoles) at which 95% of positive samples are detected. LOD is not necessarily within the linear range of an assay. LOD can be lower than Lower Limit of Quantification (LLOQ), defined as the lowest standard on the calibration curve. For further details, explore: <https://www.fda.gov/downloads/Drugs/Guidances/ucm070107.pdf>

ELEMENTS OF A BIGGER PICTURE – IDEAS BEYOND THE PROOF OF CONCEPT

Information arbitrage (PEAS Platform for the Agro-Ecosystem), ART, data-informed decision support for the agro-ecosystem (DIDA'S) and the food industry are expected outcomes. A few steps of this scenario are outlined. Target (?) is to deliver [I] through [V] for FY 2019-2020.

[I] PoC delivers app to return limited number of queries based on sensor description (xl sheet)
Result: <http://146.185.133.187/SENSEE/> ● <http://139.162.7.63/SENSEE/>

Task: App responds to query about a few sensor descriptions. Host and maintain app and DB. Provide URL to download web service and continue to bolster search functions (SENSEE 1.0).

Comments: Hard coding exact questions (syntax) is inadequate. Elasticsearch and NLP, for example, BERT (Bidirectional Encoder Representations from Transformers) is preferred and/or necessary (<https://arxiv.org/pdf/1706.03762.pdf>, <https://github.com/google-research/bert> and <https://arxiv.org/abs/1905.05950>). NLU/NLP engine may be trained to search keywords in the user's question and may eliminate the need for users to abide by restrictive syntax. At this time, the extent of the library and framework is extremely limited (only one xl sheet provided, others are expected). Therefore, the demand for NLP techniques may be rudimentary and limited to effective text representations and extraction of keywords from natural language queries.

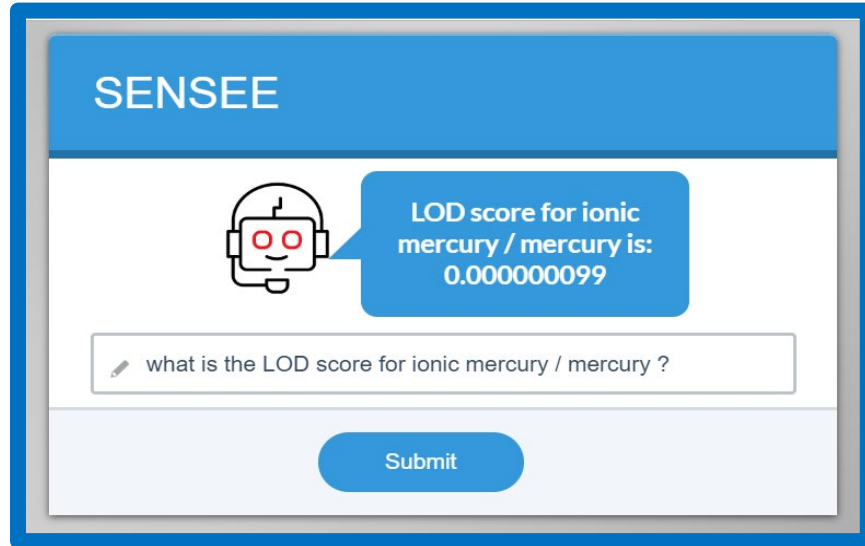
Advanced NLP expertise, semantic extraction techniques, data structures and modeling, will be required when volume and variety of sensor descriptions are likely to increase. The UI for Q&A using a web service (<http://appinventor.mit.edu>) is expected to remain simple. For more on BERT NLP explore: <http://mlexplained.com/2017/12/29/attention-is-all-you-need-explained/>

[II] Create auto-config xl tool which can be downloaded to upload sensor details (100-1000 labs)
Target: 2019

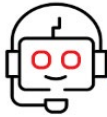
Task: Expand and scale the system to contain other types of sensors created by other labs.

Comments: How will these other labs accomplish this task? How will the other labs add to the DB? How will they create and populate new columns if the descriptor/characteristic is not present in the current DB? Most labs maintain sensor type descriptions as tables (CSV, xl). Provide a short URL which will lead to a “tool” which can be downloaded and serve as a document management system (DMS) to accept the xl document with sensor descriptions. The uploaded (ingested) document will be parsed and analyzed by system “software” using keywords (think search engine optimization). The existing DB will be updated if the table/column headings are a match. Consider these tasks: [i] Online job application sites where the resume is uploaded to a site and the portal populates its “boxes” (fields) by extracting information from the uploaded resume using metadata tools. The vast number of errors in this process often requires editing (by the user) because the rules of the parser are shoddy.

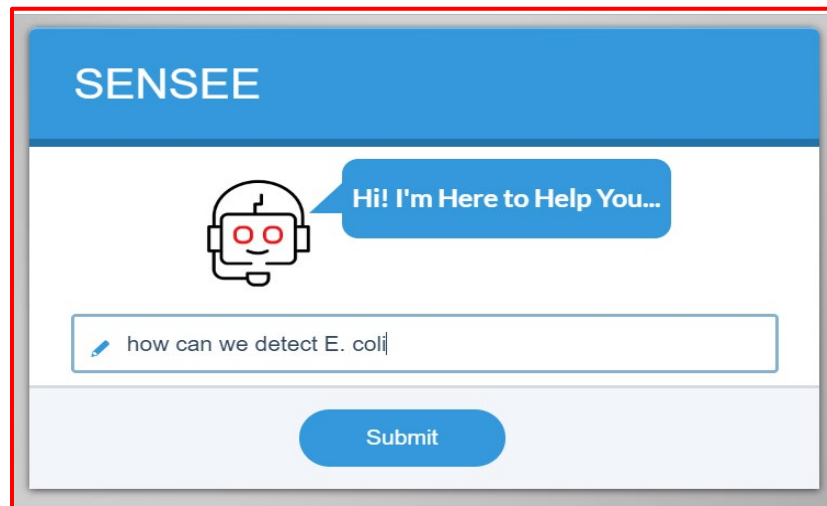
Step I – Dialog Box – <http://146.185.133.187/SENSEE1/> ● <http://139.162.7.63/SENSEE/>




SENSEE

 LOD score for ionic mercury / mercury is: 0.000000099

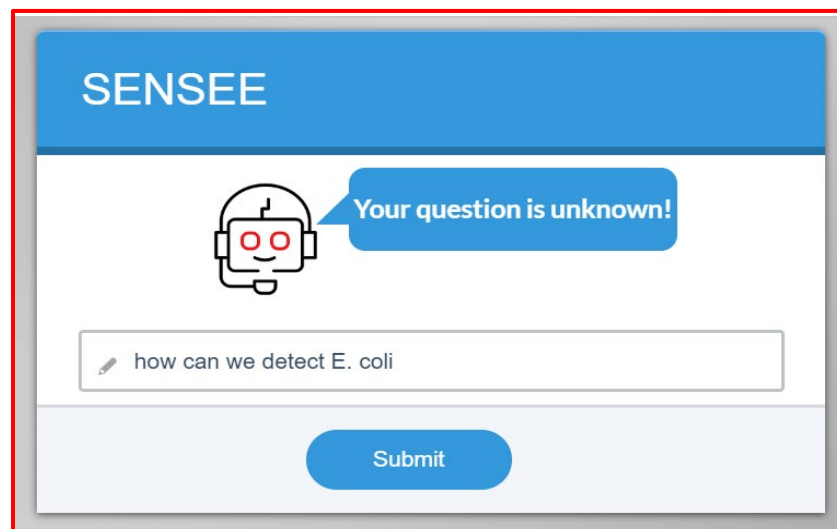
Submit




SENSEE

 Hi! I'm Here to Help You...

Submit

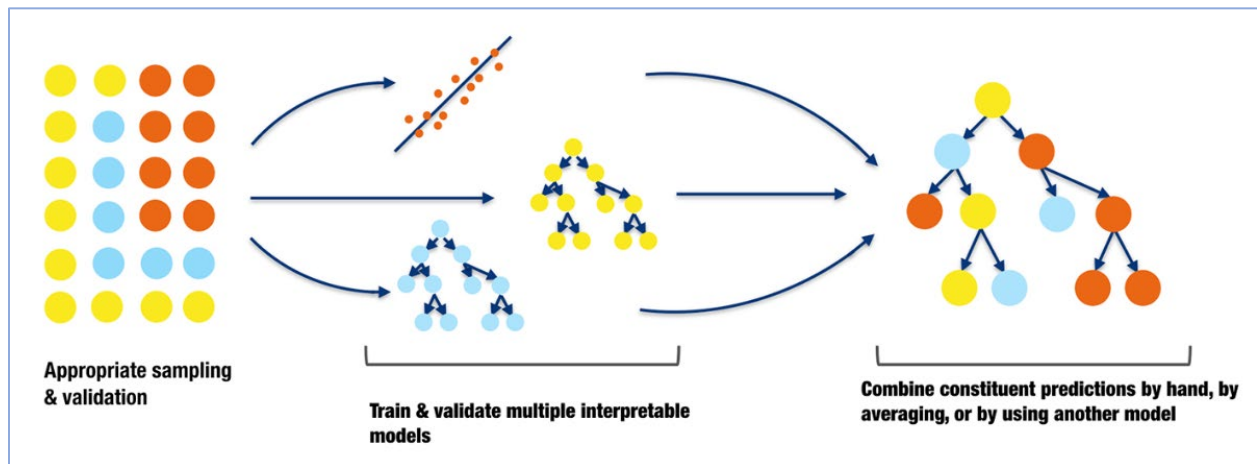
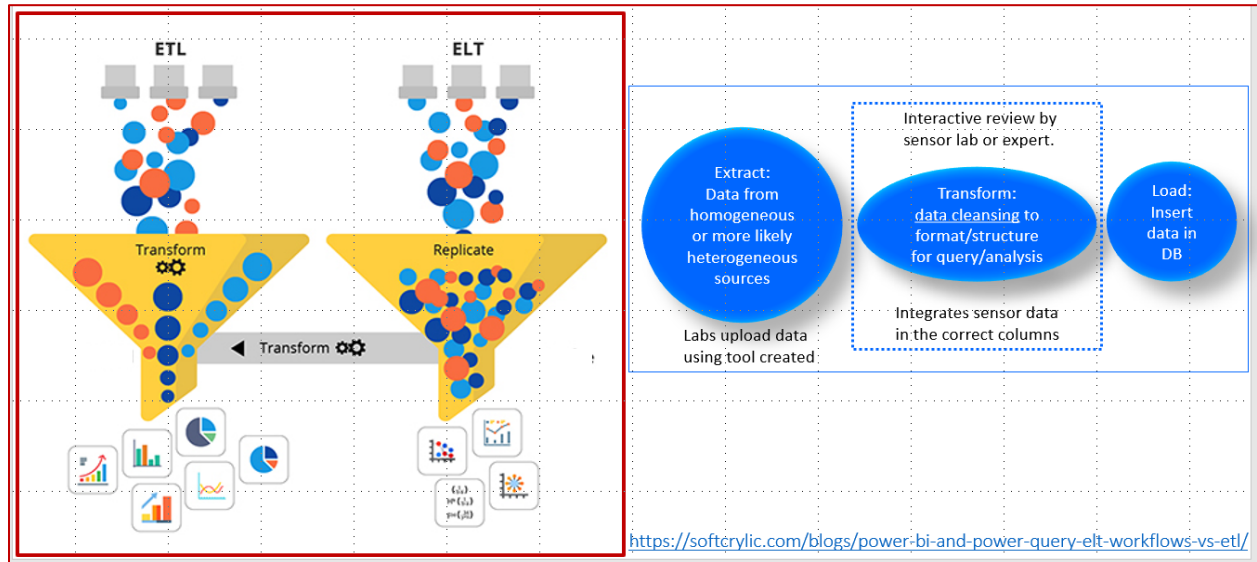
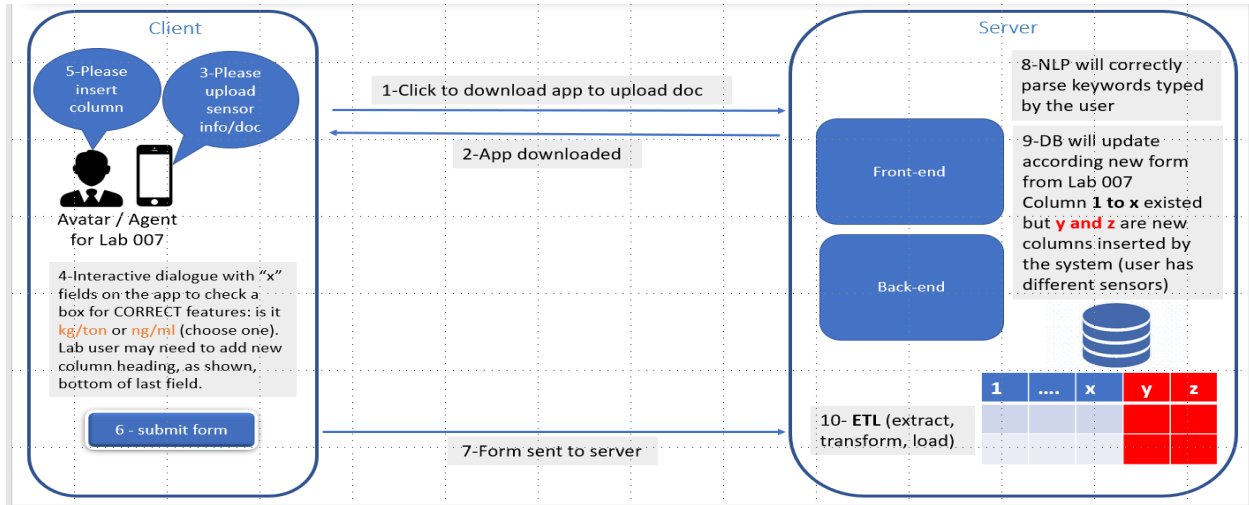


SENSEE

 Your question is unknown!

Submit

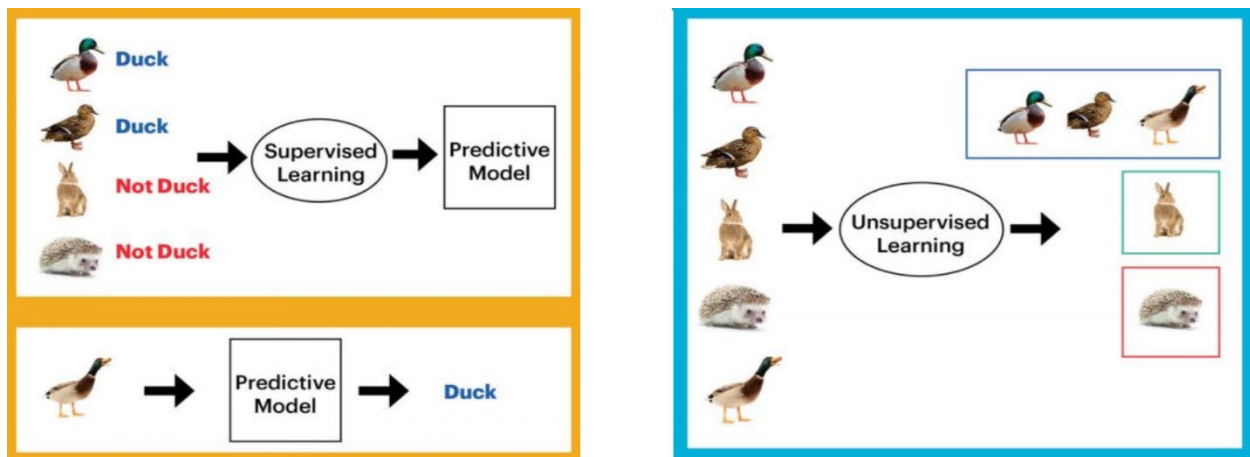
Suggested cartoon for Step II where “tool” may be downloaded via web service/mobile app



[ii] Online tax preparation systems cannot afford to be shoddy and has developed far better protocols to insert parsed data from uploaded documents (eg W2, W4, 1099 forms). In addition, the software (eg <https://turbotax.intuit.com/>) may serve as an example of (workflow) interacting with automatically-generated features and interpretation of incoming unstructured (data) sensor description. The value of this software is in the underlying dependencies and UI prompting users to accept or reject the suggestions (see <https://www.youtube.com/watch?v=WLaXFYIF4x8>).

SENSEE 1.0 tool in step II must be better than resume uploaders and approach the sophistication of the tax preparation packages. The example of tax prep software is relevant for the application in this PoC because it will allow labs to verify uploaded descriptions and characteristic values. It will be helpful (and perhaps necessary) if the DB can be auto “expanded” to create/include new column headings if a new criteria/characteristic is uncovered.

The interactive Q&A type “accept/reject” option in the tax prep software, if implemented in the tool to ingest sensor description data (in SENSEE 2.0 we will ingest and aggregate actual sensor data), will reveal a dataset of “wrong” answers when the user rejects the suggested field value. It is crucial to capture this “what was predicted” vs “what was accepted” “what was rejected” because the correct, and the incorrect input, *both*, are useful to “classify” what is correct and what is incorrect. Hence, the strength of this approach is in creating datasets for supervised learning (classification algorithms, for example, in the illustration below – duck / not duck).



When using this tool to aggregate SENSEE 1.0 sensor description data (1,000 labs?), it will be important that the application captures every recommendation shown to a user, and the outcome. The major challenge in this approach is the demand for domain specific knowledge (in this case, sensor engineering) and the ability of the individual(s) with domain knowledge to work with a software specialist who has some understanding about the domain. In order to recommend options to the user, the software must rely on a set of rules, dependencies and logic structures, which are relevant to the context of the use (in this case, sensors). For example, the units for the concentration of mercury in a sample may be in ng/ml or in mg or ppb but not in kg/ton or cubic feet. To reduce computational load, perhaps kg/ton or cubic feet, will be excluded as options, to reduce search space, and compress time to search (these metrics will be useful for evaluation).

It may be informative to review Claude Shannon's "Programming a Computer to Play Chess" (<https://vision.unipv.it/IA1/aa2009-2010/ProgrammingaComputerforPlayingChess.pdf>) where he coded into the program, knowledge of "weak positions" to limit the search space. Could we use techniques with unstructured documents with sensor information and limit the search space, for example, using topic modeling? In trying to implement these techniques, one cannot escape the need for convergence of domain knowledge with software and principles of machine learning, in tool design. (www.historyofinformation.com/detail.php?entryid=4364 and <https://journals.sagepub.com/doi/10.1177/0306312711424596>).

Recommended skill development: To combine sensor data domain expertise with machine learning. Train sensor experts to understand software and machine learning principles and vice versa (machine learning and programmers to grasp the basic tenets of sensor engineering). An exercise for students at UC Berkeley uses resume parsing. The task was to take "pasted-in" text from resumes (just normal ASCII text, no rich PDFs or other formats) to extract "skills" from the content. Using this knowledge, the task was to recommend one skill to a person, which, if acquired, may lead to a recommended job (the skill set the person already possess is one skill away from the recommended job). The goal was to provide guidance for veterans entering civilian life (<https://www.shift.org/>). Topic modeling was accomplished using genism (<https://www.machinelearningplus.com/nlp/topic-modeling-gensim-python/> and also <https://github.com/RaRe-Technologies/gensim>). See <https://github.com/jameslamb/skills> and view <http://bit.ly/JAMES-UC-BERKELEY>

[III] Create 'feature' library / downloadable 'feature tool' to extract sensor details (>1,000 labs)
Target: 2019 ● http://www.jmaxkanter.com/static/papers/DSAA_DSM_2015.pdf

Task: Accomplish the same as [II] but for >1,000 labs.

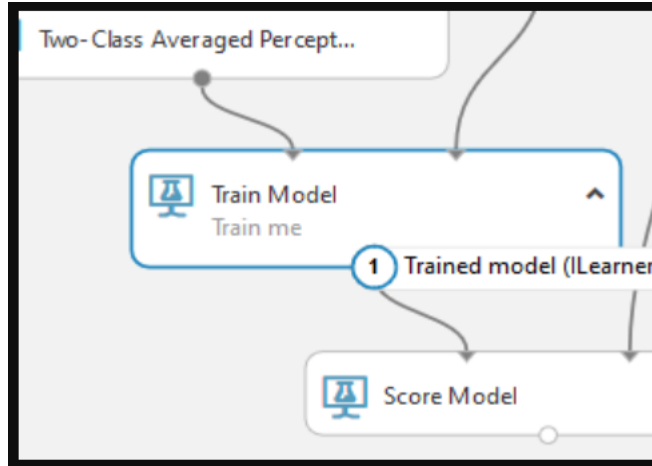
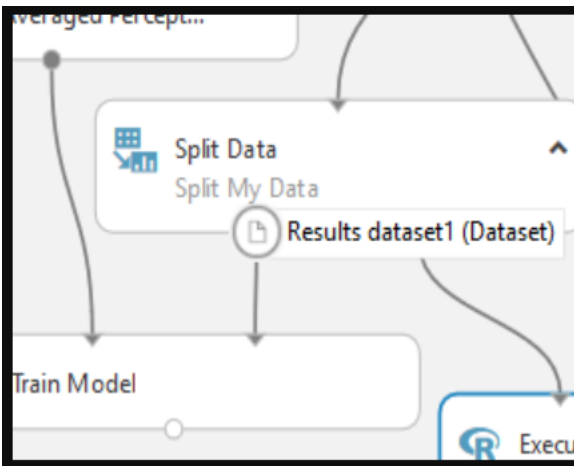
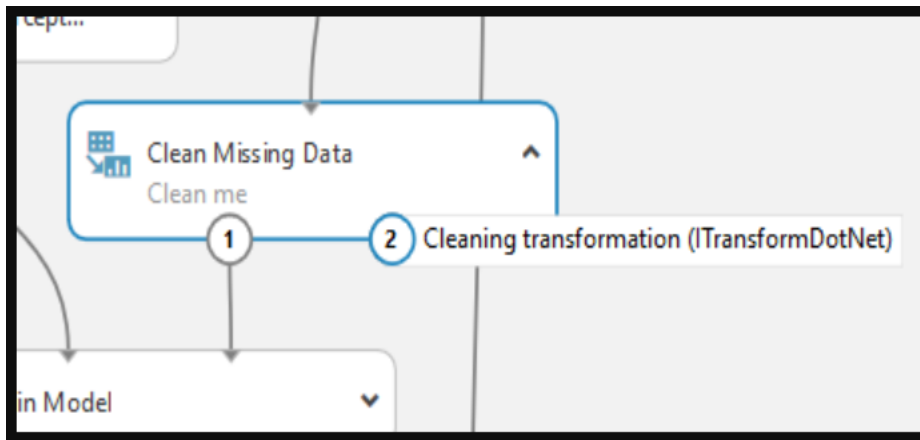
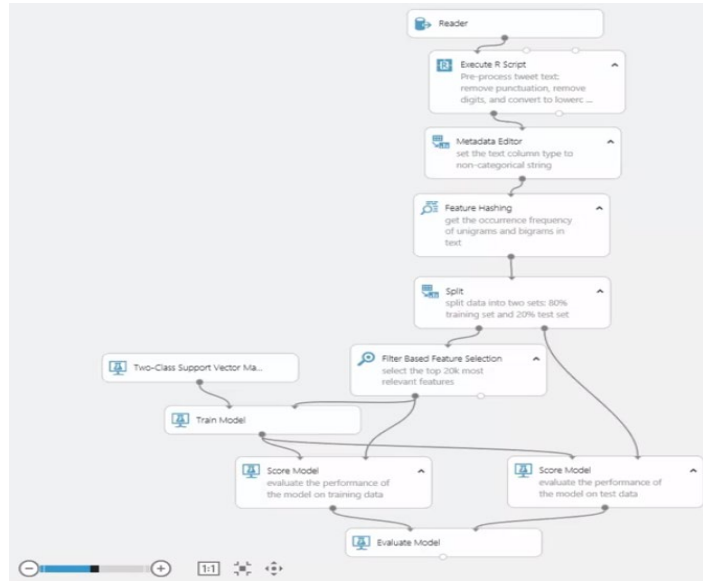
Comment: Using repository SENSEE 1.0, select features that can accommodate variety of possibilities (expected sensor types from >1,000 labs). Feature selection and feature engineering must serve at least two purposes, the software must be able to operate as a search engine and extract the feature from publications/papers related to sensors (search engine, ML, limited to the library of features). In SENSEE 2.0, feature-guided ingestion of sensor-specific data (pH, salts, temperature, analyte) where the brand of the sensor may be different (different manufacturers) but the pH data from all/any pH sensor, can be pooled into a database using the selected feature (populate the data, that is the pH data, for selected feature pH). The aim of this PoC (at this time) is to create SENSEE 1.0 as a repository for different types of sensors by aggregating *sensor descriptions* from labs, worldwide (see examples in xl sheet, link on page 3). When completed, combined SENSEE 1.0 and SENSEE 2.0 is expected to fuel *artificial reasoning tools* (ART).

[IV] Automated feature tool linked to sensor search engine SENSEE 1.0 (scale to 10,000 labs?)
Target: 2020 ● <https://blog.featurelabs.com/deep-feature-synthesis/>

Task: "Drag & Drop" tool to gather sensor type (*later*, sensor data in SENSEE 2.0). Distributed tools: feature automation ● <https://people.eecs.berkeley.edu/~dawnsong/papers/icdm-2016.pdf>

Comment: Build feature engineering "engines" to process unstructured data and automate tools to arrange it "meaningfully" to serve queries. Idiot-proof "for dummies" interface is provided to users who may rearrange "modules" (data description, knowledge extraction) using *drag & drop* tools, perhaps similar to Lego Mindstorm (www.lego.com/en-us/mindstorms/learn-to-program).

DRAG AND DROP USER INTERFACES - AGNOSTIC ABOUT USER'S KNOWLEDGE OF PROGRAMMING
 NEXT GEN LEGO MINDSTORM - EXAMPLE FROM MICROSOFT AZURE MACHINE LEARNING STUDIO



Source: <https://github.com/hning86/azuremlps>

In this approach, users are **not** required to understand programming, logic and underlying processes. If the masses are not inhibited from using the tool, it will accelerate the diffusion of the tool. Democratization of access through lego-esque, modular “drag and drop” user friendly interfaces, will catalyze adoption of the tool, not only in the agro-ecosystem (the discussion in <http://bit.ly/SIGNALS-SIGNALS>) but in any domain, for example, healthcare, manufacturing (think digital twins <https://arxiv.org/abs/1610.06467>), finance, oil & gas, logistics and transport.

Effective and efficient auto-generation and selection of features by modeling information about features (Dawn Song - <https://people.eecs.berkeley.edu/~dawnsong/>) is a milestone development, we wish to embrace. Using machine learning to *describe features of features* and form better expectations of which features might be worth generating and testing, is an incisive advance. ExploreKit feature automation approach is a positive evolution from the brute-force, opaque, model-based approaches to data transformation, which are still a part of machine learning (ML), for example, back propagation (<https://www.nature.com/articles/323533a0>) and random forests (<https://link.springer.com/content/pdf/10.1023%2FA%3A1010933404324.pdf>).

In FeatureLabs (<https://idss.mit.edu/staff/kalyan-veeramachaneni/>), feature engineering is performed relative to richer descriptions of input data and successfully applied for commercial purposes by corporations (Einstein AutoML <https://www.salesforce.com/video/1776007/> and <https://github.com/salesforce/TransmogriAI/tree/master/features/src/main/scala/com/salesforce/op/features>; also see – improving AutoML transparency – <https://arxiv.org/pdf/1902.05009.pdf>).

One aim of this project is to partner with bonafide experts to create open feature automation tools. The principles, as indicated above, will be applicable to a broad spectrum of applications.

[V] Gift SmartPath SENSEE tool (USDA/NIFA/NSF) - national/global sensor data repository
Target: 2020

Task: Monitor and Model → Detect and Predict → Diagnose and Explain → Decide and Act (actions generate outcomes, which are monitored, and the data-informed process is repeated).

Comment: Open tool will democratize access to data and can be adapted for other domains.

Future Scope (FS)

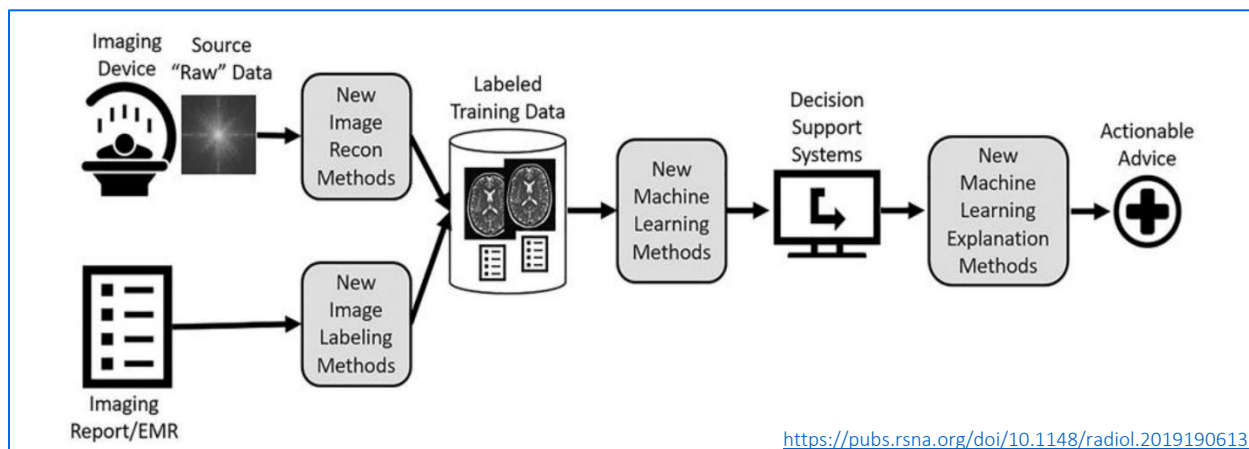
[FS-VI] Development of SERVICE – “PEAS Platform for Agro-Ecosystem” for users. Farmers and growers (food) seeking solutions from logic tools and help from ART. (Target FY 2021)

[FS-VII] Pay-A-Penny-Per-Use (**PAPPU**) data-informed decision as a service (**DIDA’S**) is a far-fetched fusion between data, science, systems and social business. Convergence of [V] and [VI] creates value from uber connectivity between sensors and may provide “meaningful” outcomes. The “meaning” will evolve if we develop tools (II, III, IV) to get the data into a form where it is anomaly-free and structured for use by logic tools in ART. Later, use of math-stat functions and ML. Turning statistical functions (or mathematical formulae) into algorithms, is not trivial. The rate limiting step is human resource. Teams must possess the confluence of skills to understand system science (sensor engineering), data science (stat, math, programming, computation) and *converge* it with their depth in *domain knowledge*, to address and solve, real-world problems.

This PoC is not a “software job” and professional programmers are unlikely to succeed because very few classical programmers can generate an/any optimizing sort algorithm, from scratch. What is referred to as “data science programming” is a type of app development which uses a set of pre-defined frameworks along with specific domain knowledge (in this case statistics) to create solutions. Before R and Python, "data science" was executed on spreadsheets, followed by statistical software (SAS, SPSS, statistical package for social sciences) in the era of desktops.

Data-informed service for the agroecosystem must be hyper-mobile, with high fault tolerance, operate close to the point of action (edge) in near real-time, accommodate engineering elements which are diverse, operate seamlessly agnostic of data standards or structure and must service consumer/user demands which may change often or fluctuate rapidly. Dynamic composability of data and synthesis of information, relevant to the context, is the desired outcome, even for **ART**.

[FS-VIII] Entrepreneurial Innovation – Users may pay for this service (see PAPPU DIDA’S) if we create a visual tool for non-expert end-users to grasp the curated information in SENSEE and how it may integrate with sensor data (**ART**) and machines (digital twins). To democratize access, this PoC advocates intuitive/cognitive maps (re-think Lego Mindstorms and topology optimization software, for example, see www.ansys.com/) which offers “drag and drop” icons (tactile, haptics) to orient users and catalyze the connectivity and complexity with lucidity, clarity and brevity. **Educating** and enabling users to make sense of the organization of unstructured knowledge will immensely demystify “blackboxes” and aid in the diffusion of **ART** tools, leading to reasonable adoption. By providing a mechanism to represent existing information, knowledge graphs in logic tools describe and enable access to other information sets. Diffusion of **ART** may lead to a better educated crowd and improve crowd-sourced (farmers, growers) **architecture to access knowledge**. It is a prelude to the development of an open platform for convergence of data and information, in a meaningful context, to move beyond logic tools in **ART** to data-informed **DIDA’S** and then to **knowledge-informed** decision as a service (**KIDS**). In 1980’s decision science, DIDAS (https://link.springer.com/chapter/10.1007/978-3-662-21637-8_2) was a control theory concept. The use of DIDA’S in this document is also about decisions and, in principle, it may resonate with “DIDAS Family” (for automatic control). The sense of **DIDA’S** in this PoC is a step after **ART** and before **KIDS**. Beyond knowledge, the extraction of ‘experience’ may enrich the outcome from **KIDS**, but it will be difficult and must include agent-based selection (**ABS**).



In the short term, to deploy **ART**, we expect to create SENSEE 1.0 and improve its ability to deal with a broad range of questions, before sourcing sensor-specific data for SENSEE 2.0 PoC.

- 1) Which sensor in the McLamore lab has the highest sensitivity?
- 2) Which sensor in the McLamore lab has the lowest LOD?
- 3) Which sensor in the McLamore lab has the highest selectivity?
- 4) Which sensor in the McLamore lab has the fastest response time?
- 5) Which sensor in the McLamore lab has the highest durability?
- 6) What is the most durable glass capillary sensor?
- 7) What sensors can be fabricated on conductive paper?
- 8) What sensors can be made with nanocellulose?
- 9) What sensors can be made with cabbage extract/anthocyanin?
- 10) What sensors are used for hydroponics research?
- 11) What sensors are used for irrigation water research?
- 12) What sensors are used for cell culture research?
- 13) What sensors are used for lake water research?
- 14) What sensors are used for wastewater research?
- 15) What sensors are used for plant roots research?
- 16) What sensors are used for coastal monitoring/seawater research?
- 17) What sensors are used for tissue culture research?
- 18) What sensors are used for stem cell development research?
- 19) What sensors are used for differentiated stem cells/neurons research?
- 20) What sensors are used for wound dressings research?
- 21) What sensors are used for osteoblast/osteoclast research?
- 22) What sensors are used for INS1 cell research?
- 23) What sensors are used for blood research?
- 24) What sensors are used for human tears research?
- 25) What sensors are used for mouse pancreas research?
- 26) What sensors are used for honeybee wax research?
- 27) What sensors are used for honeybee honey research?
- 28) What sensors are used for saliva research?
- 29) What sensors are used for food product research?
- 30) What sensors are used for food packaging research?
- 31) What sensors are used for juice research?
- 32) What sensors are used for soup/broth research?
- 33) What sensors are used for ice cream research?
- 34) What sensors are used for drinking water research?
- 35) How many sensors measure H⁺/hydronium ion/hydrogen?
- 36) How many sensors measure NH₄⁺/ammonium ion?
- 37) How many sensors measure NO/ nitrogenous radical/nitrous oxide?
- 38) How many sensors measure H₂O₂/O₃ oxygen radical/hydrogen peroxide?
- 39) How many sensors measure DO/dissolved oxygen?

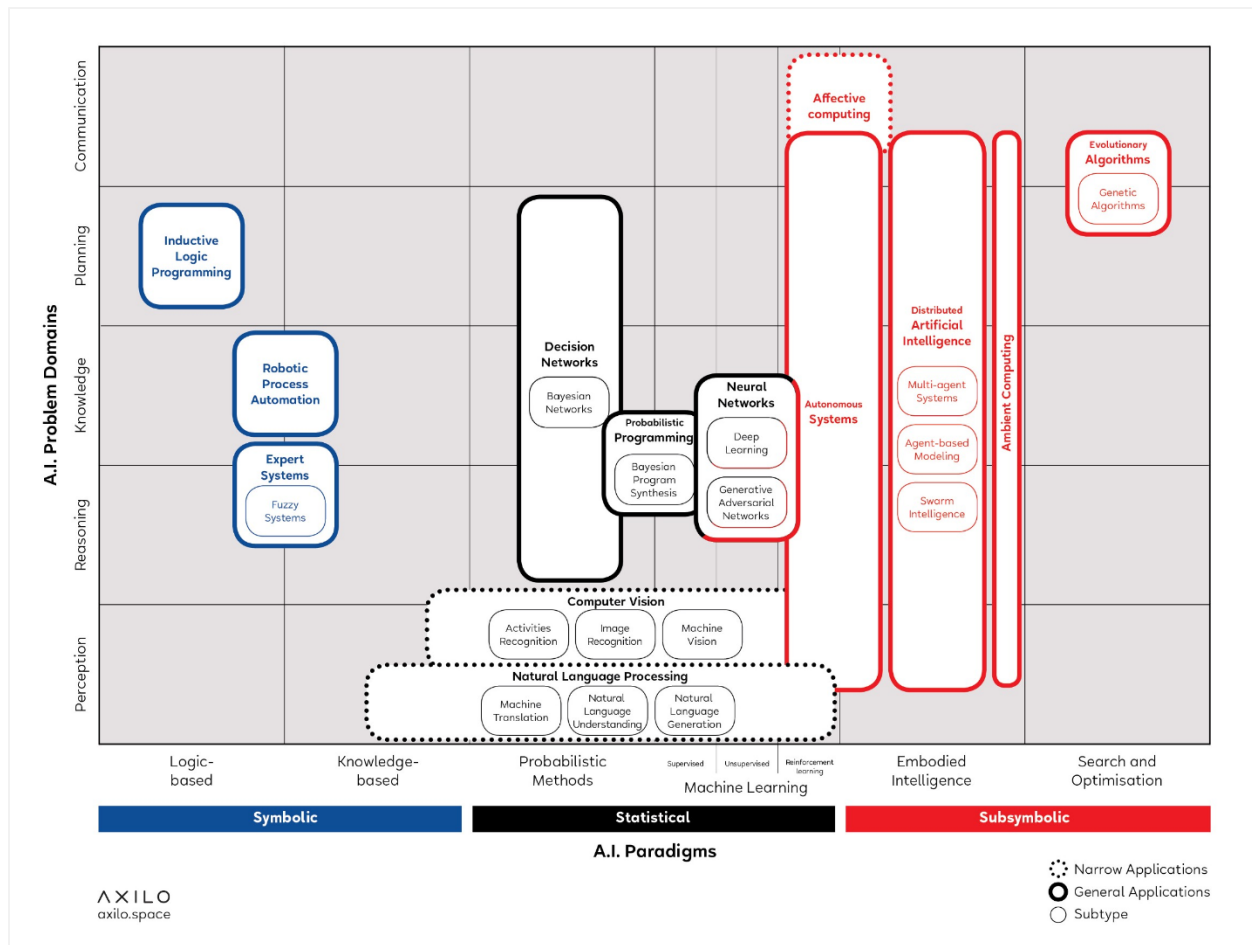
- 40) How many sensors measure K⁺/potassium ion?
- 41) How many sensors measure Ca²⁺/calcium ion?
- 42) How many sensors measure CH₃COO⁻/acetate?
- 43) How many sensors measure NO₂⁻/nitrite?
- 44) How many sensors measure NO₃⁻/nitrate?
- 45) How many sensors measure Ag⁺/silver?
- 46) How many sensors measure histamine?
- 47) How many sensors measure glutamate?
- 48) How many sensors measure catecholamine?
- 49) How many sensors measure indole acetic acid?
- 50) How many sensors measure malate?
- 51) How many sensors measure glucose?
- 52) How many sensors measure ionic mercury?
- 53) How many sensors measure methyl mercury?
- 54) How many sensors measure paraoxon?
- 55) How many sensors measure ATP/adenosine triphosphate?
- 56) How many sensors measure MBF1/multi bridging factor 1?
- 57) How many sensors measure interferon gamma?
- 58) How many sensors measure superoxide dismutase?
- 59) How many sensors measure E. coli?
- 60) How many sensors measure E. coli O157:H7?
- 61) How many sensors measure Salmonella?
- 62) How many sensors measure Listeria monocytogenes?
- 63) How many sensors measure Campylobacter?
- 64) How many sensors use carbon nanotubes?
- 65) How many sensors use graphene?
- 66) How many sensors use graphene oxide/ GOx?
- 67) How many sensors use graphite?
- 68) How many sensors use glassy carbon?
- 69) How many sensors use liquid ionophore membrane?
- 70) How many sensors use solid state ionophore membrane?
- 71) How many sensors use nanoplatinum?
- 72) How many sensors use nanoceria?
- 73) How many sensors use nano titanium dioxide/nTiO₂?
- 74) How many sensors use nano zinc dioxide/nZnO₂?
- 75) How many sensors use platinum porphyrin dye?
- 76) How many sensors use fractal materials?
- 77) How many sensors use nano palladium/nPd?
- 78) How many sensors use diamine oxidase?
- 79) How many sensors use aptamer?

- 80) How many sensors use antibody?
- 81) How many sensors use lectin?
- 82) How many sensors use phage?
- 83) How many sensors use alkanethiol?
- 84) How many sensors use nano copper/nCu?
- 85) How many sensors use copper oxide/Cu₂O?
- 86) How many sensors use phosphotriesterase?
- 87) How many sensors use chitosan/CHI?
- 88) How many sensors use PNIPAAm/ poly(N-isopropylacrylamide)?
- 89) How many sensors use hydrogel?
- 90) How many sensors measure CIP2A/ Cell Proliferation Regulating Inhibitor of Protein Phosphatase 2A?
- 91) How many sensors measure internalin A/ InLA?
- 92) How many sensors use concanavalin A / ConA?
- 93) How many sensors use mannose-binding lectin ?
- 94) How many sensors use C-type lectin?
- 95) How many sensors use specific intercellular adhesion molecule-3-grabbing nonintegrin / SIGN-R1?
- 96) How many sensors use wheat germ agglutinin N-type lectin?
- 97) How many sensors use lectin for N-acetyl-D-glucosamine (NAG)?
- 98) How many sensors use F-type lectin?
- 99) How many sensors use fucose binding lectin / FUC?
- 100) What sensors can be fabricated with glass capillary?
- 101) What sensors can be fabricated with graphene paper?
- 102) What sensors can be fabricated with laser scribed graphene/laser inscribed graphene?
- 103) What sensors can be fabricated with a platinum/iridium electrode?
- 104) What sensors can be fabricated with a 96 well microtiter plate?
- 105) What sensors can be fabricated with Pt/Ir microelectrode wire?
- 106) What sensors can be fabricated with a gold IDE?
- 107) What sensors can be fabricated with DropSense IDE?
- 108) What sensors can be fabricated with Zensor SPE?
- 109) What sensors have the lowest LOD **AND** the highest selectivity?
- 110) What sensors have the highest LOD **AND** the lowest selectivity?
- 111) What sensors have the lowest LOD **AND** the lowest selectivity?
- 112) What is the cheapest **AND** most reliable sensor for measuring mercury in water?
- 113) Which sensors can I use to detect pathogens in juice?
- 114) What is the smallest amount of glucose that a sensor can detect in tears?
- 115) Are paraoxon sensors commercially available in Canada?
- 116) How long does it take to detect salmonella with a biosensor?

- 117) How stable are LSG sensors?
- 118) What chemical components of hydroponic media can be measured with sensors?
- 119) Which sensors can be used to detect toxins in breast milk?
- 120) What is the simplest **AND** most cost-effective sensor platform for detecting glucose in buffer?
- 121) What sensors are available for testing pollutants in lake water?
- 122) What is the most common material used for fabricating hydrogen sensors?
- 123) What is the most versatile glucose sensor?
- 124) What's the most popular material platform for building ammonium sensors?
- 125) What is the lowest detection limit for ATP sensors?
- 126) How specific are calcium sensors?
- 127) Do listeria sensors have a high chance of producing false positive results?
- 128) Are wastewater sensors reusable?
- 129) What is the saturation concentration for glutamate biosensors?
- 130) Which kinds of sensors are selective towards E. coli O151:H7?
- 131) What's the widest operating range for a H₂O₂ sensor?
- 132) Which sensor has the lowest durability?
- 133) Which sensor has the highest durability?
- 134) What is the lowest LOD among all sensors?
- 135) How many different kinds of platforms have been adopted in sensor testing?
- 136) What is the best LOD for H₂O₂ testing?
- 137) What type of H₂O₂ sensor has the best selectivity?
- 138) Which platform should we use when we test the NH₄⁺ regardless of price?
- 139) Does the liquid ionophore always have better performance than the solid ionophore?
- 140) Which type of sensor has the longest response time?
- 141) What is the fastest sensor in small molecule testing?
- 142) What is the most commonly used sample in the test?
- 143) Which sensor has the largest range in Glucose test?
- 144) Which platform is most commonly used in Mclamore's lab?
- 145) Is it possible to test H₂O₂ in ocean water?
- 146) What recognition-transduction scheme do we use to detect glucose?
- 147) Is it possible for a sensor to have a response time lower than 0.1 sec?
- 148) Which platform should we use when we want to detect the NH₄⁺ in two seconds?
- 149) Could we use the LSG to detect H⁺?
- 150) Can we make a bacteria sensor whose response time is <500 seconds?
- 151) What is the response time for liquid K⁺ ionophore in detecting K⁺?
- 152) What is the most popular platform for hydrogen peroxide biosensors?
- 153) Which targets can be determined using diamine oxidase sensors?
- 154) In which samples potassium ions can be detected?

- 155) What molecules can be detected in breast milk using biosensors?
- 156) What is the difference in sensitivity between glucose biosensors based on graphene or platinum foil?
- 157) What is the most sensitive biosensor based on carbon nanotubes?
- 158) How many biosensors have been proposed for glucose determination?
- 159) Anthocyanin is used as a target for which biosensor?
- 160) Which biosensors can be used for hydroponic medium?
- 161) In which samples, glutamate was determined using biosensors?
- 162) Which biosensors were proposed for catecholamine determination?
- 163) What is the lowest limit of detection for graphene-based biosensors?
- 164) What is the maximal range for nitrate biosensors?
- 165) What platforms can be used for ammonium detection?
- 166) Most durable recognition-transduction scheme for interferon gamma biosensors?
- 167) Best limit of detection achieved with phosphotriesterase-based biosensors?
- 168) How many biosensors were described for ATP determination?
- 169) What platforms were proposed for ATP-sensitive biosensors?
- 170) What is the average LOD of K⁺ sensors?
- 171) Which platform could be used for selective glutamate analysis?
- 172) What is largest analyte/molecule for which there is a sensor in the database?
- 173) Is there any cost associated with any type of sensor?
- 174) How many labs are making sensors to detect lead in water?
- 175) Are there sensors to detect air-borne viruses in the air?





DEMISTIFYING THE ANALYTICS BLACKBOX – A PREREQUISITE FOR ADOPTION?

<https://arxiv.org/pdf/1902.05009.pdf>

Snake oil sales of “intelligent” tools in the name of “AI” is an anathema to those who respect, appreciate and understand, albeit in part, the immense contribution of scientists and engineers who delve into details in quest of robust, evidence-based, numerically-supported, i/o, even for the basic form of **artificial reasoning**. Even then, it is not a general “one-shoe-fits-all” app that can be peddled willy-nilly. If users are better equipped to ask probing and precise questions, the tools and systems (eg in this cartoon) can serve the users, perhaps with greater accuracy and precision, before the information perishes. The most common question “what happened” (**descriptive analytics**), may lead to “why did it happen” (**diagnostic analytics**). The collection of logic tools (ART) we have discussed in this document and the cartoon (above) must work in confluence to respond to the most likely follow-up question “what is going to happen, next” (**predictive analytics**) and then the obvious: “what is your recommendation, what should I do” (**prescriptive analytics**). In PAPPU DIDA’S concept of data-informed decision as a service, prescriptive analysis may suffice for human-in-the-loop systems where the actuation is human-controlled. With increasing scale of concurrent levels of operation and improving control of automation (think about 0-5 levels of autonomy, think OODA concept by John Boyd and PEAS paradigm in Agent based systems), it is not impossible that users may eventually trust and enable systems with case-specific permissions to “take action, execute” (**automated analytics**). Auto-actuation, in the SARS to SARA paradigm, is discussed in the essay with the title SARS♠AG.

PAPPU DIDA'S – BEFORE WE ASPIRE FOR KIDS

Irrespective of the strength of ideas, in this and other essays, the path to adoption is fraught with challenges. Therefore, ideas are often useless and without value unless we tackle the hardest questions, first, which defines the pragmatic aspect: will anybody pay to use this idea in reality? Ultimately it is the economics of technology which defines and controls the diffusion of ideas.

The complicated answer has several moving parts and none may be fully correct or incorrect. One canonical response is that adoption will be determined by the cost versus value paradigm. In a global economy where products are receding in the background and services (including those services which are based on products, eg, washing machines) are gaining momentum, the idea of “PEAS Platform for the Agro-Ecosystem” begs to ask whether one expects that users will buy sensors, of different types, in bulk. How will the non-expert users collect, analyze and integrate the data from the sensors. to help them in their real task, the task of food production?

The physical product (sensor) must deliver value (data, decision) which will inform responses and lead to actual work (actuation) to improve ag systems and help to increase food production.

One option is an age-old, time-tested, solution where lowered cost to the user (opex) is a function of the frequency of use and generally free from sunk or capital costs (capex). In the last century, this model was epitomized by POTS, the plain old telephone system, where the user paid only the “charge per call” which was reasonably affordable even when the per capita income was low.

Pay a penny per use (PAPPU) re-invents POTS with the qualifier that the user pays a penny (US) for each use (perhaps unwise to restrict it to one penny). The “use” may not be a thing, object or tangible product but rather a “process” which we refer to as data-informed decision as a service (DIDA'S). The “penny per use” idea may draw scorn from certain segments of investors and corporate leaders because the idea does not support the “next quarter” earnings (greed) report.

A version of PAPPU (pay a penny per unit) could stretch to fit “99 cents hamburger” model evident in PayPal's 2018 revenue (\$16 billion from 12 billion transactions, \$1.25 / transaction). The “unit” view of PAPPU may be applicable in transport, energy, water (as units delivered).

SENSEE, ART, DIDA'S and other data-informed decision-support on an open-platform calls for synergistic systems integration. The value is realized at the “end” when systems data may be synthesized to provide meaningful use in the context of the problem. It delivers information at the point of use, at the edge. Is this of actionable value for the user? Consumers may pay only for the desired outcome. Transaction cost economics is perhaps key to this *modus operandi*.

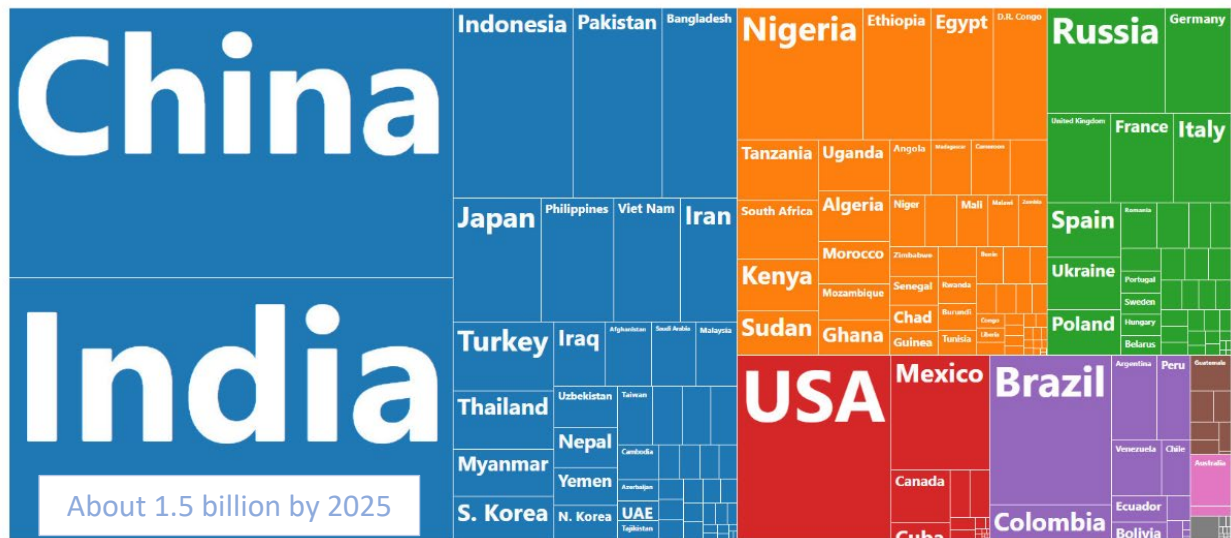
If the outcomes are dependent on a plethora of sequences in the operational process, then each process is a “profit center” and may generate a penny in revenue each time the user “touches” the system to extract information (or knowledge). If the economy can bear the economics of PAPPU then systems diffusion and adoption will continue to grow (decades) based on the economy (until saturation, when demand plateaus irrespective of cost). The number of sensors, and other data, are likely to intersect with vast number of decisions (ART, DIDA'S, KIDS). The actual *transactional volume* of payments, from ‘micro’ or ‘nano’ payments, are potentially gargantuan.

Documenting that the system was “touched” and billing/collecting that one penny is a technical challenge which requires tracking events (think IPv6, as an “indicator” for *system* activity). The task of segmenting that one penny revenue, between several service providers, may be a massive challenge in “weighted” decomposition/recomposition of events, to distribute earnings based on the degree of contribution of the provider who executed that step/event (for example, sensor manufacturer, systems integrator, platform provider, software vendor, analytics, mobile fintech).

Since no new “physics” is necessary to delineate these processes, it is safe to state that these can be accomplished without any invention but with forward thinking imagination and innovation. It is a déjà vu scenario from the “Store of the Future” (2000-2001, RFID track and trace) which sputtered and asphyxiated in the face of systems integration challenges, only to be resurrected by Amazon, which, finally, implemented the retail concept in Amazon’s GO (September 2018).

Increasingly, PAPPU (DIDA’S) will be the monetization mantra for the ART-IoT generation and the future where equality, equity and égalité may re-claim its rightful place in society striving for ethical profitability. It may take 20-30 years to overcome the resistance from despots, investors and corporate behemoths, but eventually the infectious spread of this concept may succeed in sowing a critical-mass of practitioners. The concomitant growth of infrastructure (for example, affordable access to low latency, reduced jitter, high bandwidth wireless telecommunications, 5G, trusted mobile banking) may be necessary to pave the road for PAPPU in ART and DIDA’S.

The ability to escape the dead weight of old technology (eg Africa, Asia) may accelerate the implementation of *pay a penny per unit* (PAPPU) as an integral part of the socio-economic fabric of a product-less, service-based economy, which may exclude the tiny population residing in OECD nations and/or the red and green zones in the cartoon show below.



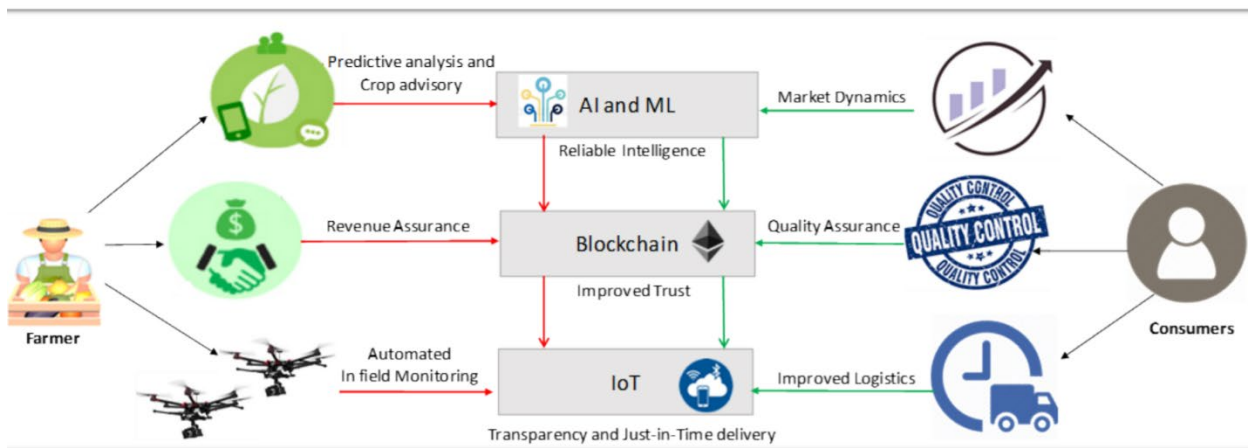
PAPPU may evolve as a preferred business model for the global economy by lowering the barrier to entry into markets where people are surviving on about \$2 per day. The impact may be especially profound on healthcare and the agroecosystem for production of food.

Because PAPPU is inextricably linked to mobile payments, distributed banking and digital finance, the pundits of social media will jump on this discussion to claim PAPPU is incomplete unless “blockchain” is integrated in the process. Blockchain hype-mongers are worse than snake oil sales and the adage or aphorism “hammer in search of a nail” seems too respectful in view of the torrent of garbage that is spewed in the name of blockchain. However, trust in transaction is undeniably central and an age-old concept (<https://www.jstor.org/stable/20752121>).

Therefore, it is important for PAPPU to provide tools to ensure safety of the payment system and other steps where verification guarantees are related to the service or product (for example, food safety). But, informed organizations may not, blindly, consider blockchain security for PAPPU.

Whether and how and in what form the concepts in blockchain may be helpful, remains to be seen. It is not entirely useless and such “solutions on steroids” deserves a place in society to counter the unethical practices that rapidly multiply in financial operations. However, such specific examples of use, and value of blockchain, may not be *generalized* as a solution for all levels of transactions. It is deceitful and malicious for blockchain proponents to tarnish all verticals and industries using the broad brush of finesse that is rampant in the financial industry.

Blockchain is erupting into an euphemism for avarice, for the sector of people involved in the process of marketing tools for blockchain. It is an anathema for >80% of the world trying to survive beyond the gluttonous grip of tools and technologies of dubious value. Blockchain is certainly not a panacea. There may be a few other low-cost ways to achieve safety, security, identification and authorization (for example, <https://dspace.mit.edu/handle/1721.1/102893>).



Chacun voit midi à sa porte – hammer in search of a nail: peddling the “blockchain” at the “center of the world view” of operations. It is not necessary for individuals in trains, planes and automobiles to wear an armor-suit. The safety belt is sufficient, although it may not be enough, in certain instances. The latter is the risk that emanates from the rewards due to progress, which society has, and will continue to, shoulder. Rather than feeding people, the burden of blockchain will starve the hungry, where food is most needed, by increasing cost of operations. Imposing rules and regulations will secure profit for the blockchain industry, deliver little for food safety and deprive nations from food. (<https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=8598784>)

FAAQ - FREQUENTLY ASKED ANGRY QUESTIONS

■ Is this really a PoC ?

■ What is the purpose of repository (pg 11) in step V ?

Explanation of the lack of purpose: unclear from SENSEE PoC alone

Steps I and II (see page 5) are indeed proofs of concept to show we can create a simple mobile dialog box to ask questions (examples on page 3) about types of sensors available from a small group of labs (10-100) who are creating sensors. One example from the McLamore Lab is in the xl sheet available from <http://bit.ly/SENSOR-LIBRARY-ERIC-MCLAMORE>

The important distinction, with respect to this discussion, is that, this is *not about sensor data alone*. We discuss *types of sensors* (SENSEE 1.0), *sensor-specific data* (SENSEE 2.0) and phases of decision support (ART, DIDA’S, KIDS – PEAS Platform for the Agro-Ecosystem).

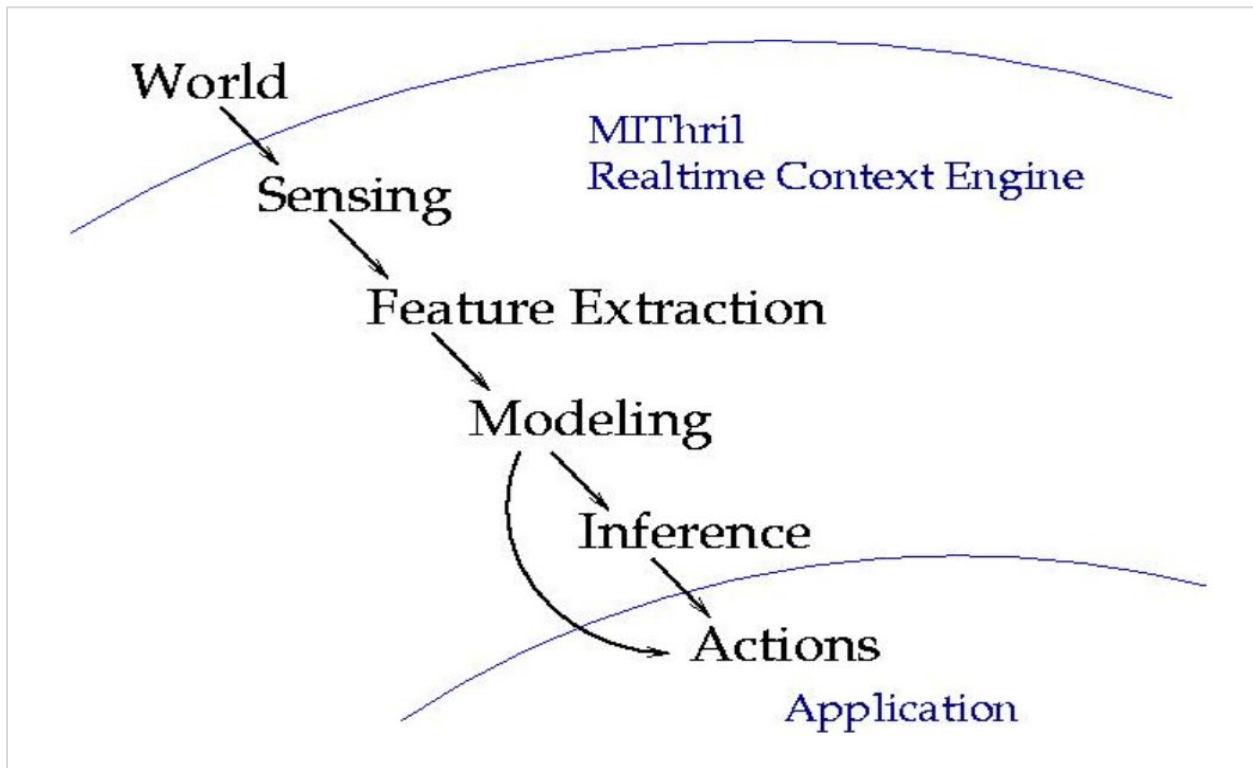
SENSEE 1.0 is the PoC which refers to characteristics, properties and features of sensors, as engineered by academic or industry labs, (tabulated in xl sheet). When we mention “users” typing in a query in the dialog box, the “user” is **NOT** a farmer, grower, consumer. SENSEE 1.0 users are experts and sensor engineers or students exploring the repository (step V). Who has made what sensors? What is the limit of detection? What platforms (impedance spectroscopy, photonics, SERS) were used to capture the signal? Critics may point out that Google has done that job and Google will retrieve millions of references to papers and documents with any key word. In defense of our aspirational step V (the repository), we wish to point out that the queries (examples on page 3) using the SENSEE 1.9 dialog box (step I) may reveal specific information, from a *curated catalog* of information, related to sensor science and engineering.

Necessary Digression: In the context of the “big picture” it may be worthwhile to understand that this “curated catalog” refers to the xl sheet with sensor specifications (example provided from McLamore Lab). In step II we will have, hopefully, extracted similar information provided by another few labs. This collection of information will be in databases (SQL, noSQL, GraphQL, SPARQL, TSDB) which will serve to retrieve responses to questions (example on page 3). Hence, this “curated catalog” in this discussion may lead to the repository (see step V on page 11). The reason for this preface to the “digression” is to point out how this “curated catalog” may morph into a “semantic data catalog” as explained in **Figure 12** in the “SITS” section of the essay series “SIGNALS” which may be downloaded from <http://bit.ly/SIGNALS-SIGNALS>. In steps I through III we may use elasticsearch and NLP to parse words in a query and match with keywords (in search engine) to retrieve the most likely answers. This *syntax-driven* process is error-prone (depends on how well the human developer has coded/trained the engine). To boost performance, semantics may remove, albeit partially, some errors due to syntax. The latter varies with expertise, mother language and social environment. Hence, the intended move to semantic databases may be facilitated by transforming this “curated catalog” (this discussion) to the future *semantic data catalog*.

One may conclude this is a repository for experts. At this time, this is true. This is the beginning of an ambitious attempt toward *synergistic integration of platforms* (SIP) which will converge data (ART), information (DIDA’S), knowledge (KIDS) and, eventually, *experience*, to suggest solutions. Users may be experts from industries, farmers, meat packers, distributors, food inspectors, grocery stores, cold chain logistics providers. It may be **any user** who may benefit from data-informed decision as a service (DIDA’S) and may even pay for the service (PAPPU). The future of *experience as a service* may be your personal mobile agent, which you lease to a buyer, or air-drop (www.imore.com/airdrop) to a local client, interested to profit from your experience.

Broad spectrum of users (above) may need different types of information, which may be in different databases. Hence, the choice of knowledge graph connectivity to synthesize and deliver a meaningful response, by selecting data and information using distributed architecture to access a multitude of resources (see figure 11 on page 28 in the “SITS” section of “SIGNALS” <http://bit.ly/SIGNALS-SIGNALS>). Extraction of data and information from the “world” may benefit from **context engine** architecture (cartoon below). The latter may be one way to create knowledge bases without reliance on ontologies, using publish/subscribe (ingest from CSV, xl, relational databases, JSON/XML feeds), perhaps in a manner analogous to CMS (content management software for data). Ontologies may become key to future knowledge extraction.

This endeavor is **ONE of the resources** (SENSEE 1.0) we aim to develop to address that *future SIP platform*. We expect that aggregation of **contextual data** and *curated* information may further improve the performance of this basic service (ART) through connectivity with other distributed resources (see “**SARSAG**” in SIGNALS <http://bit.ly/SIGNALS-SIGNALS>). To achieve that goal, the open source platform must support data interoperability (for example, DDS) between local and global databases/platforms, enable dynamic composability to pick and choose (drag & drop) data/information from diverse sources, always explore user-friendly tools for synergistic integration with domains of data, information and *crowd-sourced* knowledge, which may enable user *experiences* from the past to inform the future. Also, we expect *actual “world” sensor data* (eg temperature sensor) to be aggregated, *agnostic* of the make and model of the sensor (SENSEE 2.0). Sensor *data*, and extracted *information*, may be *more useful* for pragmatic, and profitable applications, in the near-term, that we may deliver through **ART**.



The ‘world’ in context of applications. www.media.mit.edu/wearables/mithril/context/index.html

Science and engineering have enabled an embarrassing wealth of sensors but without an organizational repository (aspirational step V on page 11) the value of these sensors may remain under-utilized. The proposal to create a World Sensor Organization (**WSO**) to address these issues, remains unexplored (Commentary [C] discusses WSO, in the PDF, “**IoT is a Metaphor**” which may be download from <https://dspace.mit.edu/handle/1721.1/111021>).

To catalyze science to serve society, in a parallel endeavor (Eric McLamore, personal communication), experts interfacing with the edge, that is, with end-users (farmers, growers, meat packers, aquaculture, retail grocery suppliers), are attempting to harvest questions which end-users may ask or *should* know, in order to better use data to inform and transform their practices (address contamination, understand regulation, use of technology). The measure of success is the outcome (**PEAS Platform for the Agro-Ecosystem**), in terms of food production at an affordable cost, of a better quality, as well as quantity, using ethical tools and practices.

To clarify, this PoC may be divided into an actual proof of concept phase (steps I and II) and a R&D approach in steps III through V (which is no longer just a PoC but a more thoughtful path to step V). The sum of PoC plus R&D is an essential (**but only one**) part of the SIP platform concept discussed in SARS♠AG (see essay “**SARS♠AG**” in <http://bit.ly/SIGNALS-SIGNALS>).

SARS♠AG combines the tools and sensors discussed in “SITS” (see essay “**SITS**” in SIGNALS <http://bit.ly/SIGNALS-SIGNALS>) with questions that **end-users** may want to ask. This **combination** makes it possible to bridge the wealth of advances in sensor research with the need for tools and technologies, on the ground, at a pragmatic level. Data-informed end-users may meaningfully converge this knowledge, with their experiences, in order to improve the outcomes (food production, food distribution, food safety, prevent food wastage, profit margins).

Questions, whose answers may help end-users, are the sign-posts for the development of **PEAS Platform for the Agro-Ecosystem**. Sensor repositories (SENSEE 1.0, SENSEE 2.0) must meaningfully connect with questions from the field-workers. Some of these questions may have nothing to do with sensor science and engineering. Thus, a tremendous amount of analysis must be invested in understanding, classifying and identifying the nature of the sources we need to connect, in order to answer some of the questions from end-users. It may be clear to the reader why multiple sources of data and connected information (knowledge graphs) may be essential.

The RASFF portal (next page) may be an example which can be adapted, in principle, to guide end-users to ask questions and organize the input in “buckets” or holders. In this approach, the input data may be amenable to classification or clustering algorithms, to help sort out the nature of the questions. If we allow “question collection” to an open format (write down top 10 questions) using an open dialog box, where anybody can ask anything, in any form, using syntax devoid of context, then extracting the key ideas from this unstructured mess (without standard keywords) may be frightfully exhaustive, if not impossible.

The RASFF approach could use keywords and harvested frequency of words or terms from this question-gathering exercise. Using tools like PCA (principal component analysis), it may be relatively easier to identify the topics covering 80% (Pareto principle) of the questions.

Using these topics, as a guide, we can begin to build / connect with contextual domains of data (for example, micro-climate from federated nano-satellite weather channels), information (example, price of bio-diesel) and knowledge (example, crowd-sourced experience of end-users, elsewhere). When synthesized, it may help us to respond, in near real-time, appropriately, to the end-user, delivering **actionable information**, perhaps 80% of the time, with respect to desired level of relevance, precision, accuracy and value, to reach a certain quality of service (QoS).

Theoretical discussions about questions, data and platforms, using power-point filled with boxes, with arrows and artificial acronyms, is easy. Providing meaningful value to the end-user is not easy. We shall strive to combine data and logic informed approaches in the context of case-specific problem-based artificial reasoning tools (**ART**). The outcome and quality of service (QoS) remains to be determined. The aspiration is to approach DIDA'S after critically evaluating the successes and failures from ART implementations, in real world scenarios with actual clients. The journey to KIDS is still amorphous, as outlined in **PEAS Platform for the Agro-Ecosystem**.

https://webgate.ec.europa.eu/rasff-window/portal/

European Commission

RASFF Portal

European Commission > RASFF Portal

Notifications list New search

Search Page Get results Clear form

Notification

Reference

Subject or and

Notified by

Open alerts

Date

Week current week [17] previous week [16] week of year

Notified between and (dd/mm/yyyy)

Type

Type

Classification withdrawn

Basis

Product

Category

Flagged as

Country

Action taken

Hazard

Category

Risk decision

Keywords

Keywords Open URL

Get results Clear form Load criteria Save criteria

Challenges in Knowledge Extraction & Application: *KIDS is a journey, not a destination*

The assumption in “**actionable information**” is the strength of **credible content** which induces humans in the loop to perform a process or execute a specific action. The **trust** in this suggestion is dependent on the depth of the connectivity between system of systems and the ability of the tool (ART) to collect, synthesize and propose a meaningful outcome. Hence, the process of delivering **value** for the user in terms of “actionable information” is **not** an instant step. It may be best described in terms of bio-mimicry. For example, if you ask a 5-year old about “errand” planning (grocery store, library, co-op, laundry), the answer may be correct or incorrect because the 5-year old may not know the locations, what you need at each location, store hours and if the traffic on the road may change while you are between errands. If you ask the same question to a 15-year old, she uses Waze and store hours of operation to customize a Google map with a sequence/pattern you may wish to follow, based on data and information (data-informed decision as a service). The 15-year old has “learned” how to plan and manage time, fit the process to parameters of family’s needs, and intuitively, understands semantics.

This PoC, SENSEE, ART, DIDA’S, KIDS, hence, are sign posts on the road ahead. We continue to learn, improve accuracy, precision and credibility, to increasingly gain the trust of the user. We continue to explore tools to address long-term “learning” and apply the results.

In the real world, tools often lead to questions about standards because a tool is not an one-off product. Standardization is viewed as an unifying process (for example, IPv6), which enables creation of tools agnostic of where (location) it is used or manufactured, as long as it is in compliance with standards. However, dynamic systems involved in decision making may be hard to standardize, primarily because of geo-political and socio-economic factors with respect to the decisions and the impact of those decisions.

Ecosystems are in a perpetual quest to develop and deploy advances in standards, which can be driven by adoption (for example, Android and Windows operating system). But, standards of decision making are far from homogeneity. The diffusion of any standard operation procedure in terms of decision making depends on the strength of measurement science (including data), interoperability of information between systems and software tools which can **combine data, analytics and information with knowledge and experience** (aspiration in ART, DIDA’S, KIDS).

This PoC “plan” is the **beginning** of analytics, which, theoretically embraces experience. **PEAS Platform for the Agro-Ecosystem** attempts to bring together the value of aggregating and querying sensor descriptions. Conventional wisdom suggests that sensor data and analytics, as “information” is more useful for end-users. The description of sensor types (PoC for SENSEE 1.0) is a step before jumping into sensor data.

It may help to remind the readers that this **planning document** is relevant to one idea from the suggestions in the series of essays (SITS, SIP-SAR, SARS♦AG and PEAS). How many types of sensors are available for any given task? What are the characteristics of the sensors in terms of signal detection, sensitivity and other key attributes? This may not interest the end-user in a farm, but it is critical to the **design of field deployment** and those in academia and industry.

This PoC creates a foundation with SENSEE 1.0 that does not contain sensor data but contains sensor descriptions (<http://bit.ly/SENSOR-LIBRARY-ERIC-MCLAMORE>). In its first version, we aim to collect sensor descriptions from about 1,000 labs using a partly automated document management system to populate the database (SENSEE 1.0). Using a simple mobile web service type app, (please request the IP address of the web service if you wish to test the usability of the app), experts may query SENSEE 1.0 to ask direct/specific questions (examples: at the beginning of this document, page 3) or use Boolean operators (for example, how many sensors use laser scribed graphene *and* plasmon resonance spectroscopy for signal transduction).

It is the aim of step II of this PoC to demonstrate [1] the ability of SENSEE 1.0 to contain a *critical mass* of sensor descriptions in the form of *curated* value fields and [2] the ability to answer a variety of questions using the simple app (user interface, dialog box) developed in step I. The ability to answer questions, group values using keywords and other combinations, depend upon the natural language processing (NLP) tools to be developed. Initially, the questions may be limited to those which may include keywords the rudimentary string parser is able to handle. This is a *learning* process which we anticipate will improve over time (if we invest) and presents opportunities to explore creative ideas (<https://openreview.net/pdf?id=rJl-b3RcF7>).

SENSEE 1.0 may provide an upload/ingestion tool for sensor labs to upload their sensor descriptions (xl file) and use interactive tools to clean/curate the fields if the ingested “data” is in the incorrect field (for example – incorrect column heading – limit of detection score inserted in the column with the heading “molecular weight in Daltons/kiloDaltons” of molecule/analyte). The utility of SENSEE 1.0 may be limited unless we have a critical mass of sensor categories and attributes in the database. Experts and students may find this tool to offer specific answers compared to PubMed or Google search using key terms. It is hard to imagine farmers, growers and meat packers, who may be interested in sensor characteristics, for example, detection of ammonia using microfluidics versus laser scribed graphene (LSG) sensors.

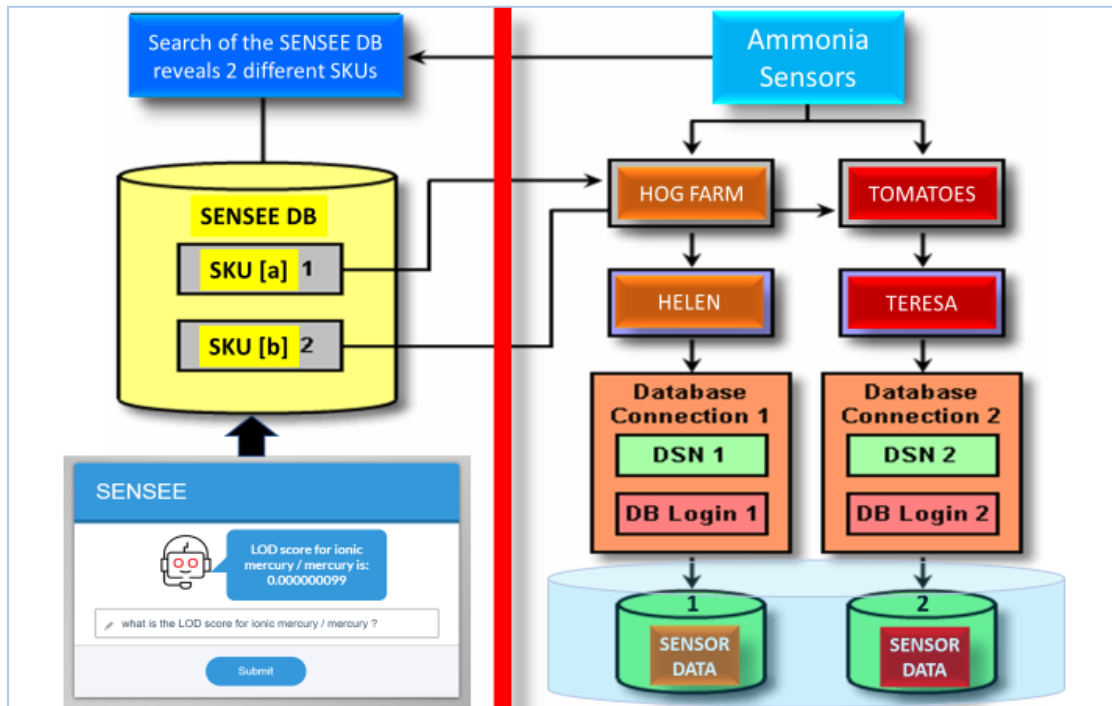
SENSEE 1.0 will continue to strengthen the search function (NLP), automating data ingestion tools, developing curation and data clean-up codes (step III). The research quest is in step IV, where the suggestion is to develop feature automation tools. ***Through all these steps we are still discussing sensor descriptions (types). We have not yet discussed sensor data.***

Each sensor, for example, ammonia sensor using [a] glass capillary or [b] LSG (as platforms) are independent sensors (*different SKUs* or stock keeping units, different items). If sensor [a] or [b] is manufactured, then it can be used to detect/quantify ammonia gas. If sensor[a] is manufactured in a small batch (100 widgets) but sensor[b] is manufactured in a large batch (10,000 widgets), then SKU[a] may have the serial numbers 1-100 and SKU[b] may have the serial numbers 1-10,000 (hypothetical).

This digression is critical to grasp the distinction between SKU and serialization. It is important for the discussion about data from sensors (SENSEE 2.0) with respect to tracking and tracing (id) of sensors, when they are in the field (often tagged with RFID tags for identification purposes). Data acquisition from sensors in use (in the field) must be specific for sensors which are related to a specific case (real world client) which is a part of a problem that we are trying to solve for the client (test bed, customer). Sensor data is the topic for the next PoC, referred to as SENSEE 2.0 in ***PEAS Platform for the Agro-Ecosystem.***

SENSOR DATA – SENSEE 2.0

At the hand of hog farmer Helen, sensor SKU[a] serial numbers 1-5, is now capable of generating *sensor data (measuring ammonia)*. At the hand of tomato grower Teresa, sensor SKU[b] serial numbers 10-25, is now capable of generating *sensor data (measuring ammonia)*.



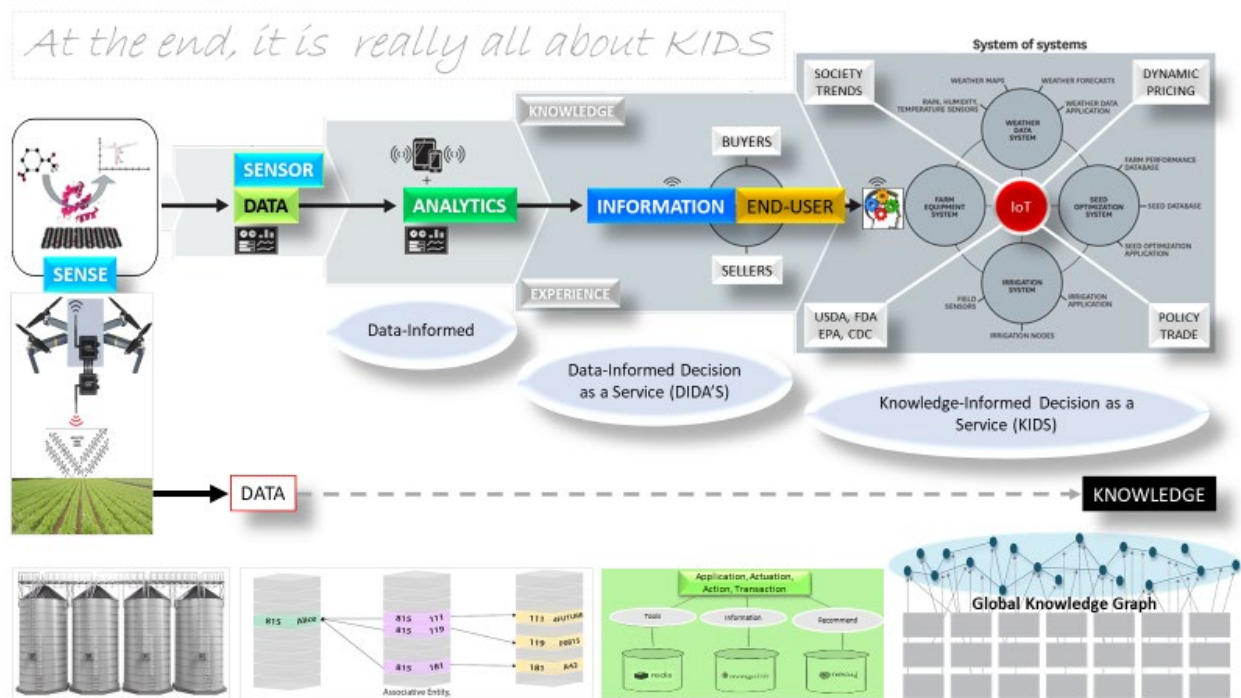
This PoC is about the LEFT side (SENSEE 1.0) where sensor descriptions are in SENSEE DB. Use of the sensors will generate sensor data – sensor data acquisition (right) is for SENSEE 2.0

This PoC does not address the sensor data database. That is the next step (SENSEE 2.0) where data is sensor-specific, case-specific, problem-based, has a purpose (end-user directed). It is used in conjunction with logic tools and data analytics in order to evolve as information expected out of the umbrella of artificial reasoning tools (ART). The latter is a step toward curating information and knowledge with respect to DIDA'S (data-informed decision as a service). ART may "crawl" for a while till it gains strength in its logic spine to walk, albeit slowly, to reach DIDA'S and hope for KIDS (knowledge-informed decision as a service).

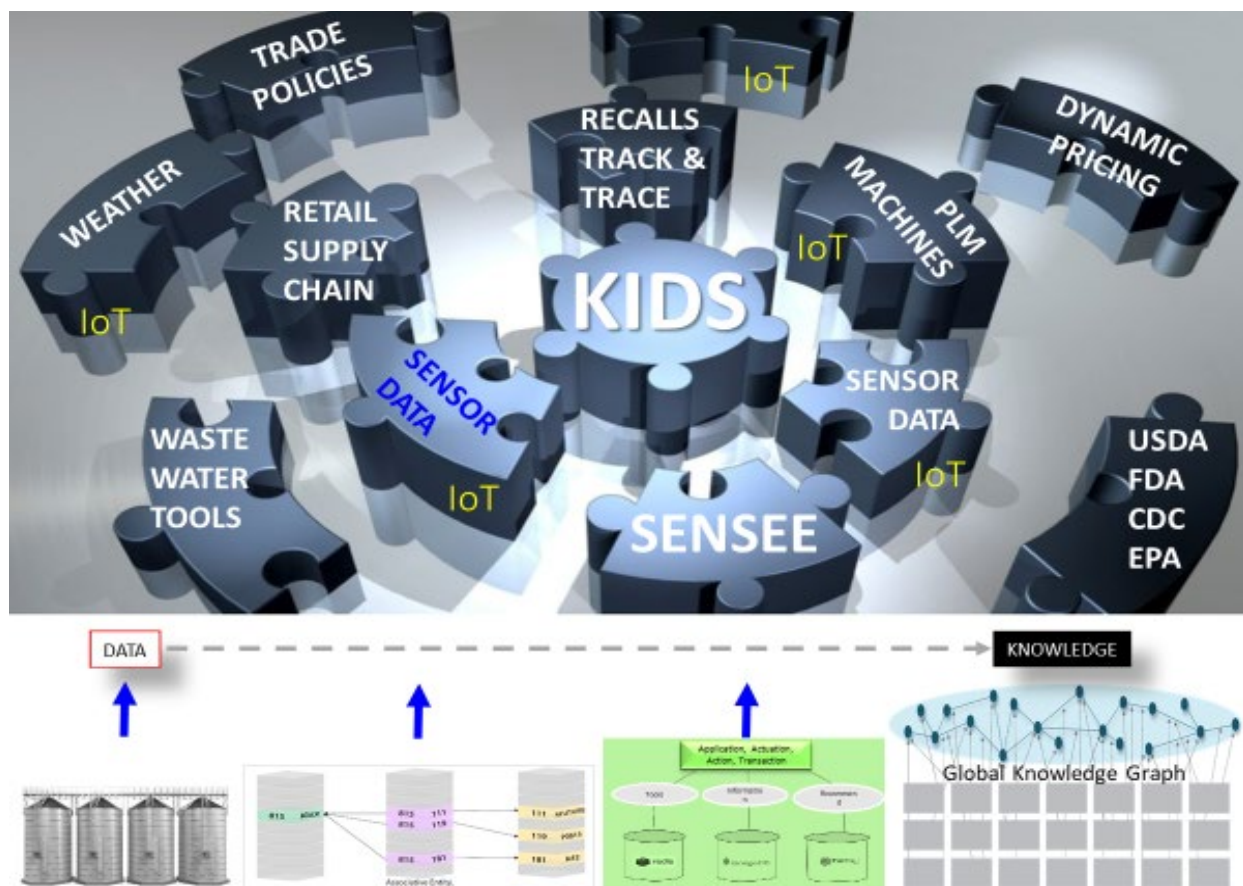
The range of questions in the next phase will include questions about sensor data. For example, the lab or manufacturer of ammonia sensors may query SENSEE 2.0, which sensor is more stable for higher concentrations of ammonia? Helen may ask when are the hogs producing the maximum volume of ammonia? Teresa may ask is there a difference between the ammonia concentrations during dawn versus dusk? **ALL** these questions are different but relying on the data from specific sensors (why data persistence is central to *different views* of data analysis and analytics). To provide value to end-users, ***SENSEE 2.0 and SENSEE 1.0 can be independent but connect when graphs "discover" them in the process of identifying resources for a case.***

DATA-INFORMED 2 KNOWLEDGE-INFORMED: KIDS ARE FAR OFF IN THE FUTURE

In the context of delivering real value to end-users, “actionable information” must move from **ART** (buzz word) to outcome. Future tools must be able to extract actionable, computable, contextual domain knowledge from informal sources of data (for example, text-based data). It is **not an easy task** in reality to augment user’s ability to perform analyses using common models, dynamic composability of modular components, sensor-specific data, environmental data (big data is a bad word) and near real-time data from the edge. In order to capture “experience” even ontological frameworks may be useless. Even if domain experts can capture “experience” in a text-based format, it is doubtful if such text may “conform” to ontological frameworks. The latter is generally useful for text-based data (<https://schema.org/>).



This cartoon summarizes the journey from data to knowledge (didn’t dare to include experience). In our phase one approach (PoC SENSEE 1.0), we focus on sensor characteristics. In phase two (not within the scope of this PoC) sensor data (bottom, left, silos) fuels data analytics and relationships between data (SENSEE 2.0 in cartoon of relations/associations between databases). Information becomes valuable to users if ART can proceed to synthesize and generate the data-informed decision as a service (DIDA’S) model (bottom cartoon, in pale green). As we approach knowledge integration phase, connectivity of local data and information with global system of systems adds value for data-informed policy decisions, understanding local dynamics and pricing in the context of market economics and trade practices. Creating GKG (global knowledge graph, and in future, labeled property graphs, LPG) is an evolutionary task, as we continue to stitch resources that can inform and provide knowledge to end-users. These “end-users” are no longer only farmers, growers, academic or manufacturers, it could include global organizations (FAO, WTO, UNDP) as well as policy forums and politicians (for example, farm bill, world customs organization, public health, other institutions, such as, FDA, CDC, WHO, ADB, EBRD, WTO).



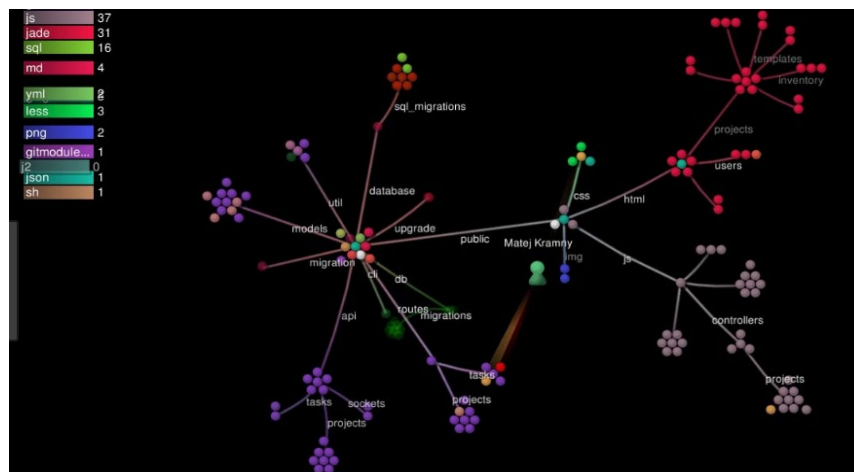
KIDS is an open plan platform concept. Platforms are comprised of multiple applications and integrated solutions with embedded tools and databases that function as complete, seamless environments. Product innovation platforms are intended to support users collaborating across domains and businesses in the *PEAS Platform for the Agro-Ecosystem*. These capabilities are increasingly needed throughout the entire extended enterprise in almost every vertical, agnostic of the type of application or function or users, including farmers, meat packers, produce growers, retail stores, customers, suppliers, and business partners. Developing open platform tools and technologies are not limited to any one domain because these modular tools can be applied, used and re-configured for re-use, almost anywhere, for example: error correction, graph and search engine algorithms, natural language processing (NLP), automated feature engineering, drag and drop tools, analytics, workflows, and services, such as KIDS, where “open” means ‘plug & play’ user friendly human-computer interactions and interoperability between system of systems. The monetization of KIDS is key for entrepreneurial innovators and investors seeking ROI. Users will ask how KIDS relevant to *my* farm or *my* manufacturing operation (think emergence of digital twins, eg, to mimic shop floor for machine tools) or *my* healthcare. Dynamic composition of the tools in the KIDS tool kit will be essential for the high degree of differentiation that must be achieved on-demand and served in real-time. To serve individual users or groups, raw data acquisition must be specific for the user’s domain and the analytical tools (algorithms) must be contextually relevant. Cybersecurity will demand that user data is sufficiently protected. KIDS will offer different views and instances to different users. Only software can deliver granular services at a feasible transaction cost. For global adoption of ART, DIDA’S, KIDS, and PEAS, embracing the *pay a penny per unit* (PAPPU) pricing model, may be a potent and vital catalyst.

Human expertise is an **embedded** component of procedures, processes and decisions in any system. However, integration of human knowledge and human-computer interactions in operational analysis, are difficult to execute (why “smart” systems are still dumb). In certain systems, for example, the agro-ecosystem, human-generated knowledge is quintessential, yet it may be captured in text-based documents, which may be inconsistent and contain domain-specific vernacular. Even more challenging are the facts and observations that humans may grasp but *unable to articulate* or capture in writing or in notes. Thus, we have lost that intuitive factoid because of our inability to sufficiently capture what we are thinking.

The adage “hard to express in words” is a normal neurological state. It may be safe to conclude that there is *no intelligence in artificial intelligence* (<https://arxiv.org/abs/1610.07862>). AR (artificial reasoning) may be the best outcome from machine learning, no matter how “deep” one claims it to be. Hence, a name change from AI to AR is long overdue. The suggestion of **ART** in this document is more appropriate rather than perpetuating the lies and myth of AI.

Integrating *knowledge and experience* can better inform (DIDA’S) decisions, rather than relying only on ART. But, operational decisions at the point of use may find it difficult to synthesize the data (for example, streaming sensor data) with knowledge systems, in near real-time, to inform the user. The end-user in the field or farm or manufacturing shop floor, is more interested in the *integrated information* rather than data streams on a slick mobile dashboard.

Relationships between knowledge domains may boil down to ontologies. In other words, knowledge extraction must include design and development of taxonomies and metadata strategies for content management. The “fit” of these strategies to text-based data and other forms of unstructured sources of experiences remains to be explored with respect to existing (and/or evolving) vocabulary/taxonomy/knowledge organization system (KOS)/ontology software. The older thesaurus standards (ANSI/NISO Z39.19 or ISO 25964), newer ontology standards (OWL, RDF), and the SKOS (Simple Knowledge Organization System) model for “controlled vocabulary” may be relevant in this context (OWL/RDF is discussed later in this document). Most organizations may need more than one kind of controlled vocabulary. Hence, combined taxonomy, thesaurus, ontology and knowledge graph structures (discussed later) are emerging (for example, graph database-based Synaptica Graphite, cartoon shown below).



Most systems are starved of information, but we have an abundance of data, albeit uncurated data, often replete with noise and/or a poor ratio of signal to noise. Relationships are key to extracting experience and knowledge (previous cartoon) in order to inform and integrate data and analytics. Smartlogic Semaphore (<https://github.com/ansible-semaphore/semaphore>) provides a good view of these connections but in reality these are rarely “available” for rapid deployment (for example, in the agro-ecosystem). The cartoon is an example of what we *think* might be helpful for knowledge supported decision systems (KIDS). Other related software tools include PoolParty, TopBraid Enterprise Data Governance’s Vocabulary Manager, Mondeca Intelligent Topic Manager and VocBench, to name a few specific suggestions, from an extensive list discussed in this book: <http://www.hedden-information.com/accidental-taxonomist/>.

Systems of the future must address this chasm between technical output (for which systems integrators want to charge money) versus the user value (the outcome for which the user is willing to pay). In any vertical, data plays a key role as a business driver. In the knowledge economy, the data analytics business will remain in the doldrums unless tools and technologies can deliver meaningful knowledge extraction mechanisms to support the context of applications.

Most corporations are eager to stop at **ART** rather than invest in DIDA’S and make sense of data in order to synthesize the *knowledge support* that end-users in the field *don’t even know* that they are missing. This is a systemic problem, not limited to agro-ecosystem. The diabolical claims made by semantic web experts, machine learning and artificial intelligence marketing arms, makes one fearful to suggest that this problem of information extraction and knowledge-informed suggestions, needs, and may benefit from, ontological frameworks, semantics, ML tools and perhaps, artificial neural networks (ANN, CNN, RNN), at some later stage, in KIDS.

We need one or more networked platforms (mobile, edge/mist/fog/cloud, federated learning, distributed sub-domains, high fault tolerance, seamless interoperability between nodes, data distribution services, ontologies) where we “drag and drop” entities to combine, select, push-pull and dynamically hybridize, multiple tools, in order to create application-specific, domain expert-curated methodologies, for classifying, clustering and quantifying data, information and knowledge. Extraction from highly unstructured data calls for advanced Natural Language Processing algorithms (<http://bit.ly/Interested-in-NLP>) which must work with graph-theoretic methods (see figure 11 on page 28 of “SIGNALS” <http://bit.ly/SIGNALS-SIGNALS>) and ontology tools, for example, Synaptica Graphite, which offers directed-graph visualizer.

Optimization of value for the user is a continuous process of labelling and analyzing diverse sources of data, before the information perishes. If text-based documents are sources of knowledge and experience, then we must find new ways to harvest that contribution in our attempt to synthesize data (external data, crowd-sourced data), information and knowledge with experience, to aid the gradual transition from artificial reasoning tools (ART) to data-informed decision as a service (DIDA’S) to knowledge-informed decision as a service (KIDS). Continuous improvement will contribute to the domain-specific enrichment (ontologies due to pecan farmers vs tomato growers, agro-ecosystem vs manufacturing). Usability and functional preferences may lead to *de facto* standards and support “organic” growth of open-source toolkits to fine-tune knowledge extraction from distributed domains and improve the value of decision support, in the context of the journey from SENSEE to ART to DIDA’S to KIDS.

BEYOND KIDS → EXTRACTION OF EXPERIENCE

Decision making is largely driven by human expertise. Automated decision-making works really well during sales presentations, using power-point. Human experts contain a wealth of tacit information that is intuitive, informally captured and explicitly under-utilized due to our inability to capture, catalog and re-use experience. For example, an experienced physician needs to see only the color of the sclera to “know” if the patient has contracted jaundice. Capturing the ontological framework of this knowledge and creating a computational equivalent of this type of “expertise” may be the Holy Grail for the future of advanced decision support. The forthcoming exodus of experienced physicians (due to Brexit?) will leave the NHS (British National Health Service) denuded of a repertoire of critical knowledge which may be irreplaceable. To the best of our knowledge, there are no mechanisms or tools in UK or anywhere else in the world, to capture such knowledge and re-use the experience to support new, or less experienced, employees or re-train other physicians who may have gaps of knowledge in the areas that were covered by the physicians who may be leaving UK.

Even if this tacit knowledge is implicitly or explicitly represented in text-based documents, these documents are not amenable to analysis using the existing tools of knowledge representation, for example, SKOS (Simple Knowledge Organization System) model for “controlled vocabulary”. These documents are likely to contain jargon, abbreviations, and domain-specific cryptic remarks, which may be difficult, if not impossible, to analyze with any “controlled vocabulary” commercial solutions. Text-based documents often yield important contextual *pattern* of information that is based on recurring experiences, which data alone cannot provide (for example, pathology report of blood cell count or streaming sensor data). *Contextual information* is useful when these patterns occur again to inform and guide decision support.

The research question is whether we can create domain-specific methods, guidelines, and toolkits to study and analyze formal and informal, text-based documents to extract patterns and other supporting information to aid future operational decisions? It will *not* be a one shoe fits all “AI” solution, rather a portfolio of domain-directed methodologies for transforming documents into a computable format, to augment our ability to integrate their value in future analyses. A group of experts may jump to standardize methods to capture this knowledge. The latter may be an acceptable and even useful approach, but just one part of a multi-part dynamic solution set which may consist of overlapping open source toolkits, and domain specific guidelines, to map unstructured patterns to symptoms, indicators and other detectable parameters (for example, smell of acetone in breath indicates excess of ketone bodies in blood, likely due to diabetes). Another group of experts may clamor to establish *best practice* guidelines for analyzing text.



The arm-chair academic and the business strategy version of this discussion will evolve with every reiteration but how closely will it reflect the complex needs of the practitioners? If we were to compile a “to-do” list for the future and compare it with actual examples of questions and problems from end-users in the field, today, we may begin to observe the gaps between the technologies we think we are combining, to answer questions, versus the non-linearity of the real issues. There are no easy solutions except for constant human involvement in decisions. Mining *user experience* does not fit the boundaries intrinsic in a scientific tool or pre-set vocabularies.

Experience is not structured to “fit” a tool or tools we may develop (as discussed above). User experience will evolve and *how it is recorded* will evolve, too. Hence the tools we thought could be useful for mining experiences from yesterday may prove to be impotent tomorrow. For example, thesaurus management software (also used for taxonomies), such as Synaptica KMS, and other products, no longer exist. If we improve the tools, combine the functionalities and aggressively pursue concurrent evolution of tools, then, it may provide a second-rate approach to harvest user experiences.

The next task is to *synthesize* extracted knowledge with technical information and data, to augment the user experience, in near real-time, at the point of use. It is a *very difficult* task.

Mind the Gap – *between tools and technologies versus real-world issues and problems*

A Sense of the Future: To-Do List for Tools and Technologies (*adapted from www.nist.gov*)

- Develop open source ontologies (schema.org) and tools for curating, cleaning, labeling, feature selection and feature engineering for text-based logs, databases, data, and information.
- Develop/standardize/innovate NLP techniques for descriptive data from int/ext ecosystems.
- Integrate extracted data with analytics, workflows, feedback loops.
- Create tools for knowledge access and visualization of components. Show real-time data (eg streaming sensor data) combining with past patterns to inform decision support / suggestions.
- Develop metrics for verifying and validating methods and calibration at the granular level of sensors and actuator. This data should aid in diagnostics and prognostics of the system.
- Data from real world test beds must be accessible by local and global partners (see Figure 16 on page 33 in “SIGNALS” <http://bit.ly/SIGNALS-SIGNALS>) for distributed learning tools.
- Focus on *value delivered* to the consumer (value is dynamic in context, *never* in equilibrium).

A Sense of the Future: Problems and Issues from Fields and Farms (*source: expert end-users*)

- Average rainfall in a drought prone village decreased from 1000 mm to 500 mm, over the last decade. Can we reduce the annual volatility of water availability for irrigation and drinking, for humans and cattle? Technologies at hand include [1] Improving Ground Water Level (IGWL) [2] Energy-Water nexus technology developed by Datamatrix Infotech and [3] tools of IoT. Key problems to address: sensing and modeling. Do we sufficiently understand the science involved in the physical processes? Without the grasp of the basic tenets, the case-specific outcomes, even if they are successful for the problem at hand, may not be generalized or reproducible, elsewhere.

- Using an improved rice growing technique (<http://tiny.cc/SAGUNA>), 3000 farmers found that in addition to increase in yield, soil carbon has also increased, soil moisture is retained for a longer duration and number of earthworms have increased. Can we study and capture the interactions and dynamics between micro-climates, microbes, minerals, nutrients and signals from the soil?
- Flood forecasting and management model using 0.20m x 020m resolution LiDAR data to build 3D terrain model. Citizens and authorities may use this information to make decisions but micro-variations in rain intensity complicates forecasting. The ripple effect involves irrigation, water management, soil moisture and erosion – the sum of which affects crops and production of food. How do we converge metrics and measurements with knowledge and experience to focus on micro-environments in order to provide operational guidance to those who are in these zones?

Sense of the Future: Meaningful Support: *Knowledge Graphs, Knowledge Supported Decisions*

Data fusion may not be information. Data-informed processes are more than **ART**. Evolution from information to knowledge may be a far more *difficult* process because the “reason” why the information may become knowledge must be represented. as a part of the general problem-solving logic. This concept from the 1950’s is at the heart of AI and integrating “reasoning” remains an unsolved problem. AI was originally referred to as artificial reasoning and shares certain principles with cybernetics (http://bitsavers.informatik.uni-stuttgart.de/pdf/rand/ipl/P-1584_Report_On_A_General_Problem-Solving_Program_Feb59.pdf). Hence, AI to AR.

The current form of data analytics and logic tools may offer a layer of ART before a true data-informed decision making (DIDA’S) system may claim success. The educated customer may benefit from DIDA’S but the less informed clients may find ART adequate for specific cases of “low hanging fruits” which may require lower level of skills, available in ART. Our elusive quest for *knowledge-supported* decision making is aspirational. It may *evolve from DIDA’S to knowledge-informed decision as a service (KIDS), if there is customer demand.*



Application of sensor data and data from devices are not limited to any one vertical. It is a systems approach which transforms data to information for users at the edge. The cartoon (above) is an application of ART to KIDS in health/healthcare where real-time information can save lives and money. The ability to connect various troves of data are critical to the point of use, which indicates a future dominated by knowledge graphs to generate the knowledge. It is not unique to healthcare. It is applicable to agro-ecosystem, energy, finance. For example, Goldman Sachs is creating social graphs which integrates email (who emailed whom), telecommunication (who called whom), trading (who traded what) and linked financial data (who sent money to whom). It has 100 million edges and 2 billion nodes (<http://bit.ly/GKG-KIDS>).

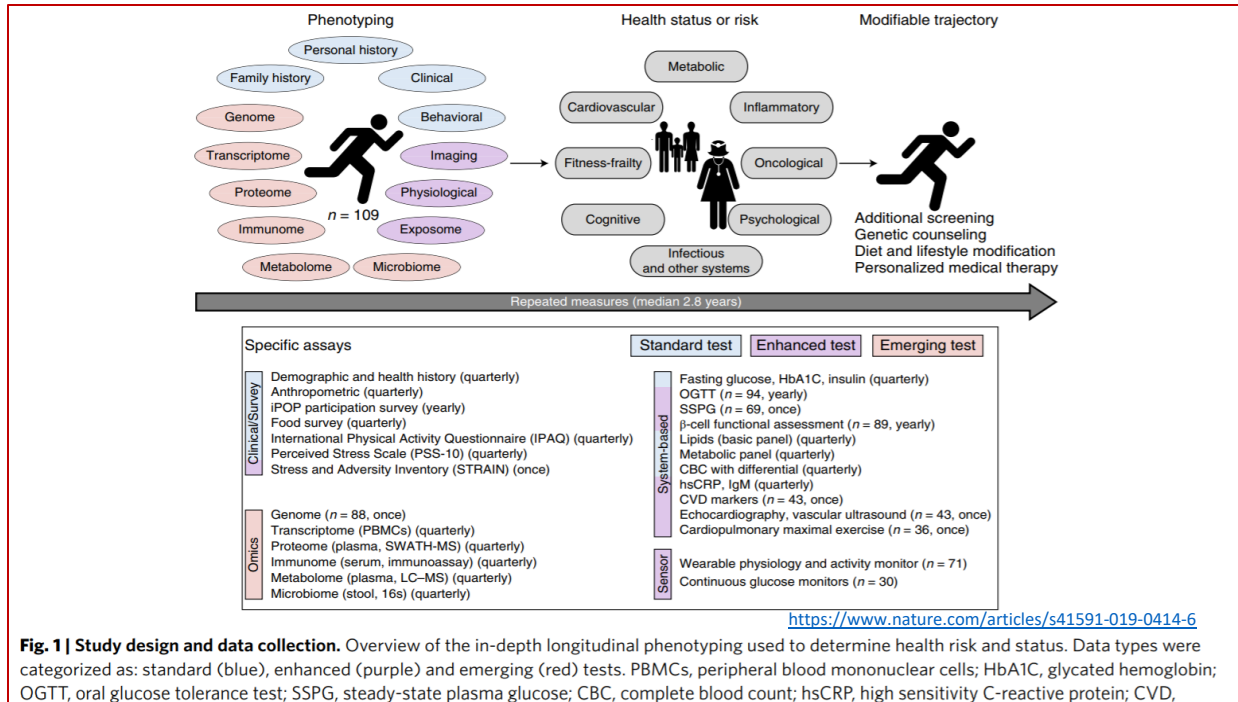
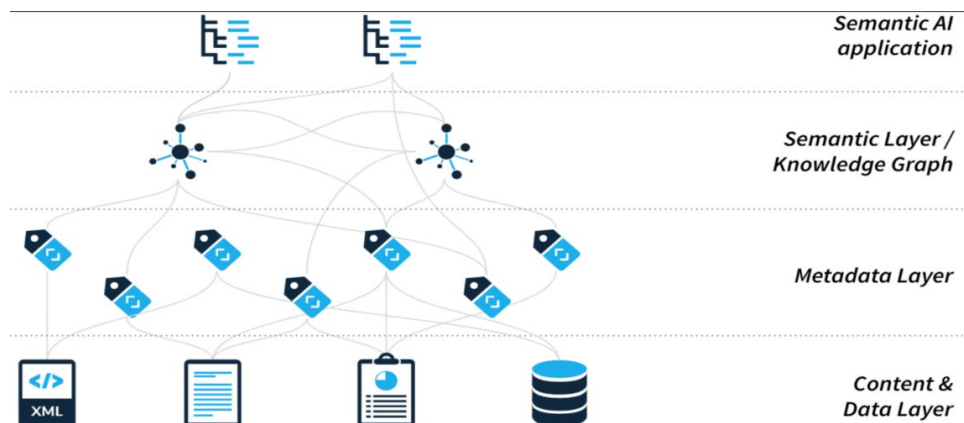


Fig. 1 | Study design and data collection. Overview of the in-depth longitudinal phenotyping used to determine health risk and status. Data types were categorized as: standard (blue), enhanced (purple) and emerging (red) tests. PBMCs, peripheral blood mononuclear cells; HbA1C, glycated hemoglobin; OGTT, oral glucose tolerance test; SSPG, steady-state plasma glucose; CBC, complete blood count; hsCRP, high sensitivity C-reactive protein; CVD,

KIDS in Health and Healthcare: From molecular profiling to behavioral changes, which may improve a healthy lifestyle, is a process which involves, for each individual, multi-year deep longitudinal studies, before actionable health discoveries may provide relevant data. If this data is sufficiently analyzed and synthesized, it may provide some information for precision health, of that one person (individual, patient). The challenge in scaling this process is the availability of qualified human resources to deconstruct and reconstruct the data in the process of extracting actionable information. Knowledge about the patient must be stored for use in the future. Barring the hype, this is a potential area for use of machine learning (ML) algorithms that can select the data from distributed databases and using knowledge networks (knowledge graph algorithms) find and weigh the relevant connections and correlations. By selecting weights as an index or metrics, ML algorithm engines may be trained to issue a set of recommendations and indicate the probability of confidence associated with each (suggestion, diagnosis, prognosis). This approach is universally applicable to any domain (data, knowledge graph, decision support) including non-human entities (digital twins). The implementation of knowledge-informed decision as a service (KIDS) starts with data. Bulk of the data from humans and machines originates from sensors.



KIDS WITH ABS → CONNECTING IN CONTEXT: DOTS, DATA AND INFORMATION

Connectivity, in context, may be a basic instinct for all life forms. This generic statement appears less trivial if we consider that plants are designed to seek out sunshine and that ability, is in part, due to fractal patterns in the organization of leaves and the phototropic plant¹ hormone auxin, which induces photomorphogenesis. For animals, the quest for food² and flight from predators, are examples of connectivity, in context.

Almost all decisions, in humans, connects various data, information and knowledge stores, in our brain. The pathways remain poorly understood, despite an avalanche of foolish claims and blasphemous stupidity³ of pompous statements from individuals dyed with hubris.



"We want to create a brain in a box."

IBM's Dharmendra Modha

An elementary form of bio-mimicry of decision systems may be at the heart of KIDS. We must be able to connect, in context, data from different domains, selected to suit the user's query, to synthesize information and knowledge, which will offer value to the user, if delivered, in time.

The connectivity we aspire to extract from global knowledge graphs (GKG) for use in ART, DIDA'S, KIDS, may find analogies from the annals of telecommunications. Networking is the bread and butter of connectivity for the telecom industry. Since GSM was introduced in 1991, the industry has pushed incessantly for increasing bandwidth, speed (data rate) and higher power for fairly expensive devices (iPhone). Circa 2015, telecoms were forced to accommodate, adapt and re-invent its practices, with the diffusion of IoT. Connectivity between vast number of devices, sending data pulses (sensor) or short bursts of data on-demand (user query) may survive on low bandwidth, low data rates, low power for IoT-type connectivity between devices, many of which are low cost devices. In other words, the opposite of the conventional wisdom espoused by the practitioners in the telecom industry of the 1990's.

IoT drove a fork in the telecom industry and non-traditional players invested in low power wide area networks (LPWAN). To counter LPWAN penetration as the key IoT backbone, frantic traditionalists created a partnership (3GPP) and agreed, in haste, on the NB-IoT standard, a mix of NB-LTE and cellular IoT (2016). Thus, emerged agile hybrid networks of traditional cellular, non-cellular, non-traditional mesh and other protocols that can take-over or hand-off any signal (eg WiFi, Bluetooth, WiMax), anywhere, anytime, from any device or any object.

¹ <https://www.untamedscience.com/biology/plants/plant-growth-hormones/>

² <http://library.mit.edu/item/002405318>

³ <https://www.foxbusiness.com/features/after-watson-ibm-looks-to-build-brain-in-a-box>

The agility, with which traditional telecom players could surmount the barriers (due to dead weight of old technology) and embrace new tools, is a lesson for the decision sciences. For the latter, churning “data-driven” into “data-informed” still falls short of customer demand. The knowledge-informed decision is far more valuable. Transition from data-informed to knowledge-informed calls for incisive changes in synthesis of data and information, for KIDS. The caveat in taking this analogy from the telecom industry, too far, is the vastly convoluted pace of creating “standards” in the data and information domain. The operational failure of the semantic web and sluggish progress in creating ontologies are indicative of the challenges facing KIDS.

An example from the telecom industry which may resonate with proponents of KIDS is the case of a “connected” car or future of semi-autonomous or autonomous vehicles. The car needs instructions in real-time with near-zero latency. It must receive software upgrades, bug fixes, send reports from sensors, enable instructions to modulate actuators and maintain constant dialog with control centers using cloud, fog or mist computing. The user and the connected car *doesn't care* if data arbitrage is being conducted over a fixed connection, WiFi, WiMax, DSRC (dedicated short-range communications⁴), C-V2X (cellular vehicle to x), SDN (software defined networking⁵) or NFV (network functions virtualization⁶). The vehicle needs *connecting*, with a certain quality of service (QoS). End-users may not care *how* the connectivity is implemented, as long as the *network-agnostic networks* can work seamlessly, in harmony, using whatever media is available (copper, fiber, wireless, LTE) to deliver the contracted quality of service, every time.

For users seeking assistance from KIDS, the user does not care which data domains the knowledge graph⁷ must connect and whether it is a RDF graph or a labeled property graph (LPG). The *quality of the outcome* is the relevant determinant of value from ART, KIDS, for the end-user. The dynamic pricing index (service fee) for KIDS may be linked to the QoS metric-on-delivery. The domains of data, data analytics and information databases, are static “nodes” or resources from the perspective of the end-user. The query from the end-user is the *trigger* to instantiate an *user-centric* selection of the nodes. In other words, *the query from the user will drive the connectivity* between data swamps, analytics and information nodes, necessary to answer *that specific question* from the user. The analogy in the networking world is referred to as application driven networking (ADN) or application centric infrastructure (ACI) and are variations of the concept commonly referred to as service-oriented architecture (SOA). The *service* call *shapes the events* which will *follow* in order to respond to the specific request.

User-centric dynamic composability to create *ad hoc* knowledge graphs will benefit from integrating Agents⁸ in the design of KIDS. One role of the Agent will be to parse the query and determine which nodes must be connected for KIDS to attempt to answer the query with a decent QoS metric. To provide a trivial analogy, imagine a busy intersection in Mumbai or Mombasa. The traffic lights aren't working due to brown out and motorists are confused by the DETOUR sign. A traffic policewoman is at the round-about, motorists are driving to the circle and policewoman directs the driver, depending on the driver's question. In KIDS, a software Agent, in the role of an “analyst” may execute the function of the policewoman, when it detects a query from an user.

⁴ <https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety>

⁵ http://publications.uni.lu/bitstream/10993/20596/1/survey_on_SDN.pdf

⁶ <http://www.ttcenter.ir/ArticleFiles/ENARTICLE/3431.pdf>

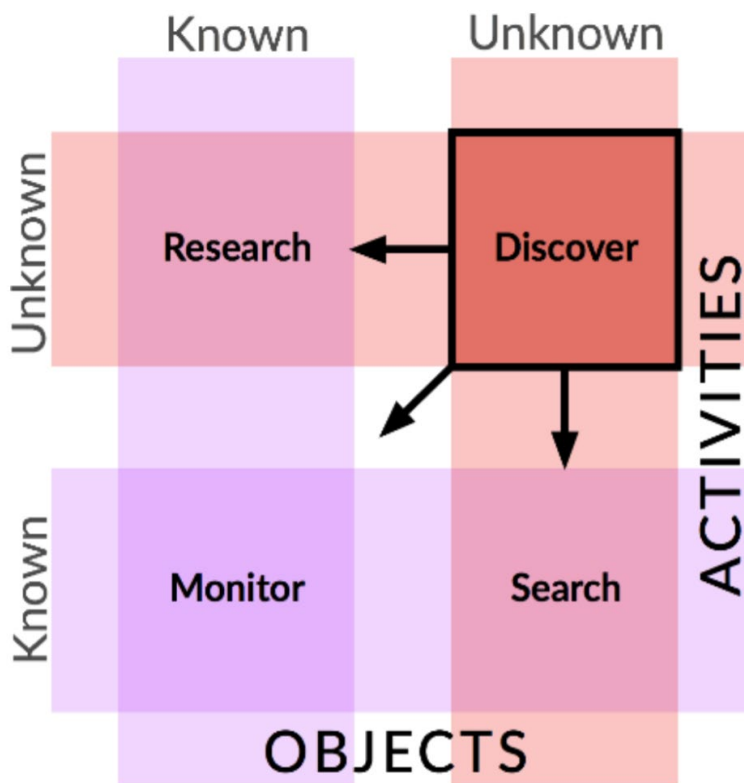
⁷ <https://googleblog.blogspot.com/2012/05/introducing-knowledge-graph-things-not.html> and <https://youtu.be/mmQl6VGvX-c>

⁸ <http://ermolayev.com/psi-public/SOTA-TR-PSI-2-2004.pdf>

What happens when the query falls in the “unknown unknown” category⁹ shown in the cartoon? Although this scenario is more prevalent in the cybersecurity domain, the principle of the solution is similar to the discussion, at hand. The Agent must work as an *analyst* in handling the queries to “discover” the “unknown unknown” concepts in the user’s query.

Discovery is a critical part of the knowledge graph future because the query-driven process must have a mechanism to find out *what* to connect, to create the knowledge graph. Data domains *relevant* and *relative* to the *context* of the query must be identified and *connected*. The principle of **R2C2** (relevance, relation, context, connect) may be key to connect correct nodes of the knowledge graph. The graph, thus constructed, and the graph network which will ensue, must be capable of extracting the relationships, correlations or convergence, the queries are seeking. This graph (linked RDF triples, relationships) may be stored in a knowledge graph database and the abstraction may be recycled or the actual instance may be re-used.

It will be remiss not to mention that one of the most egregious errors in the IoT hype is the idea that billions and trillions of devices and objects will be connected due to IoT. Even if there are trillions of things, the ability to connect is dependent on the ability of one object, with the correct tools to connect, to know and to *discover*, that there is another object, within its reach, which is safe, compatible and configured to access, and connect. Although the central role of knowledge access¹⁰ and *discovery* is an established principle, it is seldom emphasized for IoT.

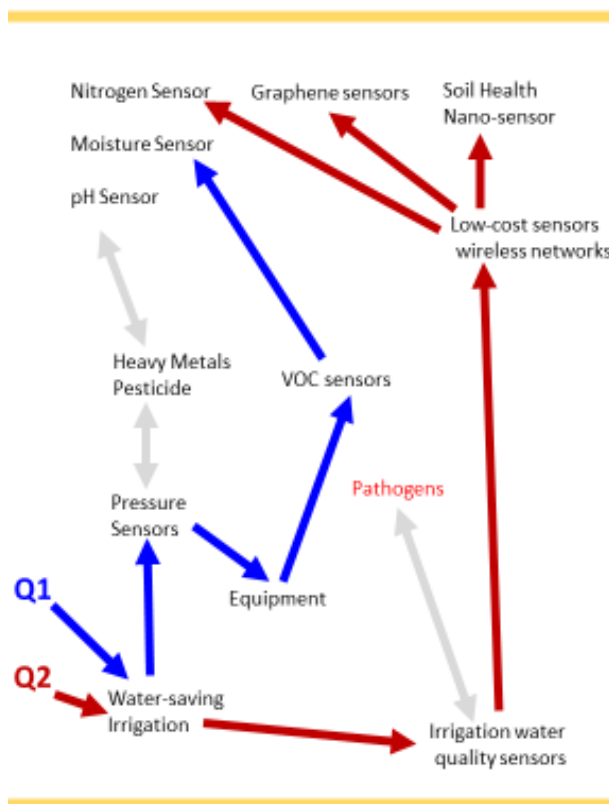


⁹ <https://agile-defense.com/wp-content/uploads/DarkLight-Game-Changing-AI-for-Cyber-Security-Brochure.pdf>

¹⁰ <http://oxygen.csail.mit.edu/KnowledgeAccess.html>

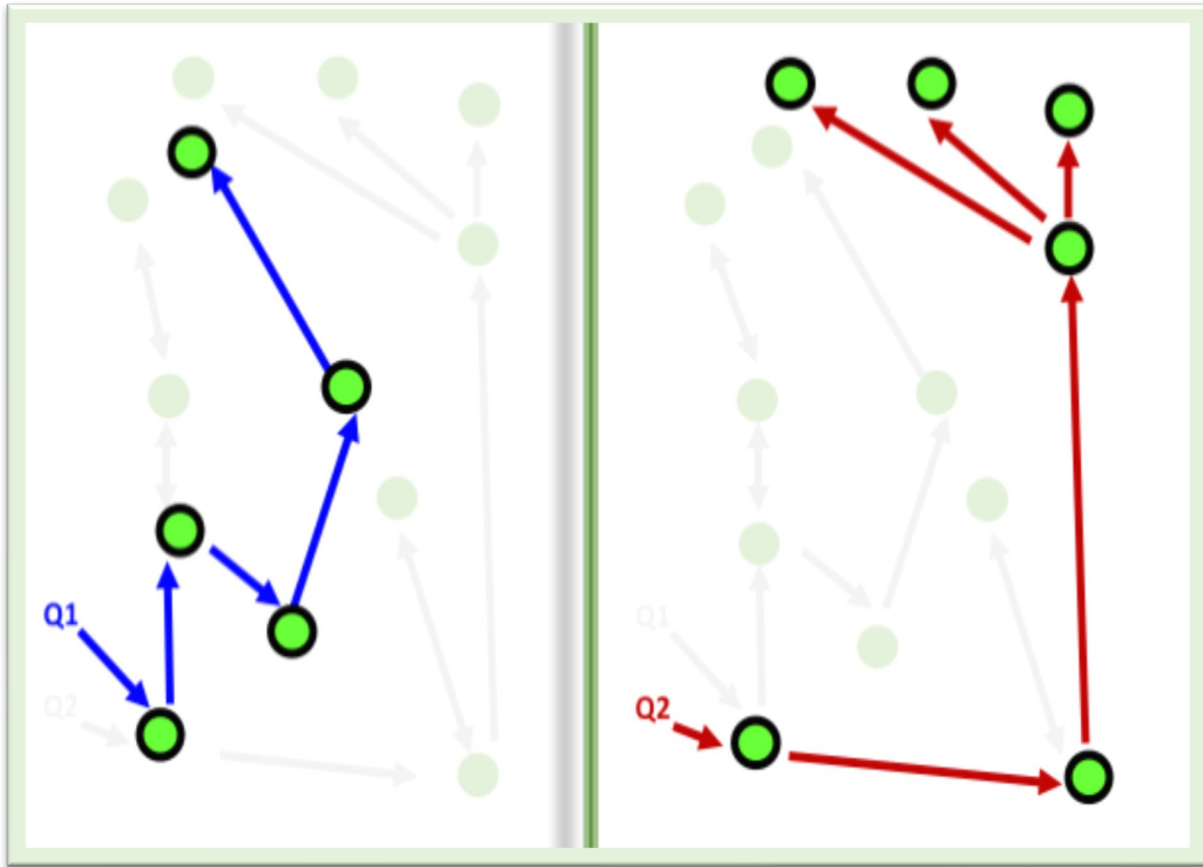
User-centric dynamic composability may also find some parallel concepts in network functions virtualization (NFV), a tool from the networking domain. The key idea of NFV is to *replace* dedicated network appliances, that is, *hardware*, such as routers and firewalls, with *software* running on commercial off-the-shelf (COTS) servers. The aim of NFV is to transform the way communication service providers (CSP) architect networks and deliver network services. In the KIDS paradigm, the CSP equivalent may be domains of data, analytics and information stores or *service providers*. In the KIDS model, examples of *service providers* (in terms of data, analytics and information) may be weather data, provided as a publish/subscribe tool from the Weather Channel, prices of commodities (food) from Bloomberg Business, pollution data in terms of particulate matter (PM2.5) in the air from feeds maintained by the EPA. In NFV, network function software is *dynamically instantiated* in various locations in the network *as needed*, without requiring the installation of new equipment. The parallel for KIDS may be the Agent which catalyzes the *dynamic composability of domains, on demand* (triggered by user's query). This *ad hoc* composition is necessary to respond to the query, in the context of the query. The Agent does not install new components. The Agent simply selects the domains which may contain contextual and related resources, which are salient create the graph, to answer the query.

Development of embedded analysts, Agents-based *selection* (ABS) in the design of software architecture¹¹ is an old concept, which is a grand idea still hiding under a bushel. KIDS with embedded ABS may be necessary to navigate available resources and stitch the correct sequence of domains to synthesize knowledge-informed decision as a service, on-demand.



KIDS cartoon illustrates various domains of data and information available to a system. Two incoming queries, both on irrigation, are asking quite different questions. Q1 appears to be interested in saving water. Knowledge graph Q1 connects the nodes which provides information about soil moisture, which may optimize water distribution by the irrigation system. Q2 is also interested in saving water but not before understanding the quality of the water and condition of the soil. Graphs for Q2 connect different domains. KIDS with embedded ABS may be the tool (hypothetical suggestion) necessary to *understand* the query (syntax, semantics, ontological schema, unstructured vernacular) and then direct the path the knowledge graph must choose to respond to Q1 and Q2 with sufficiently high QoS metric (value). The latter will allow KIDS to charge users a small fee (exceeding a contractual QoS metric triggers the pay a penny per unit scheme).

¹¹ <https://dl.acm.org/citation.cfm?id=122367>



KIDS cartoon illustrates the connectivity between different domains by overlaying a knowledge graph on top of available resources (resource agnostic) in a system, for example, agro-ecosystem. The abstraction demonstrates very different (number of nodes, edges) knowledge graphs, due to queries from end-users (Q1 and Q2 are both related to irrigation water, in this fictional scenario). Dynamic composition of these *ad hoc* knowledge graphs are query-driven, user case specific. A distant analogy from the telecom domain is the creation of virtual private networks (VPN) by building a virtual network overlay on top of multiprotocol label switching (MPLS) network components. The “brains of the network” are managed¹² by software defined networking (SDN) controller platforms, which contains a collection of “pluggable” modules to perform different network tasks. For KIDS, an equivalent “brains” platform may contain modular ABS (Agent-based selection) analysts, to direct the formation of knowledge graphs, by extracting **connectivity** structures (paths or graphs between entities, see colored circles in the cartoon) relevant to the **context** of the query. By training these tools (eg graph neural networks¹³) to parse the questions, various clusters of **meta structures** may be created to facilitate **knowledge discovery** tasks to locate¹⁴ **where** is the data or information, related and relevant to the query. These algorithms¹⁵ may add value to the embedded ABS analysts and in turn enhance the performance of KIDS.

¹² <https://www.sdxcentral.com/networking/sdn/definitions/sdn-controllers/>

¹³ https://repository.hkbu.edu.hk/cgi/viewcontent.cgi?article=1000&context=vprd_ja

¹⁴ <https://blog.cdemi.io/beginners-guide-to-understanding-bgp/>

¹⁵ <https://iswc2017.semanticweb.org/wp-content/uploads/papers/MainProceedings/272.pdf>

Extracting useful knowledge using the graph theoretic approach must be anchored to deliver *contextual meaning* of data. Hence, to connect nodes using the R2C2 principle, one must take into consideration the semantic profile of what is being connected. The data intensity of system of systems may be comparable to data intensive science projects, for example, the LHC (Large Hadron Collider) and ASKAP (Australian Square Kilometre Array Pathfinder), which generate petabytes of data, each year. If such vast volumes of data are stored in “data swamps” then we may lose its value unless curating contextual data from data swamps meets a miracle.

To make data relevant and meaningful for end-users, the applications must [1] select and coordinate data and information, [2] provide synergistic data integration between data domains (data from specific sensors or equipment, crowd sourced data), [3] enable visualization (plots, suggestions, recommendations) and/or [4] take action (actuate, execute). All of this is expected to happen in a seamless manner, in near real-time, without the need for users to understand any of the underlying representations and structure of the data.

In this vein, semantic¹⁶ tools provide categorization capabilities and may facilitate machine-encoded definitions of vocabularies (which could be different based on vernacular), concepts and terms. In addition, semantics may explain the interrelationships among them (different vocabularies residing in different documents or repositories). The challenge is (and may always will be) balancing expressivity (of semantic representation) with the complexity of defining terms (used by experts, scientists, engineers) and implementing an end-user-friendly resulting system. This balance is *application-dependent*, for example, in terms of ease of use between tomato growers and nurses. The degree to which the implementation must be user-friendly depends on the intrinsic technical competency of the users. A single solution may not fit all, even *within* groups, for example, pediatric nurse practitioners vs geriatric care nurses.

The success of semantics in this respect will be governed by a very different form of human relationship. **Leadership** in this collaborative approach will determine how the fields may progress in the future (for example, agro-ecosystem vs automotive vs health vs finance). Success of semantic structures necessary for data driven software processes will depend on peer relationships, where [a] domain experts or scientists in specific fields will form co-dependent liaisons with [b] computer scientists, as well as software architects/engineers and [c] data providers, data system administrators and so-called data scientists. Fields which are traditionally “farther” away from computer science and software engineering, for example, agriculture, chemistry, economics, must strive harder to bridge this chasm by co-locating computer science departments with agriculture, chemistry and economics, perhaps in the same building or quadrangle or emulate instances¹⁷ where agriculture is a part of a media laboratory. Without global and cultural cross-fertilization, ontological schemas and semantic catalogs of the future may be anemic, half-baked, sloppy and second grade (yet, masquerading as good enough).

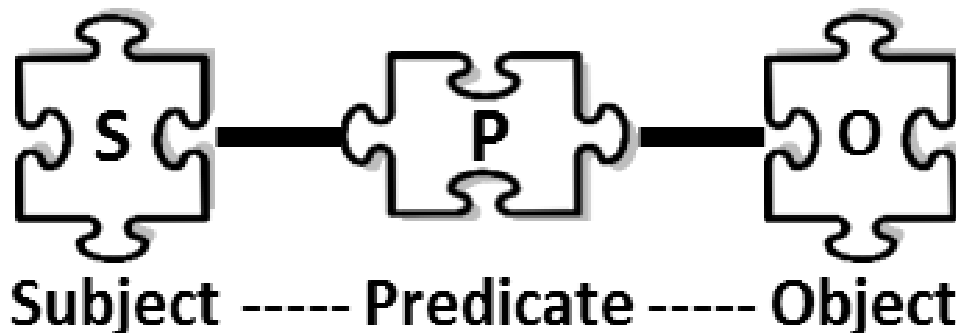
Semantic tools may be a part of data-driven, evidence-driven, reasoning solutions, logic tools (ART). Statistical and mathematical modeling-based ML may be part of logic tools, too. These are different but complementary. The distinctions may get fuzzy when we combine high volume data, analytics, distributed information and several knowledge domains, as in KIDS.

¹⁶ <https://pdfs.semanticscholar.org/9256/c883b1ecea08abc46179e2927302523a66d.pdf>

¹⁷ <https://www.media.mit.edu/groups/open-agriculture-openag/overview/>

- Deductive reasoning, syllogism & categorisation
(Aristotele, 384 BC – 322 BC)
- Formal logic & calculus ratoricator (reasoning, symbol)
(G.W. Leibniz 1646 - 1716)
- „Begriffsschrift“, technically: predicate logic
(Gottlob Frege, 1848 – 1925)
- Frames for representing stereotyped situations
(Marvin Minsky, 1974)
- Rules & expert systems
- Ontologies
(Leibniz, Kant, Gruber 1994)
- Description Logics
(Baader & Hollunder, 1991 et al.)
- Semantic Web
(Berners-Lee, Hendler, Lassila, 2001)
& Linked Data
& Knowledge Graphs

The promise of semantic tools and technology may be rooted in its ability to capture the semantics of the data with the data itself. It can capture meta-description of different kind of objects, attributes, associations, and activity into a conceptual model, which can be populated with instances of actual data. Described using OWL/RDF¹⁸ *syntax*, the conceptual model “ontology” represents the data itself in a single, consistent manner that is independent of how it is physically stored. With exceptions, ontologies formally describe taxonomies and classification networks, defining the structure of knowledge for various domains: nouns representing classes of objects and verbs representing *relationships* between the objects. Ontologies can represent information coming from heterogeneous data sources, hence, it can deal with structured, semi-structured, and unstructured data. The latter is particularly valuable for diverse end user groups.



When data is mapped against an OWL/RDF ontology, instances of the data are expressed based upon the idea of making statements about resources in the form of **subject–predicate–object** expressions. These expressions, also referred to as S-V-O (subject, verb, and object) are known as *triples* in RDF terminology. The ‘Subject’ denotes the object, and the predicate (verb) denotes a single semantic trait or aspect of the object that can be a literal value or expressed as a relationship between the subject and another object that is the target of the relationship.

¹⁸ <https://www.w3.org/OWL/>

For example, "soil pH 8" in RDF triple is **subject** denoting "soil" and **predicate** denoting "pH" and an **object** denoting "8" which is the OWL/RDF take on using the object as the subject from the entity–attribute–value model within object-oriented design: entity (soil), attribute (pH) and value (8). The object (soil) can have another attribute (contains) that points to another object (phosphate). The object (phosphate) might have an attribute (produces) another object (acidity). Yet again, the object (soil) might have an attribute (contains) another object (microbes).

This is why RDF triples, despite their shortcomings, enables the formation to link a series of relationships between two or more objects. A graph, in this context, is a linked set of RDF triples. OWL/RDF-based data model may suit certain kinds of knowledge representation better than relational models because it can fuse data from multiple relationship tables about the same object. It is the foundation on which directed graphs are built. A collection of RDF statements intrinsically represents a directed multigraph.

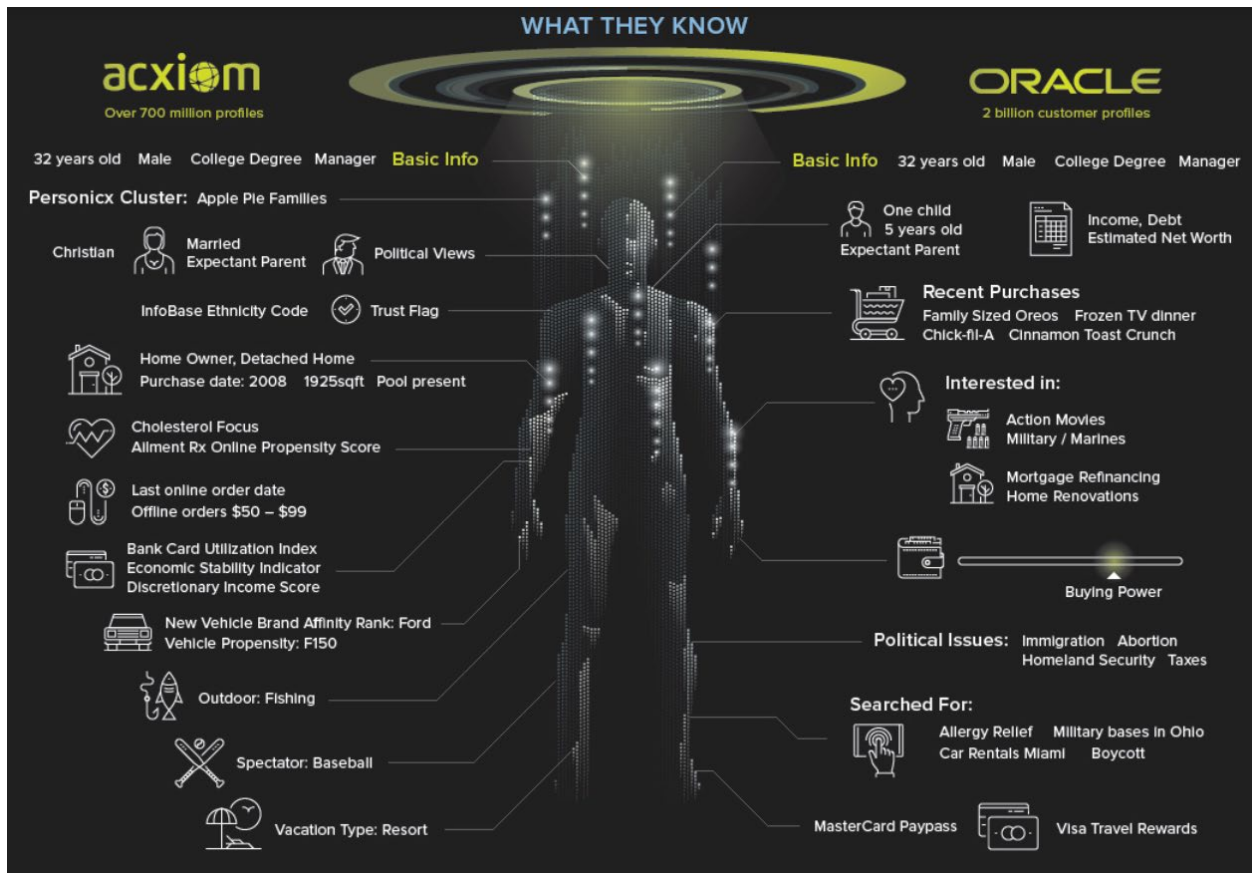
A **knowledge graph** (mentioned often in this document) is a knowledge base that is made machine readable with the help of logically consistent, linked graphs that, taken together, constitute an interrelated group of facts. RDF triple represents human knowledge in standard, machine readable form by linking a subject, predicate/verb and object. RDF representation can be visually displayed as the nodes (subjects and objects) and edges (verbs/predicates) of graphs.

The idea of *artificial reasoning in logic tools* relies on machine readable statements of facts. The expectation is that "triples" linked in a logically consistent way, via knowledge graph, will possess *reasoning* ability. When logically consistent factual triples are added to the graph, *machines can infer new links or connections*. Hence, new connections can be discovered by humans due to the *reasoning power of machines (artificial reasoning tools)*. Machines can then gain *access to the relevant data* in the *context* of these linked triples (knowledge graphs) as part of an *information service* (discussed earlier in the section KIDS WITH ABS) provided by **ART**.

For example, **ART** (artificial reasoning tools) may uncover the *relationship* between water, pH and Pb. The *machine reasons* that if pH of water in distribution pipes is less than pH 7 then the probability increases for metals, such as, lead (Pb), to leach out of the material (alloy) of the pipes (acid leaching) and increase the concentration of Pb ions in domestic drinking water supply (Pb is a neurotoxin). Having uncovered the relationship, the function of the knowledge graph (in ART) is to contribute to a solution, preferably quantitative. ART must *discover* and *locate data* to synthesize the solution and display the outcome on the end-user's mobile device. ART must discover data for each parameter, analyze and aggregate to create logical fusion. This demands data interoperability and choice of open APIs between systems, for example, the water distribution *map* (GIS), water quality *in* the distribution system (county public works database), chemistry knowledge for rate of leaching of Pb vs water pH (extract and merge the standard data with the actual pH of water, in this case). The *predictive analytics tool* may wish to forecast the (cumulative) increase in the concentration of Pb, with each passing day of inactivity. ART must display the useful version of this outcome and recommend mitigation strategy to reduce the morbidity of neurotoxicity due to Pb ions leaching from pipes into drinking water. This is the expectation from combined SENSEE 1.0 and 2.0 project, in terms of solutions for real world problems. We start with *logic tools* to deliver **ART** rather than "boil the ocean" with ML and other tools, which takes years, to reach the "knowledge-informed" quality of service (QoS).

Neither OWL/RDF standards nor graph networks or knowledge graph databases, are a panacea. They may not represent everything and all advantages are temporary. Application of graph theory will not obliterate the role of other architectures and databases. The balance of tools vs interoperability between systems, are central to “understanding and forging relationships” between relevant systems, through contextual combination of tools and confluence of ideas.

Knowledge combination/integration beyond (heterogenous) rules and ontologies are not only difficult¹⁹ but calls for *new thinking*. *The semantics of knowledge bases other than rules* (for example, descriptions of temporal processes like workflows in ART which could logically decide using logic tools when the irrigation system must turn on/off water pumps, or protocols in spatio-temporal logic) *must be integrated*. We need a higher plane of logic framework in which knowledge modules, with different native semantics, can be overlaid with meaningful semantics, preferably agnostic of linguistic bias, ideally as a “plug and play” operation, graph-friendly “drag and drop” operation for non-expert end-users, who may wish to decompose and/or re-compose the choice of logic and logic tools, based on experience or input from other expert humans in the loop. Chaperoning convergence between distributed knowledge domain(s), operational rules, data, information, and systems science, is a daunting and challenging goal (see cartoon below).



<https://www.visualcapitalist.com/personal-data-ecosystem/>

¹⁹ <http://www.kr.tuwien.ac.at/staff/tkren/pub/2008/rowschool2008.pdf>

Web of Knowledge Graph Networks are necessary for Knowledge-Informed Decision as a Service



CAN KIDS UNDERSTAND THE QUESTIONS FROM REAL-WORLD END-USERS?

The list of sensor description related questions that the PoC attempted to answer in Step I was sourced from experts and the queries (list of questions in this document) also originated from experts. Descriptions of sensors from experts or descriptions extracted from web document searches (for example doi:10.4172/2329-6798.1000111) may be in sharp contrast to queries from real-world applications where questions are from users in agro-ecosystem, retail or healthcare.

Unstructured questions from users must be sufficiently understood by KIDS, if we are aiming to provide value for real-world applications where the user may be paying a fee for the service. To make SENSEE useful to end-users, to a limited extent, we have to start with the questions from end users (*PEAS Platform for the Agro-Ecosystem*). The end-user may want to know what types of sensors are available to detect mercury, who are the manufacturers, which brands are highly rated, what is the price, what is the maintenance fee and software licensing cost. These questions may not be answered by SENSEE 1.0 but by ART, in future. The query-triggered search must be able to understand the domains that the search engine must connect in order to extract the data and information relevant to the question. The latter is beyond the scope of SENSEE 1.0 and 2.0 but expected to be a building block for artificial reasoning tools (ART).

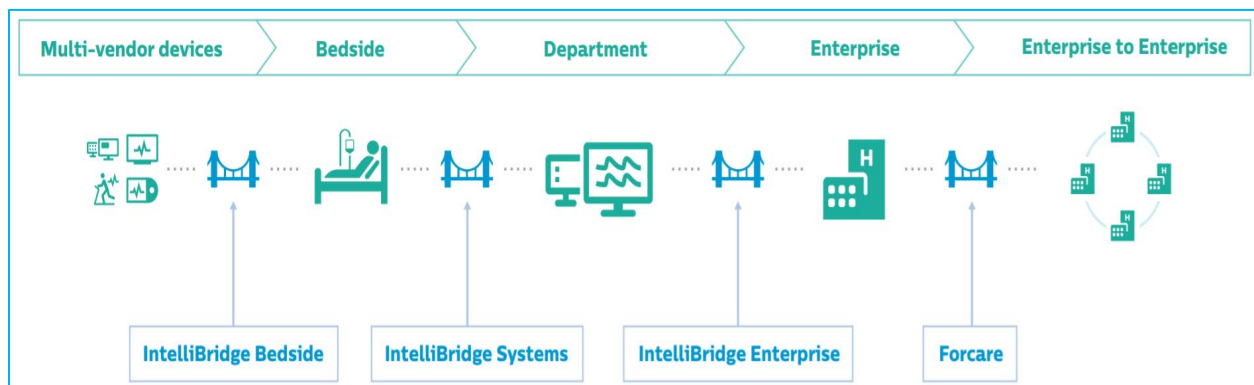
In many instances, user may ask questions about systems and technologies which may not involve sensors. For example, end-users on a farm may have a question about the amount of moisture in the soil vs the volume of water that must be dispensed by the irrigation pump system. Multiple domains must be integrated to address the diverse range of questions expected from end-users in any ecosystem.

The ability of ART, DIDA'S, KIDS, to understand the question and *relationships in the question* are critical to the success of PEAS platform. ABS analyst may be critical to evaluate and understand which direction to pursue and which domains to connect, based on the question.

When we move from SENSEE 1.0 (sensor descriptions in sensor search engine) to sensor data (SENSEE 2.0), the source of the data will be *sensors in use by end-users* (sensors deployed in farms, stores, shop floors, transportation). The end-users will have to agree to upload sensor data streams to the *open PEAS platform*. The incentive for the user is the expectation that ART (KIDS) will make sense of the data and provide end-users with actionable information. In future, perhaps, offer knowledge, to improve decision systems or aid human users in decision making.

Participation of manufacturers, who are possessive about data and dissemination from their sensors and equipment, are potential sources of conflict. It is well nigh impossible for any one manufacturer to provide the range of sensors and equipment necessary for all operations. The manufacturer-specific dashboard may always remain a data portal, short on information and devoid of knowledge. Users, however, can change the *status quo*. User-adoption of ART (KIDS) will depend on the critical mass of data and information connectivity, as well as the ability to understand questions from users and answer them with a very high QoS (quality of service).

Aggregation platforms in the agro-ecosystem may share some analogies with the lack of device data interoperability in healthcare (<https://mdpnp.mgh.harvard.edu/projects/ice-standard/>). Deaths due to lack of interoperability is calling for change (<https://www.himss.org/file/1325897>) in the healthcare system to aggregate data in the context of the patient and transform the data to information, relevant to the patient and the point of care medical professional, as well as the extended enterprise. In other words, the cartoon below may represent **KIDS in healthcare**.



Aggregation of tools on a platform is an old (<https://dspace.mit.edu/handle/1721.1/56251>) idea which may find its origins in the “bazaars” of ancient Mohenjo-Darro and Mesopotamia, the “clusters” in town centers and the modern “malls” which are almost universal. Radio, TV and movie halls aggregated music, shows and movies. Digital aggregation pioneered by Amazon, eBay and Napster is evident in the streaming platform ROKU (<https://blog.roku.com/oxygen>). In healthcare (ICE, clinical environment, [www.mdnp.org/MD PnP Program OpenICE.html](http://www.mdnp.org/MD_PnP_Program_OpenICE.html)) or in the agro-ecosystem, or most other system of systems, data aggregation offers value. KIDS is in good company and not an enigma for end-users, if they have the patience to start with ART.

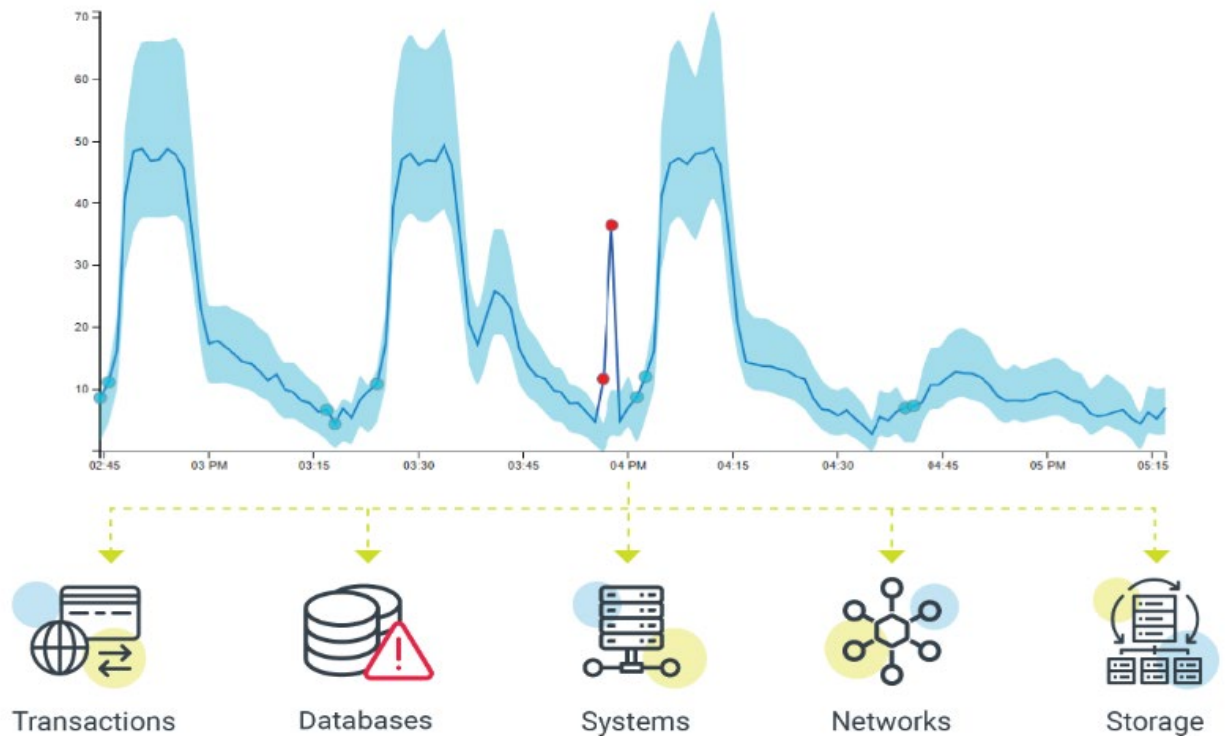
KIDS can catalyze data fusion by aggregating contextually relevant data from different systems, and provide analytical support, for decision making, in near real-time, on a mobile app through a smartphone or tablet, anytime, anywhere. Bringing the *algorithms to the data* at the edge (point of use) is possible by running computation at the edge (<http://eyeriss.mit.edu/>) and using sparse, trainable artificial neural networks (<https://arxiv.org/abs/1803.03635>) to help humans make better decisions, at the edge, before the value of the information perishes. By partially automating the system, the actionable information can also actuate sensors or systems (paradigm shift from SARS to SARA – see SARS♦AG here <http://bit.ly/SIGNALS-SIGNALS>).

ART is expected to deliver low-risk automation to solve specific problems, for example, based on the situation and feedback from the outcome (control theory feedback optimization loop), turn on/off irrigation water pumps, selectively, by distribution zones, using a GIS map.

The value of ART (logic tools and ART are not unique approaches) and the monetization potential from knowledge-informed analytics, is linked to performance of KIDS. Imagine how agent-based artificial reasoning (ABAR) bots, may continuously seek non-obvious exceptions, non-obvious correlations and non-obvious errors. Creating machine learning algorithms and deep learning tools only to search for anomalies (red dots in the cartoon, next page, example of root cause analysis) is an under-utilization of the benefits from tools of artificial reasoning (AR).

ABAR may be trained to find positive, as well as negative, correlations. Training is still in an enigmatic *black-box* domain. With greater clarity, perhaps, training can harvest crowd-sourced nuggets of knowledge. For example, an apocryphal anecdote from an ALCOA plant describes the breakdown of a chemical processing step, just days after the retirement of an experienced plant operator. When the operator was invited back to help identify the problem, it turned out that the operator used to spit in the smelted ore chamber. After his retirement, no one was spitting during that processing step. The surfactant from the spit was key. Surfactants catalyze chemical purification processes for aluminium. Hence, the value from crowd-sourced information, knowledge, experience and wisdom.

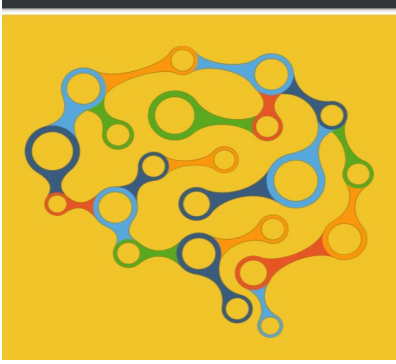
Creativity and innovation will be necessary to capture these occasional unstructured events. The next task is to integrate them with ongoing ML/DL *training tools* “educating” ABAR. How can crowd sourced wisdom train ABAR? For mass adoption, the process must have an ETL type tool (mobile capture and upload, drag and drop) for non-experts (plant managers, transportation planners, *any* end-user).



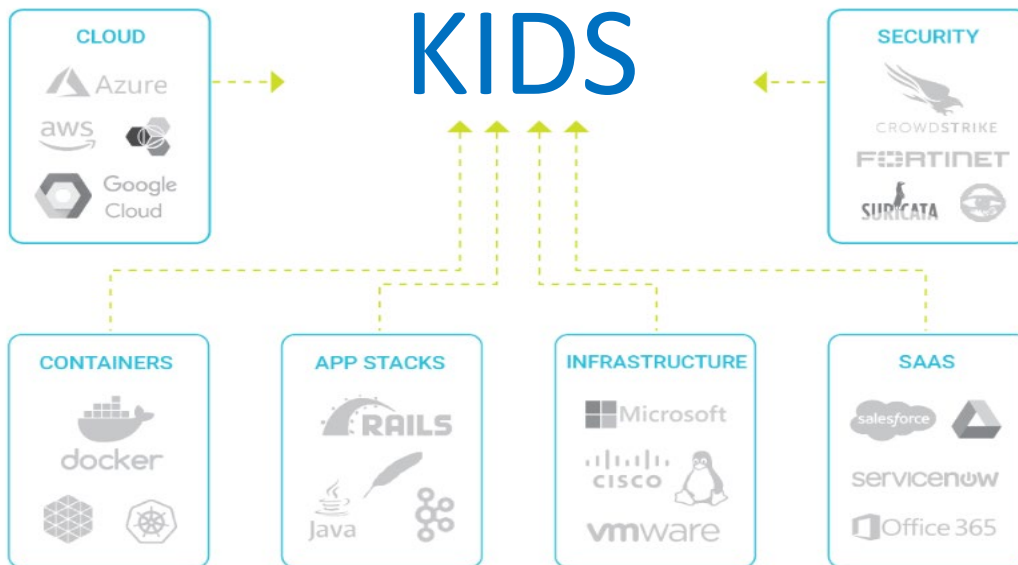
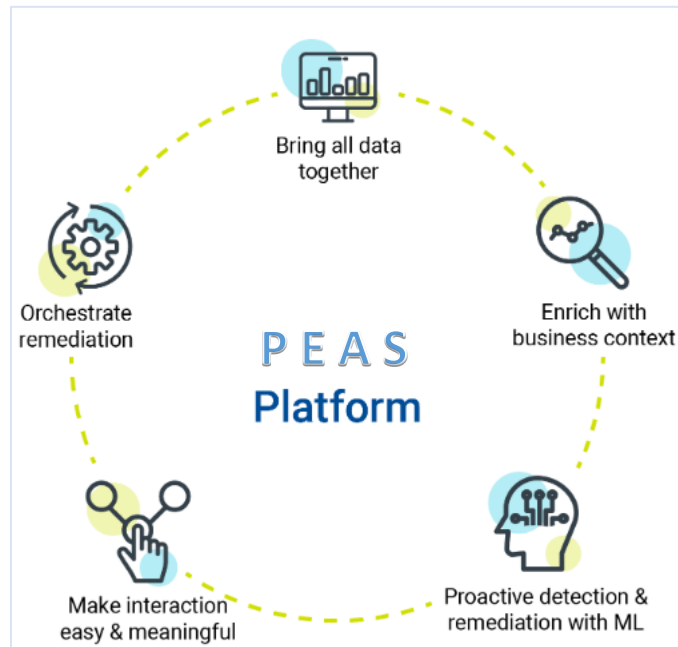
But, how will we know that a nugget of wisdom just hatched during a conversation? That is a very difficult problem. If the “nugget” is captured, how can we add it to training algorithms? One poor analogy is cooking. First, fry onions and garlic, then add spices, followed by the meat, add more aromatic spices. Another analogy is a human attached to an IV drip (intra-venous), which can drip saline, blood, morphine, antibiotics, cyanide. The key is the flexibility and modularity of adding things to a process. Do we need a “funnel” or app or API for delivery?

The outcome of training ABAR is to create an army of AKBAR (agents with knowledge-based artificial reasoning). In “[IoT is a Metaphor](#)” the attempt is to transform data/information to knowledge, and find new ways how organizations and enterprises may create value for users, through knowledge-informed decision as a service. KIDS with agent-based selection (ABS) will evolve to include AKBAR (agents with knowledge-based artificial reasoning), where mobile agents can travel *between* networks and cross-pollinate domains with information. Spread of mis-information, hence, raises its ugly head and cybersecurity considerations become central. However, it is still tempting to speculate, as mentioned elsewhere in this document, how we may “air-drop experience” from those who have it, to those who may wish to use it, for a fee.

The future demands we ask different questions, new questions, relevant and contextual questions, obvious and non-obvious questions, incisive and analytical questions. Hopefully, at least some of these next generation questions will also contain a few *correct questions*, to spur new thinking, create tools that are still cryptic among the unknown unknowns, and help us to visualize the possibilities, with *new eyes*.



The cartoon on the left and everything else discussed here is non-linear. Optimization routines, linear programming and static databases are rigid and less useful. All the rage about Hadoop is almost dead (HDFS, without transactions, search, indexing or caching, failed to solve real data problems) even though it was a NoSQL distributed data technology. Lack of semantics (context) turned Data Lakes into Data Swamps. To get out of the “swamp” we need NLP (not LP) and new eyes. We wish to use knowledge graphs (KG) and KG algorithms as a new path in the journey from data to knowledge (KIDS).



Towards building the next generation database query engine

Yesterday's DB engines are incapable of solving today's problems. [David Mack](#).

In the 1970's the relational database was born (www.seas.upenn.edu/~zives/03f/cis550/codd.pdf) and remains a staple in the industry. But, enterprise companies are beginning to explore machine learning, because databases are inadequate for the company's informational needs. Relational databases have been wildly successful, forming an essential piece of almost any application. With this success has brought a rich deluge of data into database systems. Relational databases are great at supporting the developer defined symbolic relationships in the data (e.g. purchase belongs to user), but have barely any support for the noisy, sparse, probabilistic relationships that arise within the data itself (e.g. users with higher disposable income tend to make more purchases). This limitation is reflected in query languages (e.g. SQL) themselves. They are famously unfriendly for non-technical business users, so much so that entire teams of data analysts, BI experts and data scientists are drafted to help non-technical employees access their data. A very simple query such as "get the second highest salary" translates into:

```
SELECT DISTINCT Salary FROM Employee e1 WHERE 2=Select COUNT(DISTINCT Salary) FROM Employee e2 WHERE e1.salary<=e2.salary
```

A [new generation of database query engine](#) is taking a different approach. At its core, it's very different from current database query engines:

It accepts natural language (e.g. English) instead of SQL for queries

It represents data as a mixture of sparse features instead of as items from fixed categories

In the real world, nothing fits into neat boxes. Words have many meanings. Sentences can be ambiguous. Concepts and thoughts are related to others, in many different nuanced ways. Fall-leaves, tobacco and leather seem to go together, but why exactly? Our data representation supports and embraces this deep interconnectedness. We achieve this by representing data as mixtures of sparse features (i.e. many dimensional vectors). These representations are created using learned embeddings and learned transformation functions. This allows the query engine to better use the nuance of the query's words to find relevant data. It allows it to aggregate and filter data based on learned sub-categories, of which membership is not binary.

It learns multi-step deep algorithms from examples

Many times in life, we can specify the inputs and outputs, however working out how to get between them is hard (for example, try writing a series of rules to tell if a photo is [of a hotdog](#)). ML can work out the middle part in the right circumstances. Classical algorithms, the ones readily implemented in traditional database query engines, are very rigid. Each step must be a clear-cut decision with easily specified inputs. In a learned algorithm, each step can incorporate many weak signals to work out what to do next. Furthermore, it can do many different sub-steps in parallel, weaving a much more complex solution than could be written by an engineer. This is like comparing how many people cook in the kitchen vs a recipe book: we measure ingredients by eye, combine ingredients by feel and cook it until it smells and looks good. We improvise. None of which is captured in a recipe.

How to build it

Such a radical departure from how current query engines work requires a similar departure in the underlying technology. We're using a neural network as the core of the query engine. We present the database information as tables of data and adjacency matrices (e.g. an array of a connections) to the neural network, and let it process the data and query to produce a result. The network processes the query through an [RNN](#) and learned word embedding. This provides both an array of query tokens and also an overall query vector. The data is then processed through a network reminiscent of the [Transformer architecture](#). After applying learned embeddings to data, it is passed through series of attention systems <https://arxiv.org/abs/1706.03762> and <https://arxiv.org/abs/1902.10186>. These allow the network to leverage task-specific sub-networks and to combine earlier calculations together to form complex aggregates. [Working example here](#).

Some of the sub-networks include (for our graph-processing network):

Node property recall

Edge (i.e. relationship) recall

Using previous step's output as addressing instructions for the above

Iterative message passing

Recalling previous step's output and transforming them in a range of ways

EXPLORE KEY PAPERS in this zipped folder <http://bit.ly/ML-MISC-01> and the list provided here:

<https://arxiv.org/abs/1706.03762>

<https://arxiv.org/abs/1806.01261>

<https://arxiv.org/abs/1803.03067>

<https://arxiv.org/abs/1711.09846>

<https://arxiv.org/pdf/1905.12107.pdf>

https://github.com/deepmind/graph_nets

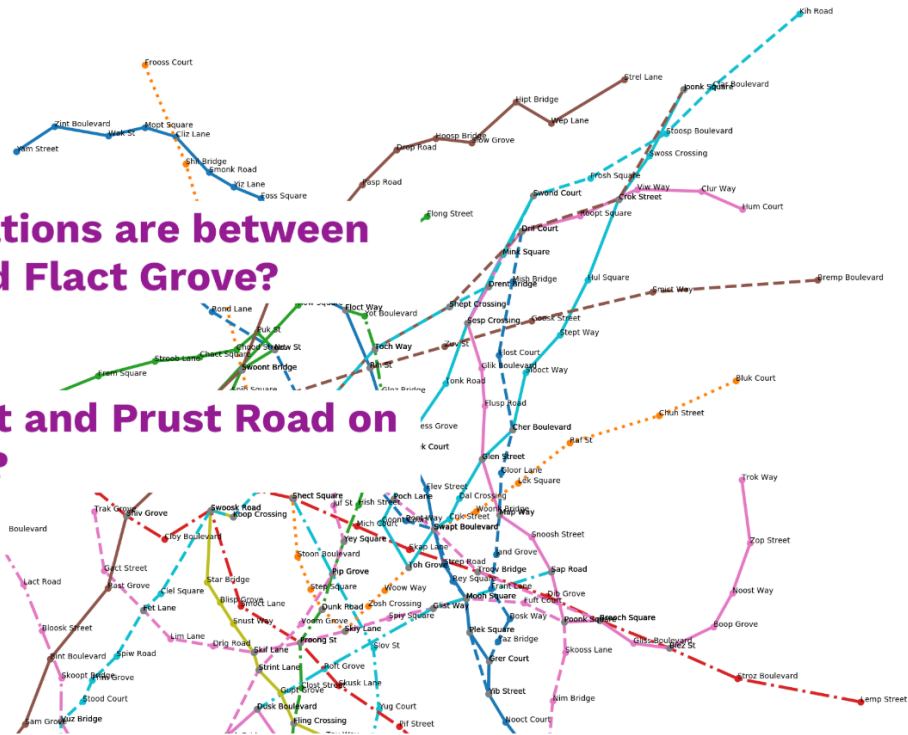
CLEVR graph: A dataset for graph question answering

How many stations are between Crar Court and Flact Grove?

Answer: 12

Are Grey Court and Prust Road on the same line?

Answer: No



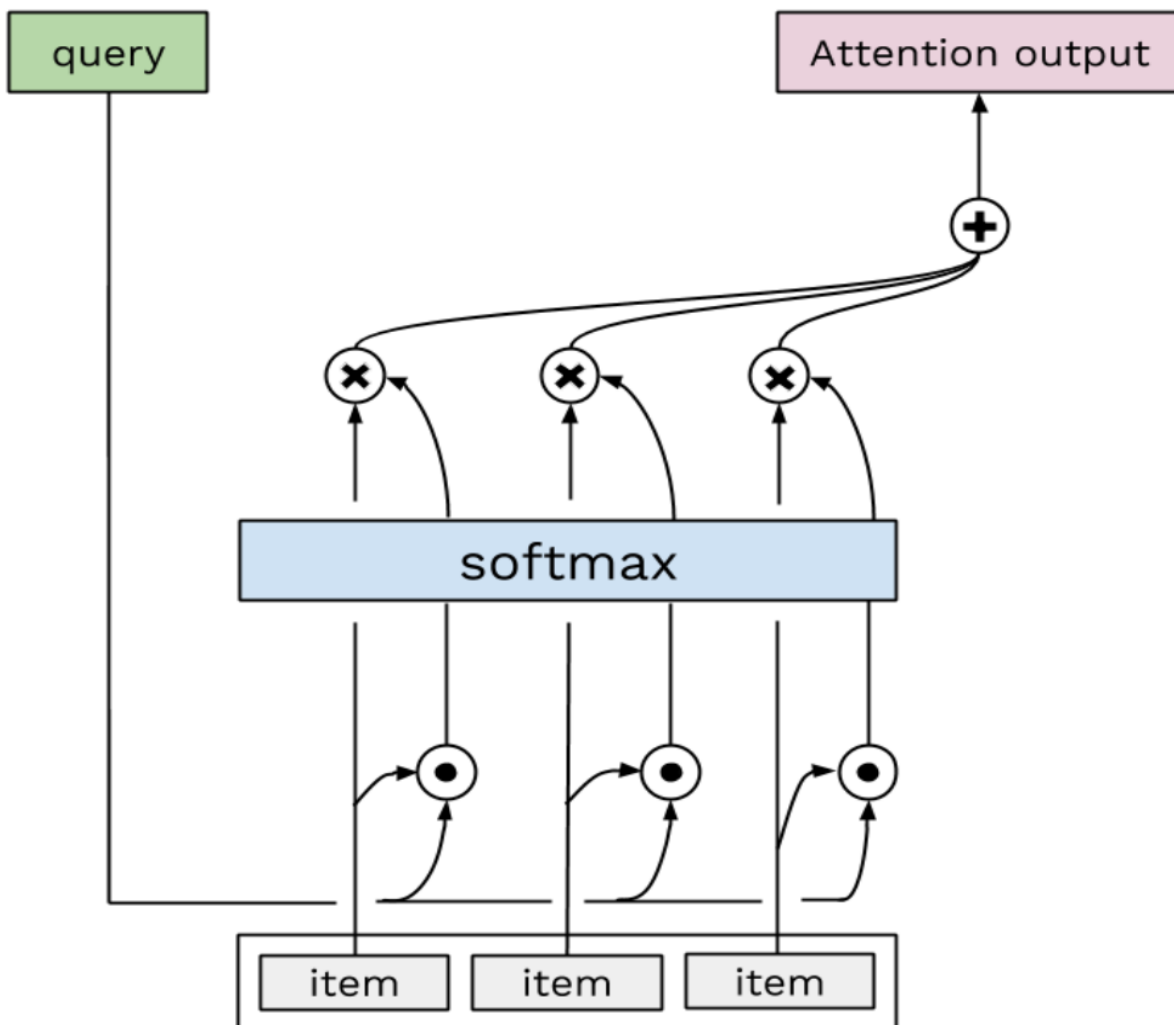
The graph data is modelled on transit networks (London tube and train network). Questions are modelled on questions typically asked by passengers (users) around mass transit (How many stops between? Where do I change?). Aim: solution to this dataset has real world applications.

- Does {Station} have disabled access?
- Is there disabled access at {Station}?
- Does {Station} have rail connections?
- Can you get rail connections at {Station}?
- How many stations are between {Station} and {Station}?
- Are {Station} and {Station} adjacent?
- Which {Architecture} station is adjacent to {Station}?
- Are {Station} and {Station} connected by the same station?
- Is there a station called {Station}?
- Is there a station called {FakeStationName}?
- Which station is adjacent to {Station} and {Station}?
- How many architectural styles does {Line} pass through?
- How many music styles does {Line} pass through?



Is “ATTENTION” insufficient?

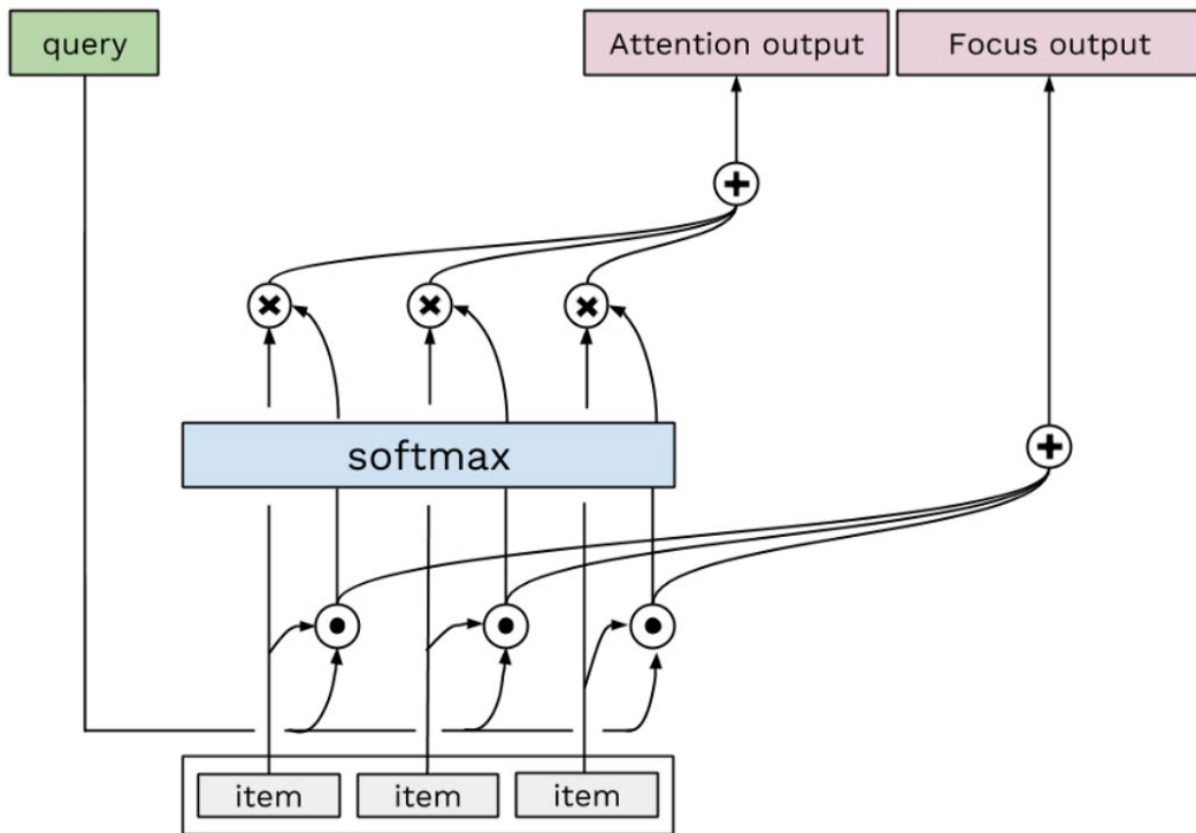
How to show if some things are not present in a list?



A popular neural-network technique for working with lists of items (e.g. translating sentences treating them as lists of words) is to apply “[attention](#)”. This is a function where a learnt “query” of what the network is looking for is compared to each item in the list, and a weighted sum of the items similar to the query is output. Attention is the basis of [current best-in-class translation models](#). The mechanism has worked particularly well because tasks can be solved by rearranging and combining list elements to form a new list (e.g. attention models have been important components in best of class [translation](#), [question-answering](#), [reasoning](#) models).

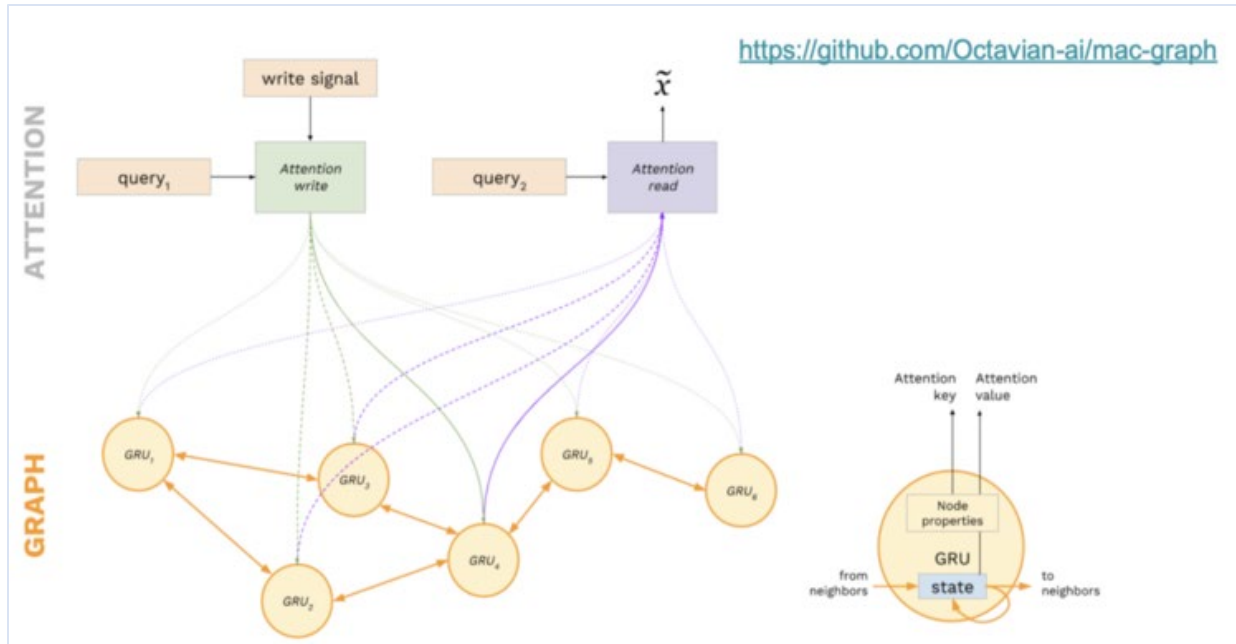
Despite attention’s versatility and success, it has a deficiency that plagued our work on [graph question answering](#): **attention does not tell us if an item is present in a list**. This first happened when we attempted to answer questions like “Is there a station called London Bridge?” and “Is Trafalgar Square station adjacent to Waterloo station?”. Our tables of graph nodes and edges have all this information for attention to extract, but attention itself was failing to successfully determine item existence. This happens because attention returns a weighted sum of the list. If the query matches (e.g. scores highly) against one item in the list, the output will be almost exactly that value. If the query did not match any items, then a sum of all the items in the list is returned. Based on attention’s output, the rest of the network cannot easily differentiate between those two situations.

The simple solution we propose is output a scalar aggregate of the raw item-query scores (e.g. before using [softmax](#)). This signal will be low if no items are similar to the query, and high if many items are. In practice this has been very effective (indeed, the only robust solution of the many we’ve tested) at solving existence questions. From now on we will refer to this signal as “focus”.



Attention with focus signal, using a summation for aggregation of raw scores

<https://github.com/Octavian-ai/attention-focus>



What is the cleanliness level of {Station} station?

How big is {Station}?

What music plays at {Station}?

What architectural style is {Station}?

Describe {Station} station's architectural style.

99.9% accuracy after 10k training steps

Is there disabled access at {Station}?

Does {Station} have rail connections?

Can you get rail connections at {Station}?

Are {Station} and {Station} adjacent?

99% accuracy after 20k training steps

Which {Architecture} station is adjacent to {Station}?

98.8% accuracy after 30k training steps

How many stations are between {Station} and {Station}?

98% accuracy up to ~9 apart after 25k training steps

Are {Station} and {Station} connected by the same station?

98% accuracy after 20k steps

Which station is adjacent to {Station} and {Station}?

Is there a station called {Station}?

99.9% accuracy after 30k training steps

Is there a station called {FakeStationName}?

Are {Station} and {Station} on the same line?

Not yet tested

How many architectural styles does {Line} pass through?

Not yet tested

How many music styles does {Line} pass through?

Not yet tested

How many sizes of station does {Line} pass through?

Not yet tested

How many stations with rail connections does {Line} pass through?

Not yet tested

Which lines is {Station} on?

Not yet tested

How many lines is {Station} on?

Not yet tested

Which stations does {Line} pass through?

Not yet tested

What's the nearest station to {Station} with disabled access?

Not yet tested

Some example questions from CLEVR graph question bank. It's a synthetic (procedurally generated) dataset which consists of 10,000 fictional transit networks modelled on the London underground. For each randomly generated transit network graph we have a single question and correct answer. Each graph used to test the network is one the network has *never seen before*. Therefore, it *cannot memorise* the answers to the questions but must learn how to extract the answer from new graphs.

The data (DIDA'S) to knowledge (KIDS) transition in my essays are eloquently explained by **Dan McCreary**. I am *copying* a few of his articles that are relevant to these essays. I have edited the content and removed leading suggestions (subtle advertising). Please access original versions from www.danmccreary.com/

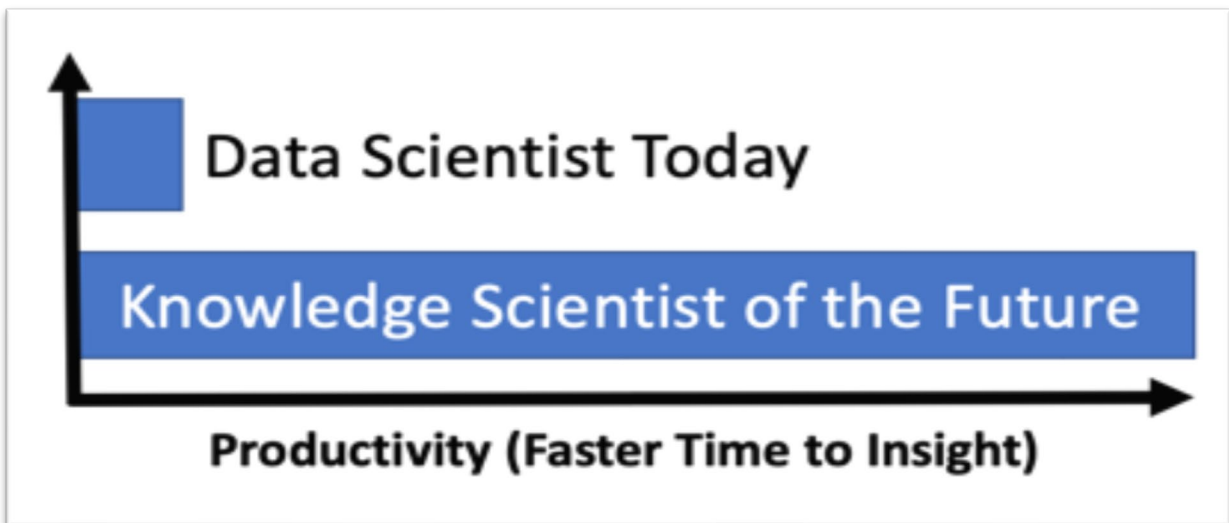
Another resource worth exploring is here <http://bit.ly/Yann-LeCun> but it contains a myriad of exaggerated claims and ideas of solutions “provided by powerpoint”.



“Imitation is the sincerest form of flattery that mediocrity can pay to greatness.”

– Oscar Wilde

From Data Science to Knowledge Science



Knowledge scientists may be more productive than data scientists because they may offer a new set of assumptions about the inputs to their models and store their insights in a knowledge graph. Their input features may remain **highly connected** to other relevant data as such as provenance and lineage metadata. An [article](#) pointed out: *Data scientists...spend from 50-80% of their time as mundane laborers, collecting and preparing unruly digital data, before it can be explored for useful nuggets.*

Cleaning up data involves data cleanup code. **Feature Store** is an attempt to build reusable artifacts for data scientists. Google and Uber have discussed their efforts to build tools to reuse features and standardize the feature engineering processes. My big concern is that many of these efforts are focused on building flat files of disconnected data. Once the features have been generated they can easily become disconnected from reality. They quickly start to lose their relationships to the real world.

An alternative approach is to build a set of tools for analysts to connect directly to a well-formed enterprise scale knowledge graph to get a subset of data and transform it to structures that are immediately useful for analysis. The results of this analysis can be used to enrich a knowledge graph. These Machine Learning approaches can complement the library of turn-key graph algorithms.

Data quality within a knowledge graph: MarkLogic is a document store where native data is stored in either JSON or XML documents. It promotes productivity through [1] document-level data quality score and [2] implicit query language-level validation of both simple and complex data structures. In MarkLogic, a built-in metadata element called the **data quality score** is usually an integer between 1 and 100 that assigned as new data enters the system. A low score (<50), indicates quality problems (missing data elements, fields out of acceptable ranges or corrupt or inconsistent data). A score of 90 may indicate that it could be used for downstream processes. Documents with a score >70 or >80 may improve search or analysis performance. To accomplish this task, a validation schema is built-in to MarkLogic. The concept of valid data is also built into W3C document query language (XQuery). Each document can be associated with a root element (within a namespace) and bound to an implicit set of rules about that document. GUI editor (oXygen XML Schema editor) allows non-programmers to create and audit data quality rules. XML Schema validation can generate a true/false Boolean value as well as a count of the number of errors in the document. Together with tools like Schematron and external data checks, each data steward can determine how to set the data quality score for various documents.

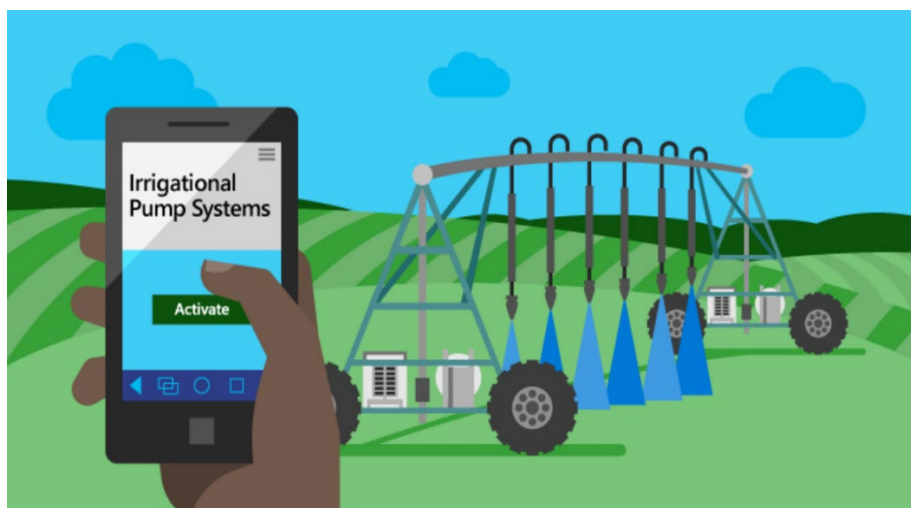
Document-level data quality scores are a natural fit with **events**, as a part of the workflow (for example, inbound call to call center, new customer purchase, subscription renewal, enrollment in a new healthcare plan, a new claim being filed, new sensor installed, new sensor data stream goes live). All of these events can be captured as complete documents, stored in streaming systems like Kafka and ingest the business event data to knowledge graphs. Data quality scores can be included in business event documents and knowledge graph (use it anywhere it is necessary for analysis).

In contrast, dumping table-by-table data from relational databases into CSV files are full of numeric codes that may not have clear meaning. Curating this low-level data from “data lakes” to deliver meaningful connected knowledge is an arduous task. Storing flattened CSV-level data and numeric codes is where features stores fall short. Once the features are extracted and stored in a data lake or object store, they become disconnected from how they were created. A new process might run on the knowledge graph that raises or lowers the score associated with a data item. However, that feature can’t easily be updated to reflect the new score. Feature scores can add latency that will prevent new

data quality scores from reflecting the current status. Perhaps, relational data architects (using tables to store data) tend to under-value document models and associating data quality score with event documents.

In summary, the quality in a graph is different than quality in a document (please explore <https://en.wikipedia.org/wiki/SHACL>). The connectedness of a vertex in a graph will also determine quality (please explore <https://www.w3.org/TR/prov-dm/>). Eventually, knowledge graph products may have a metadata layer about how data was collected and transformed during the journey from the source to the knowledge graph. As RDF fades into the annals of W3C, we see a concomitant rise of the LPG (labeled property graph) ecosystem. LPG still lacks mature machine-learning integration tools to enable knowledge science.

Note: *This is a step beyond ART toward knowledge. It signals a move, in principle, from data-informed decision as a service (DIDA'S) to knowledge-informed decision as a service (KIDS). The cartoon below is a stand-alone digital proxy for irrigation pump system. The relevance of the data and information (before pump activation) must be **correlated** with soil moisture, optimum moisture saturation desired for the crop, the weather (prediction of rain within an acceptable window of time or forecast for even higher temperature which may accelerate loss of moisture from the soil), and other relevant information in the context of this action (activating irrigation pumps). ART can aggregate the information and ABS can direct pump activation (pump speed, volume of water, duration of action, coverage area, energy consumed). Analytical engines at the edge (on mobile phones) running short neural networks (<https://arxiv.org/pdf/1803.03635.pdf>) may assist ART, ABS, KIDS. This is an observation by the author and **not** due to Dan McCreary (<http://bit.ly/GKG-KIDS>).*

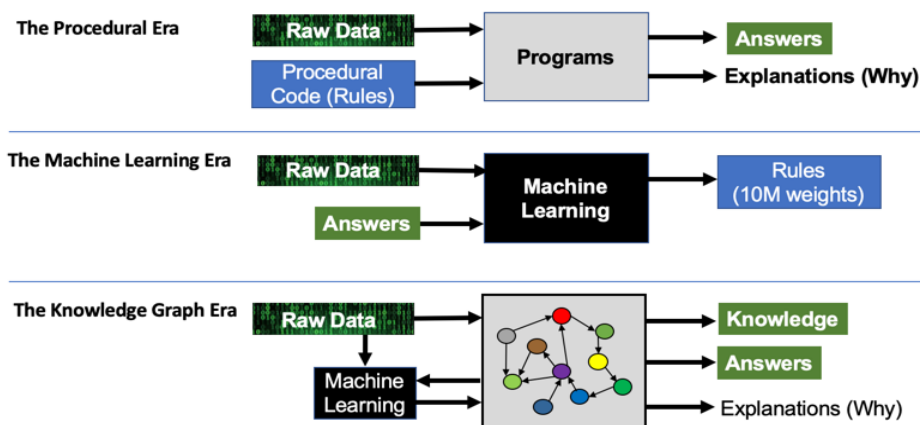


Link: <https://cloudblogs.microsoft.com/industry-blog/microsoft-in-business/2019/05/15/how-polaris-energy-services-is-transforming-the-agriculture-industry-in-the-cloud/>

Knowledge Graphs: The Third Era of Computing

“When did computing start?” A cuneiform tablet from circa 3,000 BC may hold the answer. Knowledge representation began when we wanted to remember things that were important to us. For example, ledger of financial transactions such as “X owes Y ten baskets of grain.” It was natural to store these facts in rows and columns of a table because tables were a good “natural representation” for financial transactions. These transactions records evolved into rows of symbols which represented concepts and gave birth to written languages. These representations continued for 5,000 years. Clay tablets evolved into papyrus scrolls, then Luca Pacioli’s double entry bookkeeping system, which eventually became punch cards and then flat files in COBOL, then tables in a row-store popular in relational databases and finally Enterprise Resource Planning (ERP) systems.

These tabular representations worked well when our problem had uniform data sets. By uniform we mean that each record (row) has similar attributes with similar data types. Not all problems fit well into tables. The more tables you have the more expensive the relational joins. How do we store the **analysis** of a patient chart? You might have a so-called AI agent scanning data (eg drug adherence data). What do they produce? The answer is often a list of conditions and the probability of occurrence (diabetes, asthma). Healthcare systems store these concepts in a complex hierarchy (a taxonomy) with many connections between the concepts (ontology). The AI tool may recommend next best actions. This analytical data (outcome) may not fit easily into a table. But it does fit well into a graph of connected concepts, the knowledge graph.



The bulk of developers are still writing PHP/Java/Python over tables (not graphs). In the knowledge graph era, machine learning continuously reads raw data, combines this with existing knowledge and produces new knowledge, answers and explanations. Knowledge graphs are at the core of the third era of computing, aimed to enrich shared knowledge.

Knowledge graphs combine to produce a system that not only learns from complex data, but it also can explain its decisions. We use machine learning to harvest raw data and look for patterns in this data. Machine learning finds relevant information (people, places and things) in images, texts and sound. ML converts this to new entries in our knowledge graph along with confidence weights. The data can be checked for consistency and quality by graph algorithms. The outcome from the graph is new knowledge, answers and explanations of why we made specific decisions. Our knowledge graph becomes a repository of semantically precise vertices and relationships with confidence weights retained from the machine learning processes.

However, knowledge enrichment processes are not perfect and can easily add false assertions if new facts are not curated by subject matter experts (promotes fake news).

The justified emergence of knowledge graphs as a buzzword surrounds its ability to use very large distributed graph databases to store complex networks of concepts that can be “traversed” using a highly parallel graph query language. Knowledge graphs in Google, Facebook, LinkedIn, Amazon (product graph) and Pinterest (interest graph) have over 100 billion vertices, thus solving the scalability problems for graph databases.

In the past, the predominant way of building knowledge graphs was to use hand coded knowledge and an inference engine that could leverage higher-level RDF-based standards such as RDFS, OWL and SKOS. Now organizations are using machine learning to build seed concept graphs using natural language processing (NLP). There is also a strong shift to use the more flexible labeled-property-graphs (LPGs) to do similar reasoning (<http://bit.ly/WHY-ARTIFICIAL-REASONING>).

- ◆ <https://medium.com/@dmccreary/how-knowledge-graphs-promote-fake-news-362947220ea8>
- ◆ <https://medium.com/@dmccreary/blockologies-a-pattern-language-for-ai-data-flows-de9f4507547>

Data models in NoSQL and NewSQL databases

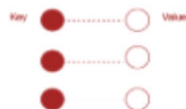
Designers classify NoSQL and NewSQL database types by their structure or data model. Key-value stores, for example, consist of a very simple data model: keys and values.

Databases can include one or more data models. Hadoop has a primary data model (such as key-value or document) and at least one secondary (such as relational or graph).

The data models shown in this illustration vary from the simple (left) to the more complex (bottom). The more complex models (such as relational and graph) allow end users to perform more sophisticated querying directly.

Key-value or row store

Key-value stores offer very high speed via the least complicated data model—anything can be stored as a value, as long as each value is associated with a key or name.



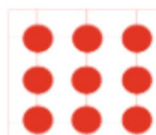
Wide-column

Wide-column stores are also fast and are nearly as simple as key-value stores. They include a primary key, an optional secondary key, and anything stored as a value.



Relational NewSQL store

Relational NewSQL stores are designed for web-scale applications, but still require up-front schemas, joins, and table management that can be labor intensive.



Document JSON or XML

Document stores contain data objects that are inherently hierarchical, tree-like structures.



Property graph

In a property graph store, each node or edge consists of a key and a value, called a property.



RDF graph

For semantic clarity and ease of integration, RDF graphs use unique web-style addresses for both nodes and edges.



Dynamic graph

Dynamic graphs monitor changing nodes and interactions between the nodes, and interpret those interactions as edges.



Source: Neo Technology, Malware Account, GraphStream, and PaaS, 2011-2015.
 Neo Technology, "What is a Graph Database?" <http://neo4j.com/whitepapers/graph-databases/>, accessed April 18, 2015.
 Malware Account, "Neo4j: Data Management in Graph Databases," ©2014 Twitter, presentation slide, <http://www.slideshare.net/malwareaccount/neo4j>, accessed April 16, 2015.
 "GraphStream," <http://en.wikipedia.org/wiki/GraphStream>, accessed April 16, 2015.



◆ Di ◆ Data-informed ◆ exploration of the tessellated facets of our elusive quest for meaning

64 ◆ Exploring how sensor repositories may be helpful. See Figure 11 on page 28 – <http://bit.ly/SIGNALS-SIGNALS>

“SIGNALS” contains a series of essays spewing amorphous thoughts:

1. SITS
2. SIP-SAR
3. SARS♠AG
4. ART
5. PEAS ----- **You are here**

Please review “SIGNALS”

- Download PDF from MIT Library

<https://dspace.mit.edu/handle/1721.1/111021>

Alternate <http://bit.ly/SIGNALS-SIGNALS>

SIGNALS is part of the collection of essays (book)

“IoT is a Metaphor” (see Commentary E)

Please review “IoT is a Metaphor”

- Download PDF from MIT Library

<https://dspace.mit.edu/handle/1721.1/111021>

The page numbers in the PDF do not match the document page numbers at the bottom of the pages. This PDF is made up of a few separate documents which were then combined.

Hence, the temporary mis-match of page numbers. Apologies.





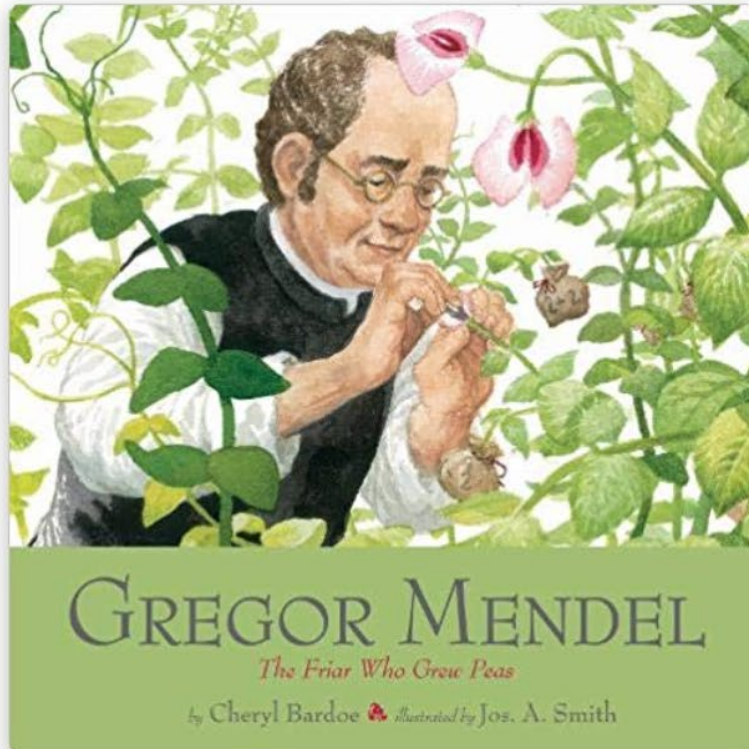
PLATFORM

PEAS is mnemonic borrowed from the literature on Agent based systems (ABS) designed (modeled) to address systems performance (P) in the context of environment (E) of operation, events or processes or systems, to be actuated (A), based on information from primary sources, for example, sensor (S) data.

<http://bit.ly/P-E-A-S> and https://link.springer.com/chapter/10.1007/978-981-10-8258-0_8



Gregor Mendel: The Friar Who Grew Peas



PEAS

Platform for the Agro-Ecosystem

Eric Scott McLamore¹ and Shoumen Palit Austin Datta^{1,2,3}

¹ Nano-Bio Sensors Lab, Department of Agricultural and Biological Engineering, University of Florida, Gainesville, FL 32611

² Auto-ID Labs, Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139

³ MDPnP Lab, Department of Anesthesiology, Massachusetts General Hospital, Harvard Medical School, Cambridge, MA 02139

- **P**erformance
- **E**nvironment
- **A**ctuators
- **S**ensors

PEAS PLATFORM

for the

Agro-Ecosystem

Decision Science for Agriculture and Agri-Business

– **P**erformance

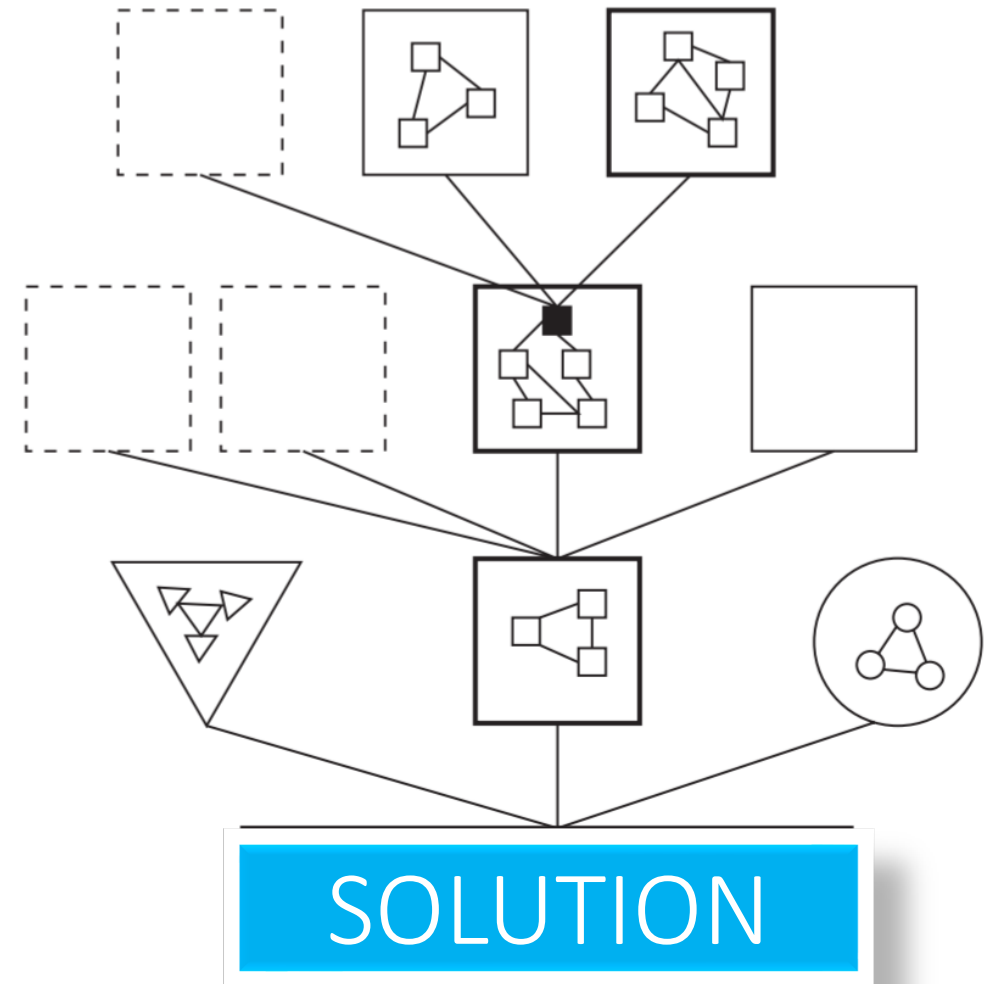
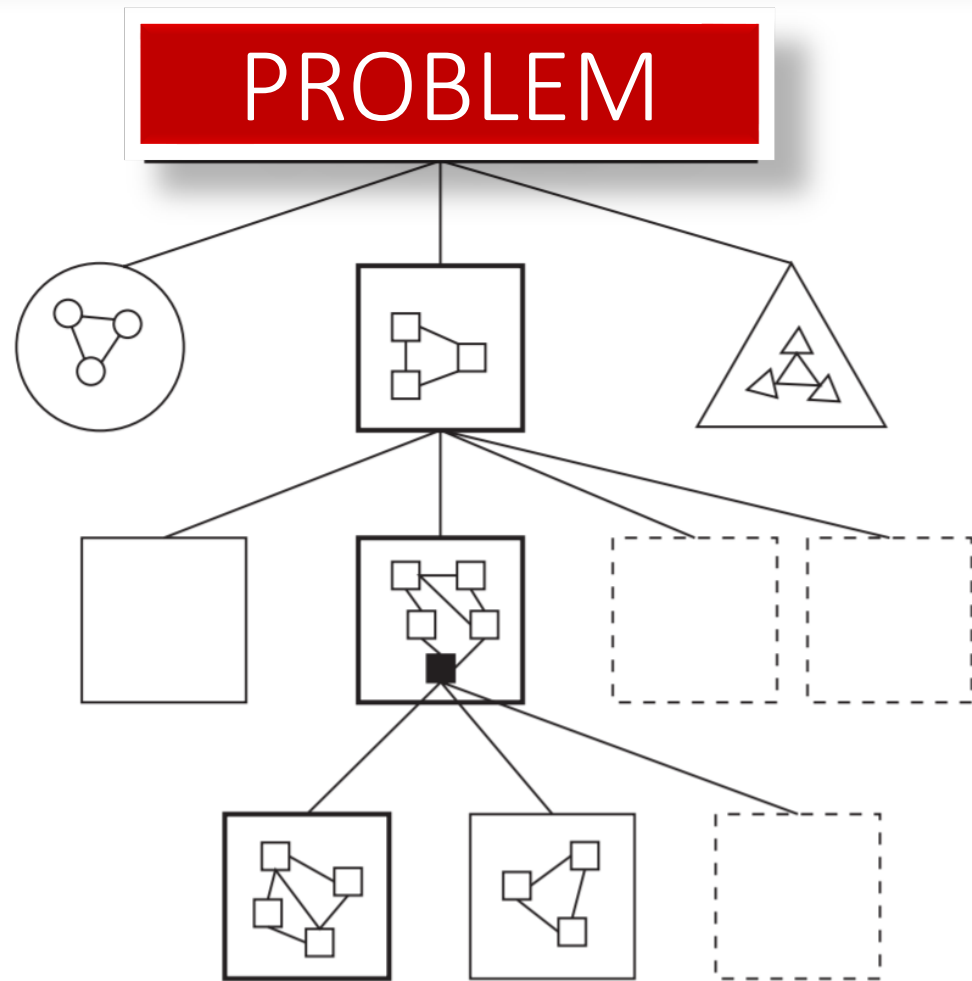
KIDS

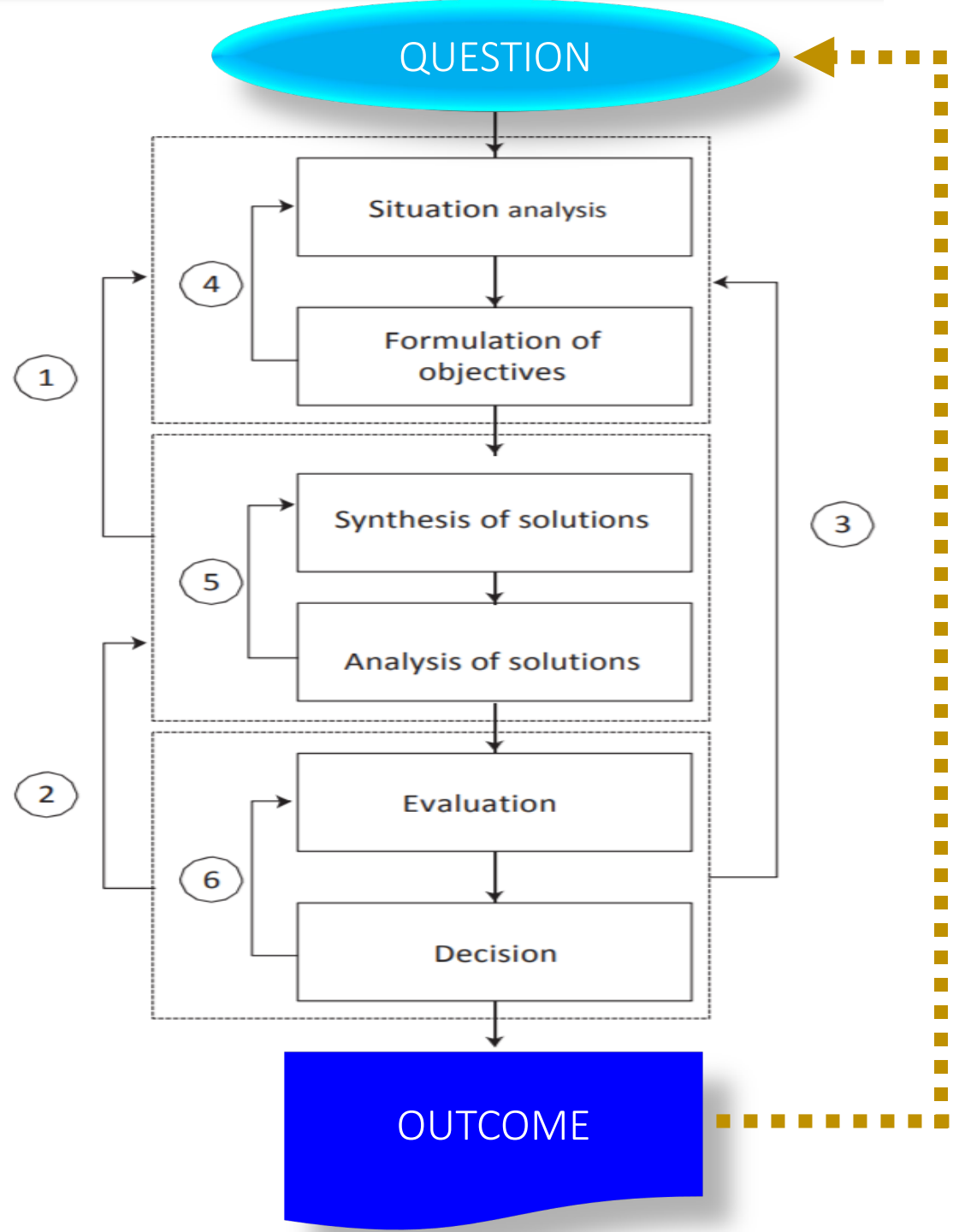
– **S**ensors

Knowledge-Informed Decision as a Service

KIDS

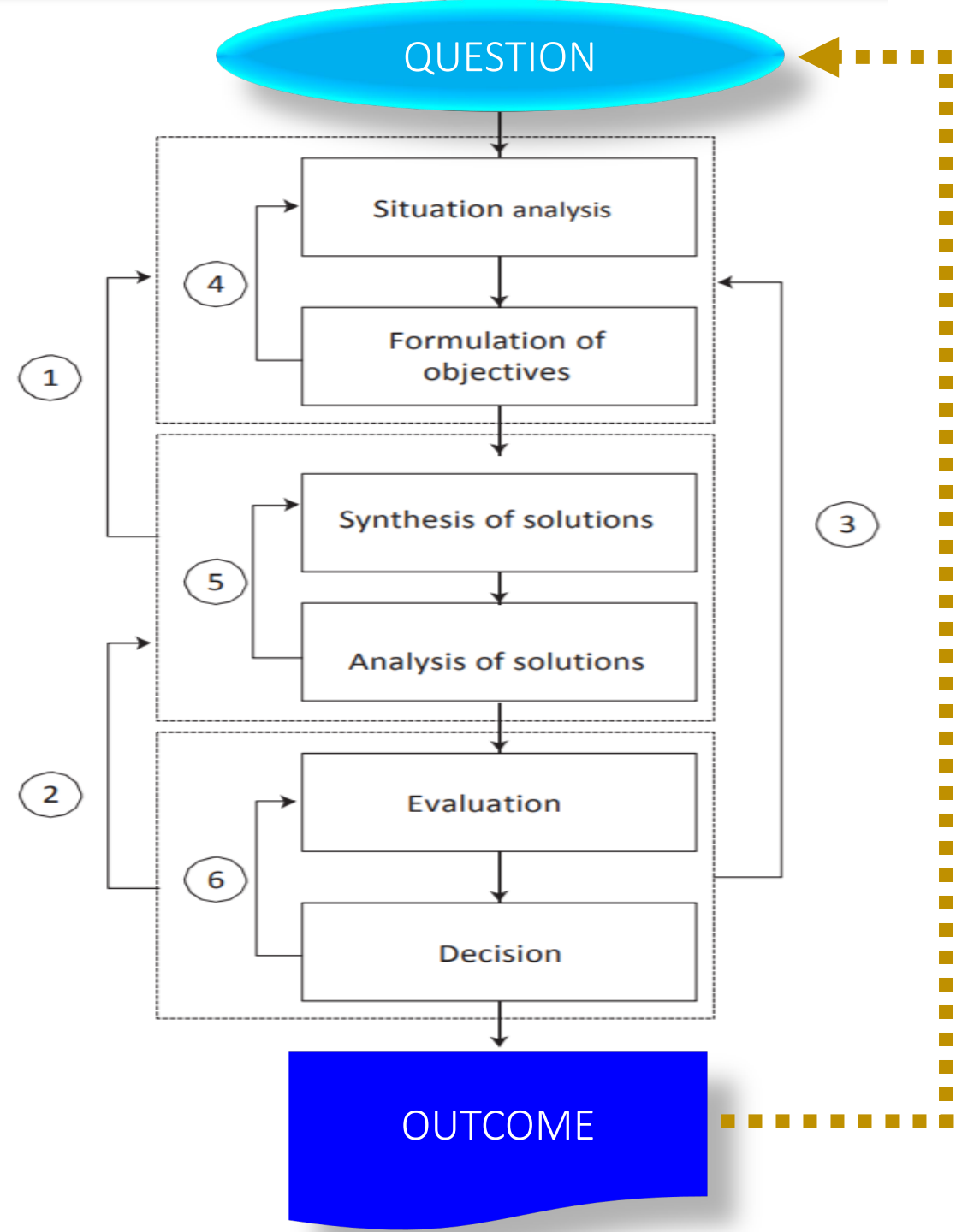
The outcome and the value of the service is the key performance indicator.





A Systems Engineering Approach?

- What is the problem? Is it the correct problem to address?
- Boundaries of the problem space (dynamic vs static).
- Principal influences/mechanisms relative to the context of the problem and problem space.
- Needs a new or re-configured solution?
- What are the solution/system boundaries?
- Requirements of the solution space (system, design goals)
- Feasibility (contextual, technical, economic, social, ecological)
- Solution space to be reconstructed based on existing system or create/innovate architecture to execute solution system?

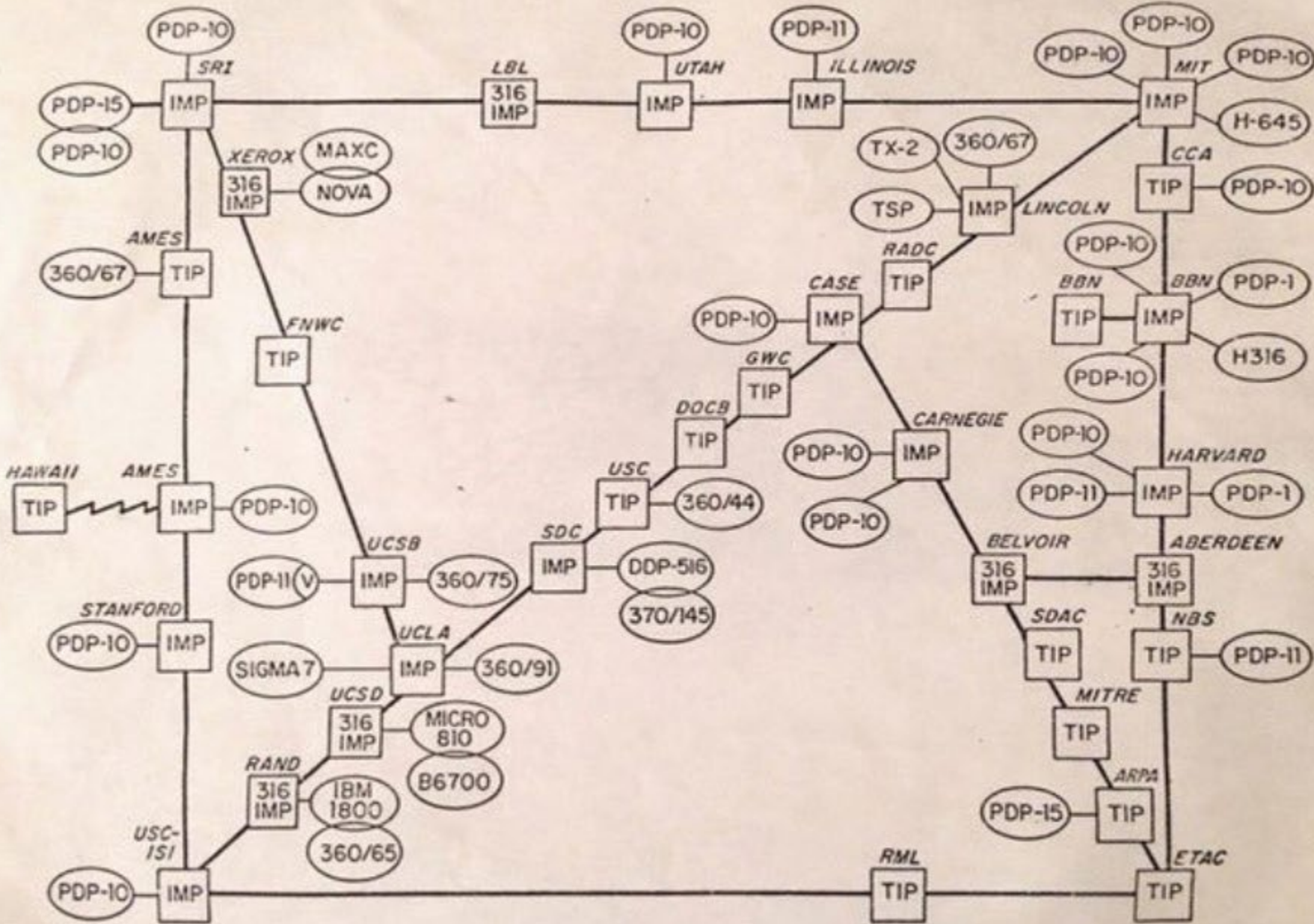


What is


KIDS

Knowledge-Informed Decision as a Service

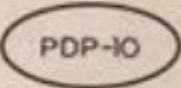
ARPA NETWORK, LOGICAL MAP, MAY 1973



Information

 INFORMATION



Computer

 PDP-10
Computer

Locations


HARVARD STANFORD
RAND MIT

Connecting devices

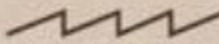
 TIP  IMP

Terminal Interface Processor Interface Message Processor

Phone Lines



Satellite Link



PLATEFORM

KIDS

Knowledge-Informed Decision as a Service

KIDS is an open plan platform concept. Platforms are comprised of multiple applications and integrated solutions with embedded tools and databases that function as complete, seamless environments. Product innovation platforms are intended to support groups of users collaborating across various levels, domains, business units, and the ecosystem. These capabilities are increasingly needed throughout the entire extended enterprise in almost every vertical, agnostic of the type of application or function or users, including farmers, meat packers, produce growers, retail stores, customers, suppliers, and business partners. Developing open platform tools and technologies are not limited to any one domain because graph networks can overlay and configured for use, almost anywhere. KIDS also includes error correction, search engine algorithms, NLU/NLP (natural language processing), automated feature engineering, drag and drop functions, data analytics, workflows, and open services with plug & play interfaces. Human-computer interactions and data interoperability between system of systems are key elements in the KIDS model.

PLATFORM

What are the questions?

ABOUT AGRO-ECOSYSTEM

This discussion is about FEWS. But we focus on a tiny part of the science and engineering issues at the nexus of food, energy, water and sanitation (FEWS). Our emphasis is on agriculture and food.

KIDS aims to answer questions from end-users.

For KIDS, food growers and farmers in the field, are the customers.



Dilbert.com DilbertCartoonist@gmail.com



2-25-14 ©2014 Scott Adams, Inc. /Dist. by Universal Uclick



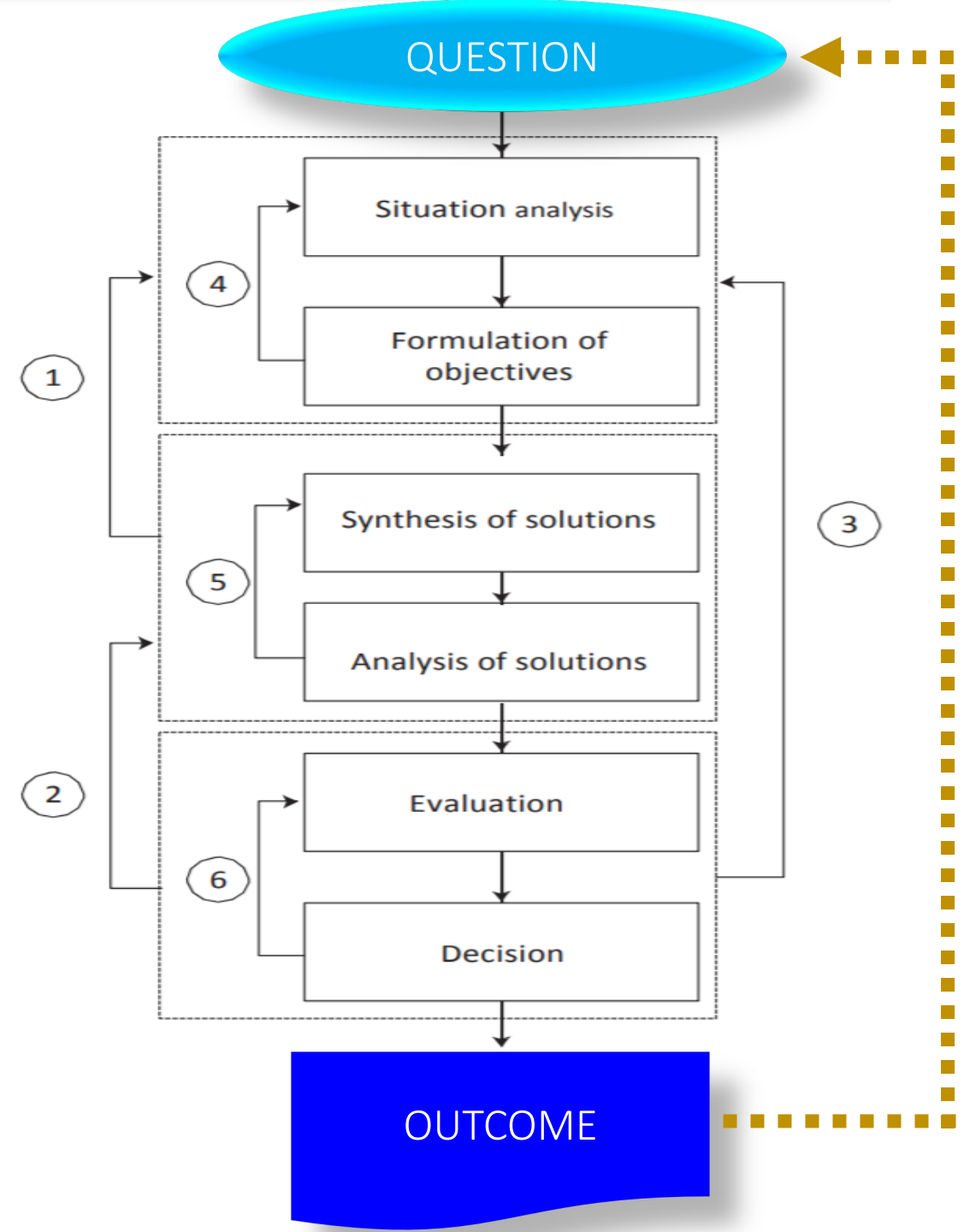
An educated consumer is the best customer.

Example of question from end-user

How can I maximize yield without sacrificing my values and reduce cost but not use wastewater?

Systems engineering approach can guide but it is woefully inadequate. Cannot stay in the “box” if we wish to answer.

How can I
maximize yield
without sacrificing
my values and
reduce cost but not
use wastewater?



How can I maximize yield without sacrificing my values and reduce cost but not use wastewater?

The complexity of this question indicates the challenge for decision support system

Systems engineering approach may need several cycles of deconstruction and reconstruction to analyze the question and disassemble the sub-systems, components and data, necessary to attempt to answer the question.

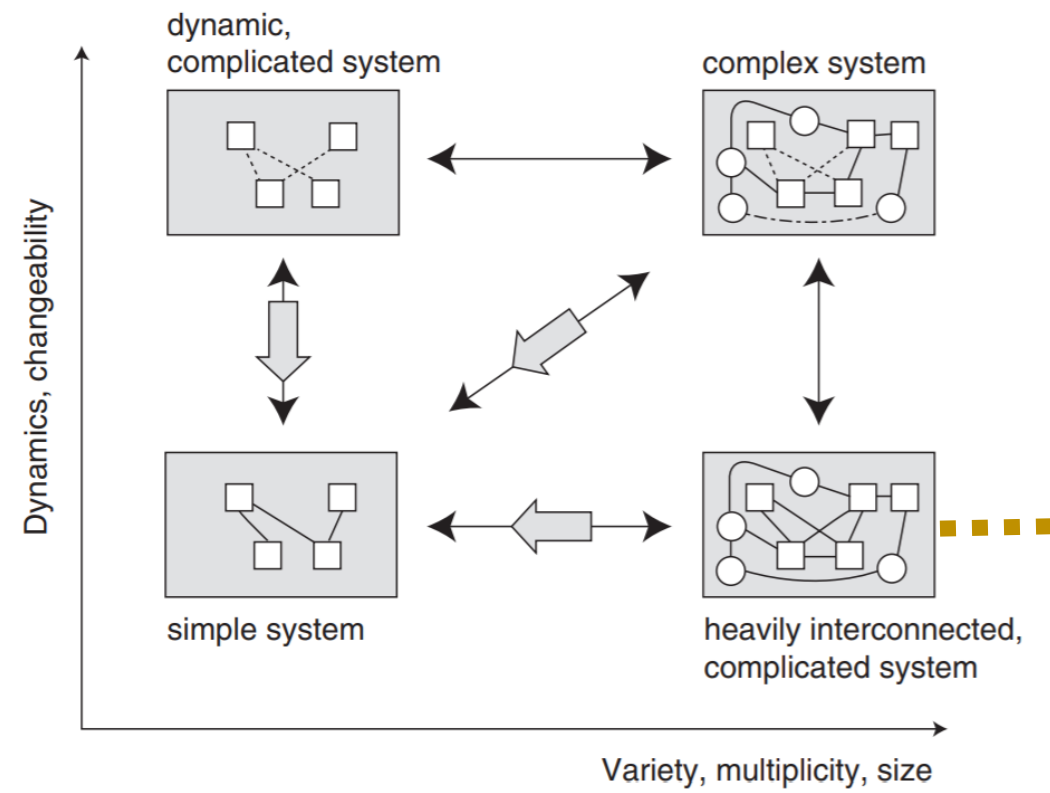
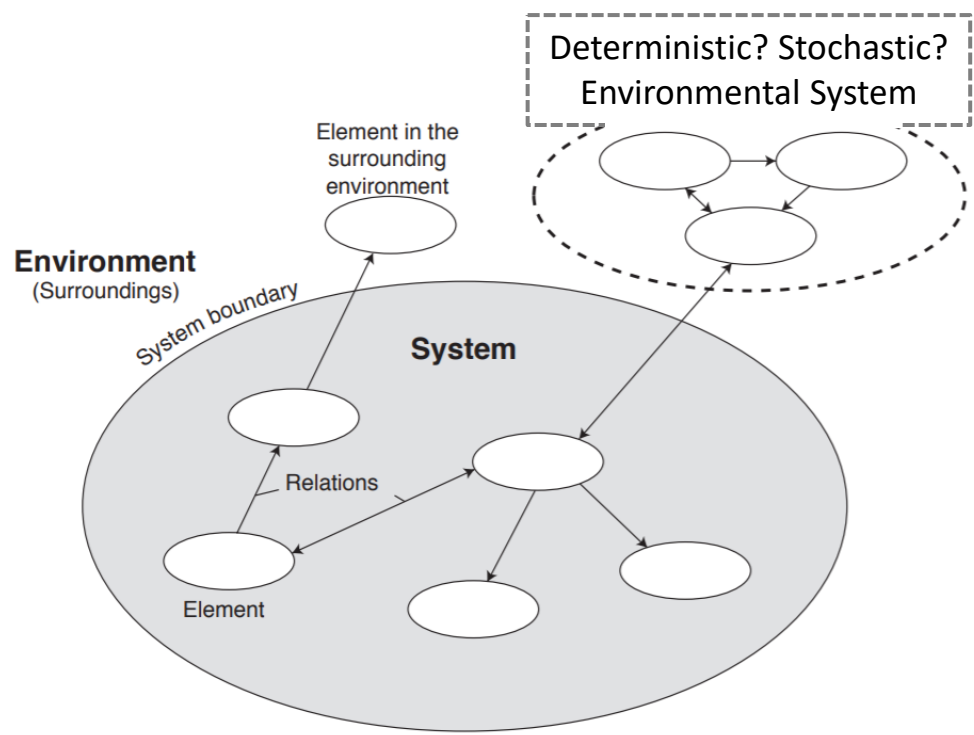
How can I maximize yield without sacrificing my values and reduce cost but not use wastewater?

“sacrificing my values”

Prevailing decision systems are **data-informed**. Even extraction of actionable “information” stretches the reality. The semantics of this question represents an ecosystem of social “values” with respect to “sacrifices” which are personal in context of the user and her community. There are no tools or systems that can even attempt to answer the first part of the question to any degree of user satisfaction. In the short term, any answer may fail to meet an appreciable quality of service [QoS] level for which the user may recognize the value and may be willing to pay a fee (to receive the service). The best we are capable of delivering is the data-informed decision as a service (**DIDA’S**) which may be relevant to the cost and quality of the waste water which the user is seeking.

Beyond the horizon of data-informed decision as a service (decision support system)

How can I maximize yield without sacrificing my values and reduce cost but not use wastewater? ←



From a systems perspective, we have a heavily interconnected, complicated system

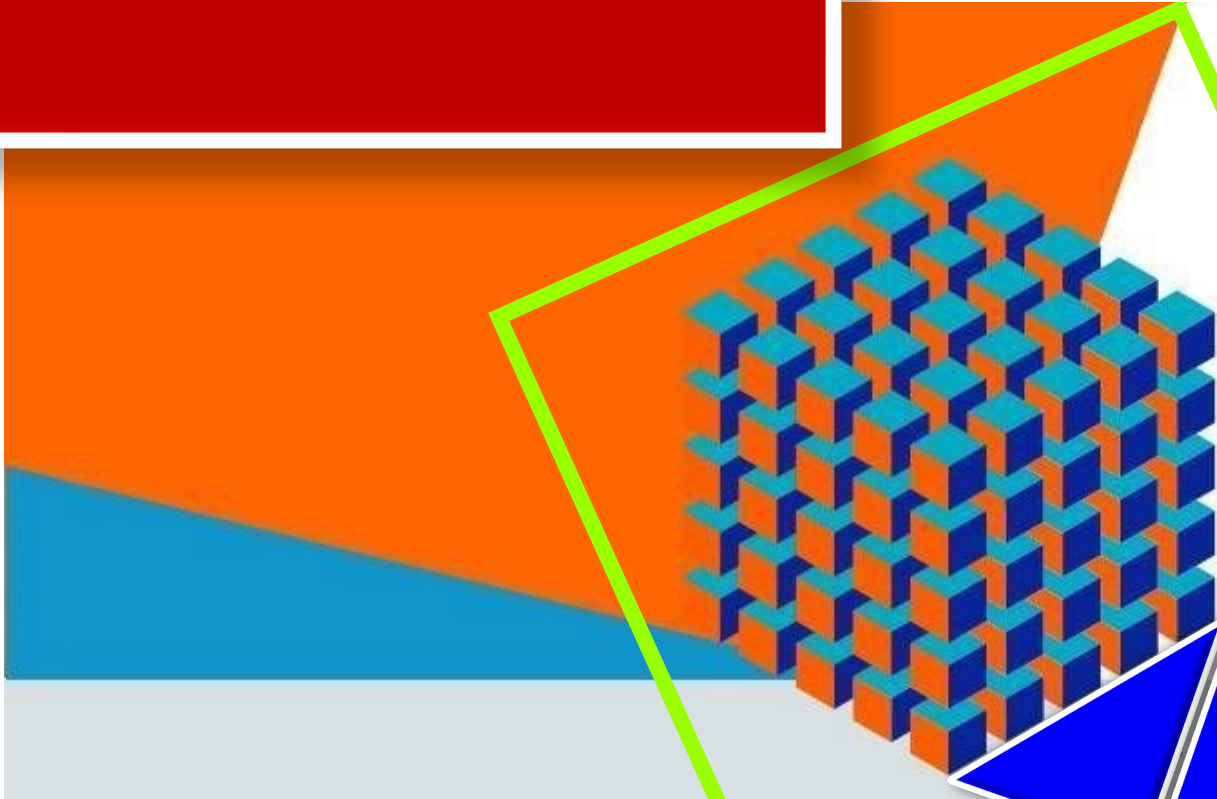
How can I maximize yield without sacrificing my values and reduce cost but not use wastewater?

What happened to KIDS?

We initiated this discussion with **KIDS**, knowledge-informed decision as a service, but the user's question is compelling us to admit systemic inadequacies. Hence, we are stepping down, considerably, to recognize that the best outcome, at the present, may be limited to **DIDA'S** or data-informed decision as a service and stretch (?) our abilities to extract actionable information.

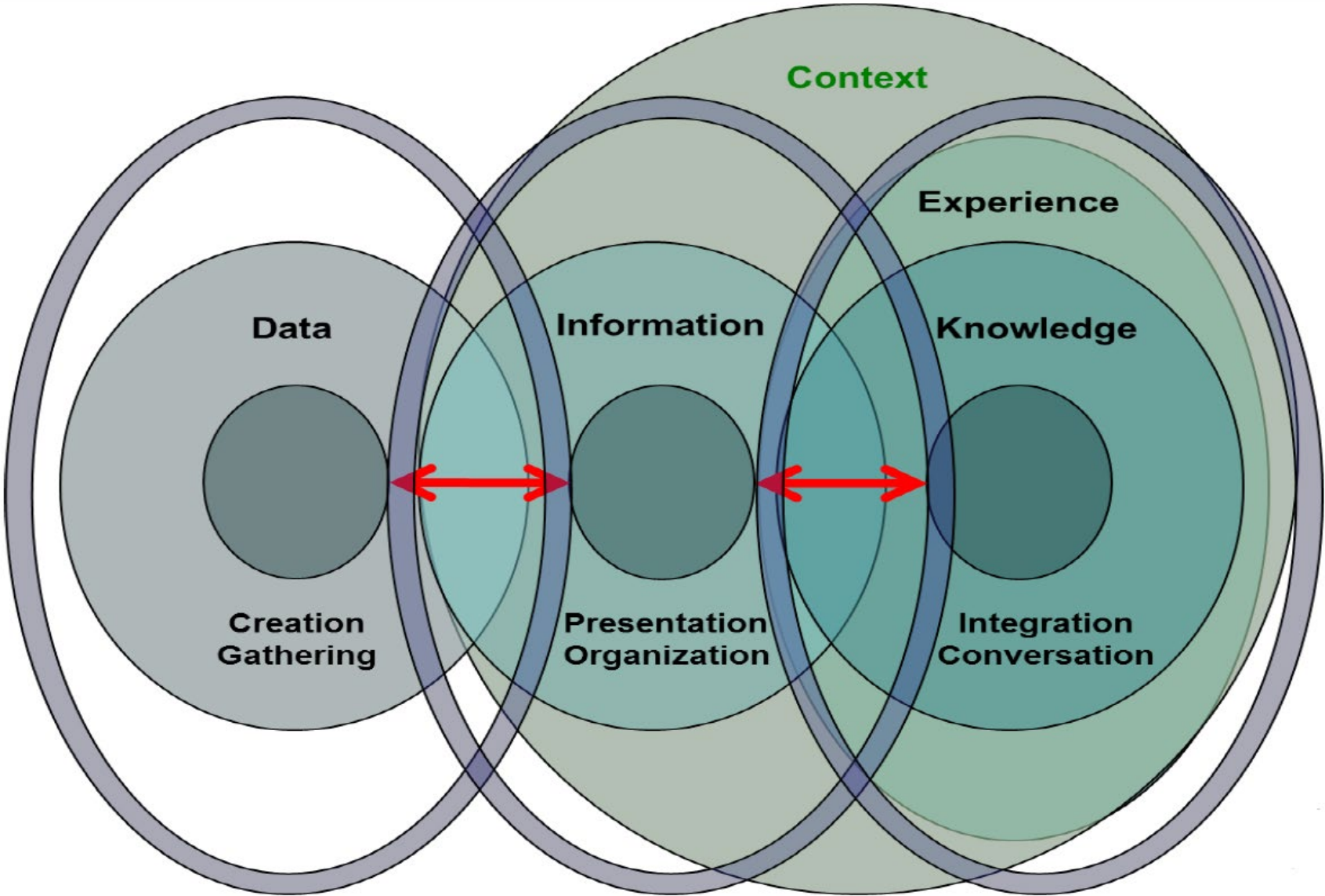
SUMMARY

- 1) Data \neq Information \neq Knowledge
- 2)
- 3)
- 4)



**DATA IS NOT
INFORMATION
GENERATING
DATA OR DATA
ACQUISITION
IS NOT INFO**

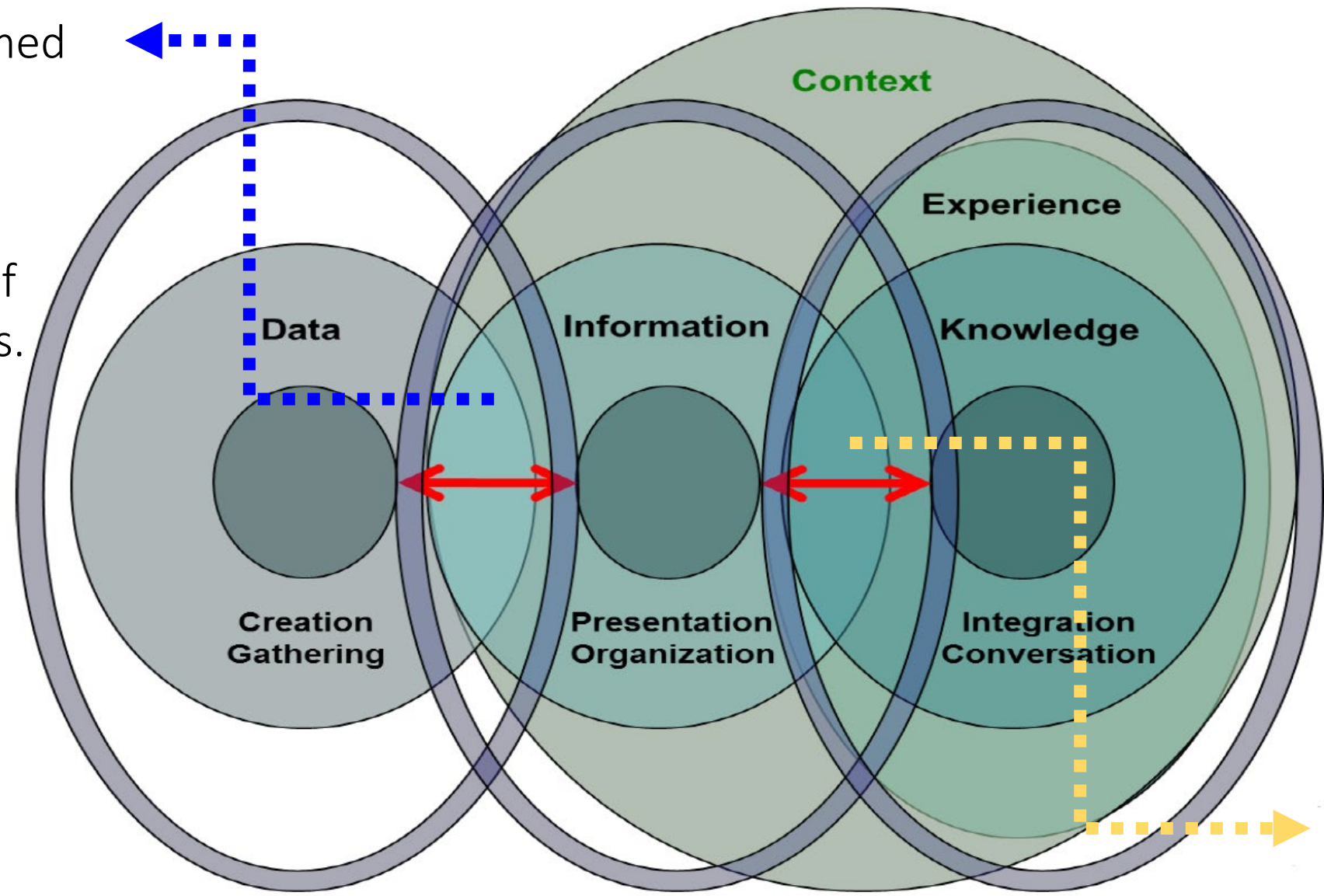
In terms of knowledge from data, our current status is analogous to 1950's, when TV was fuzzy black, greyish white, grainy & dull.



Cartoon: Jim Hendler

In terms of knowledge from data, our current status is analogous to 1950's, when TV was fuzzy black, greyish white, grainy & dull.

Data-informed may be the best case scenario at this stage of our systems.



Knowledge-informed is the Holy Grail. It may be decades away from reality. KIDS may aspire to reach this zone if artificial reasoning can escape the AI mis-information assault and move beyond classical expert systems.

Mind the Gap

There is a
vast
chasm between

data-informed

vs

knowledge-informed



<https://www.forbes.com/sites/joshlinkner/2016/02/08/mind-the-gap>

<http://www.kr.tuwien.ac.at/staff/tkren/pub/2008/rowschool2008.pdf>

KIDS

Knowledge-Informed Decision as a Service

Convergence → *A Sense of the Future*

PLATFORM

How can I maximize yield without sacrificing my values and reduce cost but not use wastewater?

DIDA'S

Data-Informed Decision as a Service

First, successfully deploy DIDA'S and create tools to extract actionable information. Then we may re-visit how to create KIDS, knowledge-informed decision as a service.

How can I maximize yield without sacrificing my values and reduce cost but not use wastewater?

In the context of DIDA'S (Data-Informed Decision as a Service), re-visit the user's question with respect to cost, quality of wastewater and wastewater treatment.

How can I maximize yield without sacrificing my values and reduce cost but not use wastewater?

In the context of DIDA'S (Data-Informed Decision as a Service), re-visit the user's question with respect to cost, quality of wastewater and wastewater treatment.

If we dissect deeper with our reductionist approach, we determine the need to answer the user's question in terms of water quality. What data DIDA'S may require for water quality?

How can I maximize yield without sacrificing my values and reduce cost but not use wastewater?

In the context of DIDA'S (Data-Informed Decision as a Service), re-visit the user's question with respect to cost, quality of wastewater and wastewater treatment.

If we dissect deeper with our reductionist approach, we determine the need to answer the user's question in terms of water quality. What data DIDA'S may require for water quality?

SENSOR DATA



In the context of DIDA'S (Data-Informed Decision as a Service), re-visit the user's question with respect to performance, environment, actuators and sensors (PEAS).



- **P**erformance
- **E**nvironment
- **A**ctuators
- **S**ensors

In the context of DIDA'S (Data-Informed Decision as a Service), re-visit the user's question with respect to performance, environment, actuators and sensor data.

DIDA'S

- Performance
- Environment
- Actuators
- Sensors

DIDA'S

- Performance
- Environment
- Actuators
- Sensors

KIDS

How can I maximize yield without sacrificing my values and reduce cost but not use wastewater?

In the context of DIDA'S (Data-Informed Decision as a Service), re-visit the user's question with respect to cost, quality of wastewater and wastewater treatment.

If we dissect deeper with our reductionist approach, we determine the need to answer the user's question in terms of water quality. What data DIDA'S may require for water quality?

1. Data from multiple sensors for water quality monitoring
2. Cost and pricing data for comparative analysis
3. Wastewater treatment tools and technologies

How can I maximize yield without sacrificing my values and reduce cost but not use wastewater?

Even the apparently simpler part of the question requires **multiple** sources of **data** and **convergence** of information to provide a sufficiently data-informed service to the user.

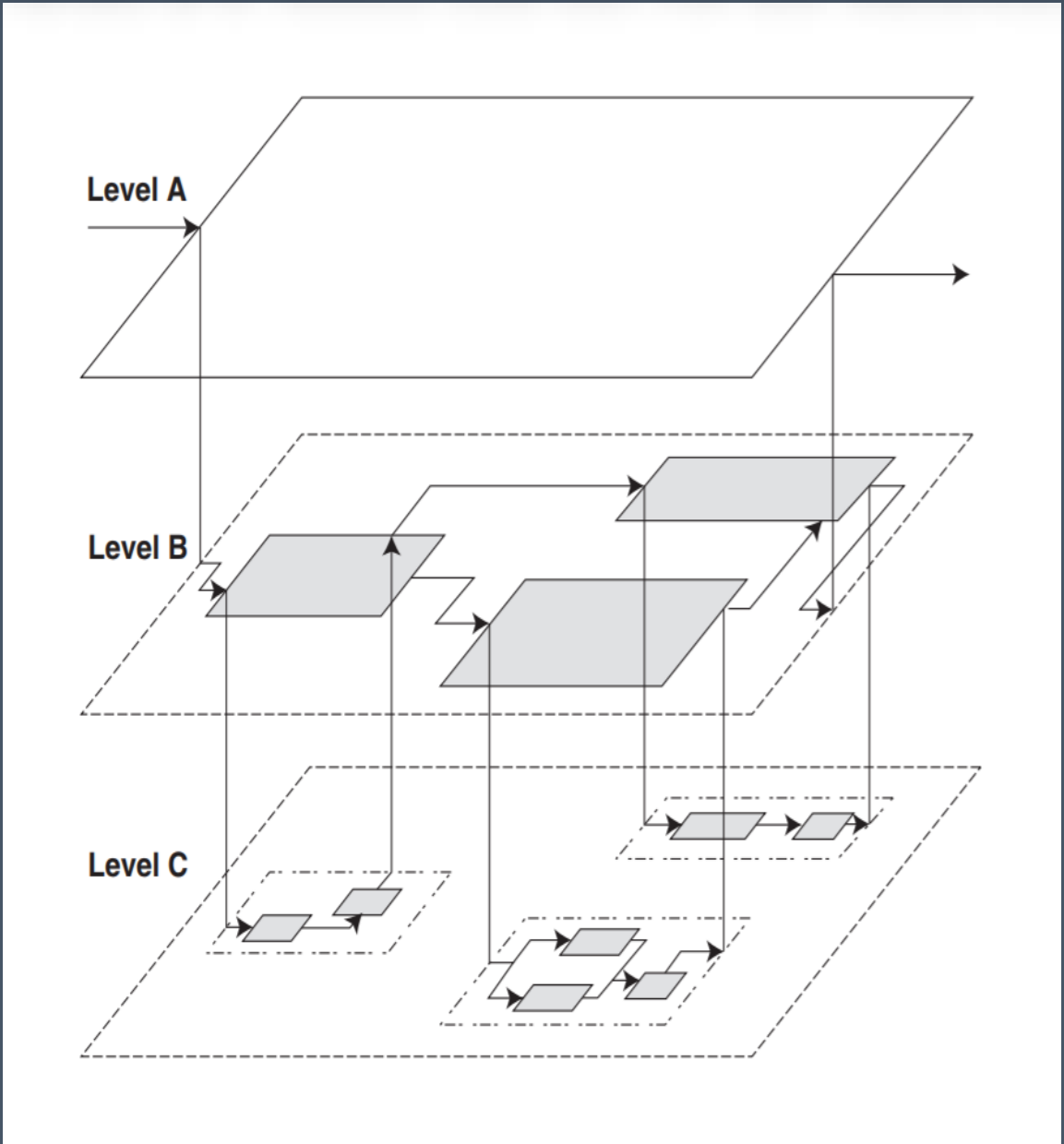
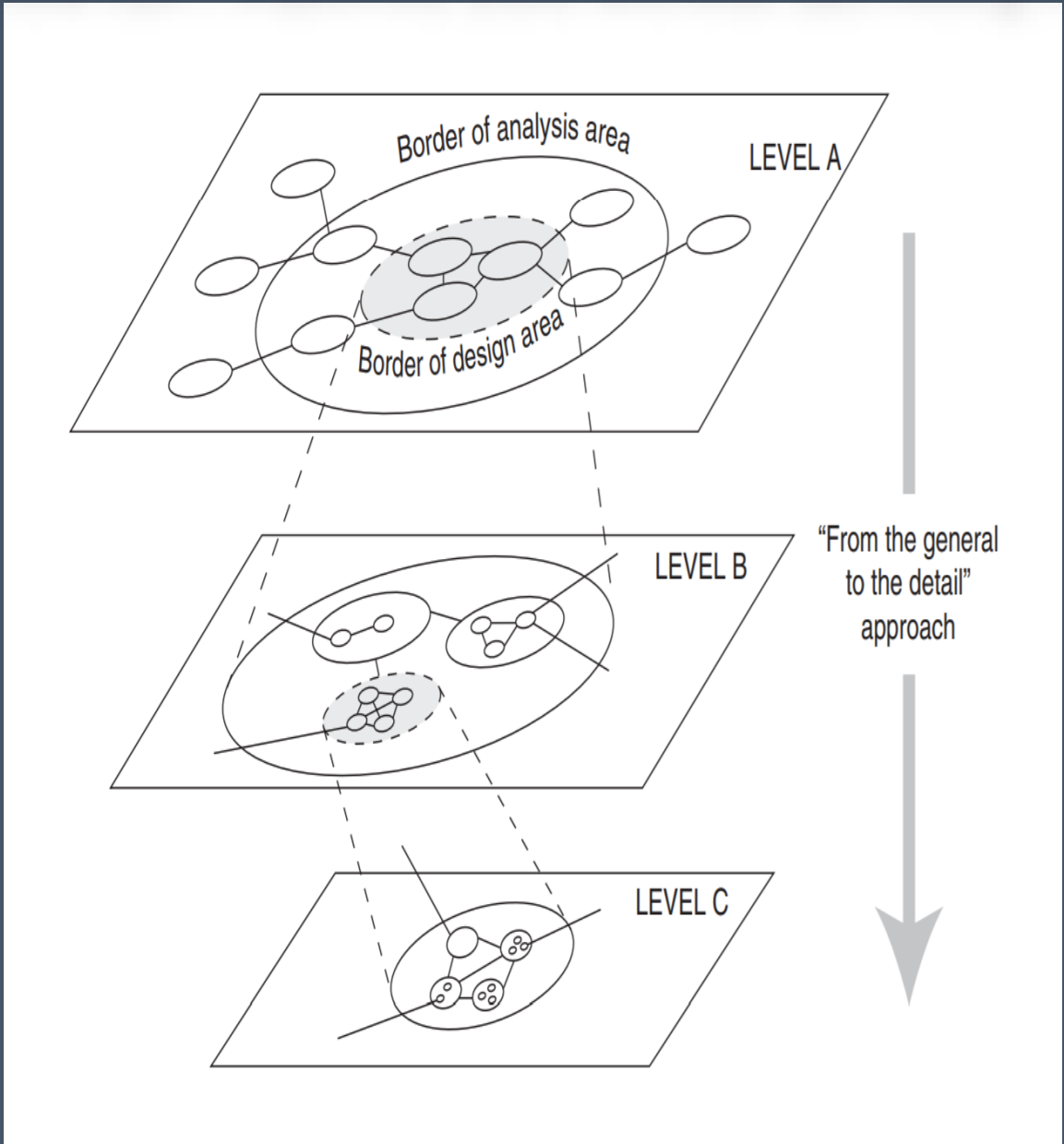
1. Data from multiple sensors for water quality monitoring
2. Cost and pricing data for comparative analysis
3. Wastewater treatment tools and technologies

How can I maximize yield without sacrificing my values and reduce cost but not use wastewater?

Data fusion and convergence of information are only a part of the data-informed *service* users expect. The tasks are to delineate relationships germane to the question, select relevant data, connect, catalyze data fusion, synthesize information, extract “actionable” information, and deliver to a mobile device, in time, contextually relevant recommendation, of value, to the end-user.

1. Data from multiple sensors for water quality monitoring
2. Cost and pricing data for comparative analysis
3. Wastewater treatment tools and technologies

How can I maximize yield without sacrificing my values and reduce cost but not use wastewater?



From a systems engineering approach, deconstruct the question in terms of data granularity.

How can I maximize yield without sacrificing my values and reduce cost but not use wastewater?

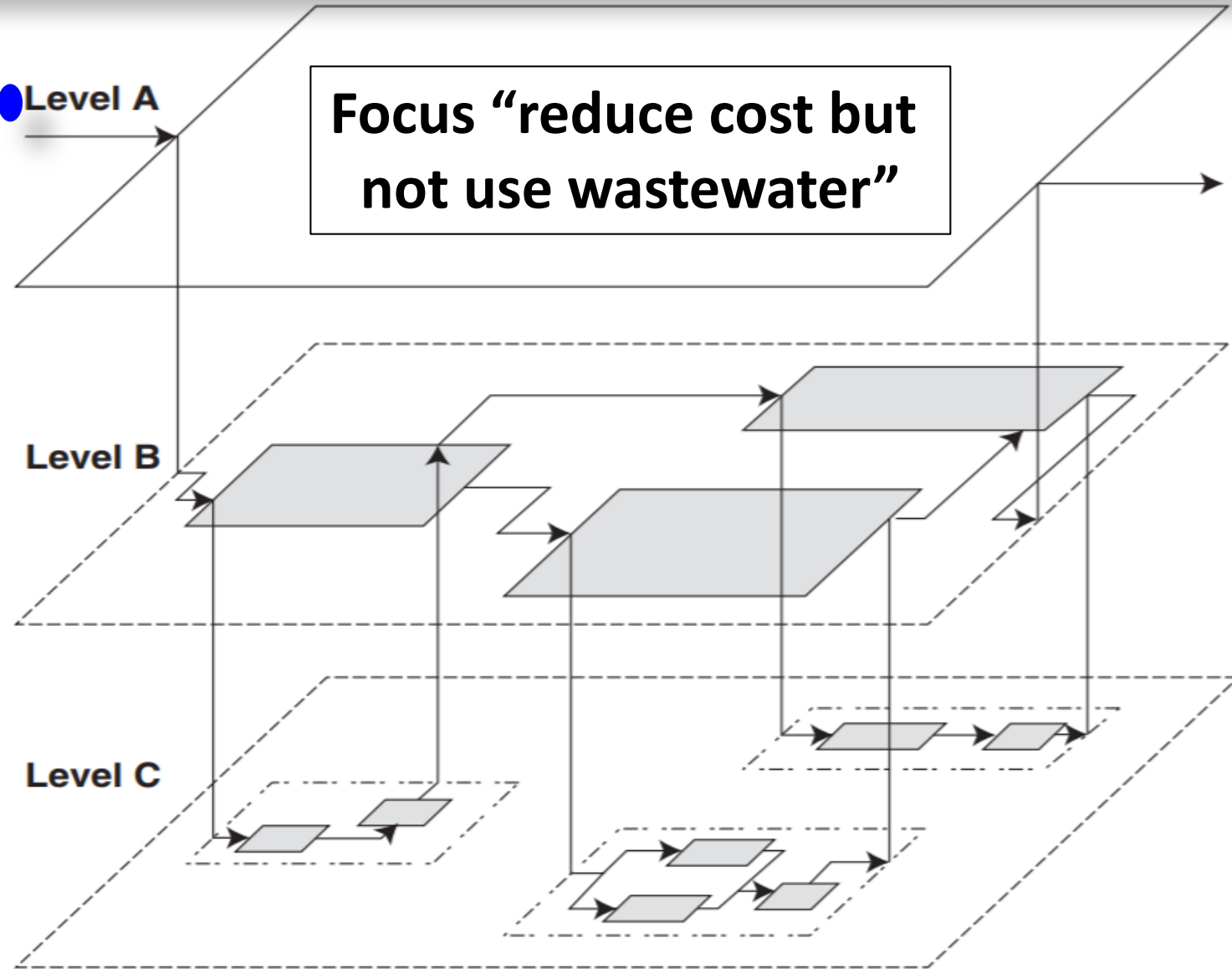
Focus “reduce cost but not use wastewater”

Level A

Focus “reduce cost but not use wastewater”

Level B

Level C



How can I maximize yield without sacrificing my values and reduce cost but not use wastewater?

Focus “reduce cost but not use wastewater”

● Level A

Focus “reduce cost but not use wastewater”

- Factors affecting cost
- Sensors to determine water quality
- Tools necessary for treatment of wastewater

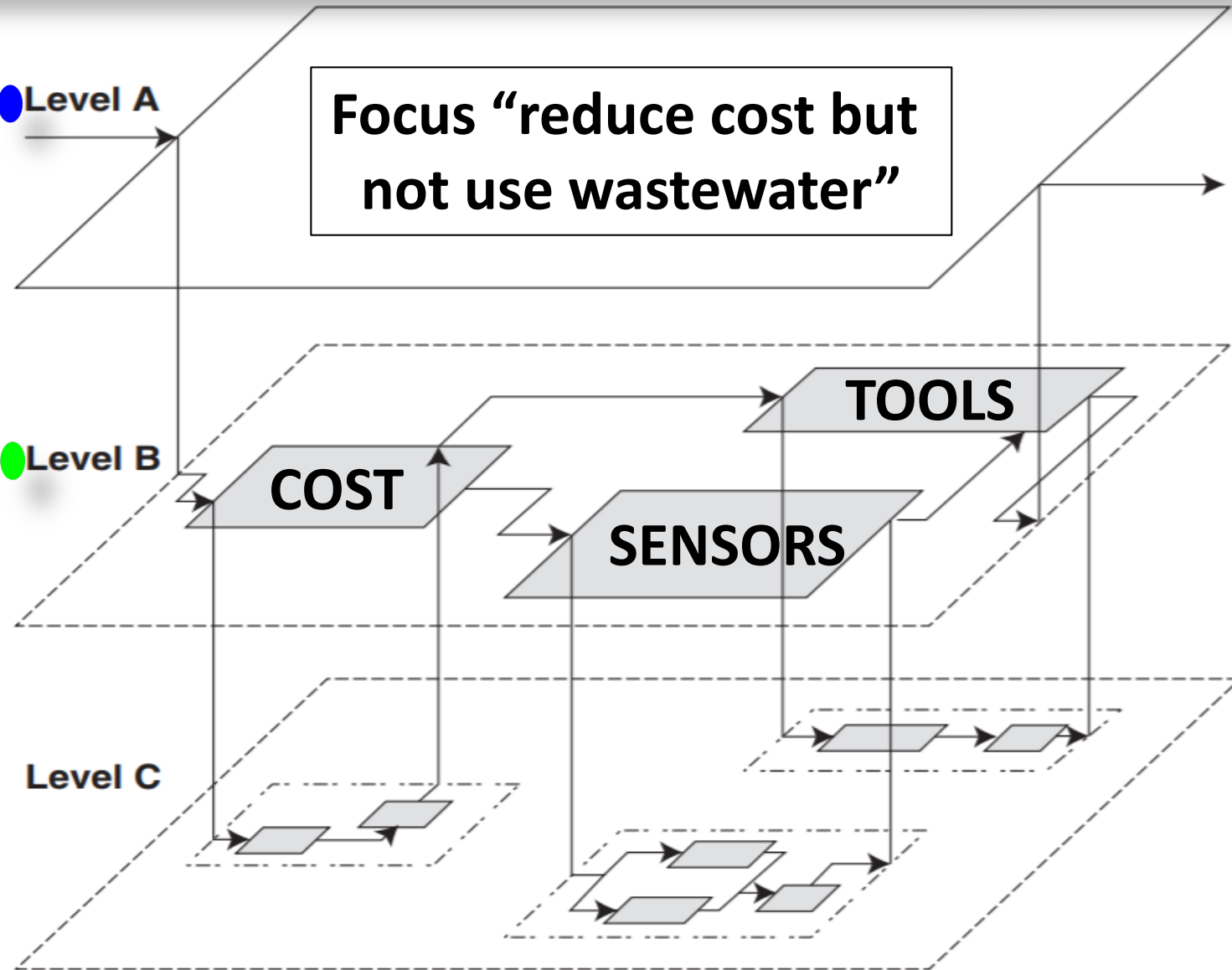
● Level B

COST

SENSORS

TOOLS

Level C



How can I maximize yield without sacrificing my values and reduce cost but not use wastewater?

Focus “reduce cost but not use wastewater”

Level A

Focus “reduce cost but not use wastewater”

-Factors affecting cost
-Sensors to determine water quality
-Tools necessary for treatment of wastewater

Level B

COST

SENSORS

TOOLS

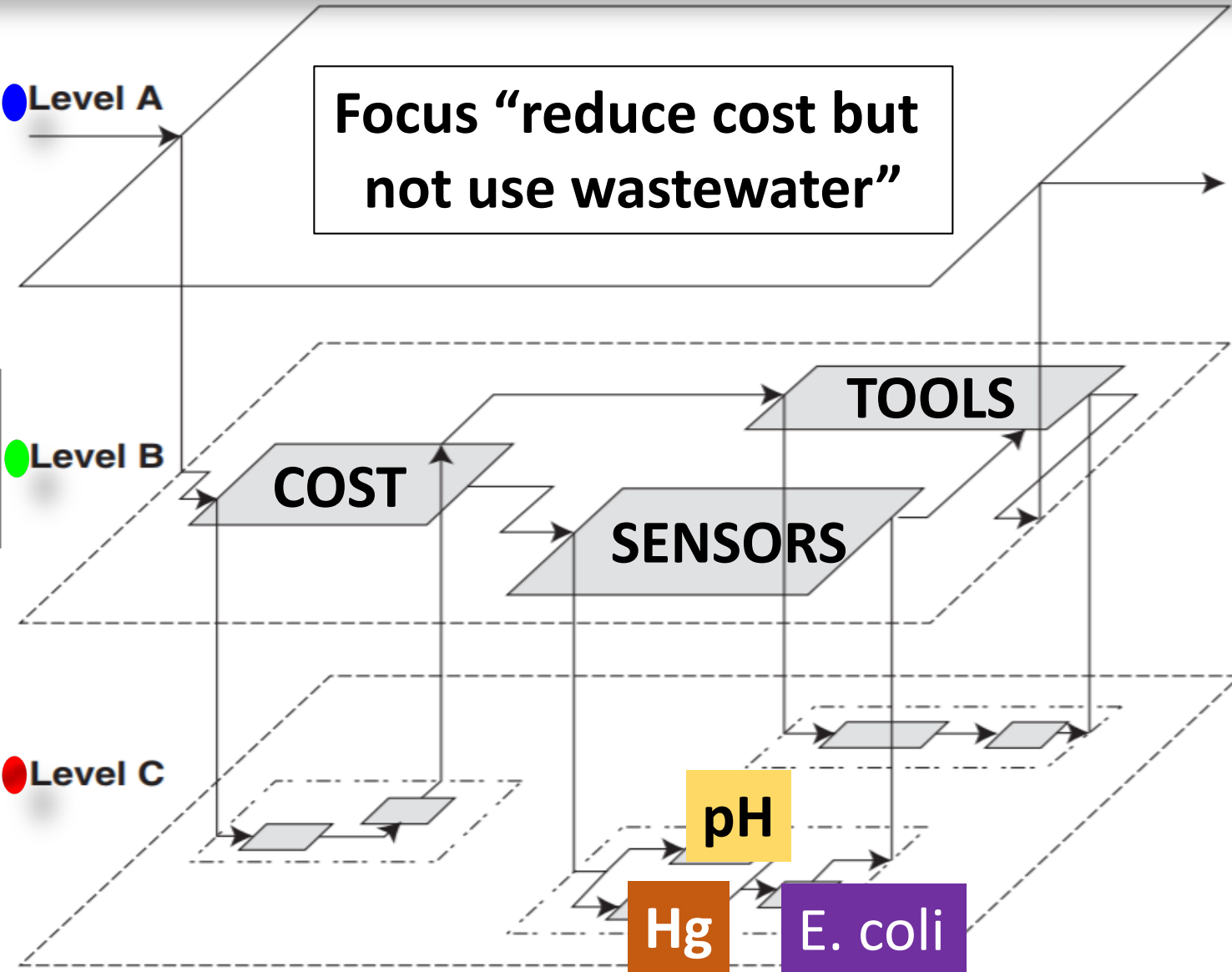
▪ Sensors to determine water quality
- Heavy metal pollution (Mercury)
- Microbial contaminants (E. coli)
- Chemical characteristics (pH)

Level C

pH

Hg

E. coli



Raw Data Source

Denominator

Granularity of Deconstruction – Where is the data source?

Focus “reduce cost but not use wastewater”

● **Level A**

Focus “reduce cost but not use wastewater”

-Factors affecting cost
-Sensors to determine water quality
-Tools necessary for treatment of wastewater

● **Level B**

COST

SENSORS

TOOLS

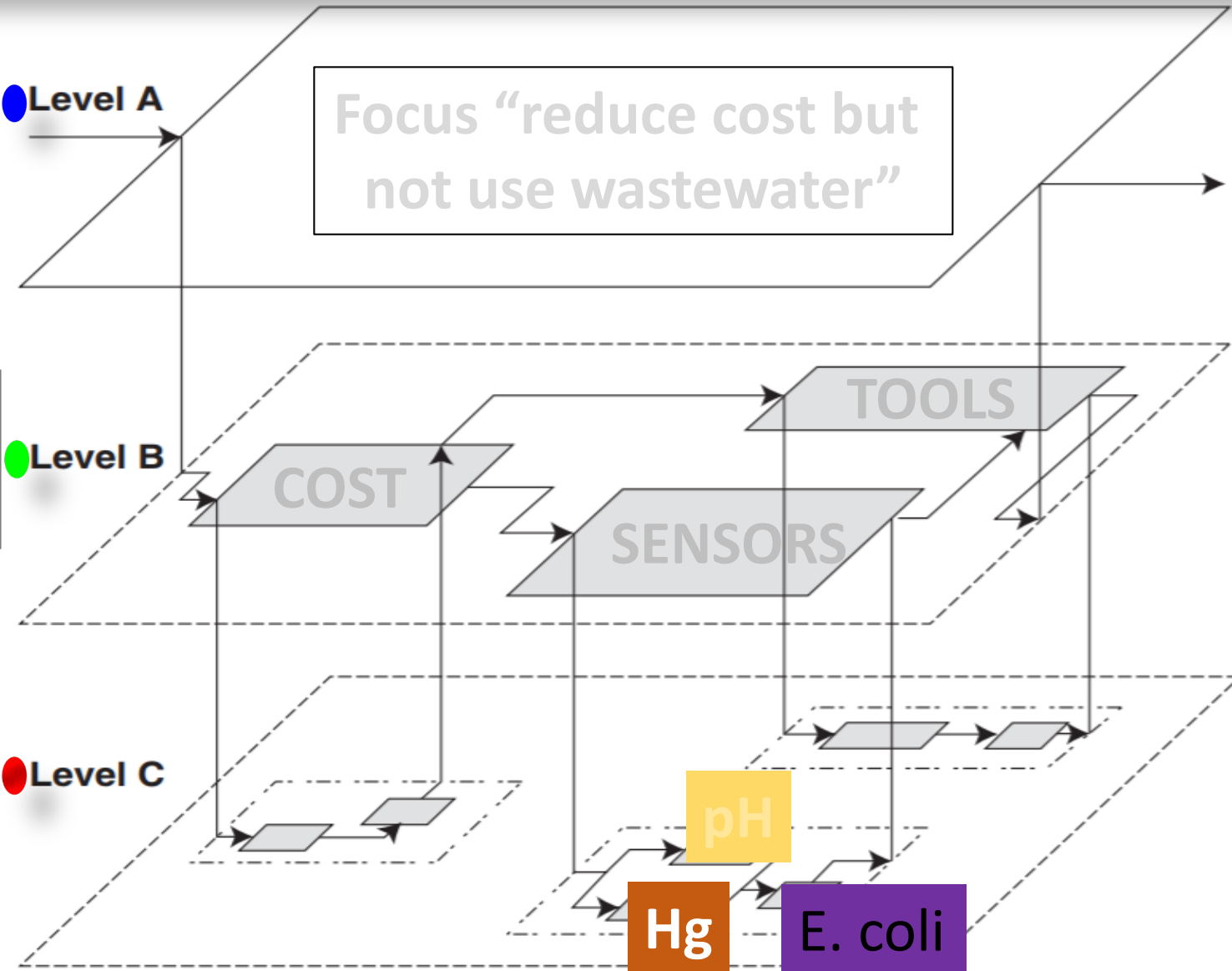
▪ Sensors to determine water quality
- Heavy metal pollution (Mercury)
- Microbial contaminants (E. coli)
- Chemical characteristics (pH)

● **Level C**

pH

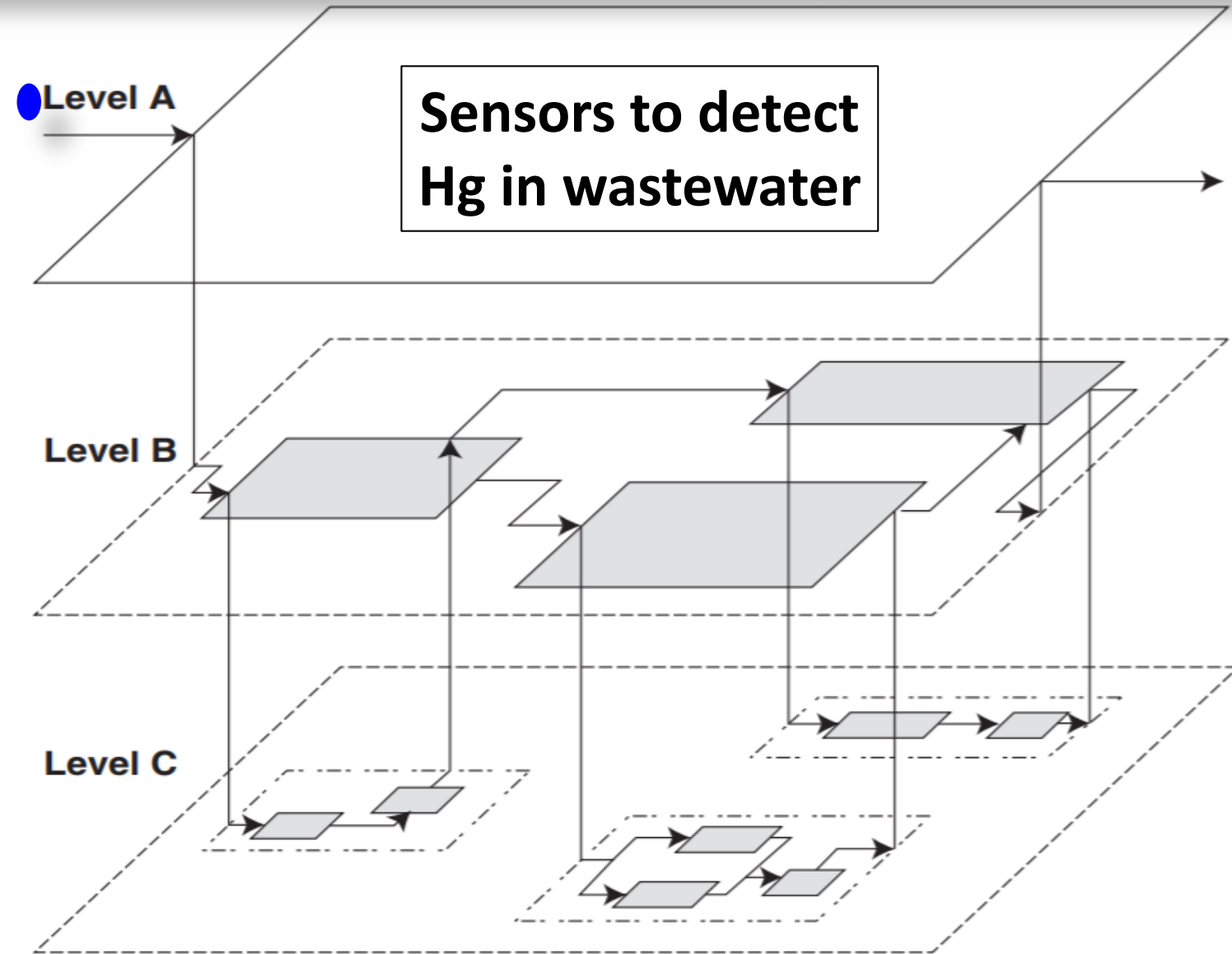
Hg

E. coli



Granularity of Deconstruction – Sensors to Detect Mercury

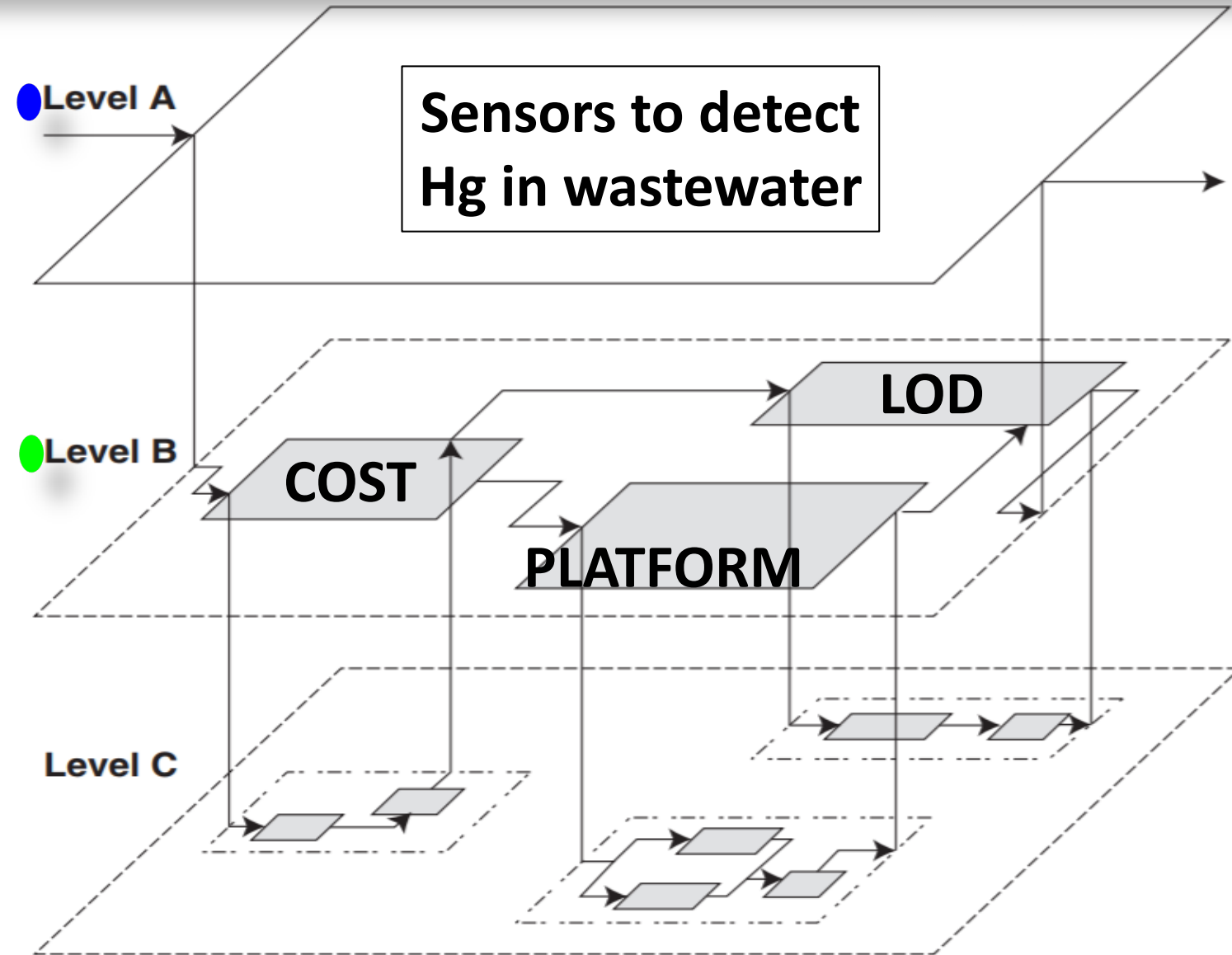
Sensors to detect Mercury (Hg) in wastewater



Granularity of Deconstruction – Sensors to Detect Mercury

Sensors to detect Mercury (Hg) in wastewater

- Cost of sensors
- Limit of Detection (LOD) necessary for use
- Which platform is best for the specific use

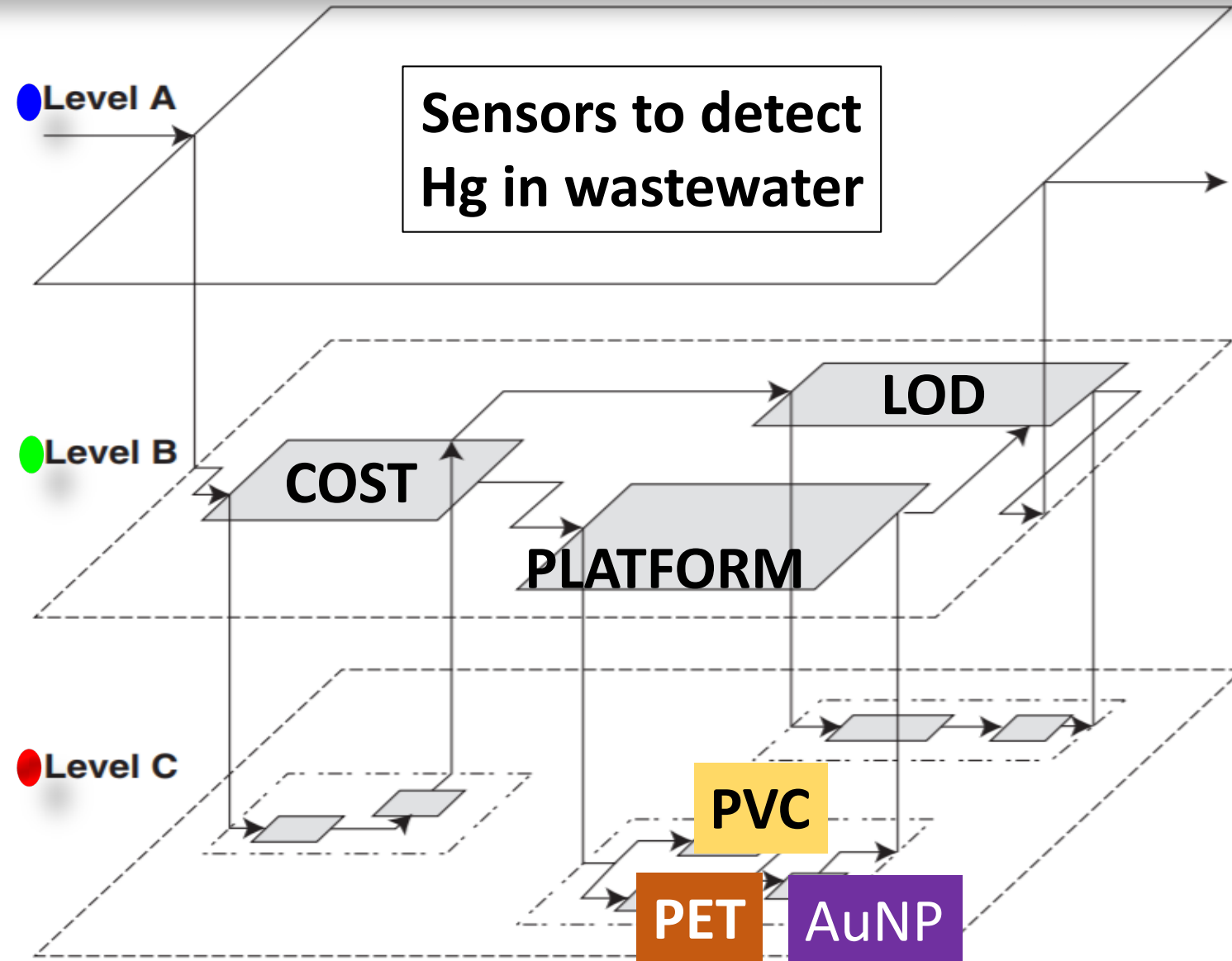


Granularity of Deconstruction – Sensors to Detect Mercury

Sensors to detect Mercury (Hg) in wastewater

- Cost of sensors
- Limit of Detection (LOD) necessary for use
- Which platform is best for the specific use

- Platforms for Mercury (Hg) sensor
 - Poly(vinyl chloride) (PVC) membrane
 - Photoinduced electron transfer (PET)
 - Gold-nanoparticle (AuNP)



Granularity of Deconstruction: Several types of sensors to detect Mercury

A	B	C	D	E	F	G	H	I	J
Device number	MW [Da]	Category	Target	Recognition-transduction scheme	Platform	Range (LOD)	Range (max tested)	Selectivity (interferent species tested)	Response time [sec]
1	201	heavy metal	mercury (Hg2+)	AuNP		1.00E-08	NR	NR	60
2	201	heavy metal	mercury (Hg2+)	MIP??	Sol gel	5.00E-06	NR	NR	600
3	201	heavy metal	mercury (Hg2+)	Rhodamine		1.00E-07	NR	NR	60
4	201	heavy metal	mercury (Hg2+)			5.00E-07	NR	95%	60
5	201	heavy metal	mercury (Hg2+)	foldamer	micelle	5.00E-07	NR	99%	60
6	201	heavy metal	mercury (Hg2+)	corroloe derivative	PVC	5.60E-06	NR	NR	300
7	201	heavy metal	mercury (Hg2+)	tetraarylborate		3.00E-07	NR	NR	60
8	201	heavy metal	mercury (Hg2+)			1.00E-07	NR	poor over Ag+	60
9	201	heavy metal	mercury (Hg2+)	polythiophene		3.00E-05	NR	90%	60
10	201	heavy metal	mercury (Hg2+)	thiosemicarbazone		5.00E-06	NR	NR	60
11	201	heavy metal	mercury (Hg2+)	dansylcarboxamide		1.00E-05	5.00E-04	NR	60
12	201	heavy metal	mercury (Hg2+)	quenching		3.00E-06	5.50E-05	excellent	60
13	201	heavy metal	mercury (Hg2+)	DNAzyme		2.40E-09	NR	excellent (transition/heavy metals)	60
14	201	heavy metal	mercury (Hg2+)	chromo-ionophore assembly	PVC	3.40E-08	NR	poor (heavy metals)	60
15	201	heavy metal	mercury (Hg2+)	AuNP		5.00E-09	1.00E-05	excellent (transition/heavy metals)	600
16	201	heavy metal	mercury (Hg2+)			1.00E-08	2.00E-04	excellent (transition/heavy metals)	60
17	201	heavy metal	mercury (Hg2+)	Rhodamine 6G	AuNP	6.00E-11	3.60E-08	excellent (transition/heavy metals)	60
18	201	heavy metal	mercury (Hg2+)	Cholic acid		5.00E-08	NR	good (MeHg/transition/heavy metals)	60
19	201	heavy metal	mercury (Hg2+)	thiacalixarene		2.00E-06	8.50E-06	good (poor over Ag+)	60
20	201	heavy metal	mercury (Hg2+)			7.00E-07	NR	poor over Cu+	60
21	201	heavy metal	mercury (Hg2+)	anthraquinone/urea		5.0E-05	2.0E-04	poor	60
22	201	heavy metal	mercury (Hg2+)	anthracene/ionophore hybrid	PET	1.0E-06		poor over Fe3+	60
23	201	heavy metal	mercury (Hg2+)	oligonucleotide	AuNP	1.0E-07	1.0E-06	poor over Pb3+	60
24	201	heavy metal	mercury (Hg2+)	oligonucleotide		4.2E-08	6.7E-07	moderate	60
25	201	heavy metal	mercury (Hg2+)			5.0E-08		excellent (transition/heavy metals)	60
26	201	heavy metal	mercury (Hg2+)	phosphorescent iridium(III) complex		2.0E-05		excellent (transition/heavy metals)	60
27	201	heavy metal	mercury (Hg2+)	MerR protein		1.0E-08		NR	60
28	201	heavy metal	mercury (Hg2+)			1.0E-06		NR	60

Which sensor to choose? Which sensor has the lowest limit of detection?

Which sensor to choose? Which sensor has the lowest limit of detection?

Users wish to explore sensor categories and attributes ?

Which sensor to choose? Which sensor has the lowest limit of detection?

Users wish to explore sensor categories and attributes ?

End-users, as well as experts, may benefit from information about different sensors, by categories and list of attributes, which may be suitable for use.

Which sensor to choose? Which sensor has the lowest limit of detection?

SENsor SEarch Engine

Which sensor to choose? Which sensor has the lowest limit of detection?

SENsensor **SE**arch Engine

SENSEE

Delving deeper into the granularity of the data necessary for DIDA'S to be sufficiently data-informed, we arrive at one data source:

SENSORS for DIDA'S

Sensor data as a source of data for data-informed decision as a service (DIDA'S)

Sensor data still remains a key denominator when we move from data-informed (DIDA'S) to knowledge-informed (KIDS)

SENSORS for DIDA'S KIDS

Sensors for knowledge-informed decision as a service (KIDS)

SKIDS



In granular terms, DIDA'S and KIDS, still needs to choose sensor type.

SENsor **SE**arch **E**ngine

SENSEEE

In granular terms, the outcome from DIDA'S and KIDS, depends on data.

Data from Sensors

SENSEEE

At the most granular level, first we need to *choose the sensor* and then proceed to harvest *data* from specific sensor(s).

FOR SOME OF THE QUESTIONS, THIS IS A PRE-REQUISITE FOR DIDA'S and KIDS.

Hence, we start searching for suitable sensor categories and attributes.

SENsor SEarch Engine

SENSEEE

Then, we seek data from sensors (relevant to the real world questions).

Data from Sensors

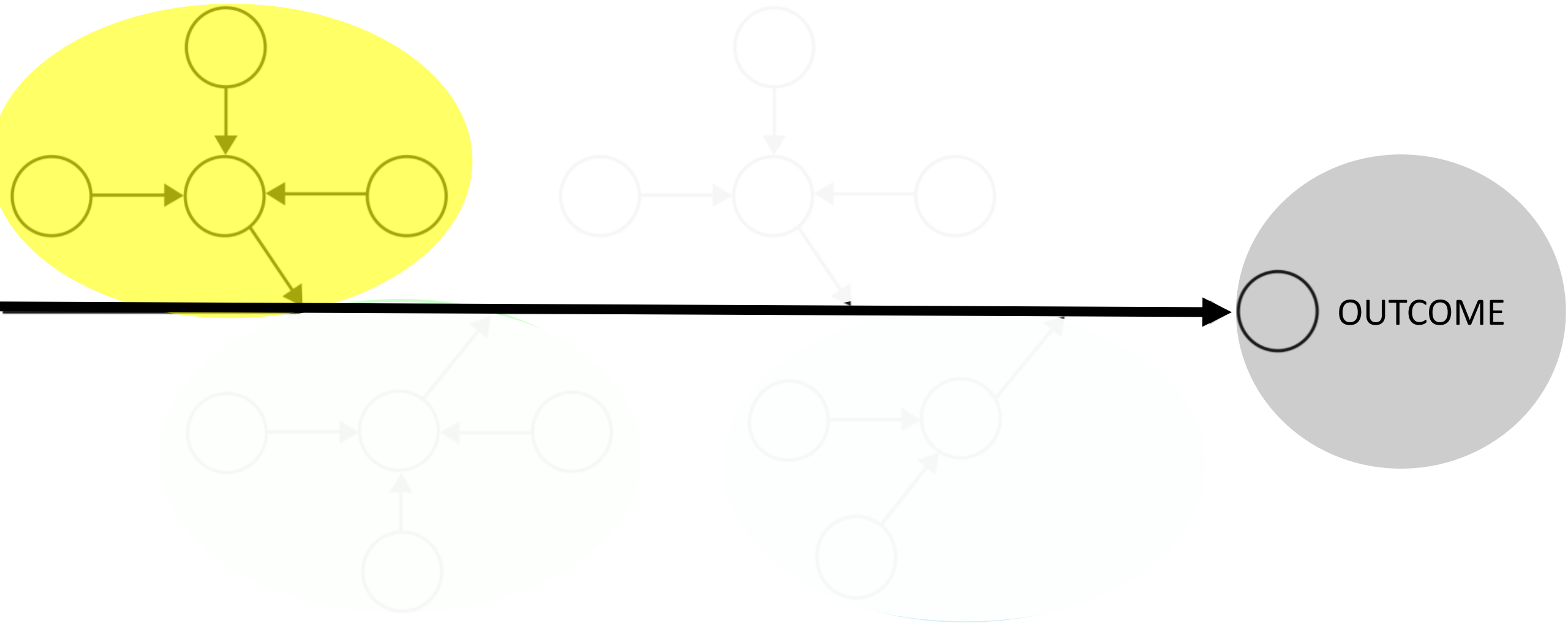
SENSEEE

We need sensors, and sensor data, to fuel the outcome.

Data-informed (DIDA'S)

Knowledge-informed (KIDS)

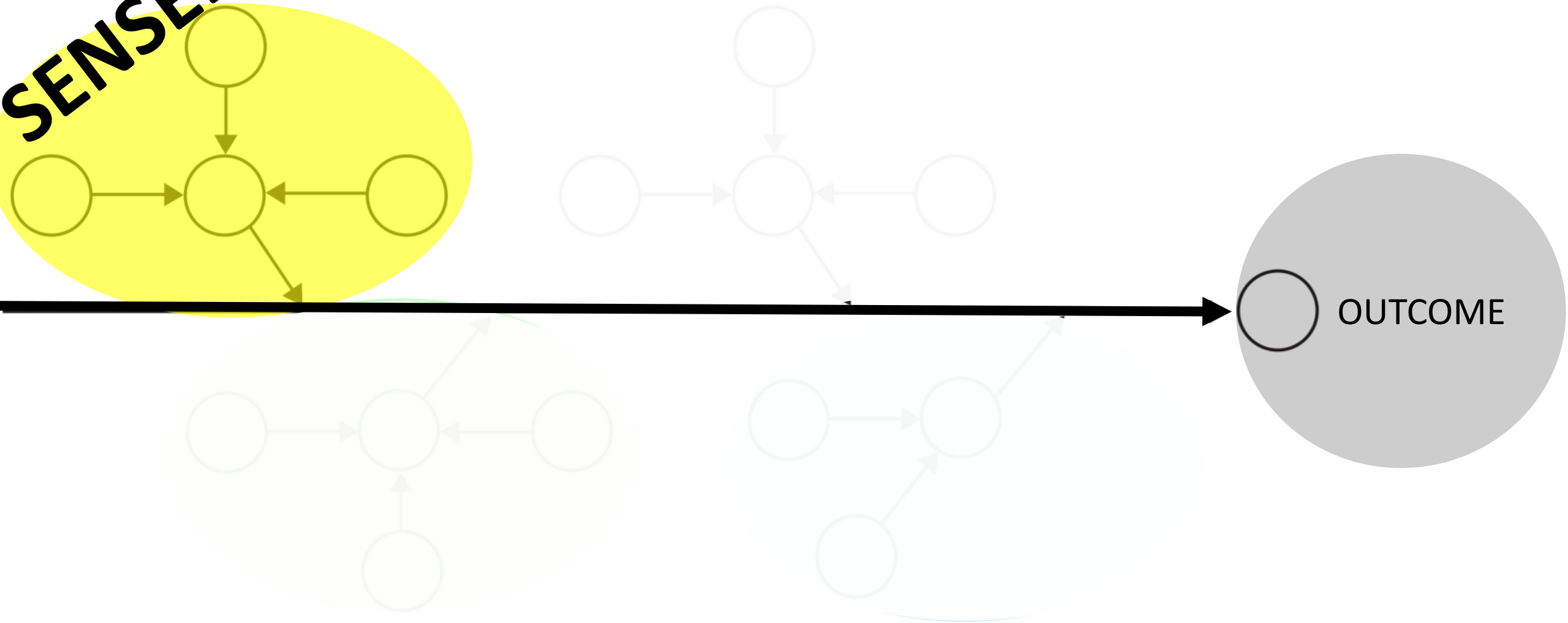
Sensor & sensor data



How can I maximize yield without sacrificing my values and reduce cost but not use wastewater?

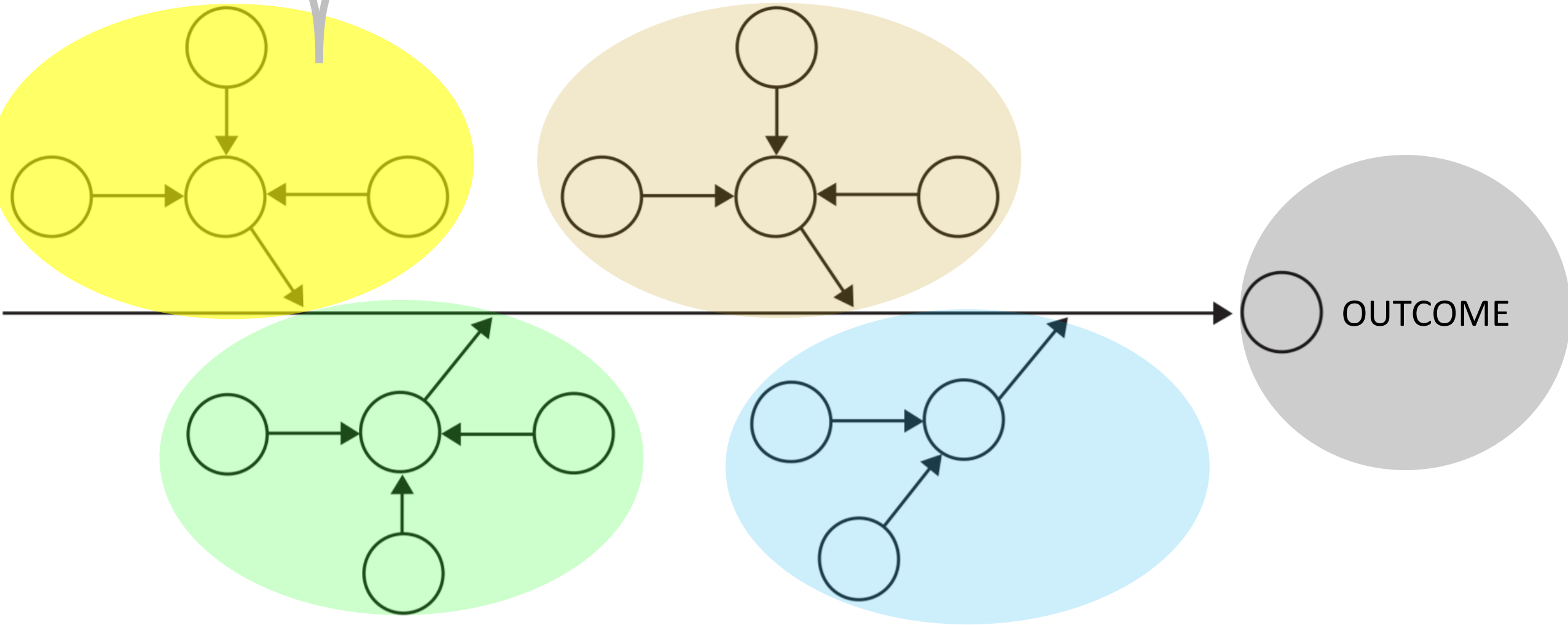
Sensor & sensor data

SENSEE



How can I maximize yield without sacrificing my values and reduce cost but not use wastewater?

Sensor & sensor data may be long way from information



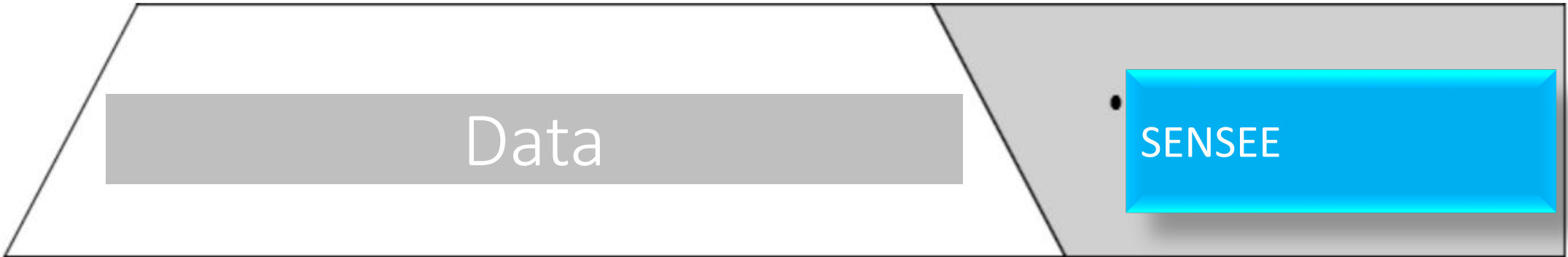
http://www.ihl.org/education/IHIOpenSchool/resources/Assets/CauseandEffect_Instructions.pdf

How can I maximize yield without sacrificing my values and reduce cost but not use wastewater?

To summarize the steps

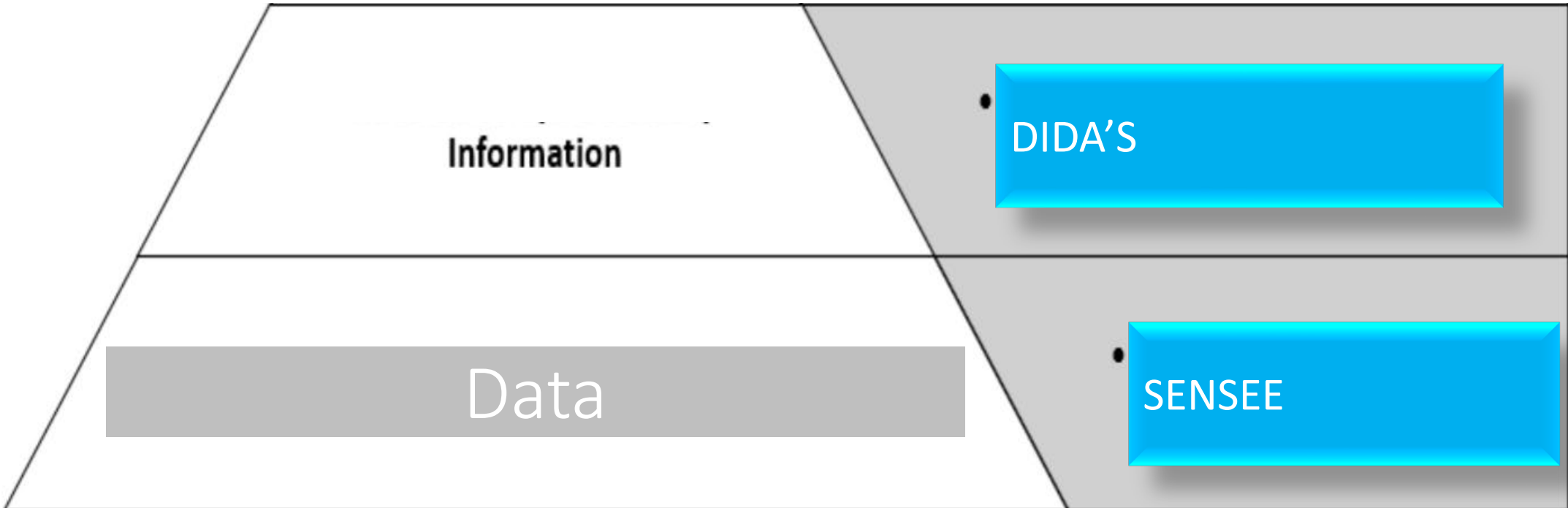


Data



Data

SENSEE

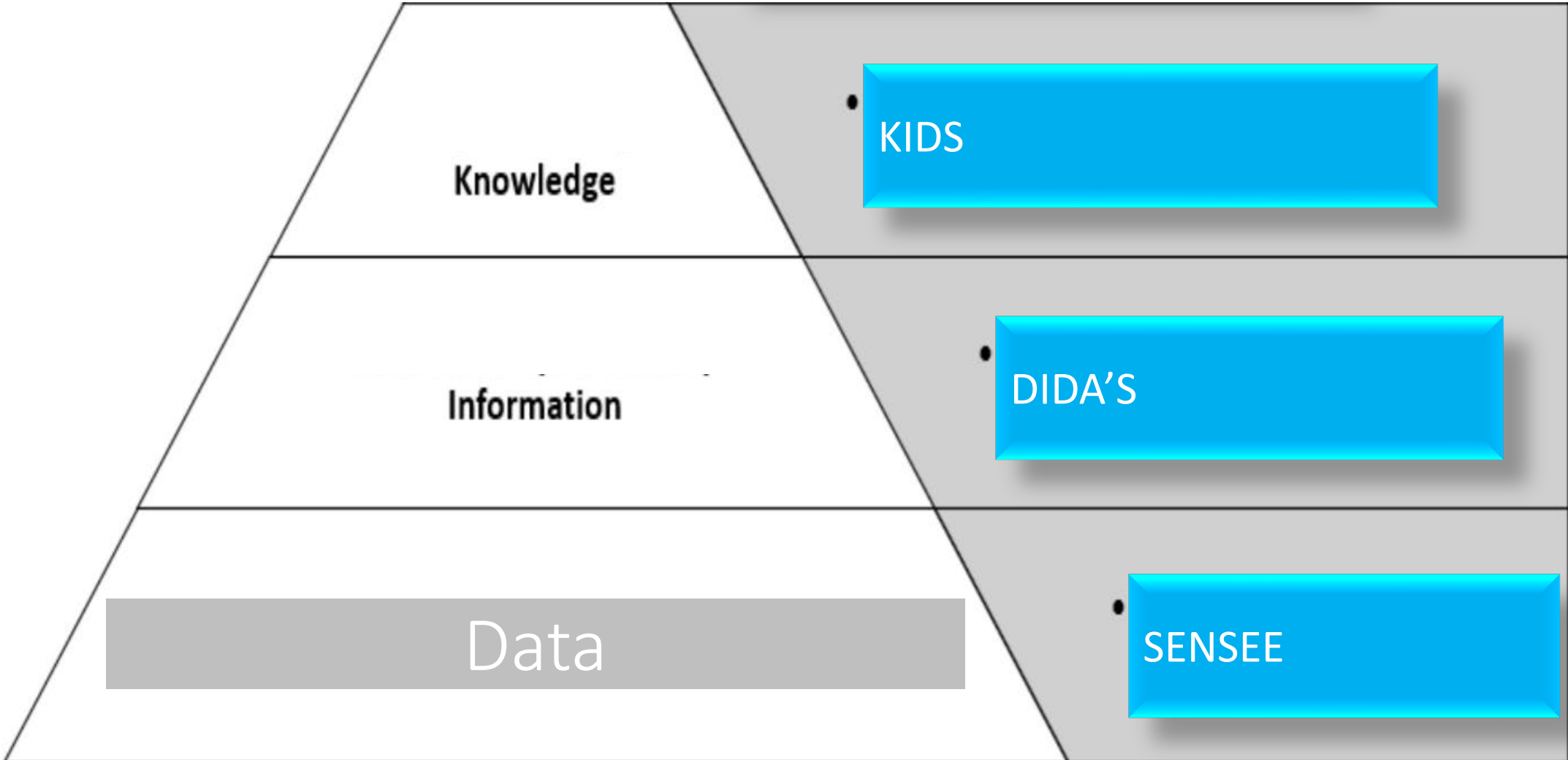


Information

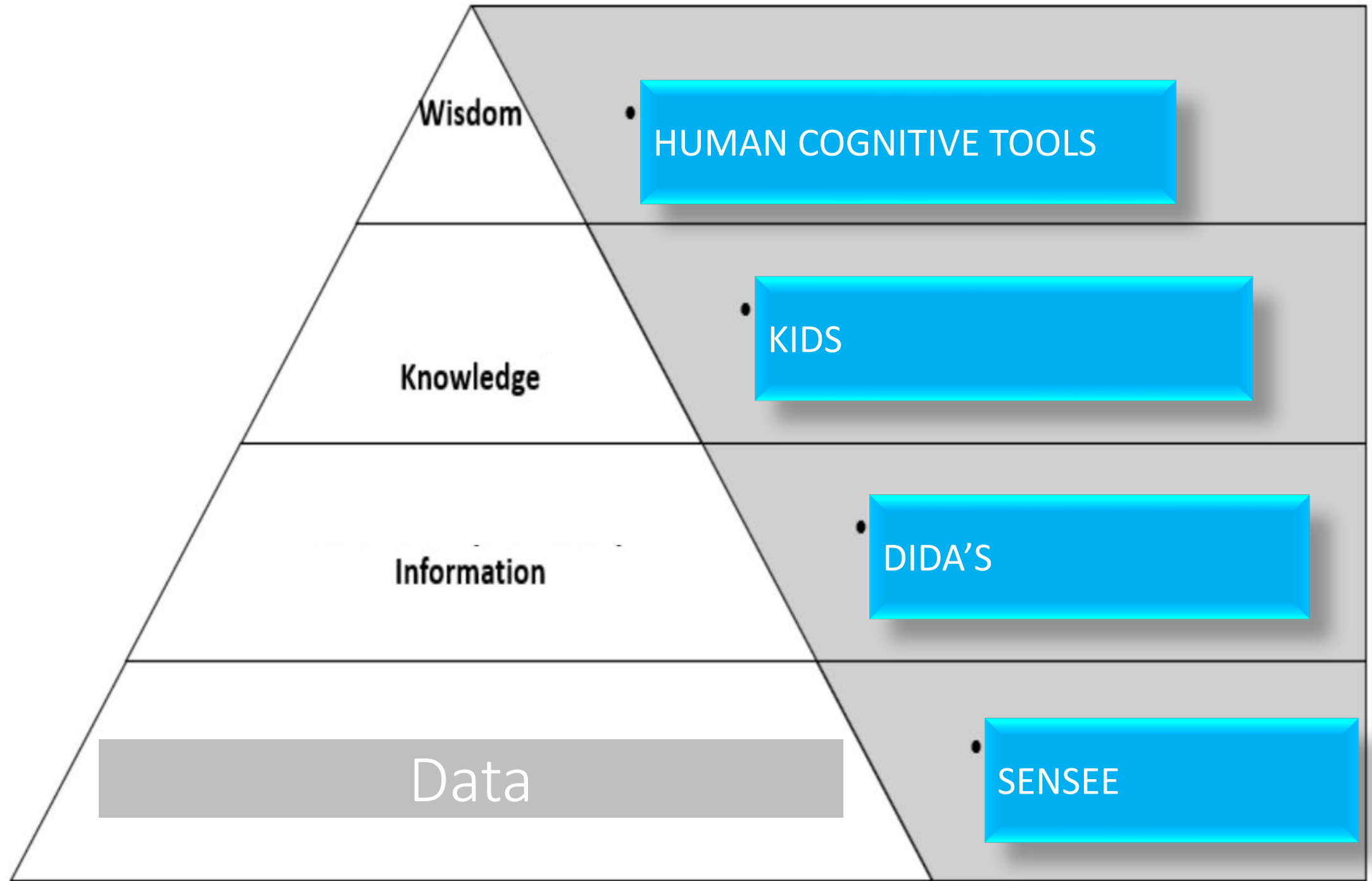
DIDA'S

Data

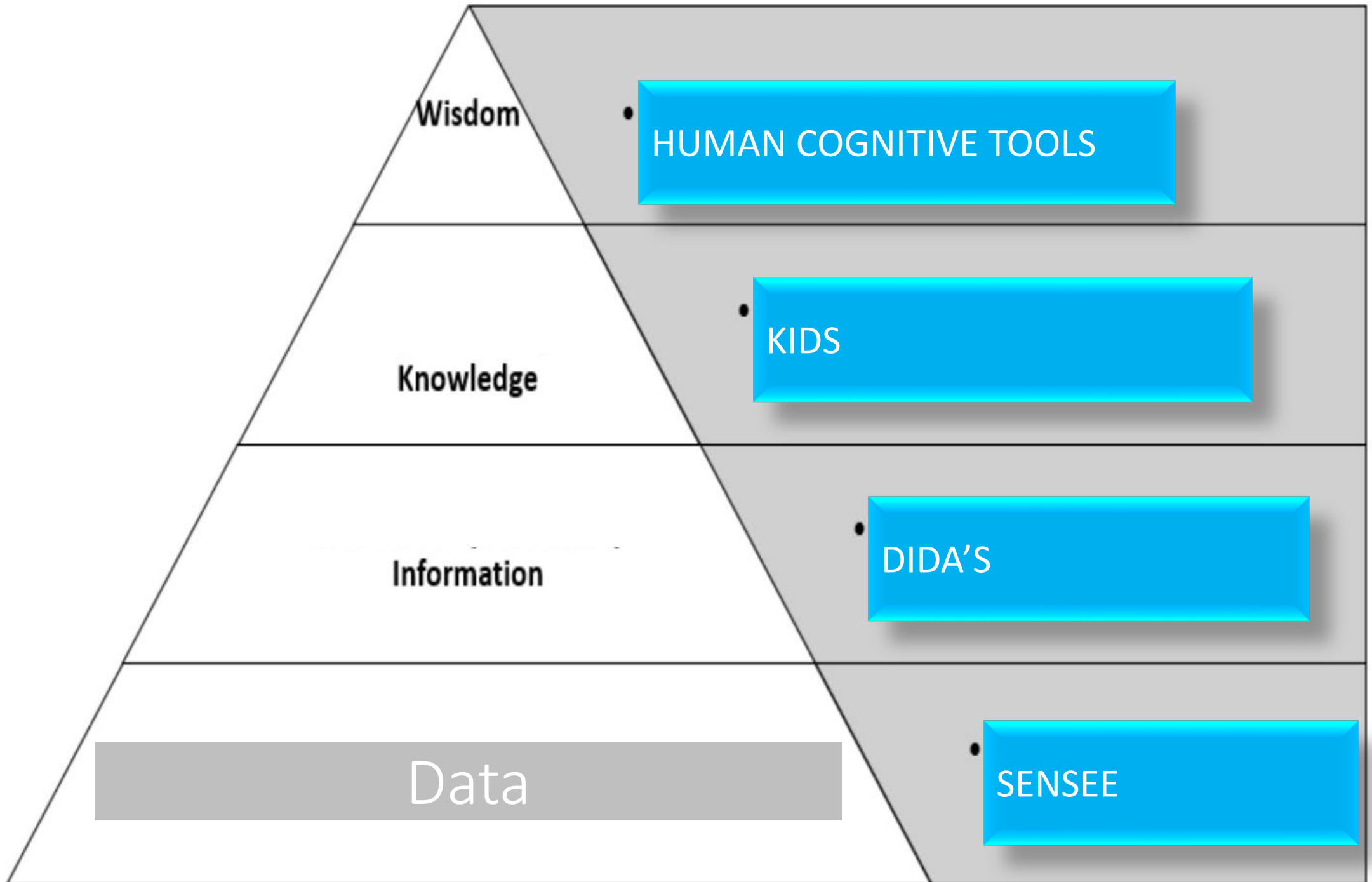
SENSEE



SYNERGISTIC INTEGRATION



PEAS PLATFORM



Digital Transformation

is about the life cycle of data as it transforms to information and contributes to better decisions

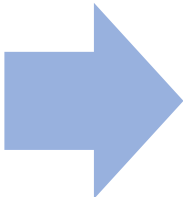
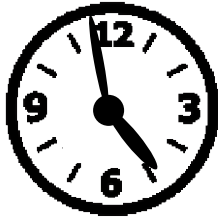
Are we immersed in **data** swamps?
Actions depend on **information**.
Informed by **knowledge**.
Learn from **experience**.

Unbeknownst to us, we are in a perpetual quest for knowledge. Every day, in every action, we undertake the journey from data and information to knowledge. In the process we are learning, in each step, from our experiences, no matter how small and agnostic of the scenarios (social actions, academic activities, business pursuits, ideas and opinions).

Convergence

every step of the journey

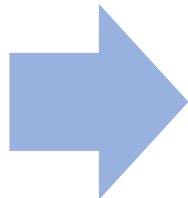
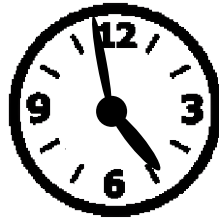
Social Domain



Situation

Time constraint

Social Domain



Situation

Time constraint

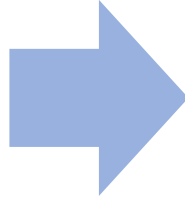
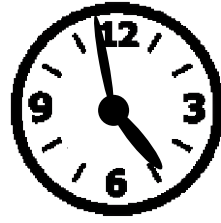
Engineering Domain



Sensor reading

Local knowledge

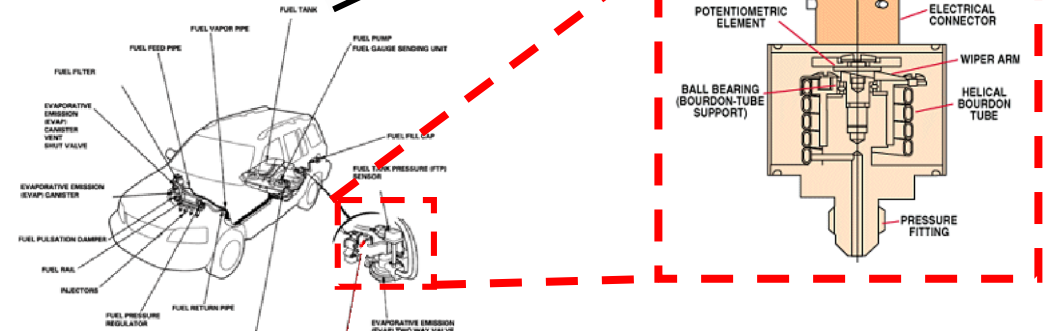
Social Domain



Situation

Time constraint

Information domain



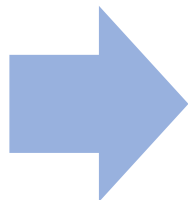
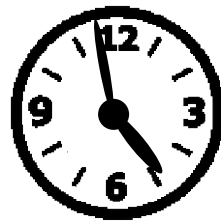
Engineering Domain



Sensor reading

Local knowledge

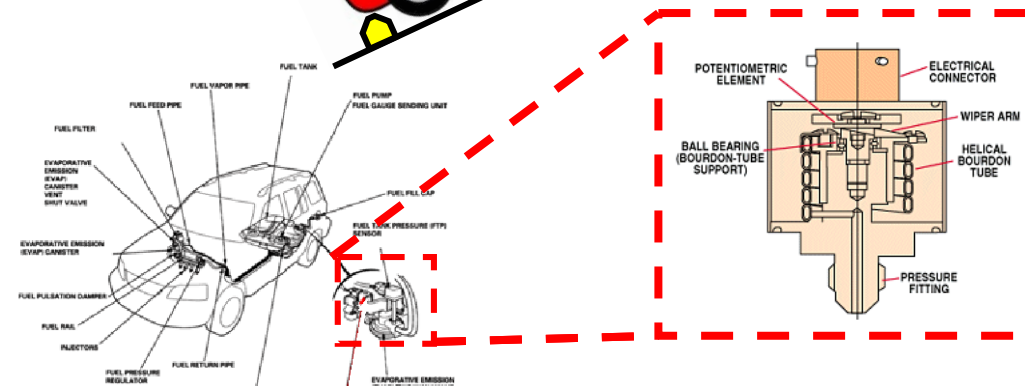
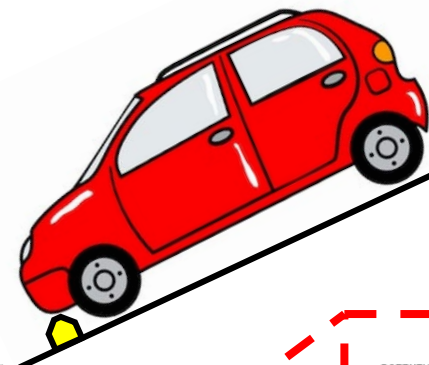
Social Domain



Situation

Time constraint

Information domain



Engineering Domain

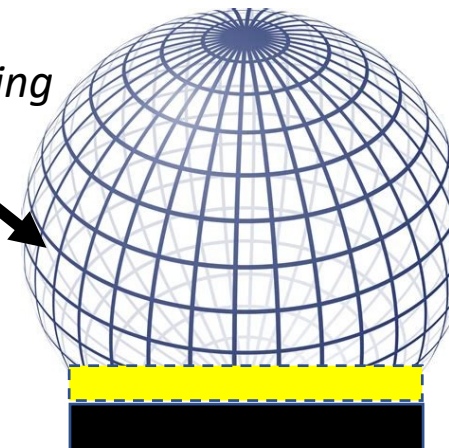


Sensor reading

Local knowledge

Scientific domain

Functional working space



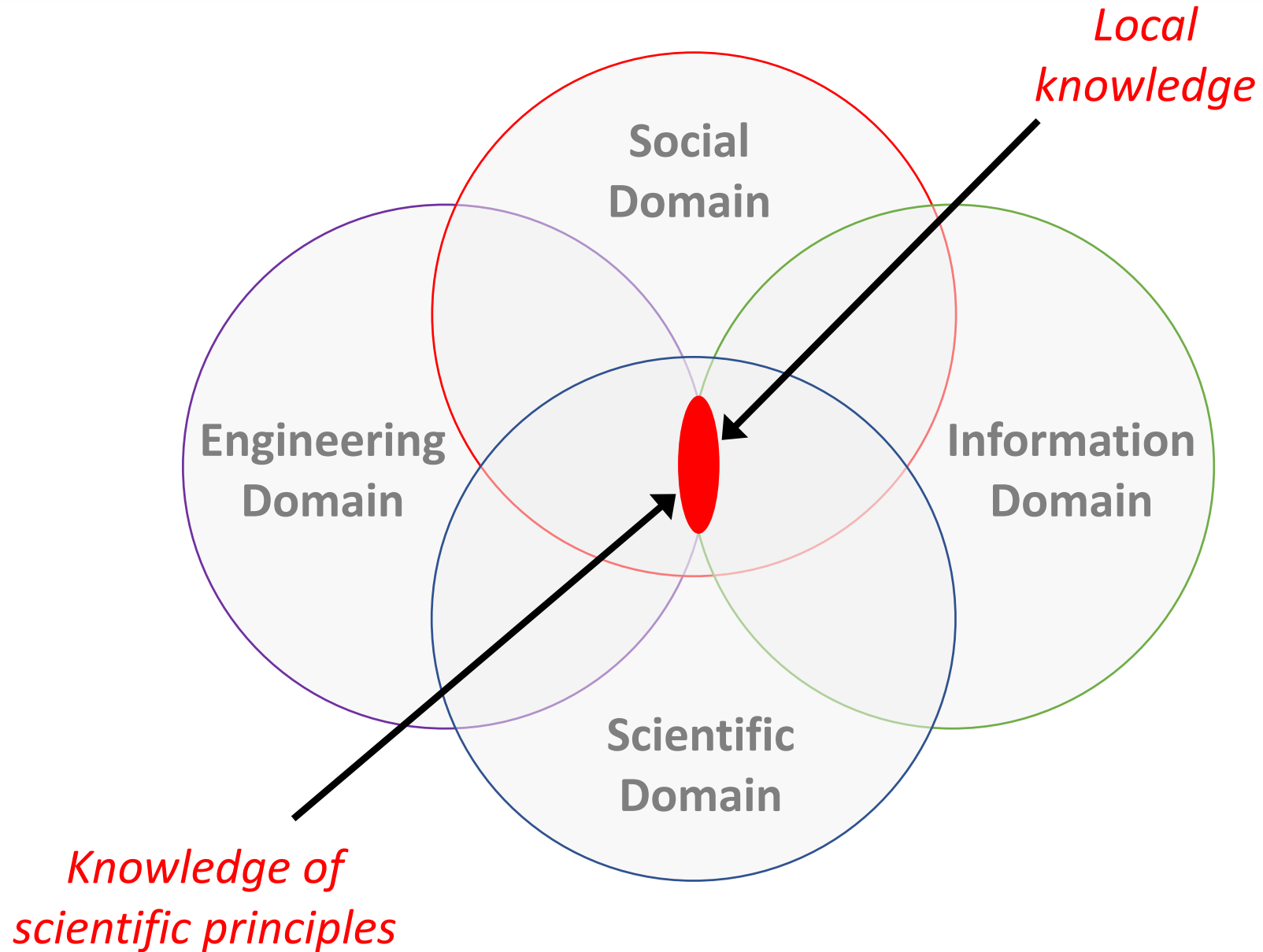
$$\frac{\partial C}{\partial t} = \chi \frac{\partial^2 C}{\partial x^2}$$

$$Z = \frac{E(t)}{I(t)} = Z_o (\cos \psi + j \sin \psi)$$

Knowledge of scientific principles

Sensor surface

Convergence



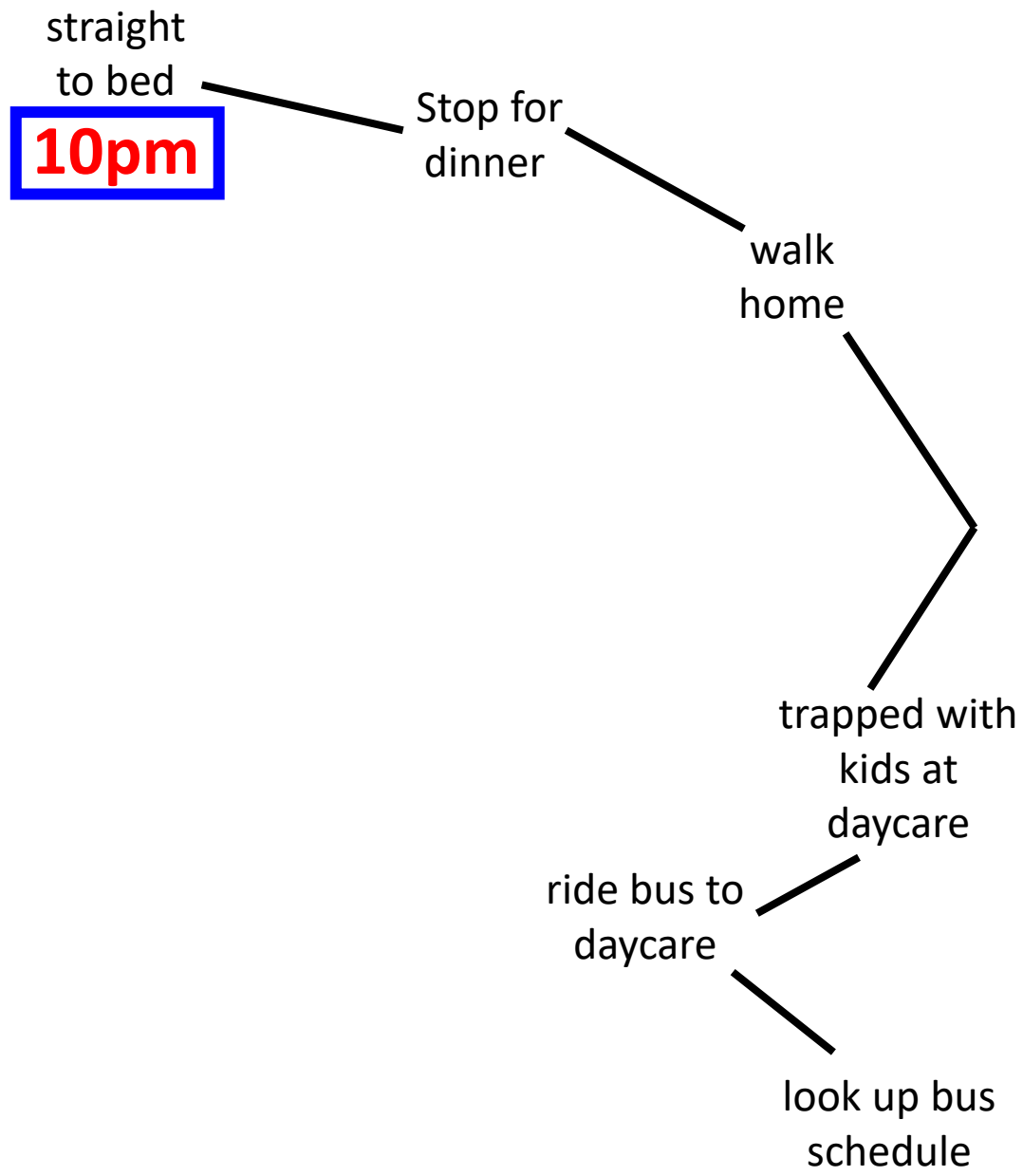
For humans, it is child's play

For systems, it's still a difficult task to select what is relevant, relative to the context, and connect (**R2C2**), distributed data, to extract information, to aid decisions or execute action for the situation, based on actionable knowledge.

Child Happiness Scale

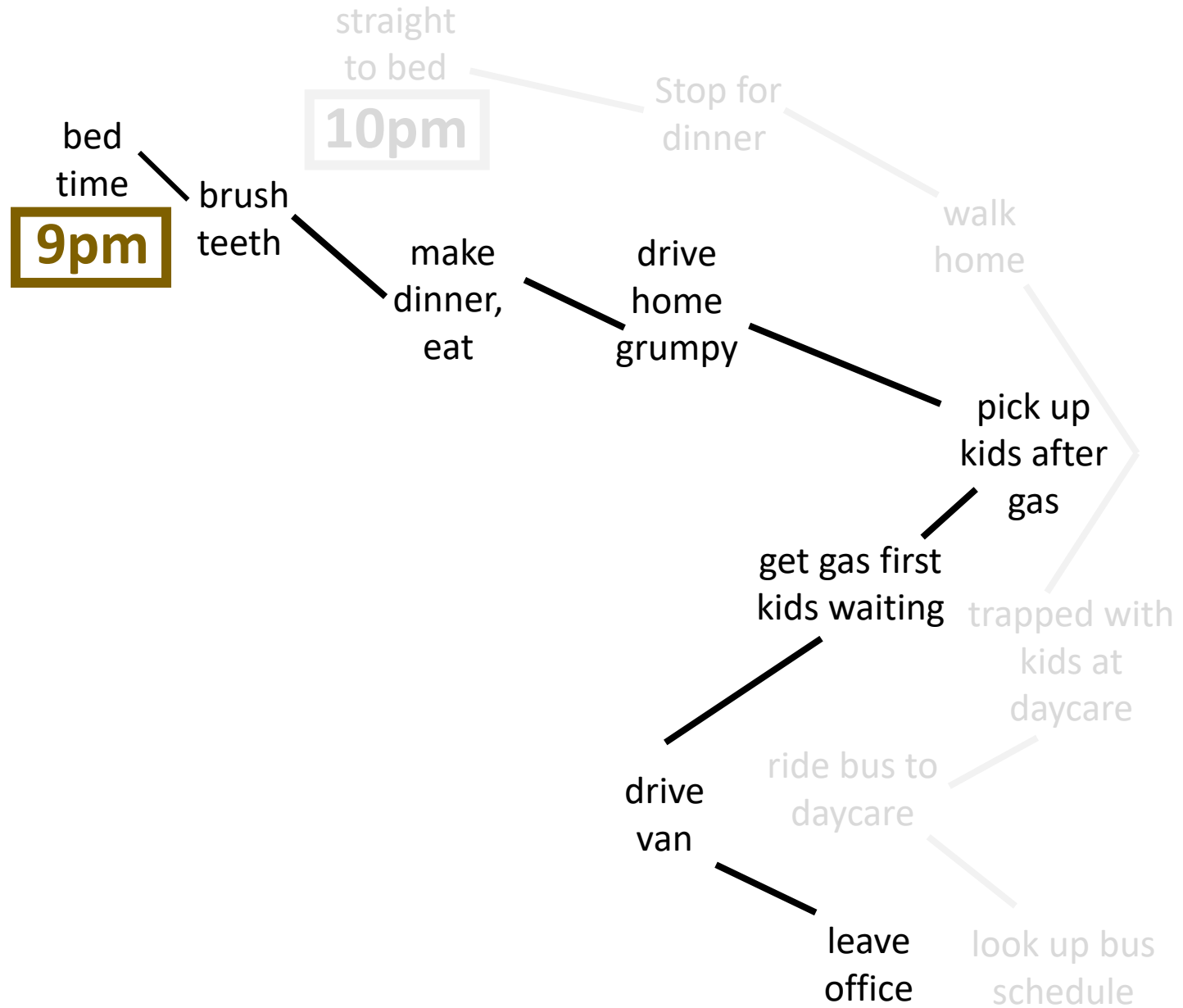


Time



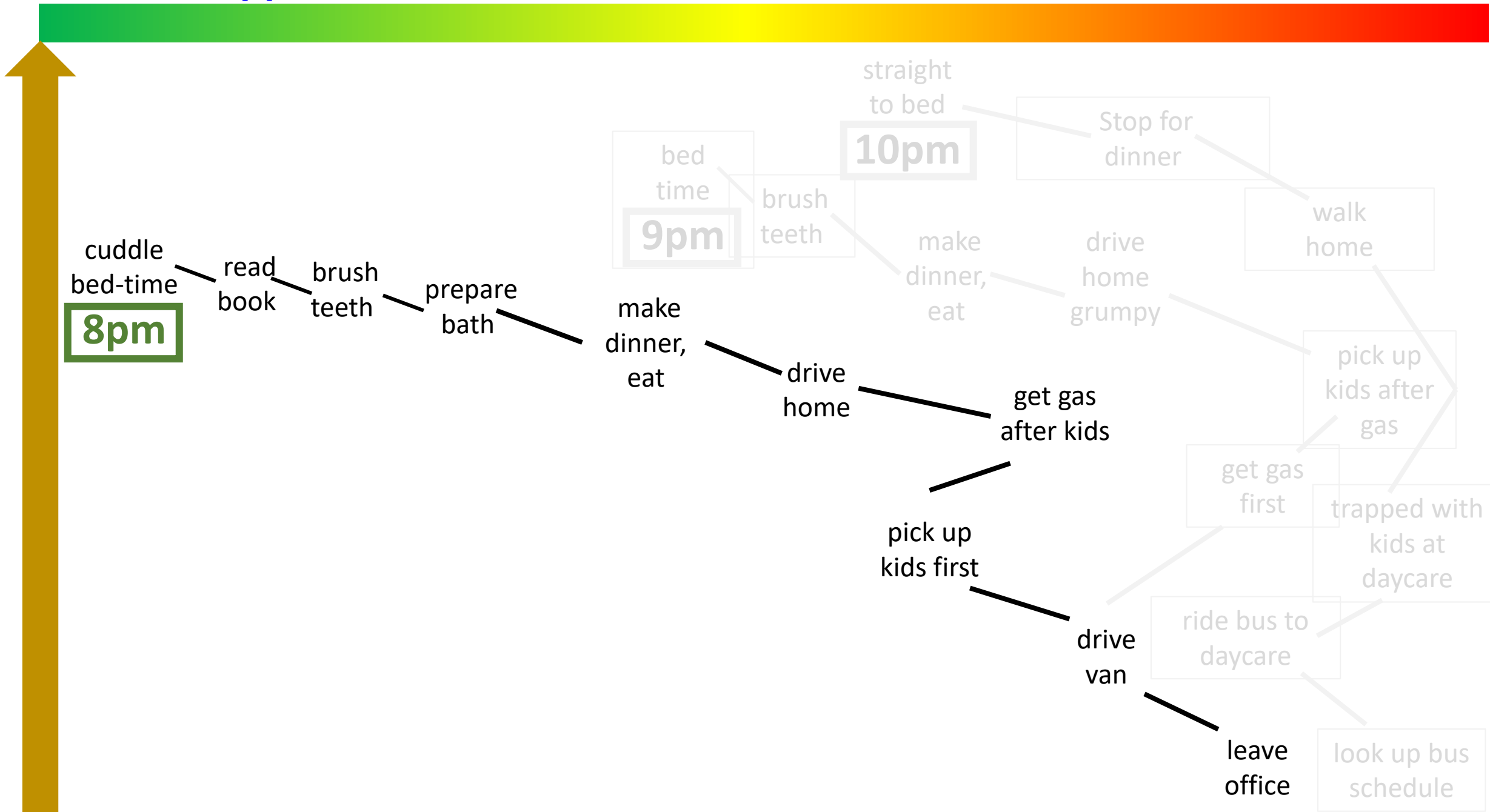
Child Happiness Scale

Time



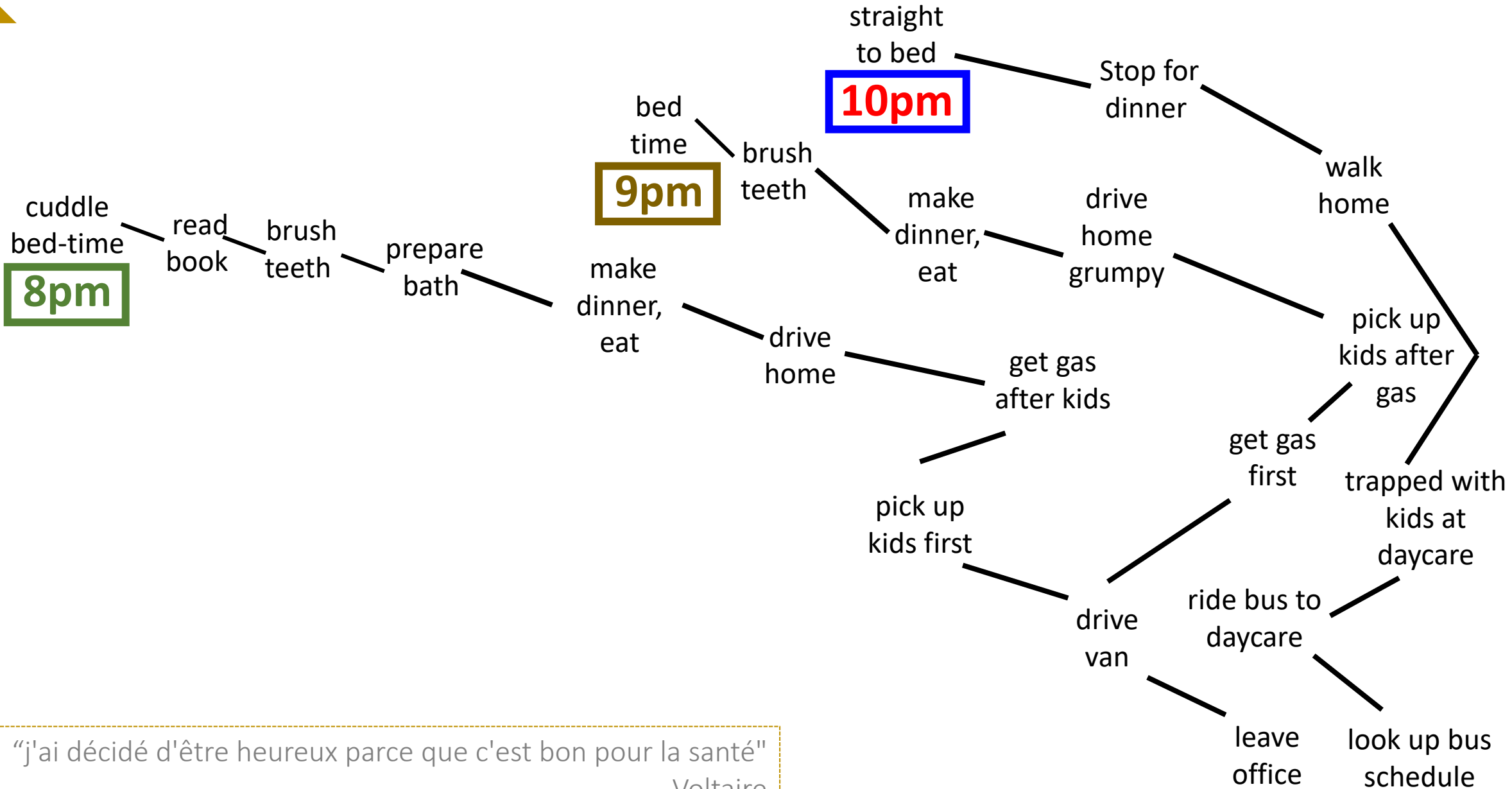
Child Happiness Scale

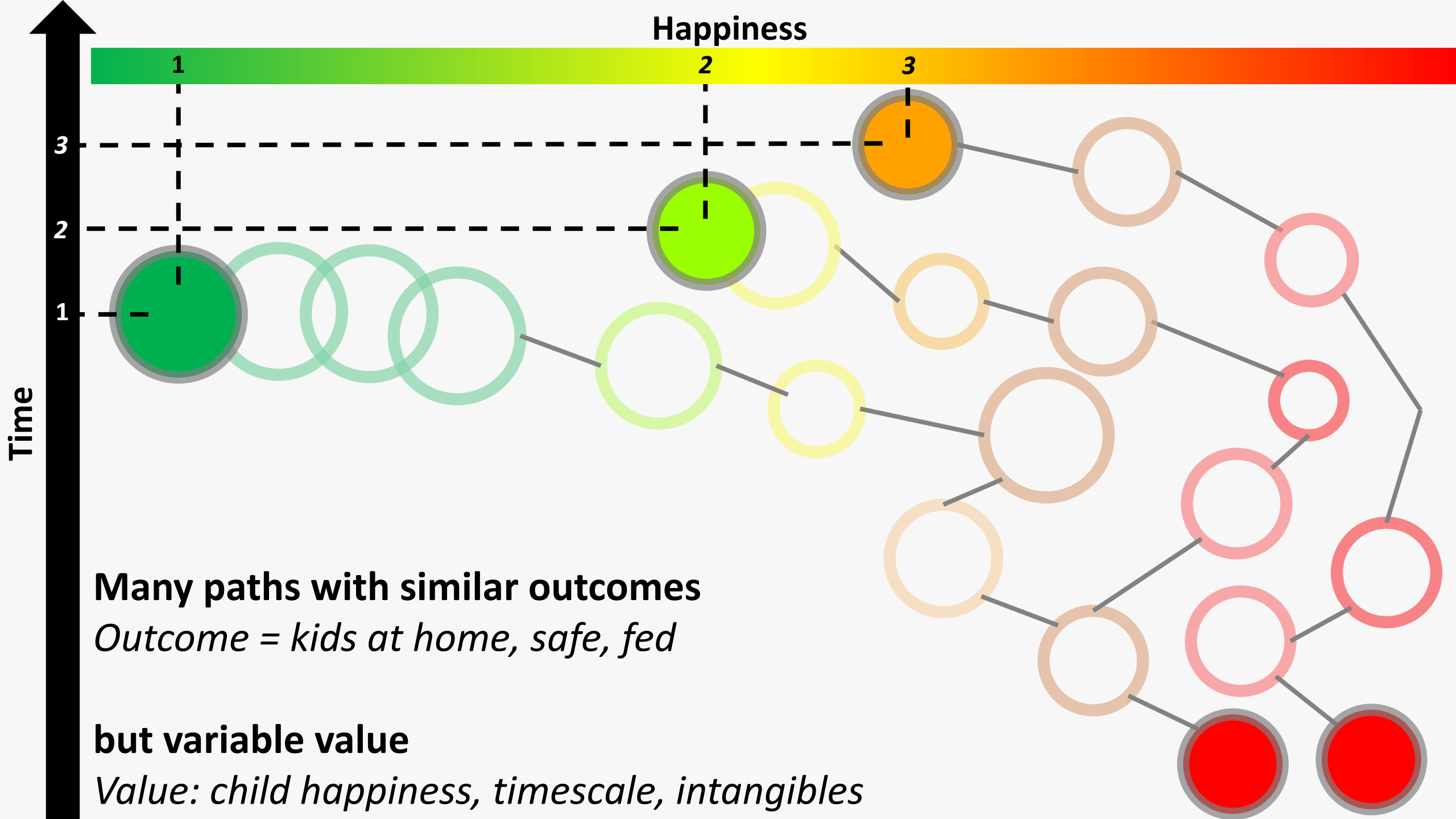
Time

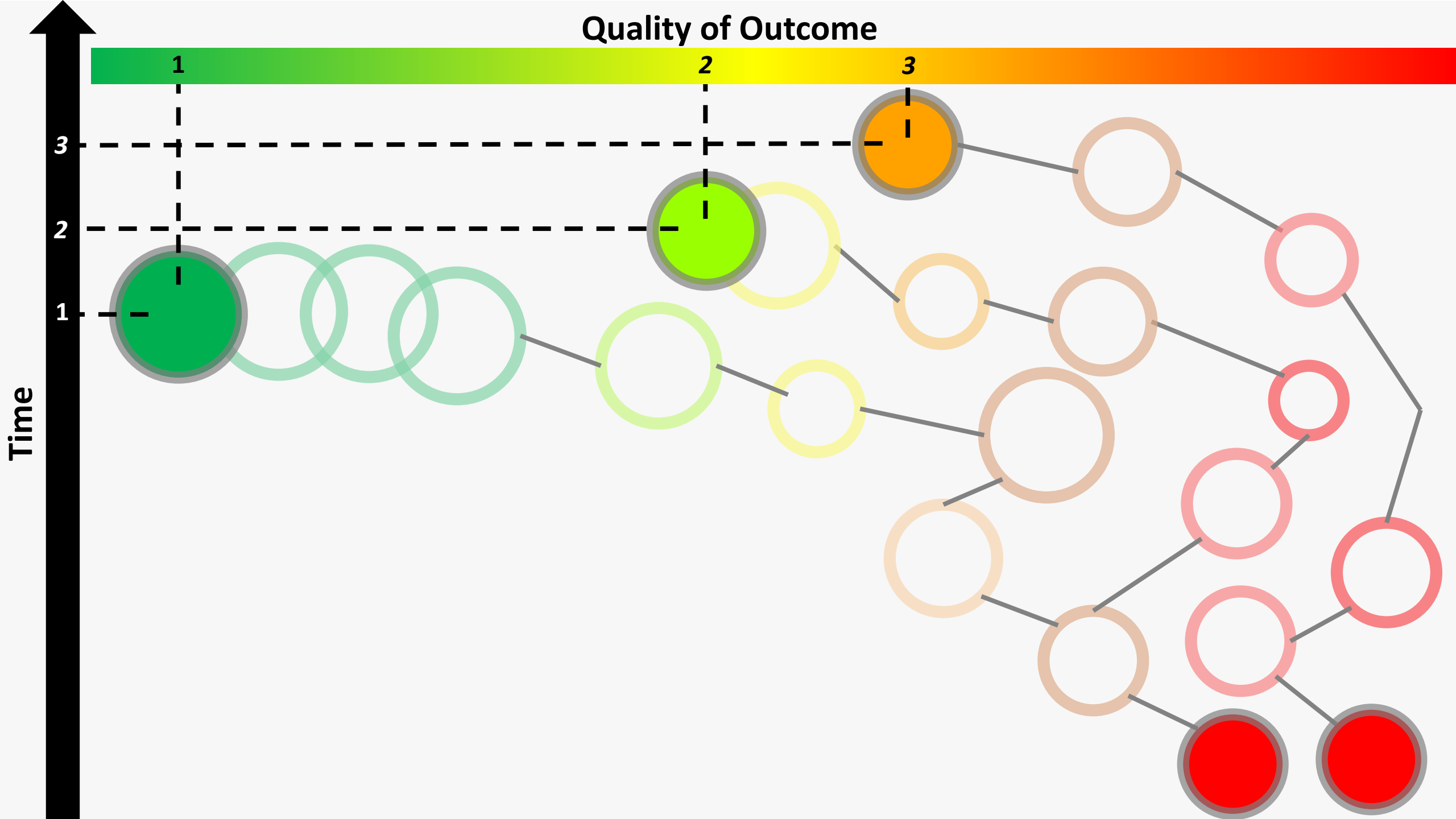


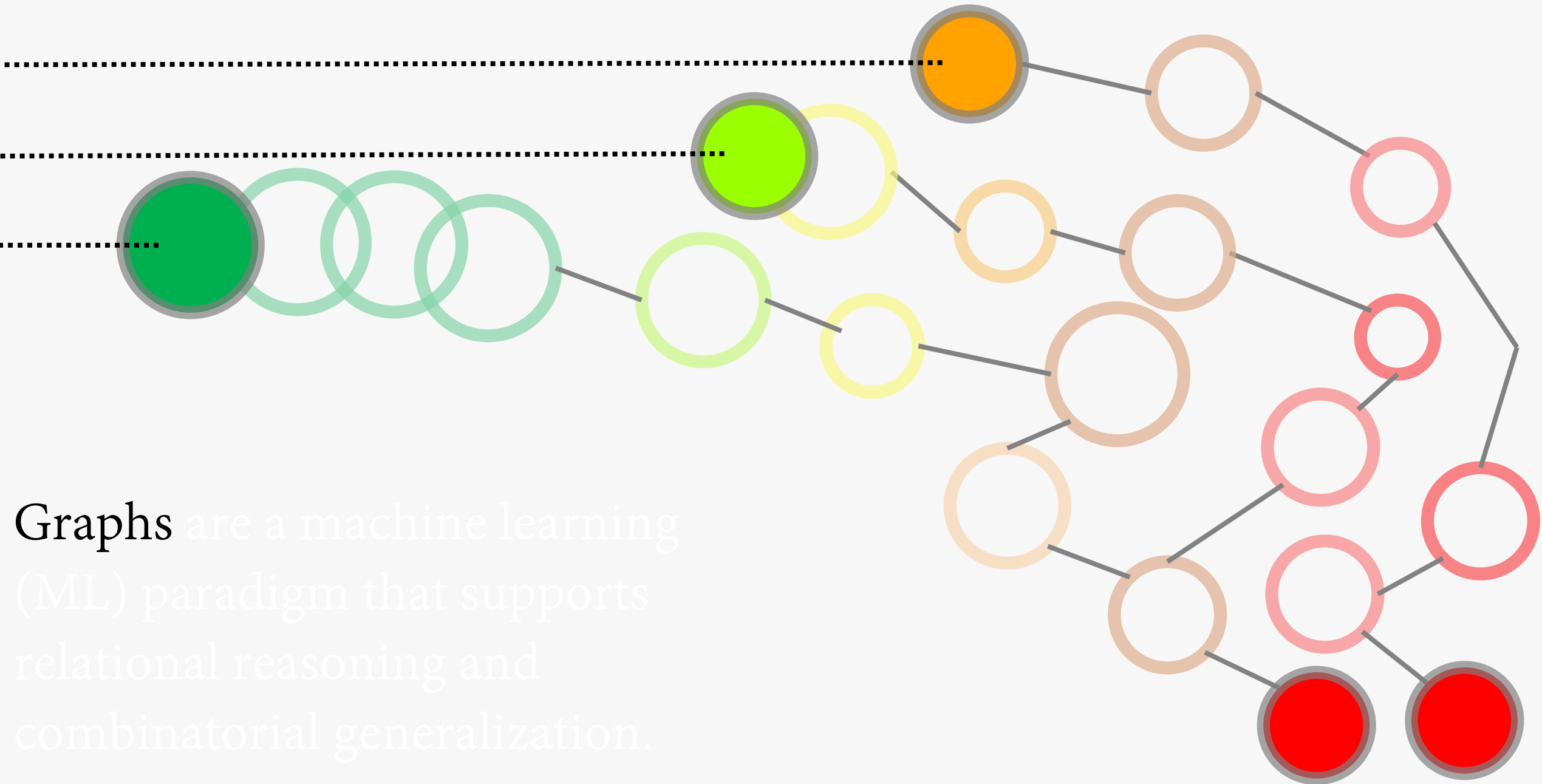
Child Happiness Scale (clap along if you feel like happiness is the truth)

Time



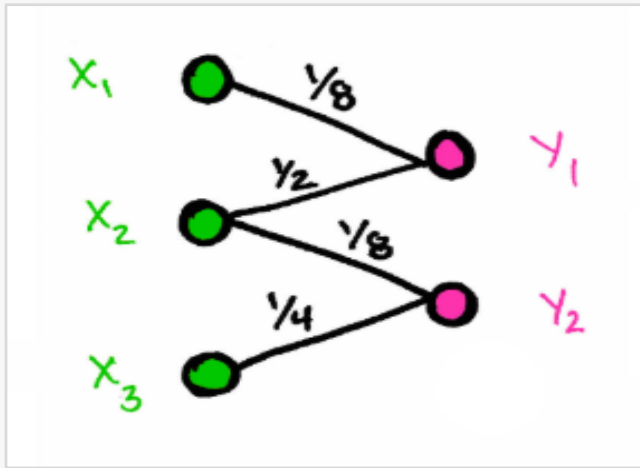
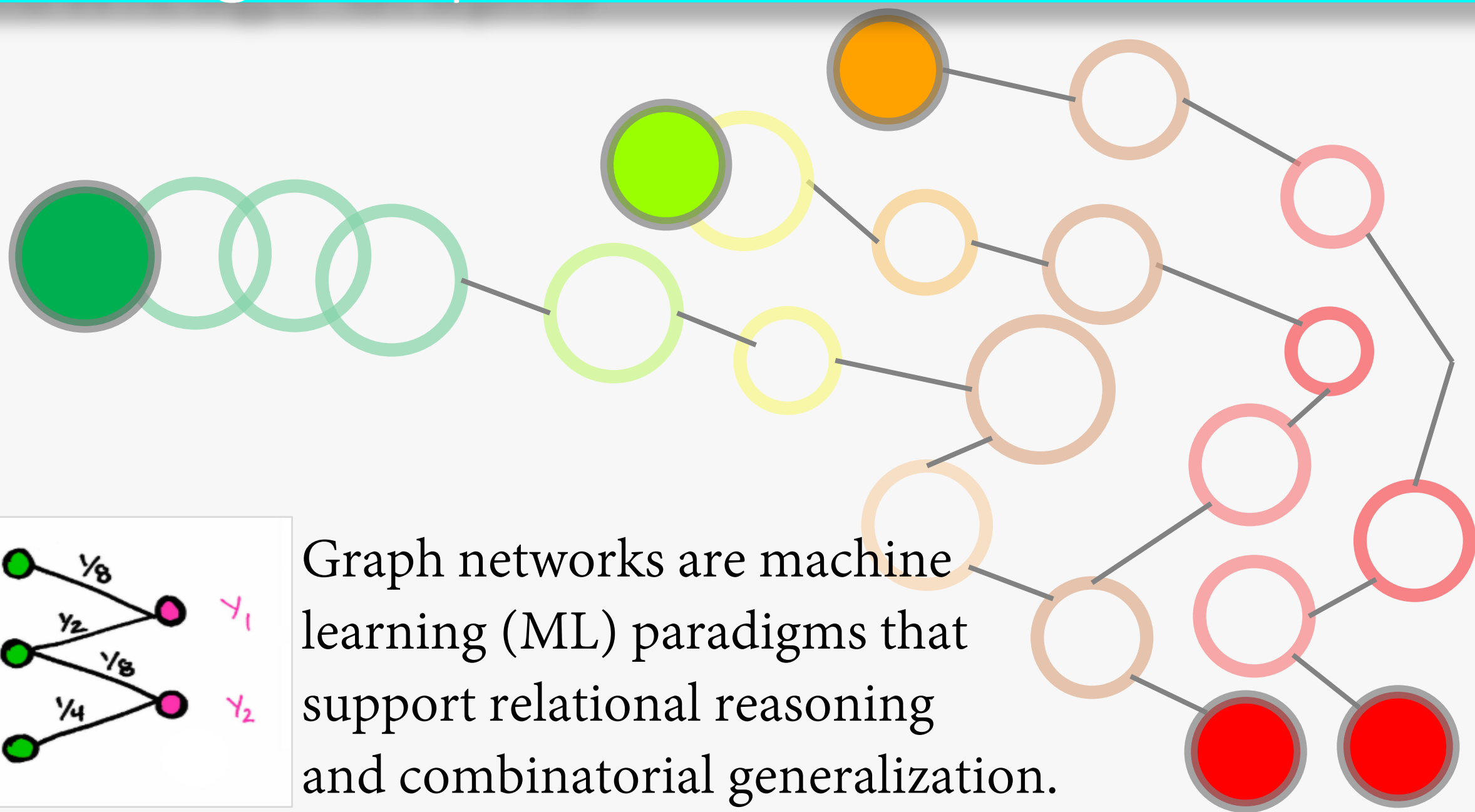






Graphs are a machine learning (ML) paradigm that supports relational reasoning and combinatorial generalization.

Knowledge Graphs



Graph networks are machine learning (ML) paradigms that support relational reasoning and combinatorial generalization.

BOOK - <http://bit.ly/Knowledge-Representation>

<http://www.mkbergman.com/2244/a-common-sense-view-of-knowledge-graphs/>

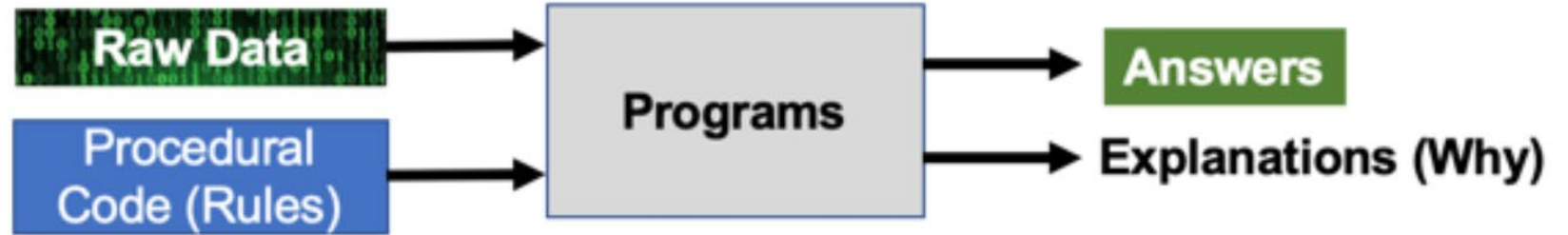


<https://www.springer.com/gp/book/9783319980911>

http://www.mkbergman.com/wp-content/themes/ai3v2/images/2012Posts/ontology_build.gif

Knowledge Graphs: The core of the 3rd era of computing

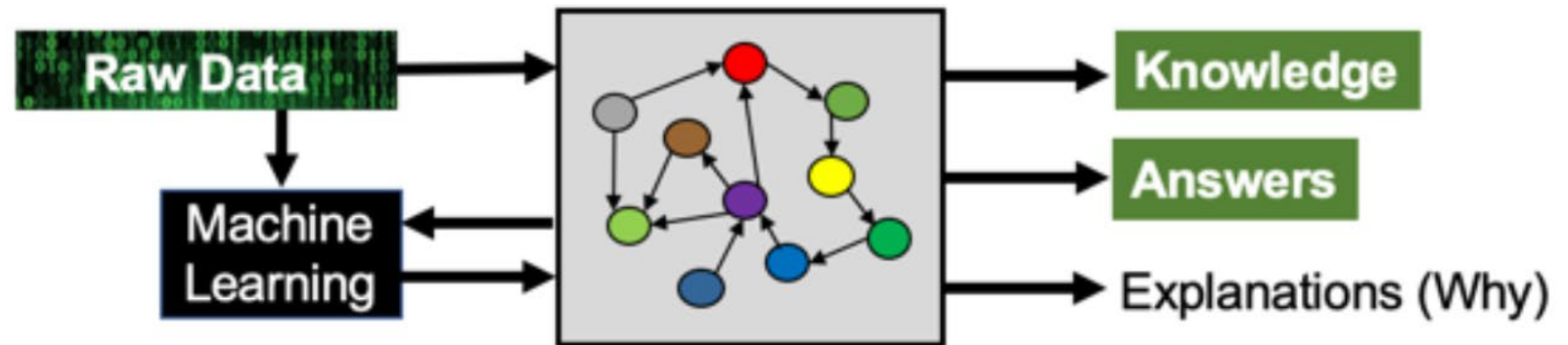
The Procedural Era



The Machine Learning Era



The Knowledge Graph Era

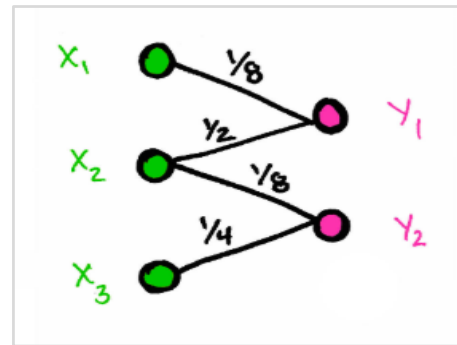


@dmccreary

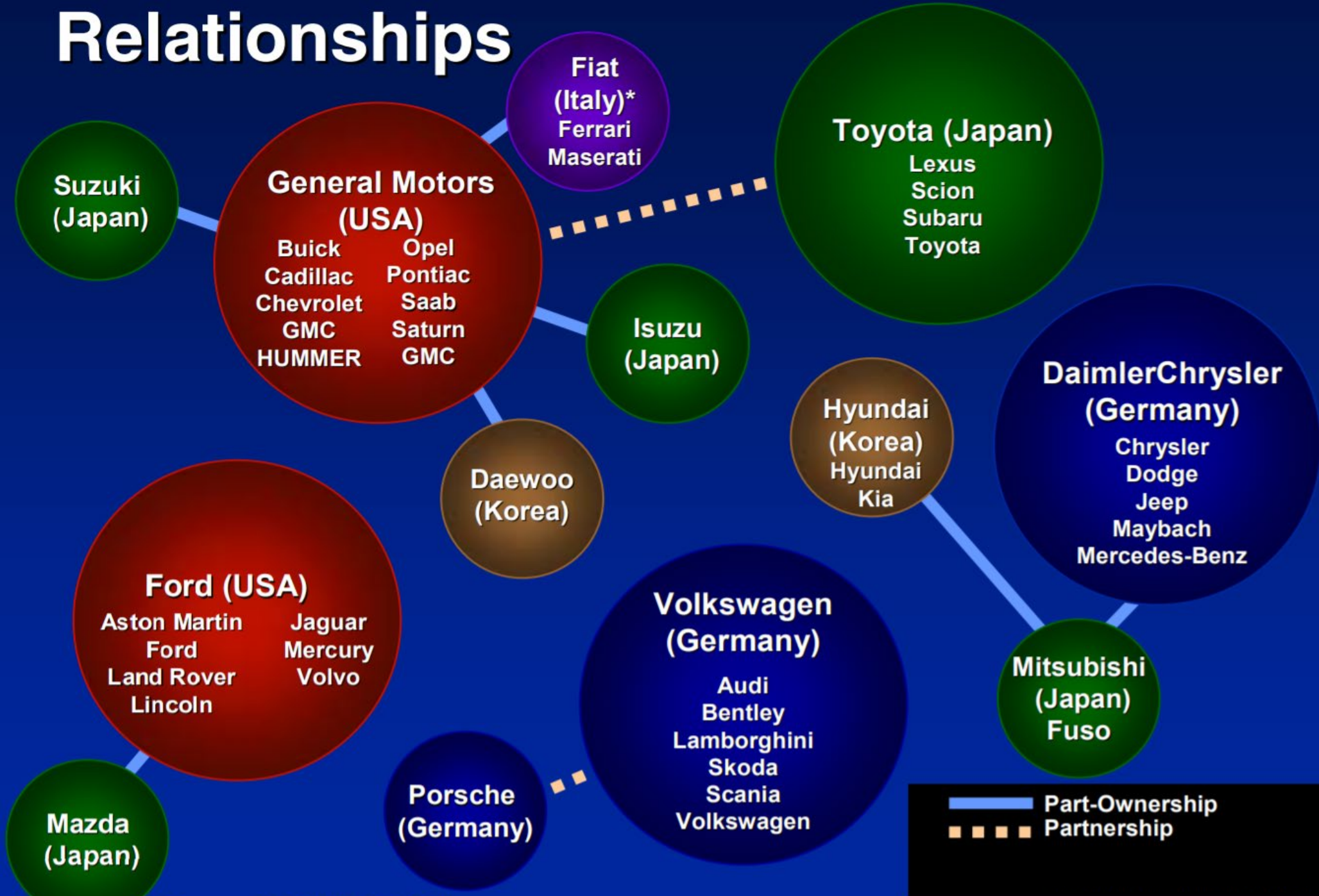
Use machine learning to continuously enrich knowledge

RELATIONSHIPS

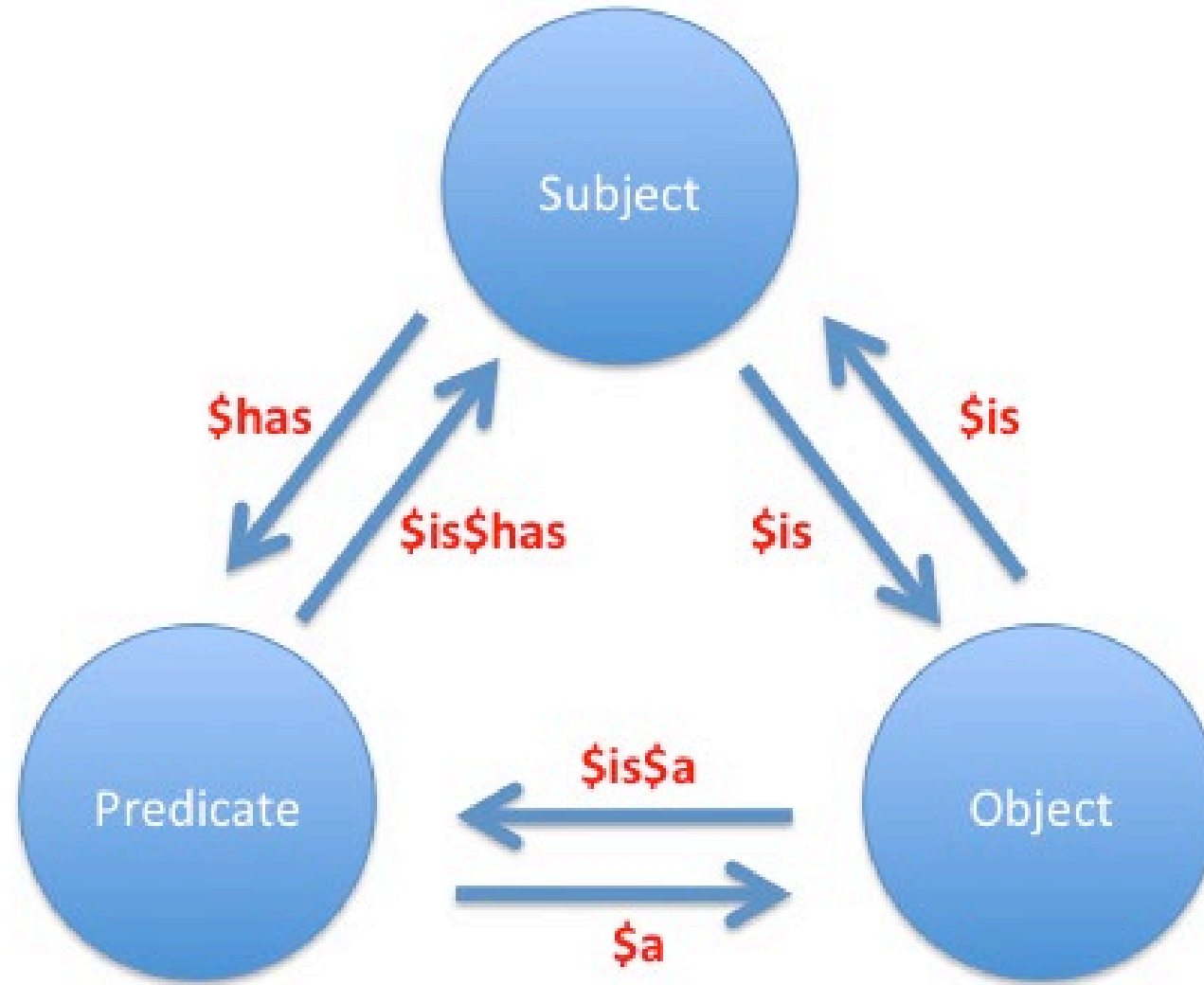
between entities are critical in the context of making decisions. Data available to the human mind (or the system) in the context of entities or objects or processes, under consideration, are used directly (as data) or converted to information (by humans) to fuel decisions (outcomes). Knowledge graphs are a form of **bio-mimicry** tool, to enable non-human computer systems to understand relationships between entities, objects, processes, people, and things (think IoT, internet of things). Resource Description Framework (**RDF**) is a standard to describe resources and is based on principles of linguistics (noun, verb, subject, predicate).



Relationships



RDF expresses RELATIONSHIPS as “triples” which are based on principles of linguistics (noun, verb, subject, predicate).

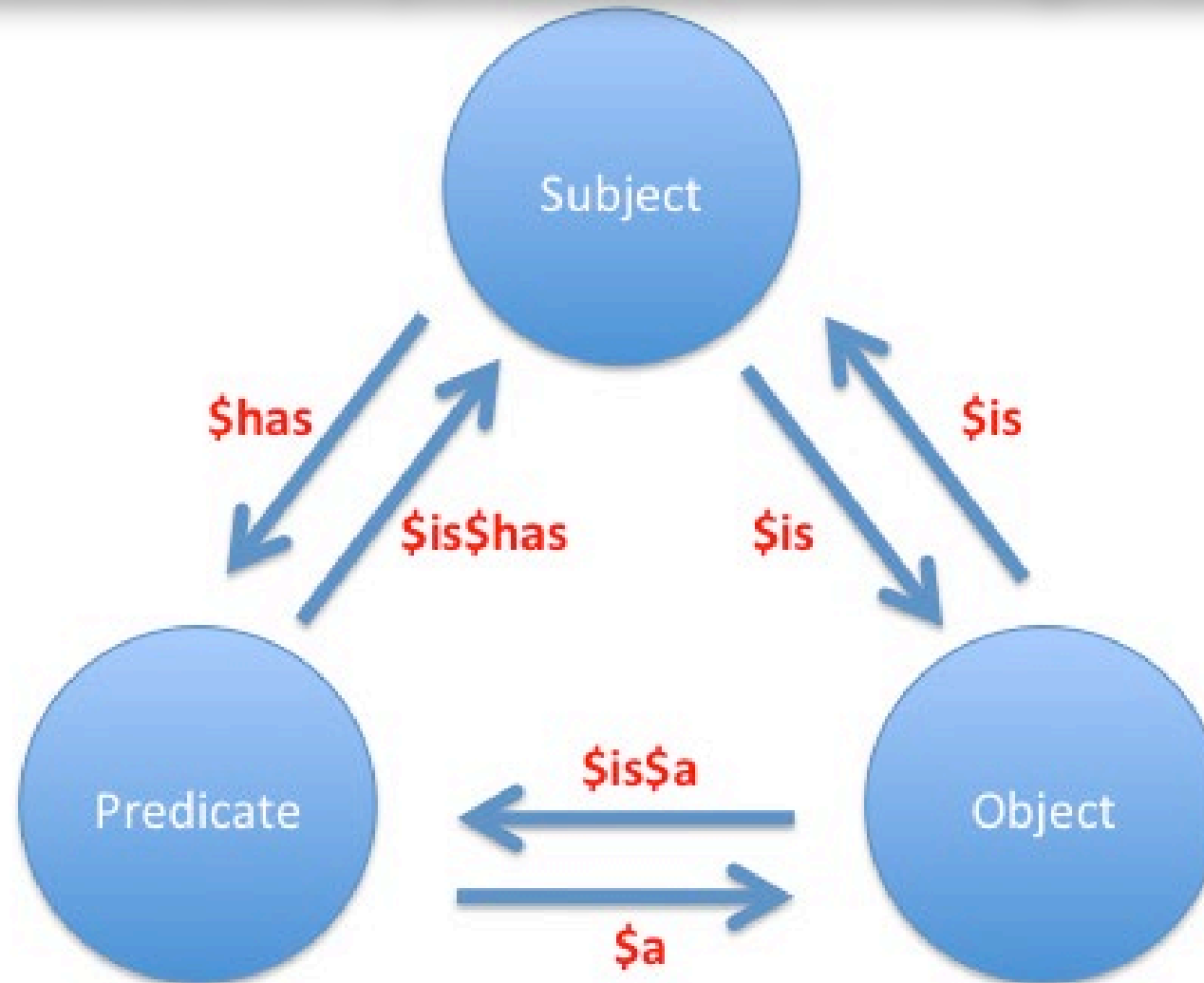


Drummond Reed

Resource Description Framework (RDF) is a standard to describe resources. It is written in XML and machine-readable.

Linguistics, Relationships and Knowledge Graph Networks

In the "Golden Triangle" of metagraph relationships: $\$has\a (which is literally $\$has/\$has/\$a$) defines a subset of $\$has$ relationships in which the predicate is also an object. Asserting a predicate **as an object** is different than asserting it **as a predicate**. Neither implies that the other exists. They have a logical relationship, it is the same predicate involved in both cases, but asserting it as a predicate does not mean it is also an object, and asserting is as an object does not need it to be also a predicate.



$\$$ is a subsegment delimiter (Global Context Symbols)
<https://wiki.oasis-open.org/xri/XriThree/GcsDelimiter>

Are computational standards, syntax semantics and ontologies influenced by linguistic bias?

Subject	Predicate	
	linking verb	subject complement noun or adjective
The aliens	were	killers.
The rats	are	ugly.
The griff	is	grafunkulous.

- The predicate is the action
- Action verbs are easy to identify, but remember **verbs of being**: am, is, are, were, was
- A sentence *can* have more than one predicate

Subject and Predicate



What is a Subject?

- *A subject is the person or thing that is doing an action, or the person or thing that is the focus of the sentence*

What is a Predicate?

- *The predicate of the sentence is the part that contains the action.*

What happens when the RDF ontology creator speaks a language where the rules of English grammar are not applicable?



At the heart of the predicate is a **verb**. In addition to the verb, a predicate can contain **direct objects, indirect objects, and various kinds of phrases**.

A sentence has two parts: the subject and the predicate. The subject is what the sentence is about, and the predicate is a comment about the subject.

www.grammar-monster.com/glossary/predicate.htm

Examples of Predicates of Sentences

Here are some examples of predicates. In each example, the predicate of the sentence is shaded and the verb in the predicate is in bold.

- Elvis **lives**.
- Adam **lives** in Bangor.
- The telegram **contained** exciting news.
- The girls in our office **are** experienced instructors.
- They **are** experienced instructors, who acquired their experience in France.

Predicates in Clauses

A **clause** contains a subject and predicate too. The examples below are all clauses not sentences. The predicate is shaded and the verb of the clause is in bold.

- who **lives** with her mother
(The subject is the **relative pronoun** *who*.)
- which **was** somewhat unexpected
(The subject is the **relative pronoun** *which*.)
- that **points** to the North Pole
(The subject is the **relative pronoun** *that*.)

www.grammar-monster.com/glossary/predicate.htm

Why RDF may be just a part of the solution: Is linguistic bias embedded in the grammatical context of RDF triples?

https://lists.w3.org/Archives/Public/www-archive/2005Feb/att-0050/eswc-118n.pdf

Semantic Standards in other languages?

概念词关联导航

基本属性 全选

Current Class 中成药

清除查询条件

序号	属性名称	选择当前列	查询条件	查询内容
1	OTC分类	<input checked="" type="checkbox"/>	包含	
2	中药保护品种	<input checked="" type="checkbox"/>	包含	
3	临床应用	<input checked="" type="checkbox"/>	包含	
4	主治症	<input checked="" type="checkbox"/>	包含	心脏病
5	别名	<input checked="" type="checkbox"/>	包含	
6	制备方法	<input type="checkbox"/>		
7	剂型	<input type="checkbox"/>		
8	功效	<input type="checkbox"/>		
9	包装规格	<input type="checkbox"/>		

提交查询

序号	属性名称	选择当前列	查询条件	查询内容
1	原发病	<input type="checkbox"/>	包含	
2	并发症	<input type="checkbox"/>	包含	
3	疾病名称	<input type="checkbox"/>	包含	
4	疾病症状	<input type="checkbox"/>	包含	
5	病症候类型	<input type="checkbox"/>	包含	

提交查询 添加条件

相关概念属性

序号	概念名称	查看概念属性
1	药品销售状况	→
2	疾病	→
3	药物成分	→

Related Classes

Figure 4 DartSearch. The default user interface for DartSearch.

Knowledge Graphs relevant to SENSEE, ART, & DIDA'S KIDS

When data is mapped against an OWL/RDF ontology, instances of the data are expressed based upon the idea of making statements about resources in the form of **subject–predicate–object** expressions. These expressions are known as *triples* in RDF terminology. The ‘Subject’ denotes the object, and the predicate denotes a single semantic trait or aspect of the object that can be a literal value or expressed as a relationship between the subject and another object that is the target of the relationship. For example, the notion “The soil has a pH of 8” in RDF triple is **subject** denoting “soil” and **predicate** denoting “pH” and an **object** denoting “8” which is the OWL/RDF take on using the object as the subject from the classical entity–attribute–value model within object-oriented design: object (soil), attribute (pH) and value (8). The object (soil) can also have another attribute (contains) that can point to another object (phosphate). The object (phosphate) might have an attribute (produces) another object (acidity). Yet again, the object (soil) might have an attribute (contains) another object (microbes). This is one reason why RDF triples, despite their shortcomings and potential for linguistic bias, enables the formation, to link a series of relationships, between two or more objects. The latter is the foundation on which directed graphs can be built. Hence, knowledge graphs.

Subject – predicate – direct object.

Ex: Mateo quiere comprar un bate nuevo.

subject

predicate
with two
verbs

direct object phrase.

Ontology Languages

https://www.slideshare.net/don_willems/what-are-ontologies

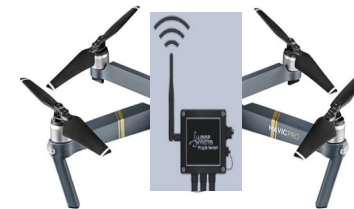
SUBJECT	PREDICATE	OBJECT
Elstar	sub class of	Apple
Elstar	label	“Elstar”
Apple	label	“Apple”
Apple	total production	69,569,612

Which / what nodes are the graphs connecting?

Which / what nodes are the graphs connecting?



Nodes connected by graphs



Must be connected to a mobile device?



<https://www.aac.or.at/smart-farming>

<https://www.findlight.net/blog/2018/09/01/spectroscopy-precision-agriculture/>

http://trajectorymagazine.com/wp-content/uploads/2017/04/TRJ-009-Q1-2013_Final.pdf

Connected KIDS



<https://www.aac.or.at/smart-farming>

<https://www.findlight.net/blog/2018/09/01/spectroscopy-precision-agriculture/>

http://trajectorymagazine.com/wp-content/uploads/2017/04/TRJ-009-Q1-2013_Final.pdf

PORTABLE SPEC

Connect KIDS PEAS to other ecosystems



<https://www.aac.or.at/smart-farming>

<https://www.findlight.net/blog/2018/09/01/spectroscopy-precision-agriculture/>

http://trajectorymagazine.com/wp-content/uploads/2017/04/TRJ-009-Q1-2013_Final.pdf

Web of Knowledge Graph Networks are necessary for ART, DIDA'S, KIDS

Chromosomes of Knowledge



<https://www.aac.or.at/smart-farming>

<https://www.findlight.net/blog/2018/09/01/spectroscopy-precision-agriculture/>

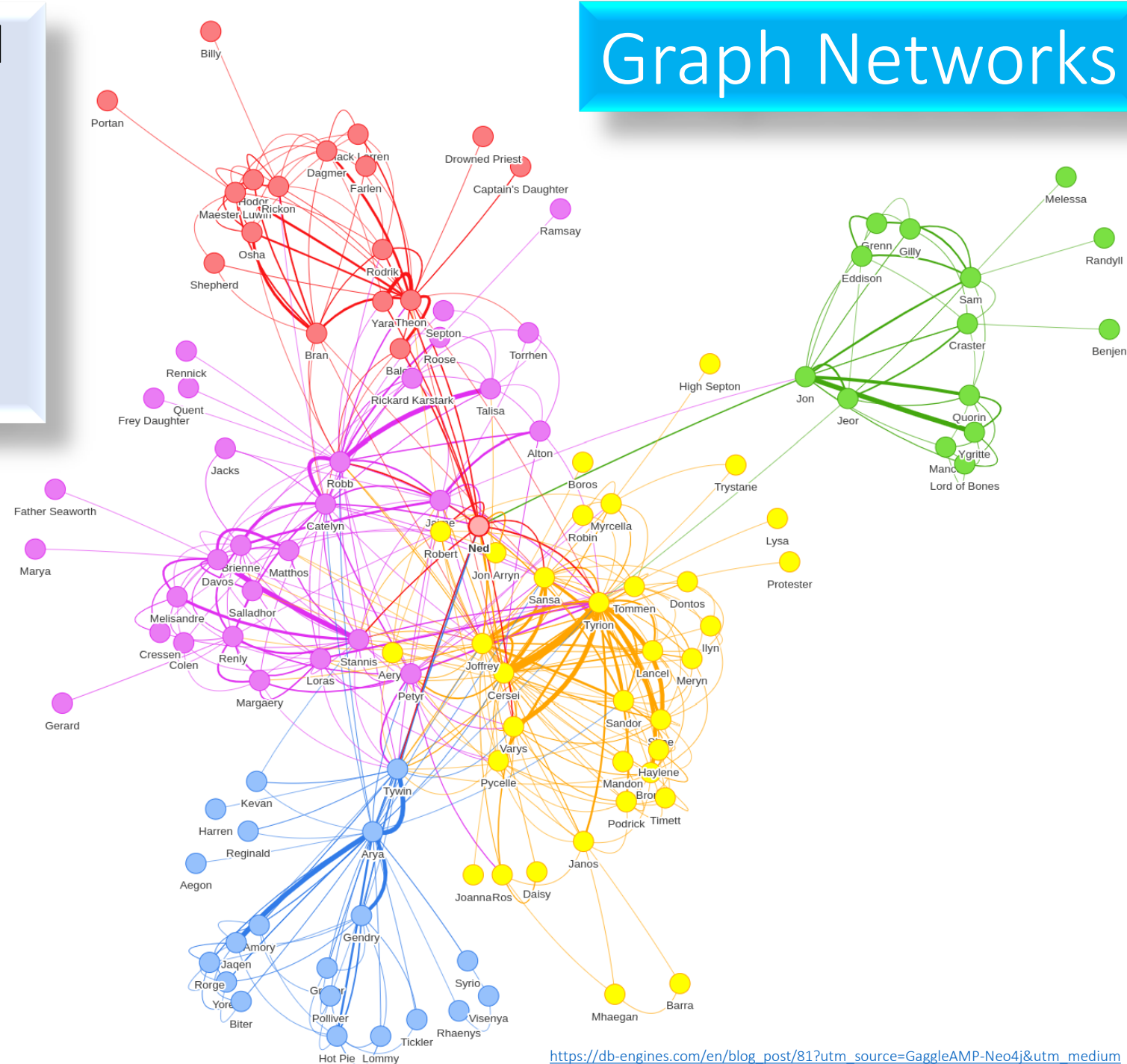
http://trajectorymagazine.com/wp-content/uploads/2017/04/TRJ-009-Q1-2013_Final.pdf

Graph Networks

Increased adoption of tools based on graph theory. HTAP integrates graph transactions (OLTP) and analytic processing (OLAP) using graph databases and graph algorithms (relationships are key).

Graph algorithms provide one of the most potent approaches to analyzing connected data because their mathematical calculations are specifically built to operate on relationships. There are many types of graph algorithms and categories. The three classic categories consider the overall nature of the graph: pathfinding, centrality, and community detection. However, other graph algorithms such as similarity and link prediction algorithms consider and compare specific nodes.

- Pathfinding (and search) algorithms are fundamental to graph analytics and algorithms and explore routes between nodes. These algorithms are used to identify optimal routes for uses such as logistics planning, least cost routing, and gaming simulation.
- Centrality algorithms help us understand the roles and impact of individual nodes in a graph. They're useful because they identify the most important nodes and help us understand group dynamics such as credibility, accessibility, the speed at which things spread, and bridges between groups.
- Community algorithms evaluate related sets of nodes, finding communities where members have more relationships within the group. Identifying these related sets reveals clusters of nodes, isolated groups, and network structure. This helps infer similar behavior or preferences of peer groups, estimate resiliency, find nested relationships, and prepare data for other analyses.
- Similarity algorithms look at how alike individual nodes are. By comparing the properties and attributes of nodes, we can identify the most similar entity and score differences. This helps build more personalized recommendations as well as develop ontologies and hierarchies.
- Link Prediction algorithms consider the proximity of nodes as well as structural elements, such as potential triangles between nodes, to estimate the likelihood of a new relationship forming or that undocumented connections exist. This class of algorithms has many applications from drug repurposing to criminal investigations.



Web of Knowledge Graph – Select List of References

[0] BOOK - <http://bit.ly/Knowledge-Representation>

[1] P. Bonatti, S. Decker, A. Polleres and V. Presutti. Knowledge Graphs: New Directions for Knowledge Representation on the Semantic Web, Dagstuhl Seminar 18371, 2019.

[2] E. Marchi and O. Miguel. On the Structure of the Teaching-learning Interactive Process, International Journal of Game Theory, 3 (2), 1974.

[3] R. Bakker. Knowledge Graphs: Representation and Structuring of Scientific Knowledge, Ph.D. Thesis, University of Twente, Enschede. 1987.

[4] L. Ehrlinger and W. Wöß. Towards a Definition of Knowledge Graphs. SEMANTiCS, 2016.

[5] A Common Sense View of Knowledge Graphs. July 2019. <http://www.mkbergman.com/2244/a-common-sense-view-of-knowledge-graphs/>

[6] P. Domingos. "A Few Useful Things to Know about Machine Learning." Communications of the ACM 55(10): 78 – 87, 2012

[7] A. Sheth, S. Parera, S. Wijaratne, K. Thirunarayan. "Knowledge will propel machine understanding of content: extrapolating from current examples." Proceedings of the International Conference on Web Intelligence. ACM, 2017.

[8] M. Noura, A. Gyrard, S. Heil, M. Gaedke. Automatic Knowledge Extraction to build Semantic Web of Things Applications. IEEE IoT Journal 2019

[9] S. Bhatt, S. Padhee, A. Sheth, K. Chen, V. Shalin, D. Doran, B. Minnery. "Knowledge Graph Enhanced Community Detection and Characterization." Proceedings of the Twelfth ACM International Conference on Web Search and Data Mining. ACM, 2019.

[10] M. Nickel, K. Murphy, V. Tresp, and E. Gabrilovich. A review of relational ML for knowledge graphs. IEEE Proceedings 104(1), 11-33, 2015

[11] H. Paulheim. Knowledge graph refinement: A survey of approaches and evaluation methods. Semantic web, 8(3), pp.489-508, 2017

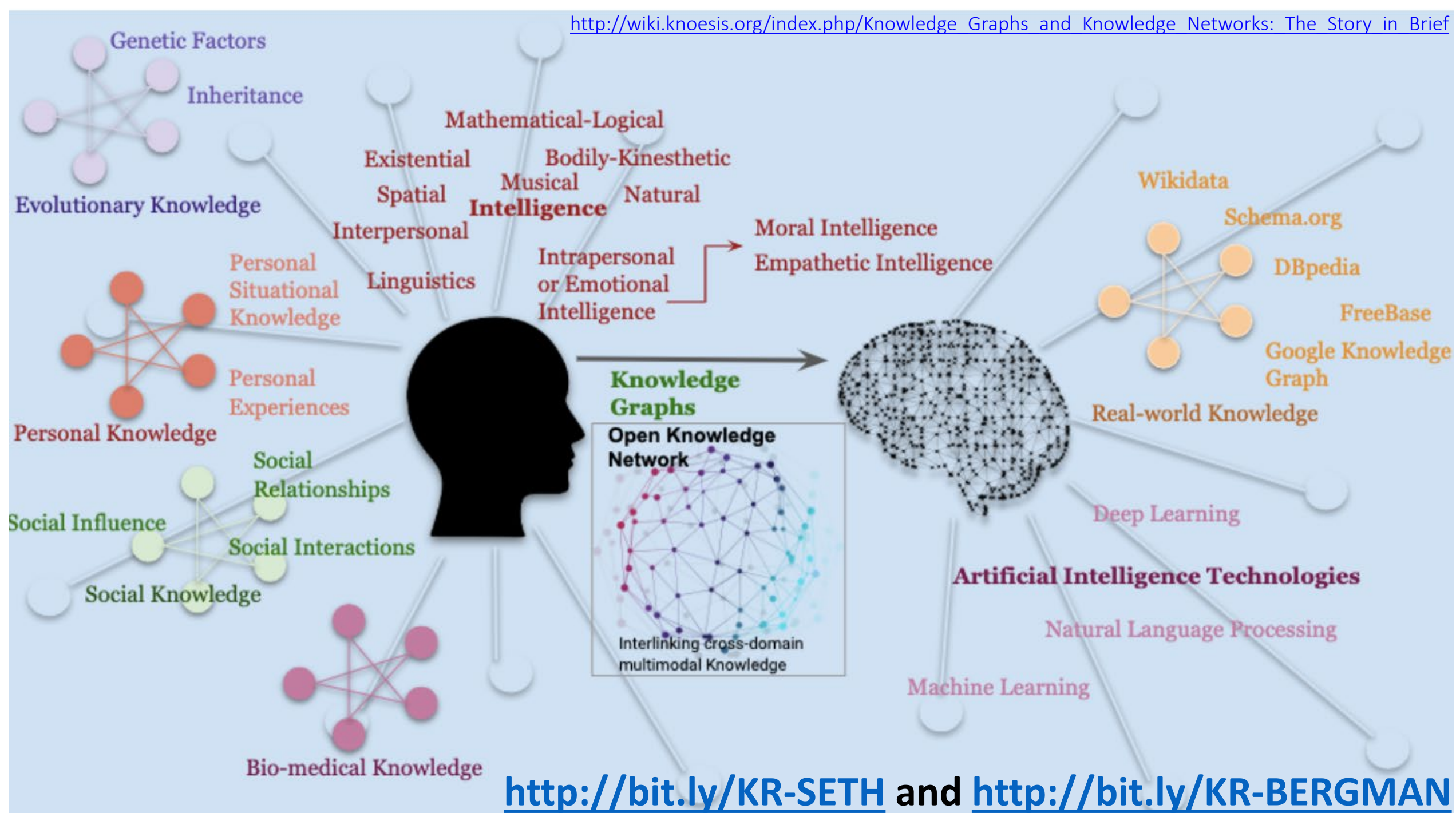
[12] S. Lalithsena, S. Perera, P. Kapanipathi, and A. Sheth. Domain-specific hierarchical subgraph extraction: A recommendation use case. In IEEE International Conference on Big Data (Big Data) (pp. 666-675). IEEE, 2017.

[13] R. Trivedi, H. Dai, Y. Wang, L. Song. "Know-evolve: Deep temporal reasoning for dynamic knowledge graphs. In Proceedings of the 34th International Conference on Machine Learning-Volume 70 (pp. 3462-3471). JMLR. org, 2017.

[14] OKN: Open Knowledge Network: Creating the Semantic Information Infrastructure for the Future (Summary of the Big Data IWG Workshop), October 4–5, 2017. November 2018. <https://www.nitr.gov/news/Open-Knowledge-Network-Workshop-Report-2018.aspx>

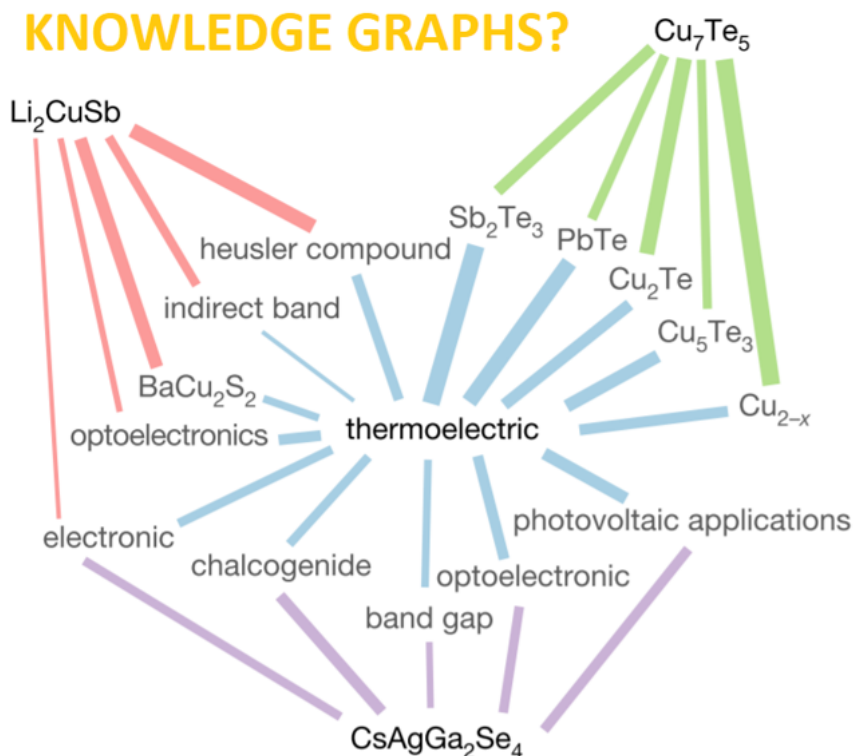
[15] P. Ekman. "Basic Emotions", in Dalgleish, T; Power, M (eds.), Handbook of Cognition and Emotion, Sussex, UK: John Wiley & Sons, 1999.

[16] Amit Sheth, Swati Padhee, Amelie Gyrard, 'Knowledge Graphs and Knowledge Networks - The Story in Brief,' IEEE Internet Computing, July-Aug 2019 http://wiki.knoesis.org/index.php/Knowledge_Graphs_and_Knowledge_Networks:_The_Story_in_Brief



Novel Paradigm for Machine-Assisted Graph Theoretic Approach to Mine Non-Obvious Relationships

The width of the edges between 'thermoelectric' and the context words (blue) is proportional to the cosine similarity between the word embeddings of the nodes, whereas the width of the edges between the materials and the context words (red, green and purple) is proportional to the cosine similarity between the word embeddings of context words and the output embedding of the material. The context words are top context words according to the sum of the edge weights between the material and the word 'thermoelectric'.



<https://doi.org/10.1038/s41586-019-1335-8>

Unsupervised word embeddings capture latent knowledge from materials science literature

Vahe Tshitoyan^{1,3*}, John Dagdelen^{1,2}, Leigh Weston¹, Alexander Dunn^{1,2}, Ziqin Rong¹, Olga Kononova², Kristin A. Persson^{1,2}, Gerbrand Ceder^{1,2*} & Anubhav Jain^{1*}

<https://www.nature.com/articles/s41586-019-1335-8>

Novel Paradigm for Machine-Assisted Graph Theoretic Approach to Mine Non-Obvious Relationships

KNOWLEDGE GRAPHS?

Scientific progress relies on the confluence of efficient assimilation of existing knowledge in order to minimize re-invention. The methodology in this paper may create a tool to plumb the depths of the unknown unknowns, where catalysts for scientific breakthroughs often reside. The authors are incisive to point out that this approach may be "generalized to other language models, such that the probability of an entity (a material or molecule) co-occurring with words, that represent a target application or property, can be treated as an indicator of performance."

Entity-relationship mode remains the "bread and butter" of context-awareness while RDF is a more general model of entities (nodes) and relationships. Thus, the paper strengthens the notion that knowledge graphs may aid in unleashing new ideas. Context-aware embeddings such as NLP BERT or ELMo may improve predictions. This document (PEAS) and the accompanying ideas (SIGNALS) are in quest of these tools. The paper indicates the potential for new research at the nexus of natural language processing, linguistics, semantics, and science, to advance knowledge discovery.

Artificial Reasoning Outcomes → Reasonable Expectations

It is easy to illustrate, but quite difficult for systems to claim real 'knowledge' discovery.

Can graph networks catalyze data to reveal information?

But, beware of snake oil sales and stupidity

**BEWARE
OF
STUPIDITY**

<https://emoshape.com/emoshape-enhances-its-cutting-edge-emotion-chip-with-the-addition-of-cloud-service/>

EMOSHAPE
EMOTIONS NEXT FRONTIER

[Emotion Synthesis](#)

[Products](#)

[Order](#)

[News](#)

Emoshape Enhances Its Cutting Edge Emotion Chip with the Addition of Cloud Service

On: [Jun 03](#) / Author: [Patrick Levy-Rosenthal](#) / Categories: [Uncategorized](#) /

**EPU III
CLOUD
TECHNOLOGY
2019**

256 EPU's instances per rack

unity

**UNREAL
ENGINE**

EMOSHAPE
EMOTIONS NEXT FRONTIER

The Lowest Common Denominator

We are immersed in **data** swamps.
Actions depend on **information**.
Informed by **knowledge**.
Learn from **experience**.

*SENSEE → Choose sensors and then
harvest DATA from specific SENSORS*

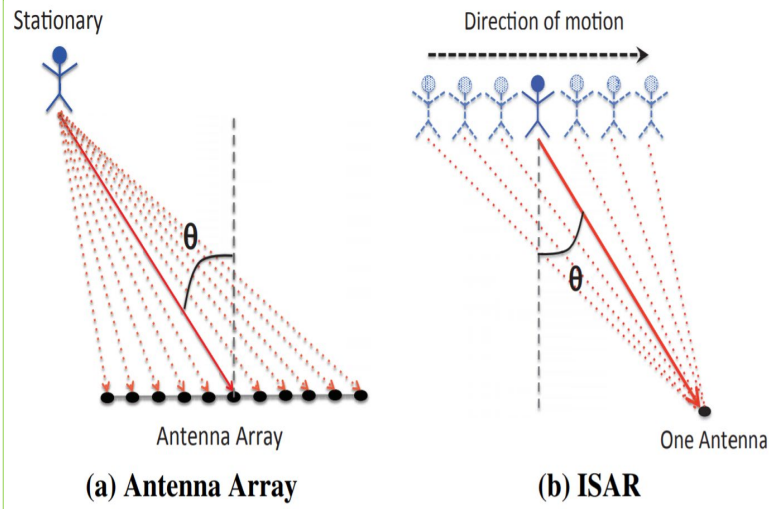
SENSE



SENSE

Don't bind.
Reflect

C
O
N
V
E
R
G
E



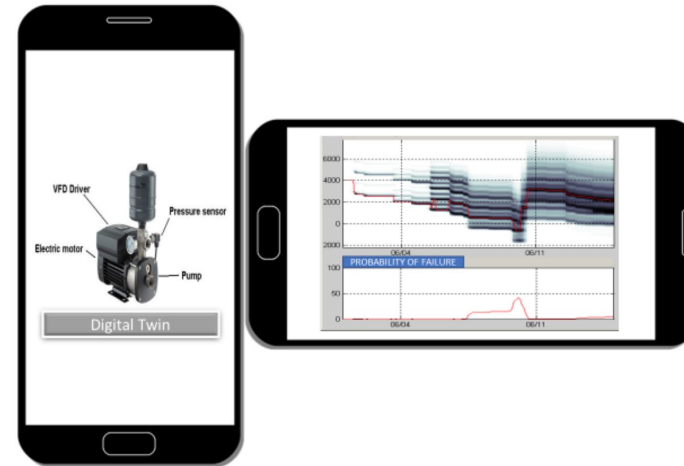
SENSE RF REFLECTION



TRANSMIT



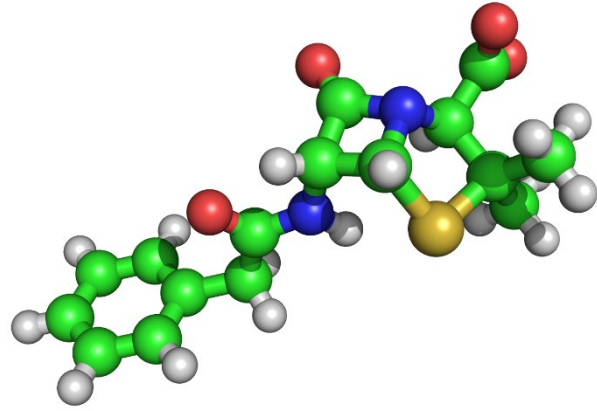
ANALYZE



DECISION SUPPORT

S
Y
N
E
R
G
I
Z
E

C
O
N
V
E
R
G
E



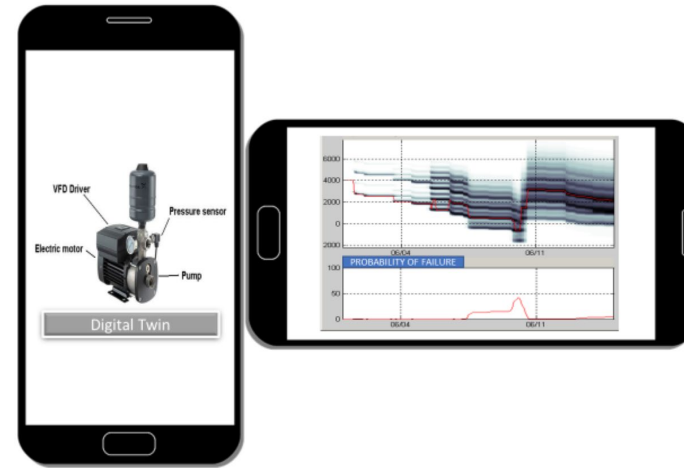
SENSE
BINDING OF ANALYTE



ANALYZE



TRANSMIT



DECISION SUPPORT

S
Y
N
E
R
G
I
Z
E

How does a sensor work? Sensors that bind analytes.

← → ↻ <https://onlinelibrary-wiley-com.libproxy.mit.edu/doi/pdf/10.1002/anie.199423751>

The Key–Lock Theory and the Induced Fit Theory

1 / 4

REVIEWS

There are sensors that may not bind analytes but are activated by reflected radio waves (WiFi, radar, sonar)

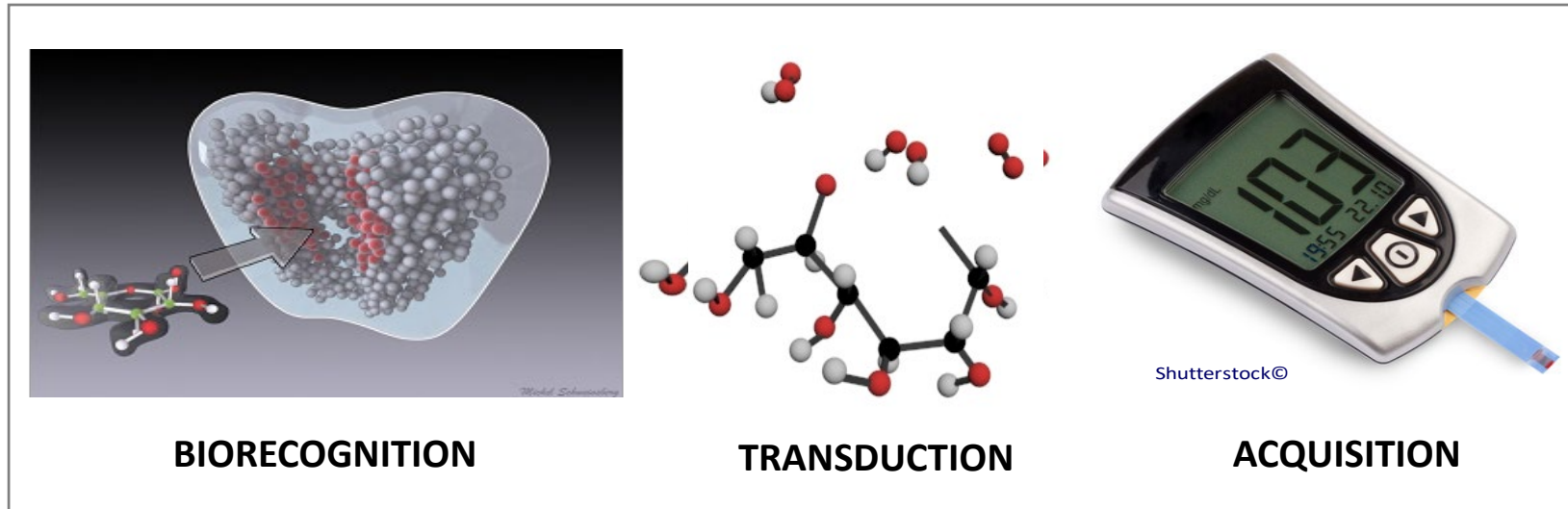
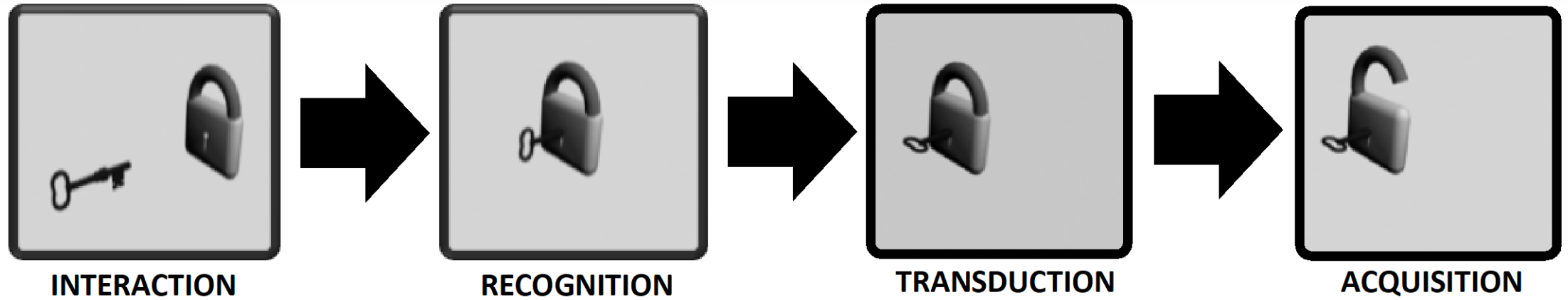
The Key–Lock Theory and the Induced Fit Theory

Daniel E. Koshland, Jr.

It is a great pleasure for me to contribute to this symposium honoring the great scientist Emil Fischer. My graduate thesis required me to synthesize [1-¹⁴C]glucose, which introduced me to the famous Fischer–Kiliani synthesis of glucose and mannose from arabinose and HCN.^[1] I was also particularly intrigued with his classic key–lock (or template) theory of enzyme specificity,^[2, 3] which like all great theories seemed so obvious once one understood it.

<https://onlinelibrary.wiley.com/doi/abs/10.1002/anie.199423751>

How does a sensor work? The classical glucometer.



Step 1) Biorecognition

Step 2) Binding and transduction

Step 3) Acquisition and data analytics

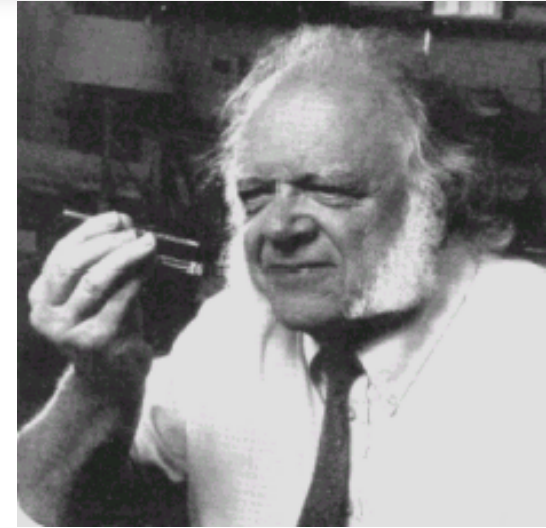
Unchanged: 1962 Classical Chemistry of Clark and Lyons

<https://nyaspubs.onlinelibrary.wiley.com/doi/pdf/10.1111/j.1749-6632.1962.tb13623.x>

ELECTRODE SYSTEMS FOR CONTINUOUS MONITORING IN CARDIOVASCULAR SURGERY

Leland C. Clark, Jr., and Champ Lyons
Medical College of Alabama, Birmingham, Ala.

Instruments capable of continuously indicating the chemical composition of blood have proved to be useful in controlling heart-lung machines, in regulating operative and postoperative management of patients, and in teaching and research. At first, such instruments were used with sensors mounted directly in the extracorporeal blood circuit that is used for perfusion of open-heart surgery patients.¹ Later, continuous monitoring of both machine and patients was conducted by means of continuous withdrawal of blood pumped into external cuvettes equipped with appropriate sensors.



Leland C. Clark, Jr. (1959)

Unchanged: 1962 Classical Chemistry of Clark and Lyons

<https://nyaspubs.onlinelibrary.wiley.com/doi/pdf/10.1111/j.1749-6632.1962.tb13623.x>

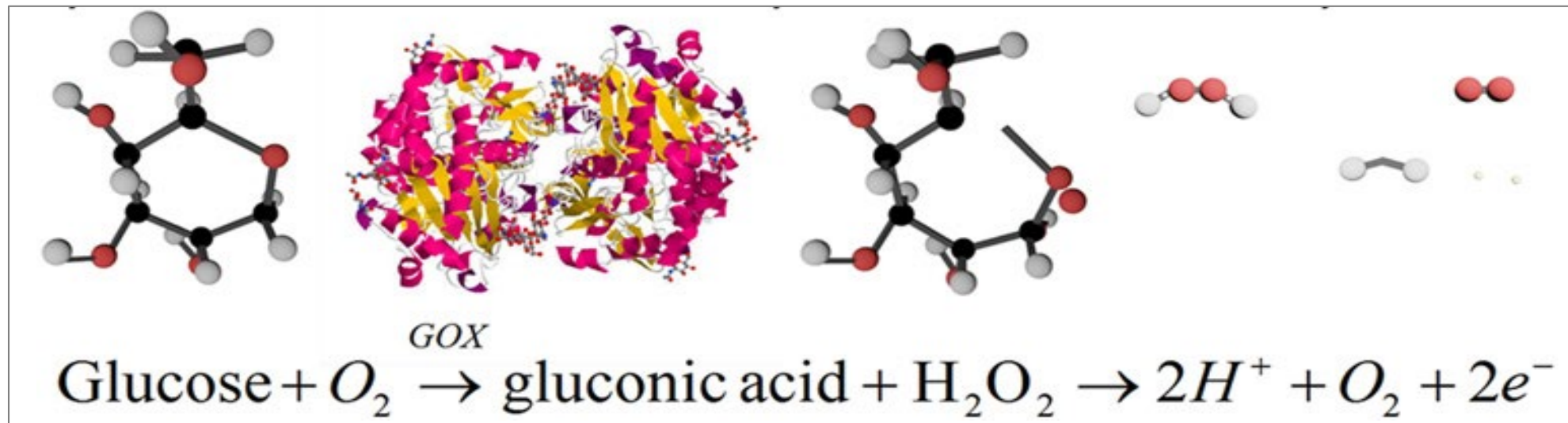
ELECTRODE SYSTEMS FOR CONTINUOUS MONITORING IN CARDIOVASCULAR SURGERY

Leland C. Clark, Jr., and Champ Lyons
Medical College of Alabama, Birmingham, Ala.

Instruments capable of continuously indicating the chemical composition of blood have proved to be useful in controlling heart-lung machines, in regulating operative and postoperative management of patients, and in teaching and research. At first, such instruments were used with sensors mounted directly in the extracorporeal blood circuit that is used for perfusion of open-heart surgery patients.¹ Later, continuous monitoring of both machine and patients was conducted by means of continuous withdrawal of blood pumped into external cuvettes equipped with appropriate sensors.



Leland C. Clark, Jr. (1959)



Glucometer – The Evolution of its Form and Function



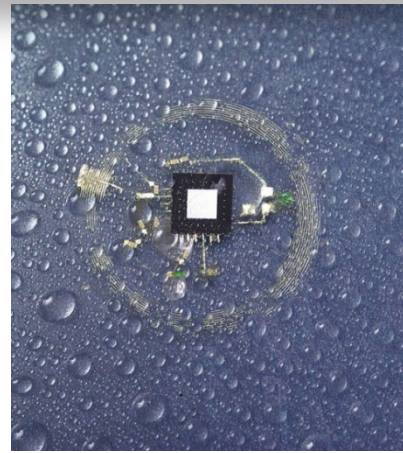
Paper based
(Whitesides)



Noninvasive
glycemic
monitoring
(Wang)



WISP: Wearable
Interactive
Stamp Platform
(MC10)



Resorbable
(Rogers)



Contact lens
(Google, Inc.)



Stretchable fabric
(Bhargava-UF)

Function	Form (elements and structure)
What a system does/could do	What a system is/could be
Creates behavior	Is aggregated and decomposed
Is a source of benefit/value	Is a source of costs
Requires form	Enables function

Source: E. Crawley, MIT Course Material

Glucometer – The Evolution of its Form and Function

https://onlinelibrary.wiley.com/doi/abs/10.1002/ami.200603817



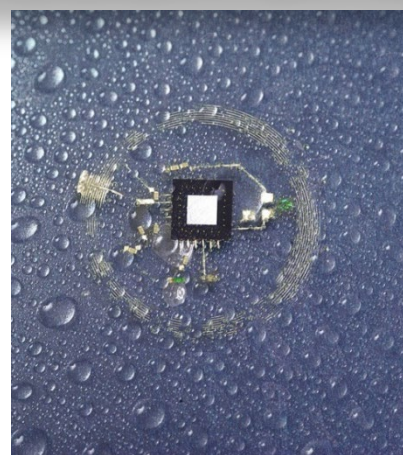
Paper based
(Whitesides)



Noninvasive
glycemic
monitoring
(Wang)



WISP: Wearable
Interactive
Stamp Platform
(MC10)



Resorbable
(Rogers)

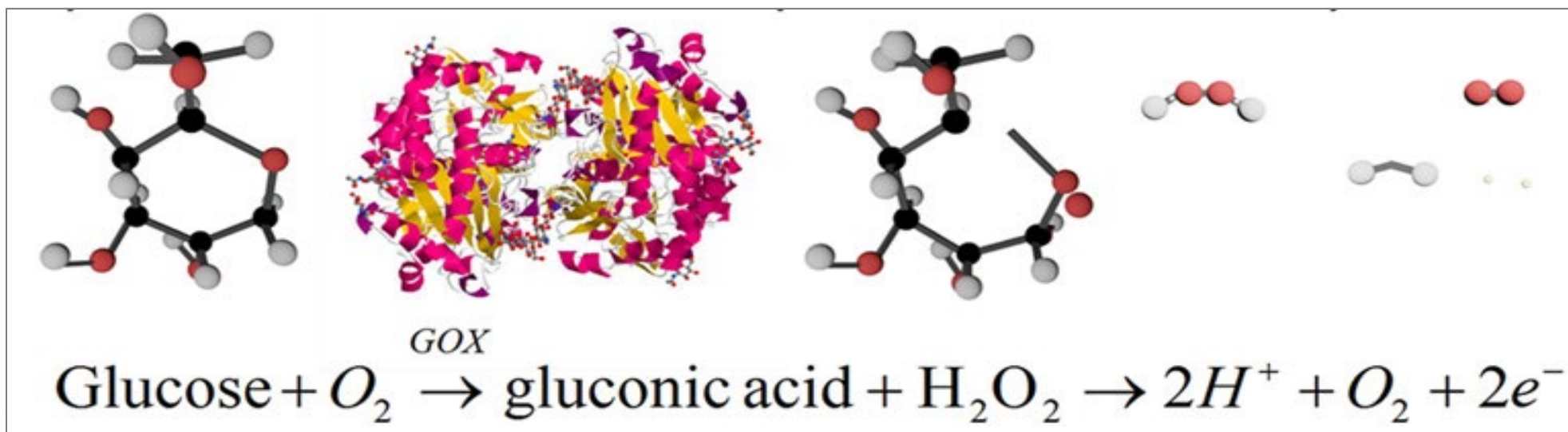


Contact lens
(Google, Inc.)



Stretchable fabric
(Bhargava-UF)

<https://www.cientperiodique.com/article/CPQME-2-1-40.pdf>

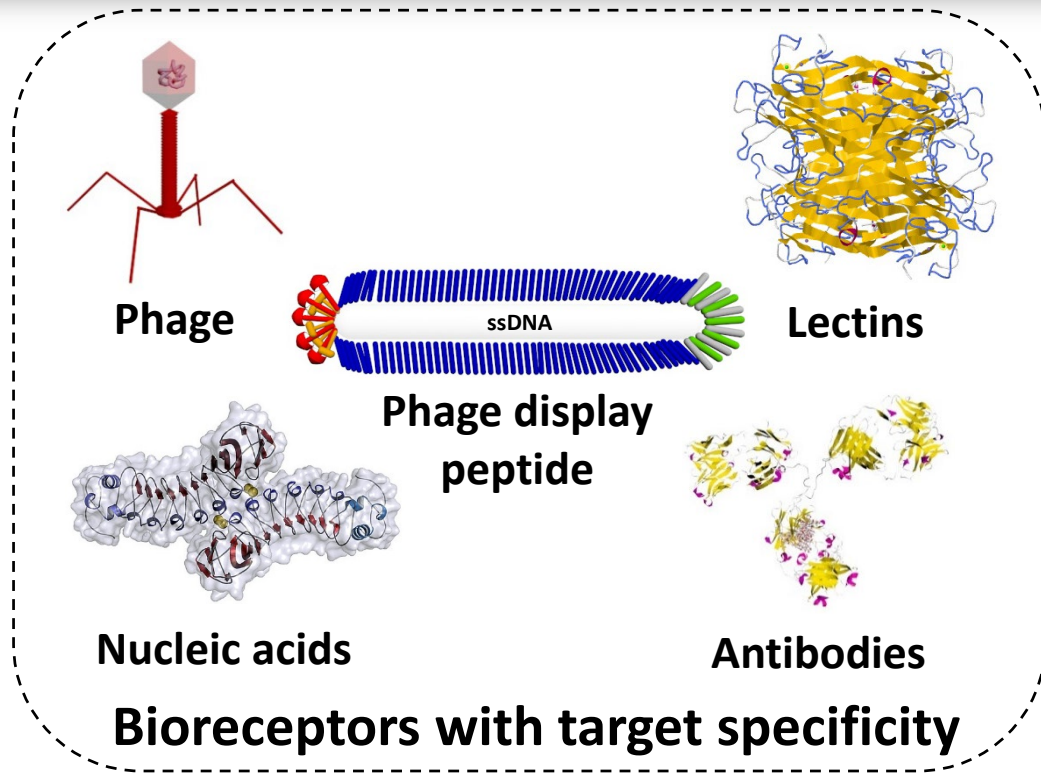


The core chemistry
developed by Clark
and Lyons has not
changed since 1962.

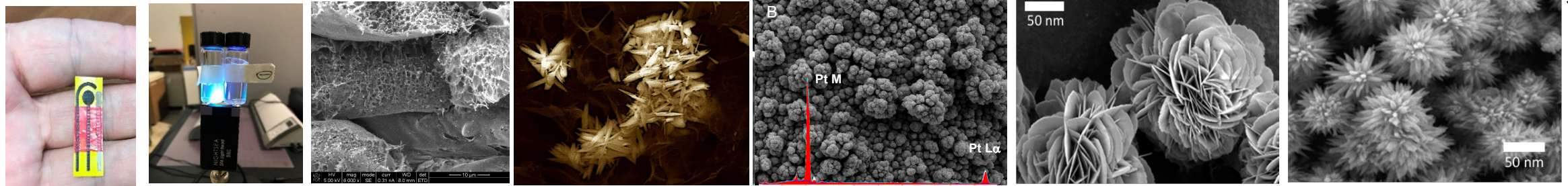
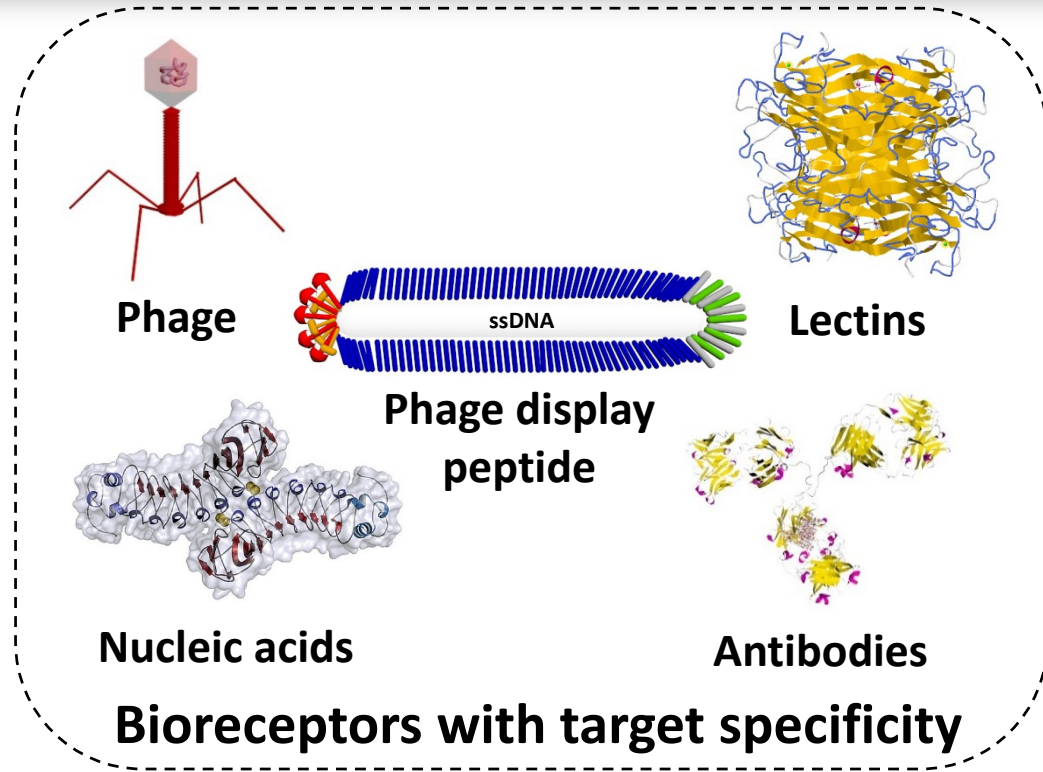
Evolution of Sensors ♦ Nano-bio Sensors

<https://emclamor.wixsite.com/mclamorelab>

Evolution of Sensors ♦ Nano-bio Sensors

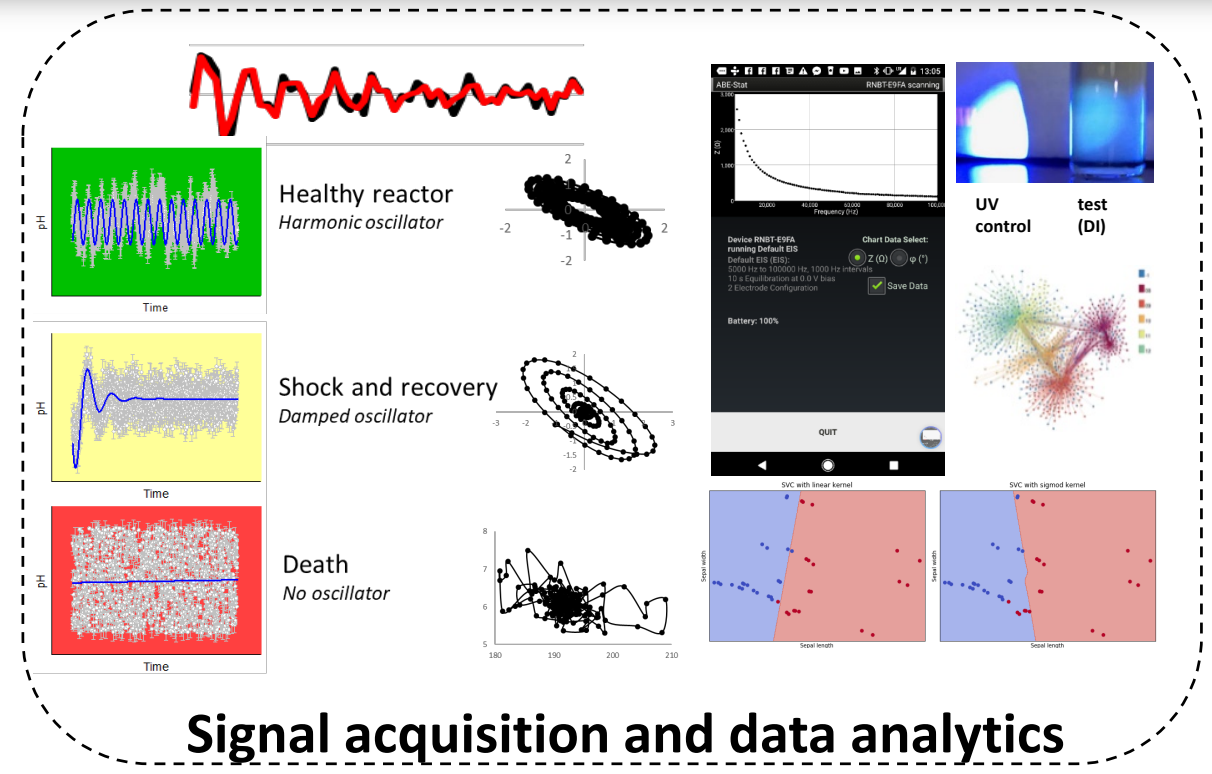
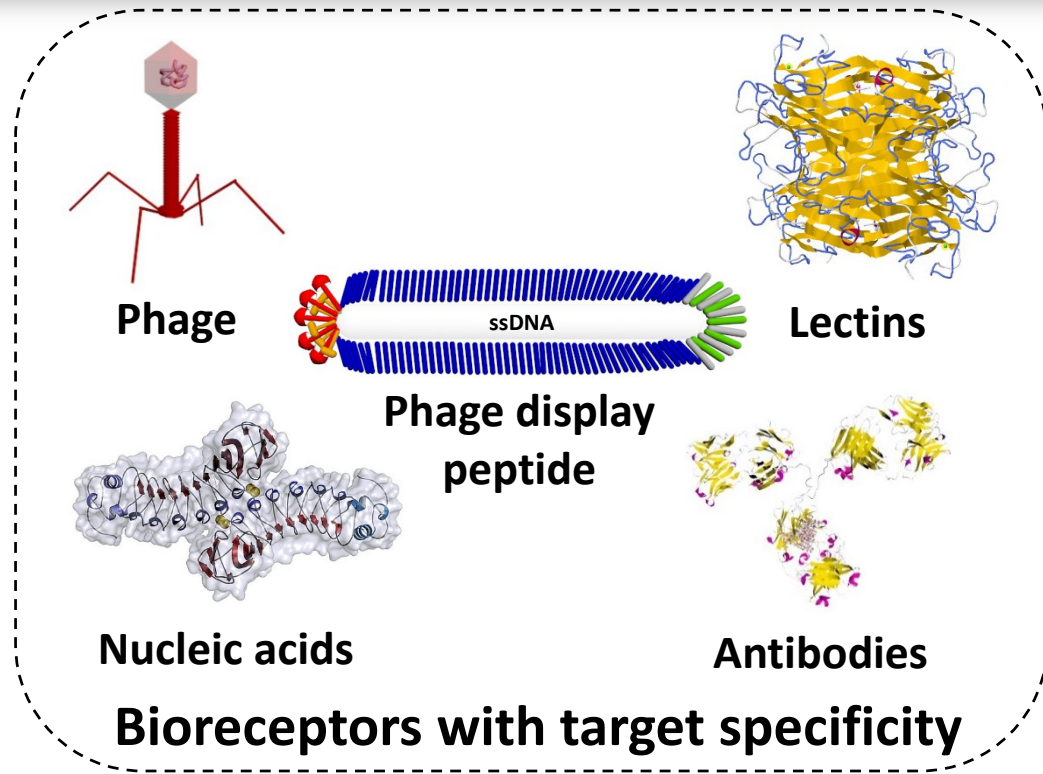


Evolution of Sensors ♦ Nano-bio Sensors

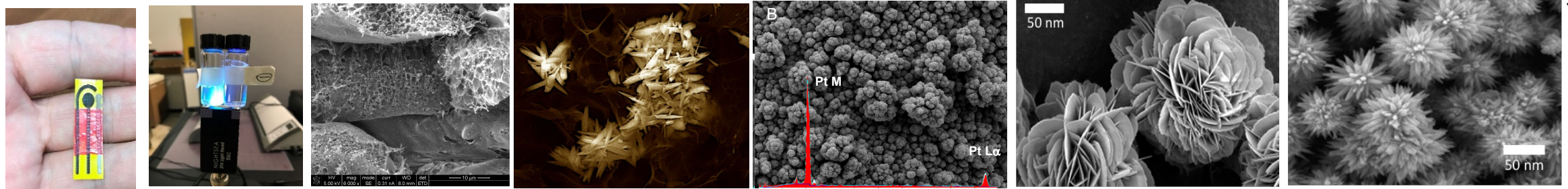


Nanomaterials improve signal transduction

Evolution of Sensors ♦ Nano-bio Sensors

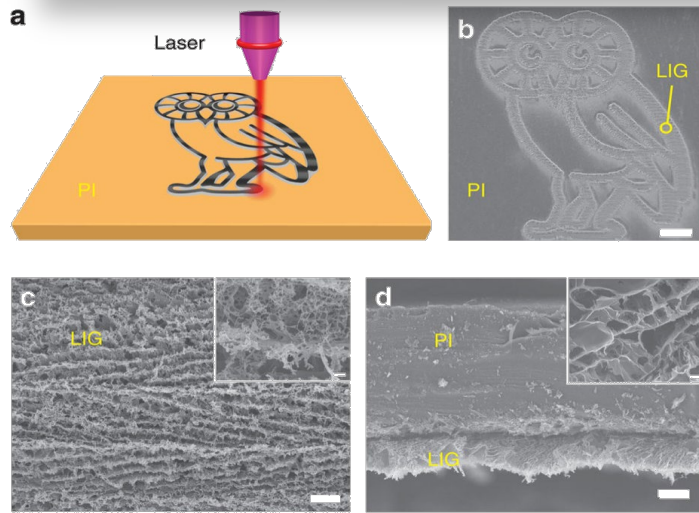


<https://emclamor.wixsite.com/mclamorelab>



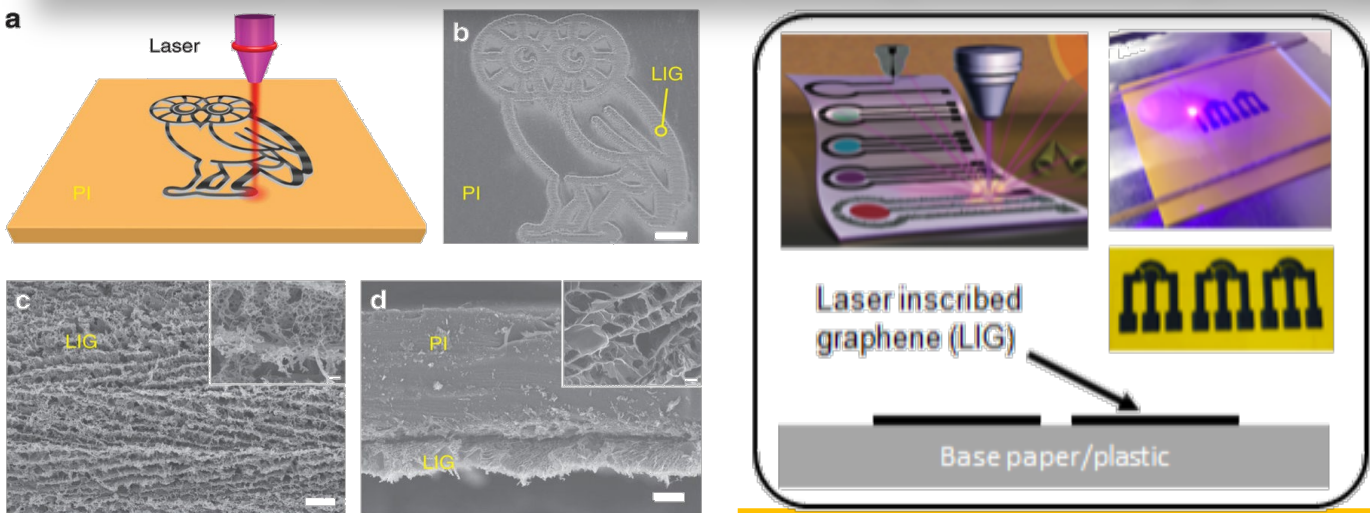
Nanomaterials improve signal transduction

Laser Inscribed Graphene (LIG)



Lin et. al. (2014) develops LIG for supercapacitors

Laser Inscribed Graphene (LIG)

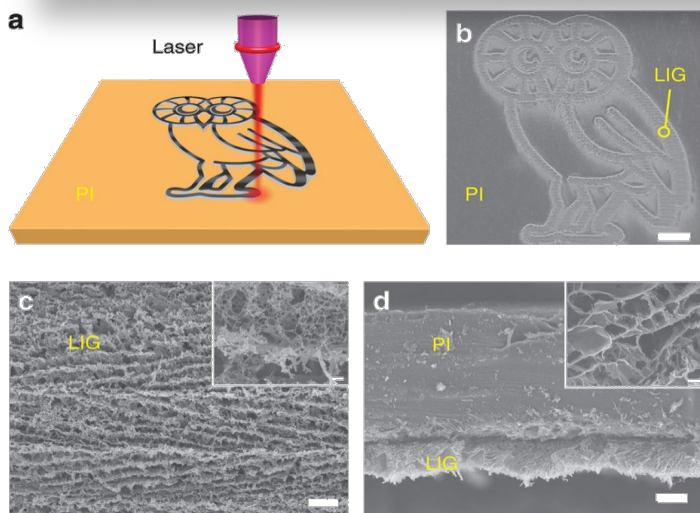


Lin et. al. (2014) develops LIG for supercapacitors

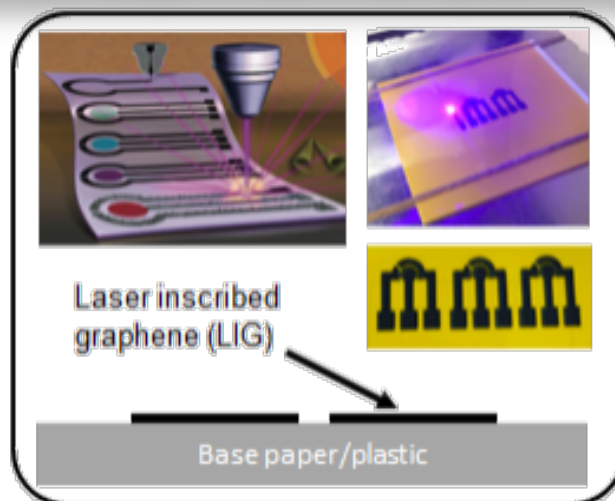
- ### LIG for Sensing
- Sugars, organics
 - Tehrani et. al. (2016);
 - Nayak et. al. (2016);
 - Vanegas et al (2018)
 - Ions
 - Garland et al (2019)

Evolution of Sensors ♦ 3D Printed Nano-bio Sensors

Laser Inscribed Graphene (LIG)



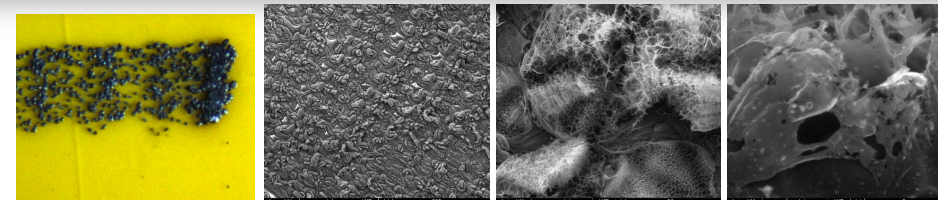
Lin et. al. (2014) develops LIG for supercapacitors



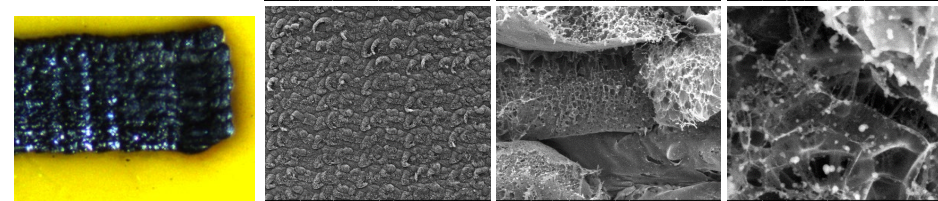
LIG for Sensing

- Sugars, organics
 - Tehrani et. al. (2016);
 - Nayak et. al. (2016);
 - Vanegas et al (2018)
- Ions
 - Garland et al (2019)

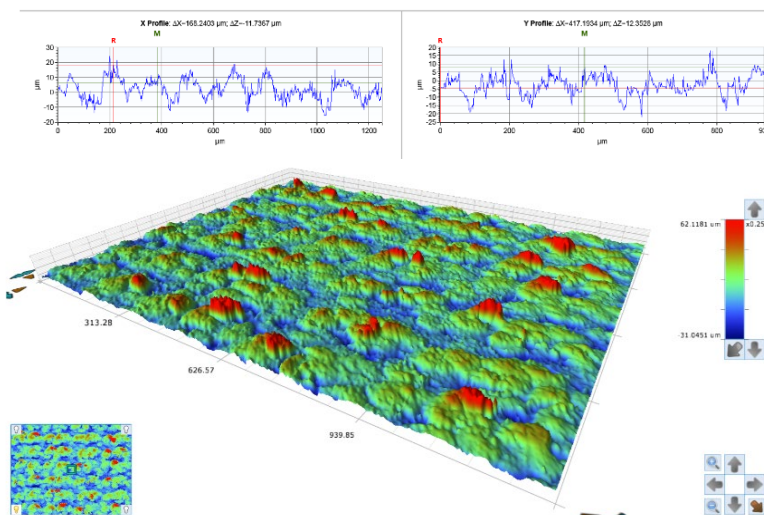
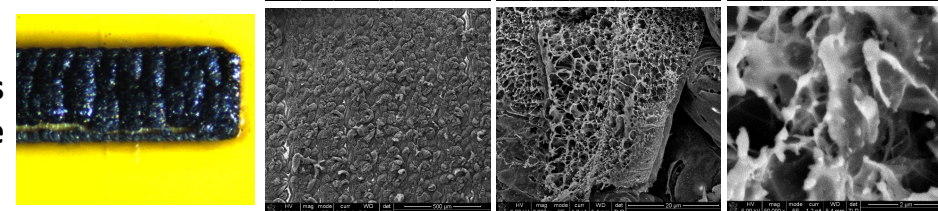
10 ms pulse



30 ms pulse



50 ms pulse



Problem

Platform

Coating

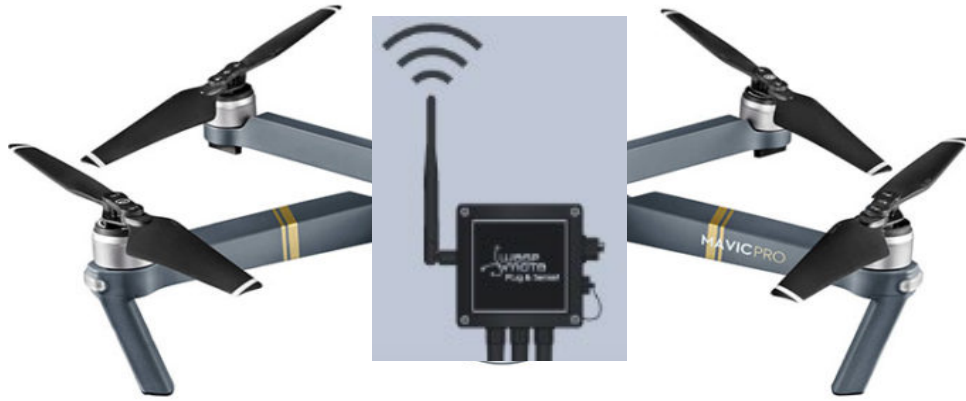
Proof of concept

Field validation

Data analytics

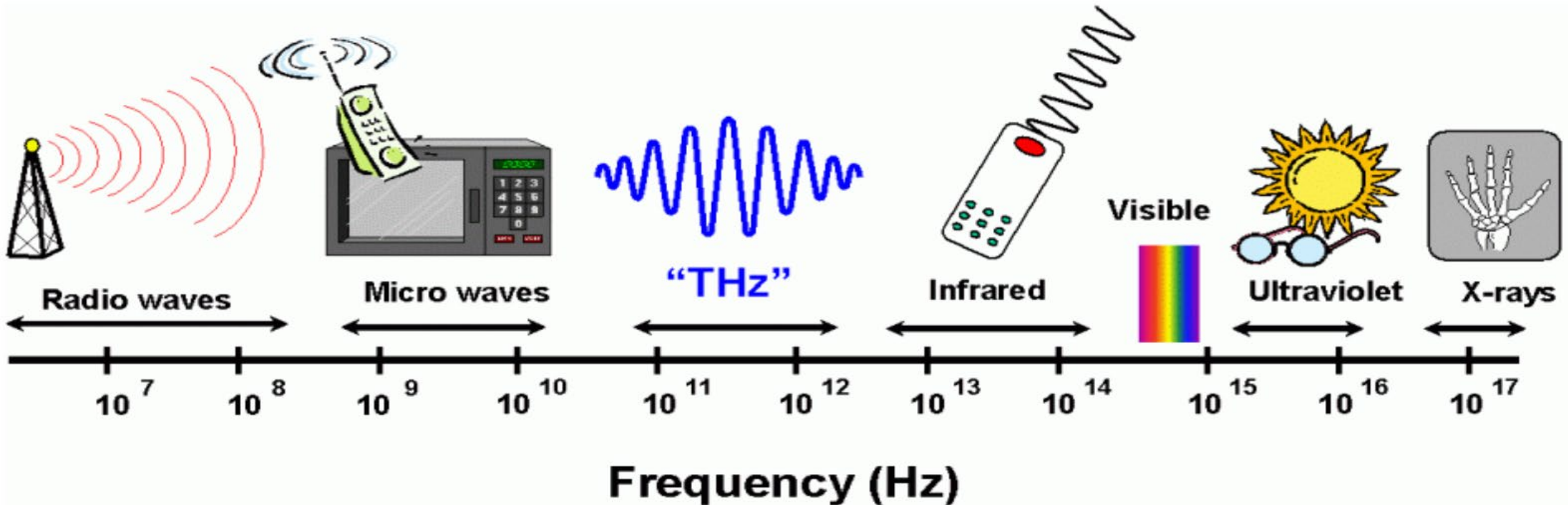
Decision support

Drones carrying Mobile Sensors acquire Reflected RF Signals

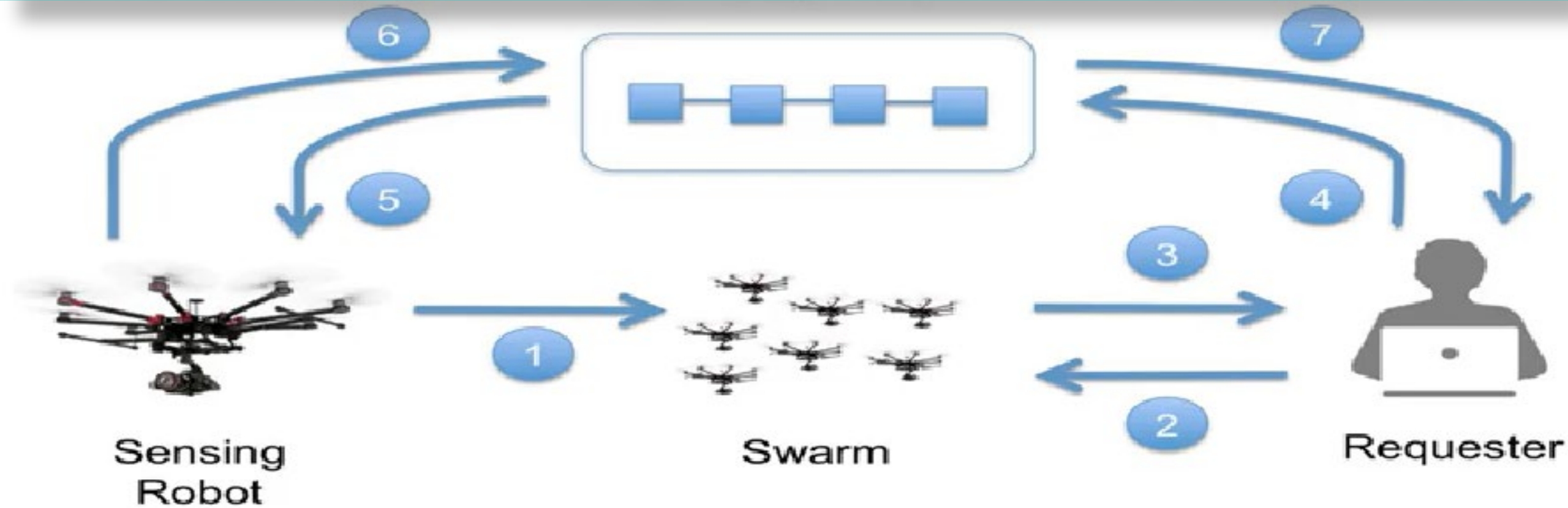


Terahertz (THz) spectrum, occupying frequency range between 0.3 and 3 THz, has potential for transformative applications in communication, sensing, spectroscopy, and imaging due to its desirable properties such as non-ionizing photon energy, penetration capability through optically opaque materials, unique spectral signatures for macro-molecules and chemicals.

<https://www.nature.com/articles/s41467-019-09868-6>



Rent-a-Robot drone-swarm "plug & play" remote sensors to collect desired data



- 1** Robot subscribes
- 2** User requests info
- 3** Robot's address is sent

- 4** Payment is sent
- 5** Payment is received

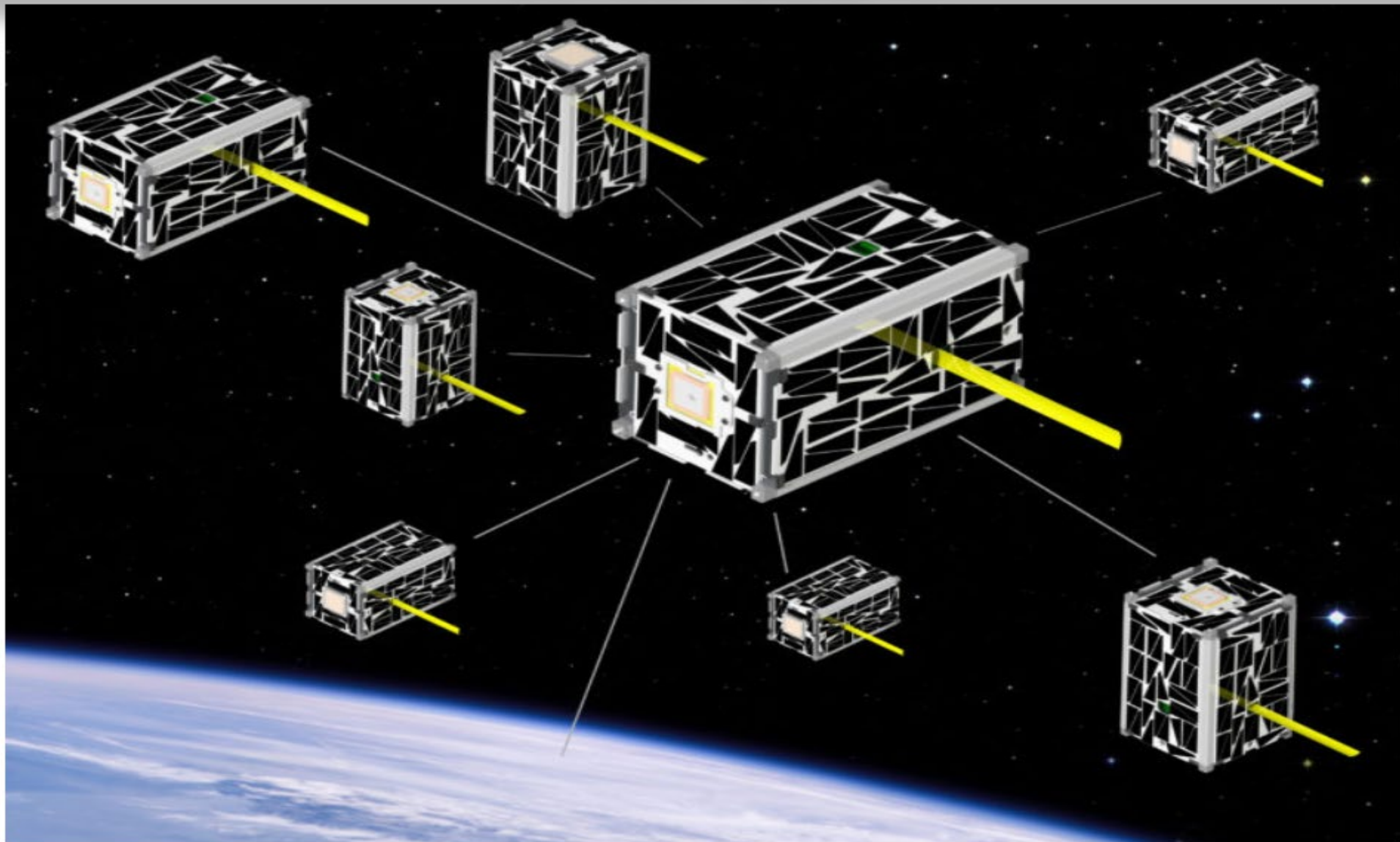
- 6** Info is sent
- 7** Info is received

Mobile Sensor Swarms deployed on Drones-on-Demand



Swarm Intelligence, Swarm Robotics, Mobile Robotics

Sensor Swarm



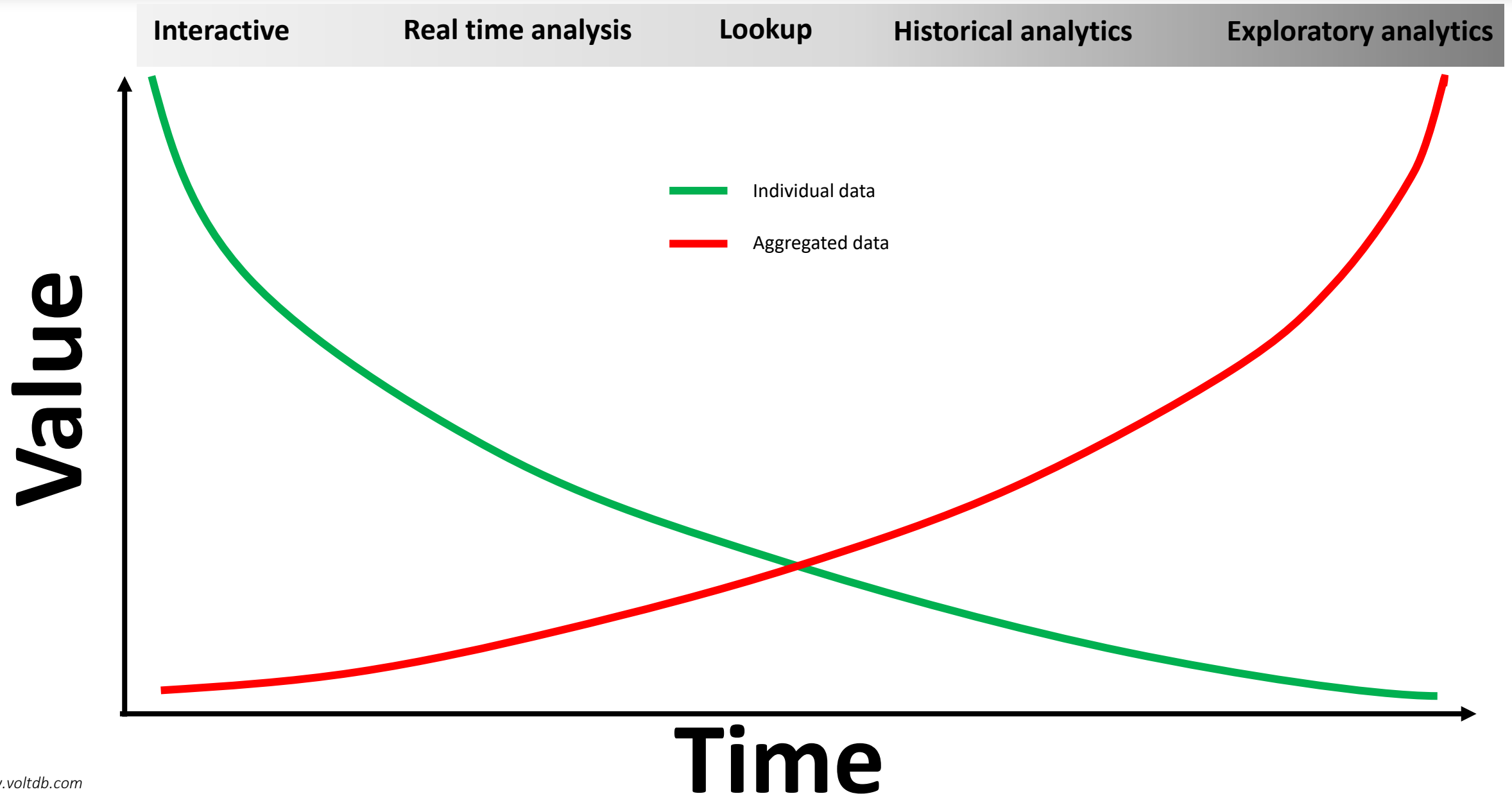
NASA and Lockheed Martin have been studying how small satellites could be knit together into a distributed swarm. (NASA Illustration)

Crowd-sourced radiation sensor data after the explosion Fukushima Daiichi Nuclear Power Plant in Ōkuma (2013)

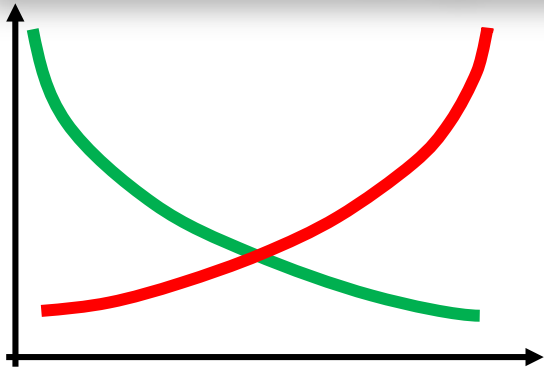


DATA from SENSORS

Is data perishable?

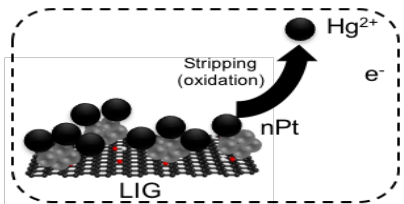


Varying Time-Sensitivity of Data from Sensors

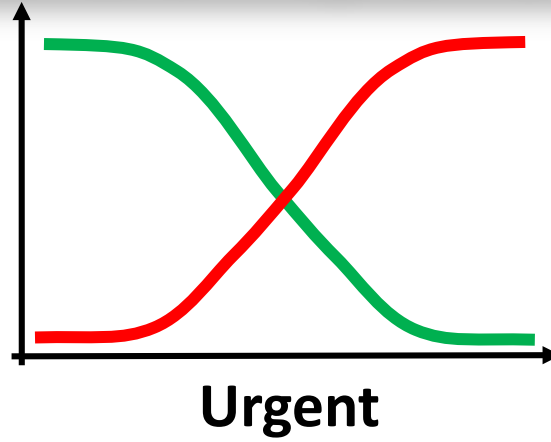
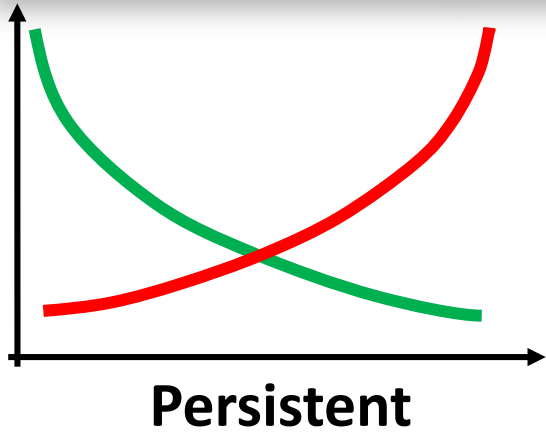


Persistent

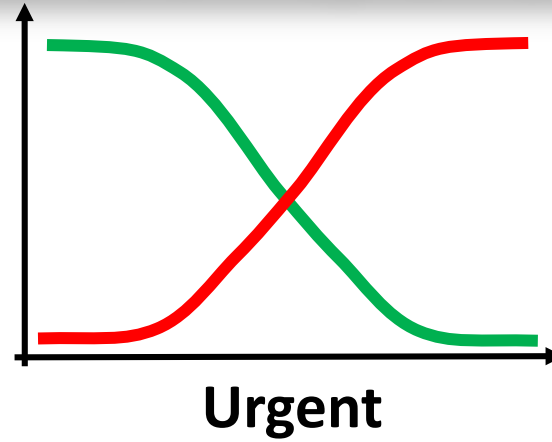
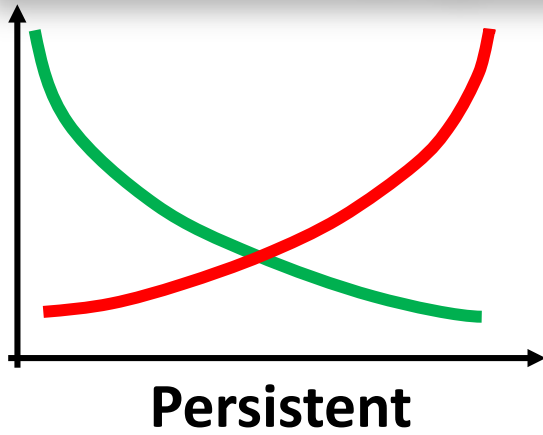
- Soil health
 - Erosion, degradation
- Agrochemical runoff
 - Nutrients, agrochemicals
- Land use change
 - Deforestation, mining



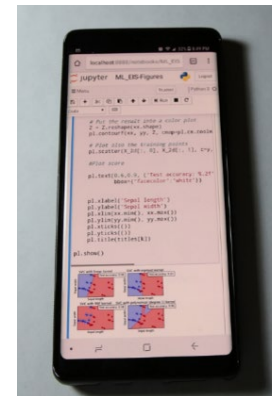
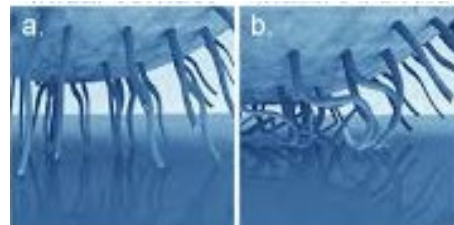
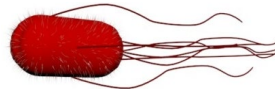
Varying Time-Sensitivity of Data from Sensors



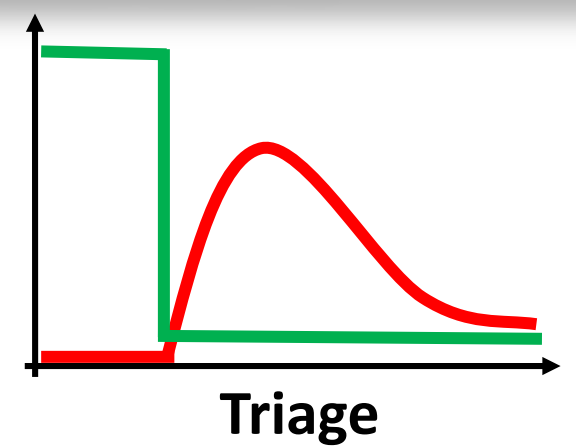
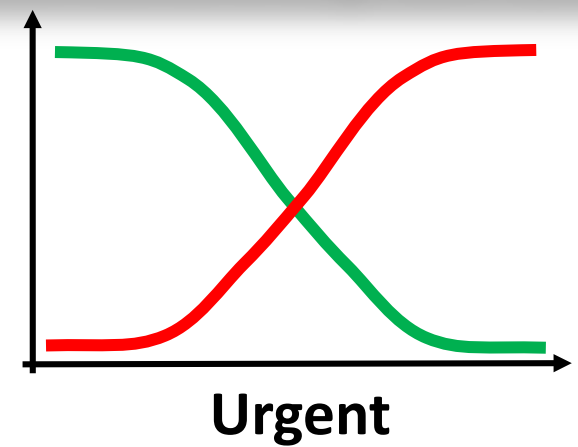
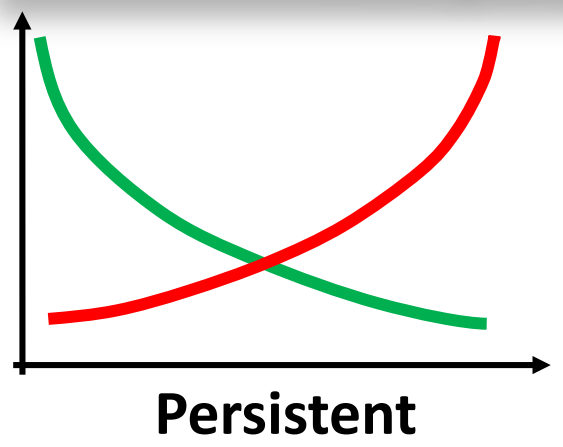
Varying Time-Sensitivity of Data from Sensors



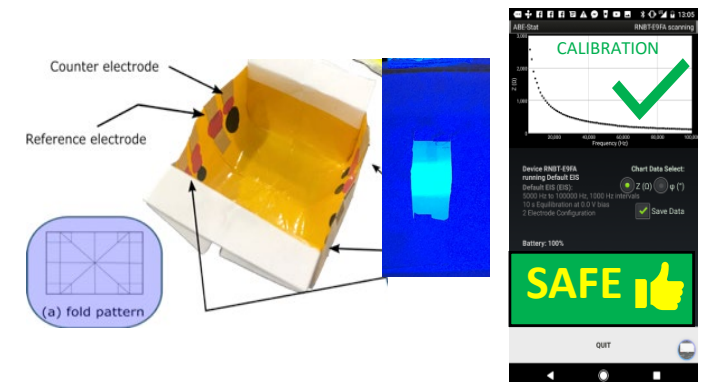
- Water scarcity
 - Quantity, quality
- Climate change
- Solid waste/wastewater
 - Pathogens, heavy metals



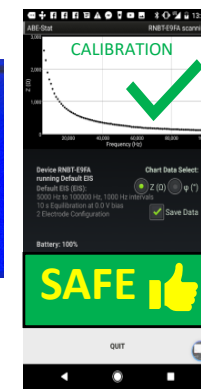
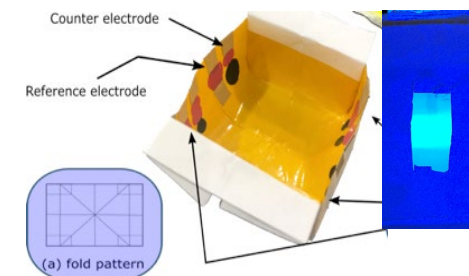
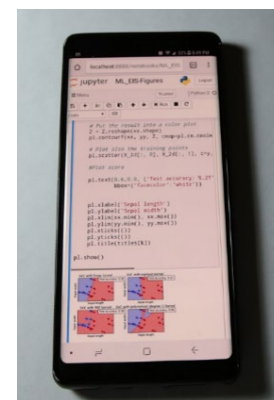
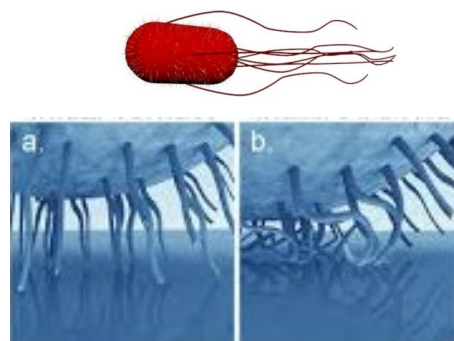
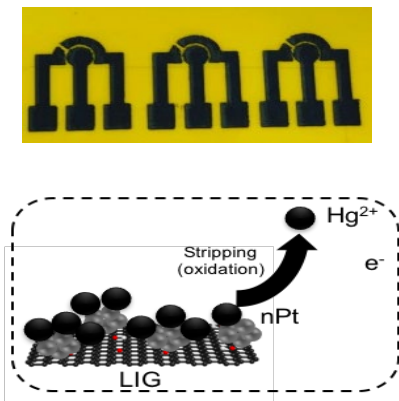
Varying Time-Sensitivity of Data from Sensors



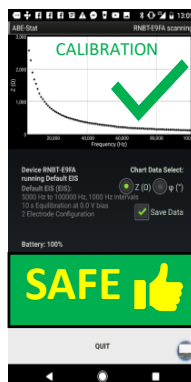
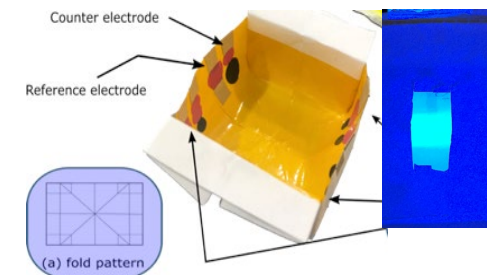
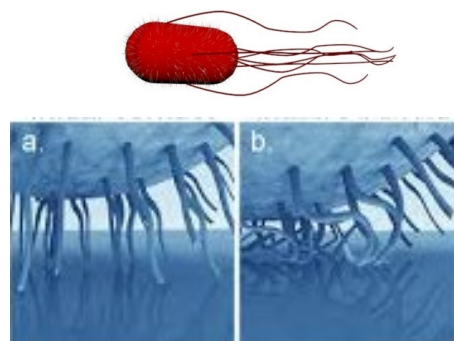
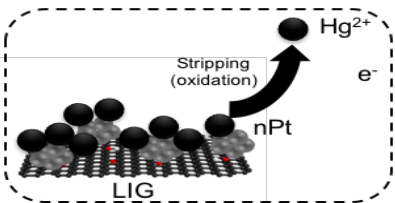
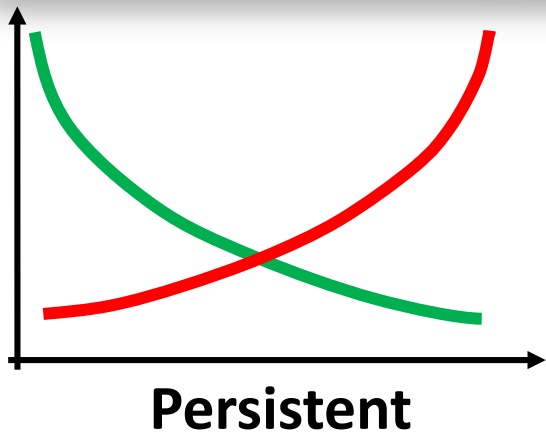
- Natural disaster
- Attack on infrastructure



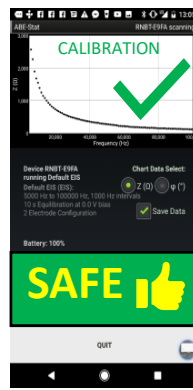
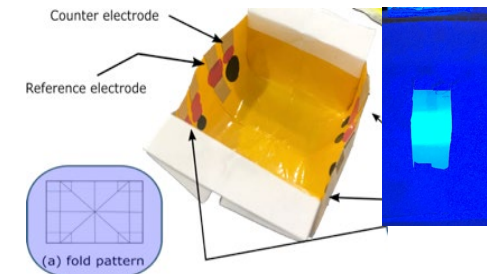
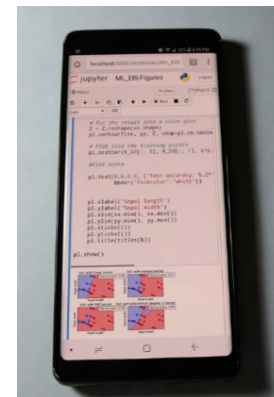
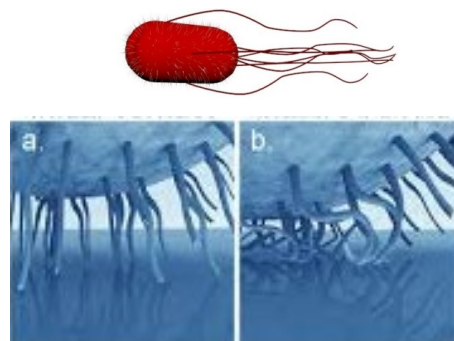
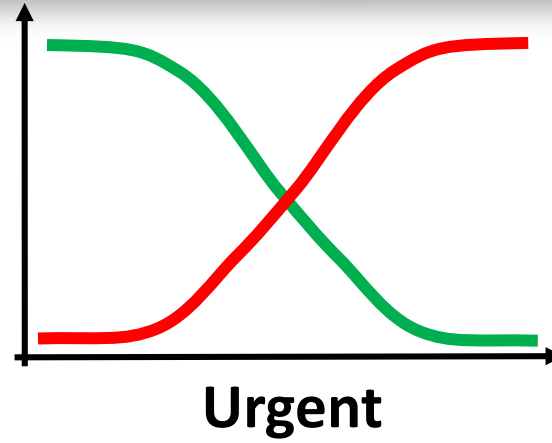
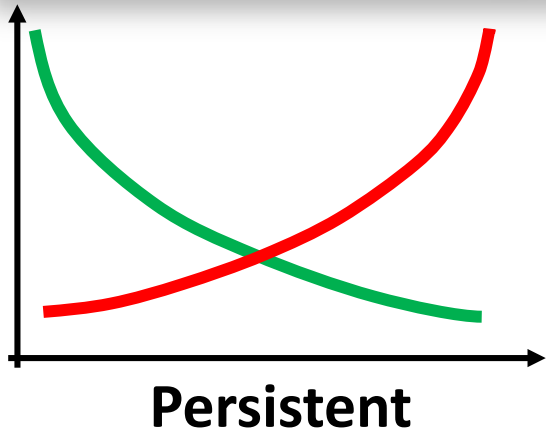
Data from the Perspective of Sensors



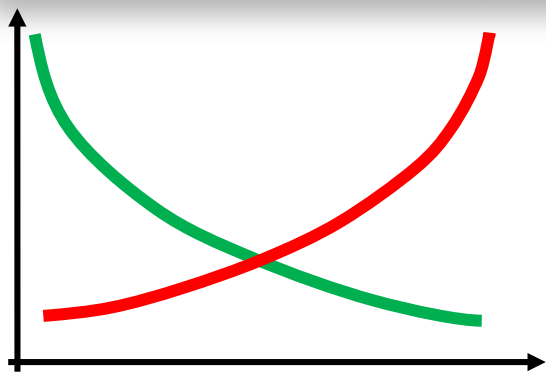
Data from the Perspective of Sensors



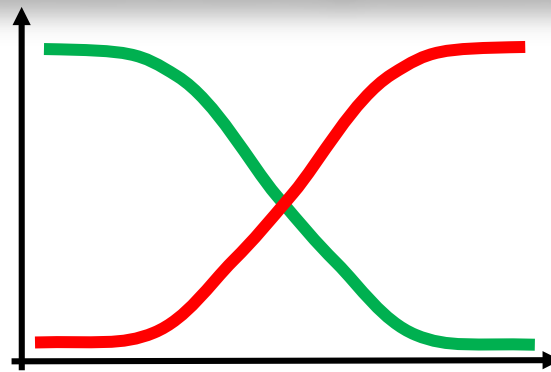
Data from the Perspective of Sensors



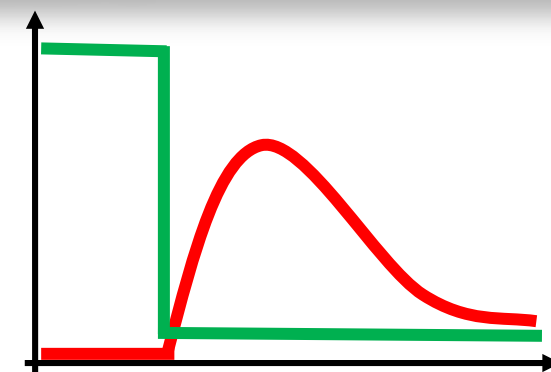
Data from the Perspective of Sensors



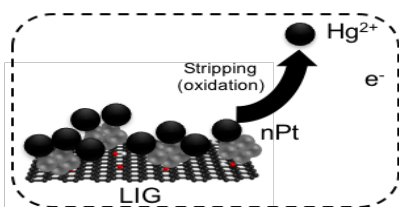
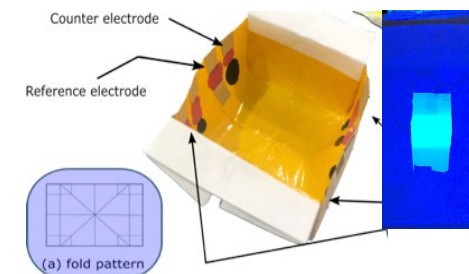
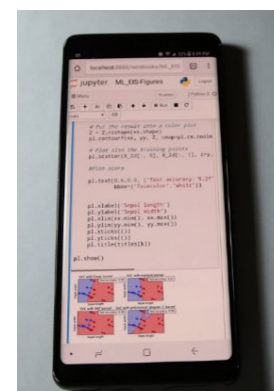
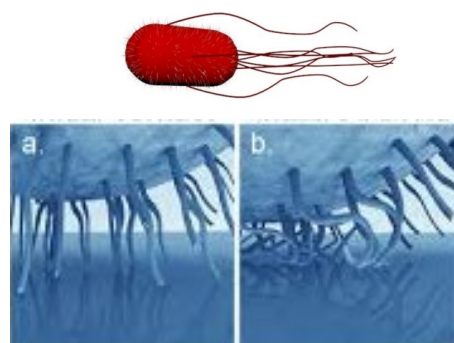
Persistent



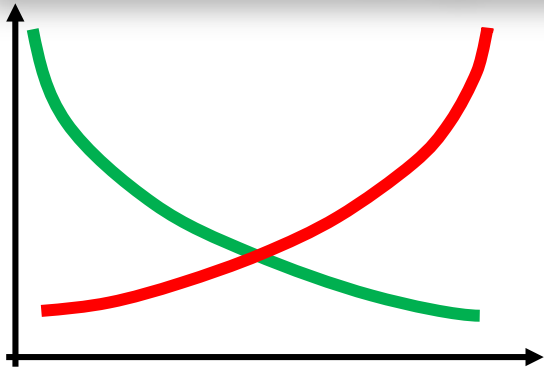
Urgent



Triage

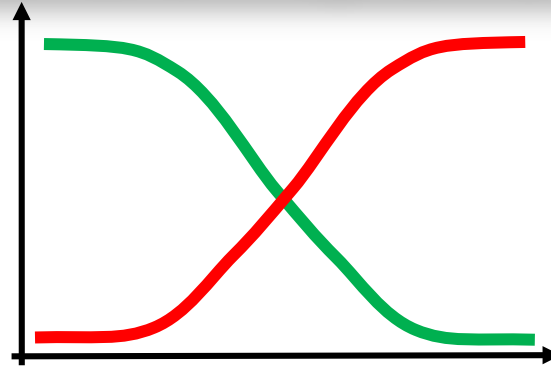


Varying Time-Sensitivity of Data from Sensors



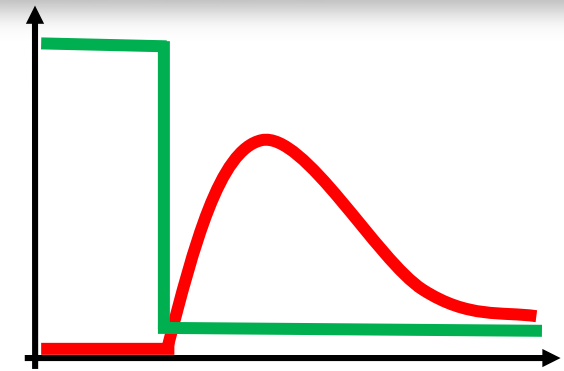
Persistent

- Soil health
 - Erosion, degradation
- Agrochemical runoff
 - Nutrients, agrochemicals
- Land use change
 - Deforestation, mining



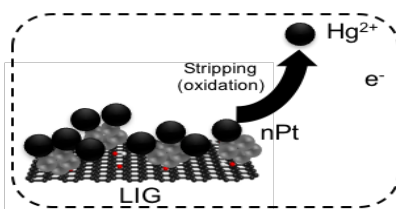
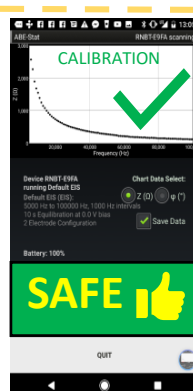
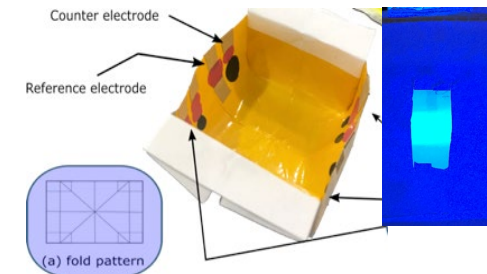
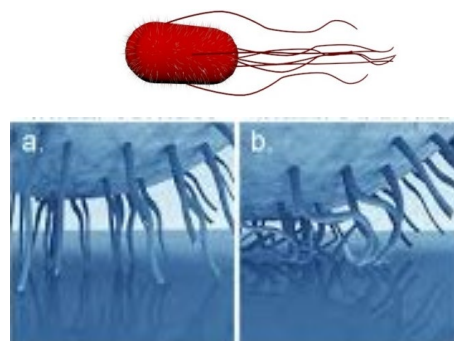
Urgent

- Water scarcity
 - Quantity, quality
- Climate change
- Solid waste/wastewater
 - Pathogens, heavy metals

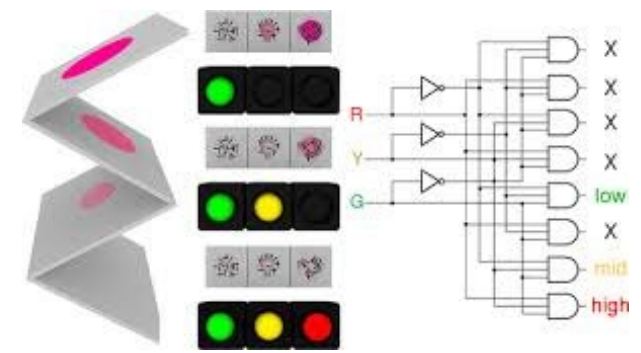
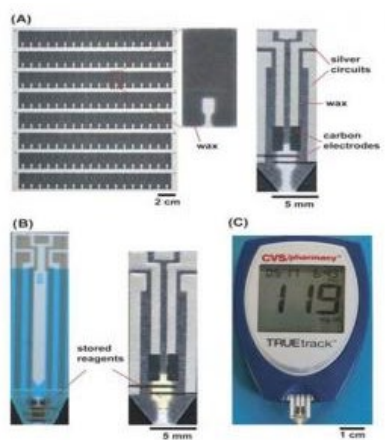
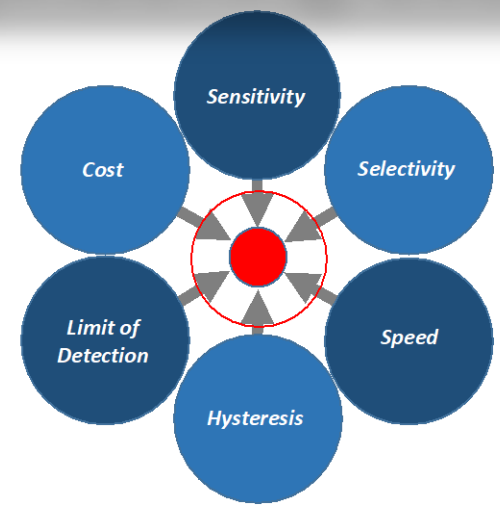
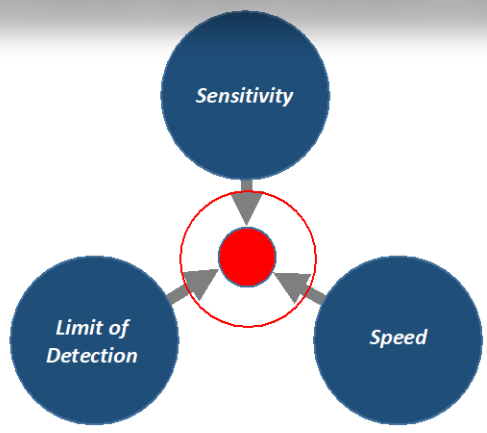


Triage

- Natural disaster
- Attack on infrastructure



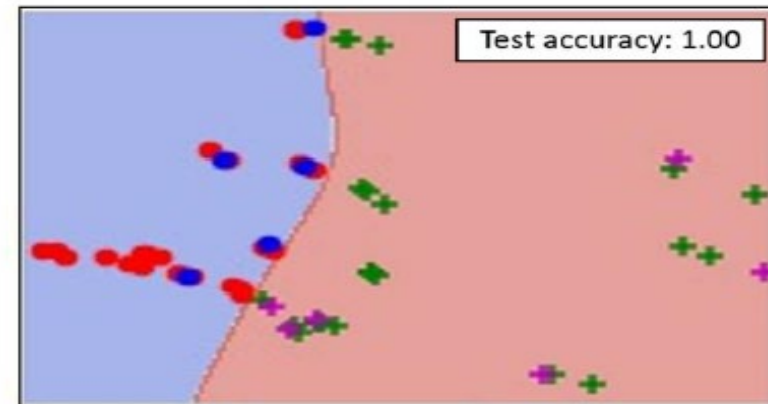
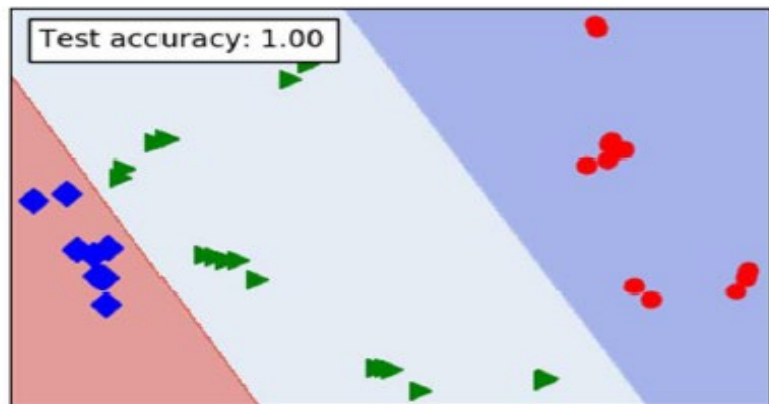
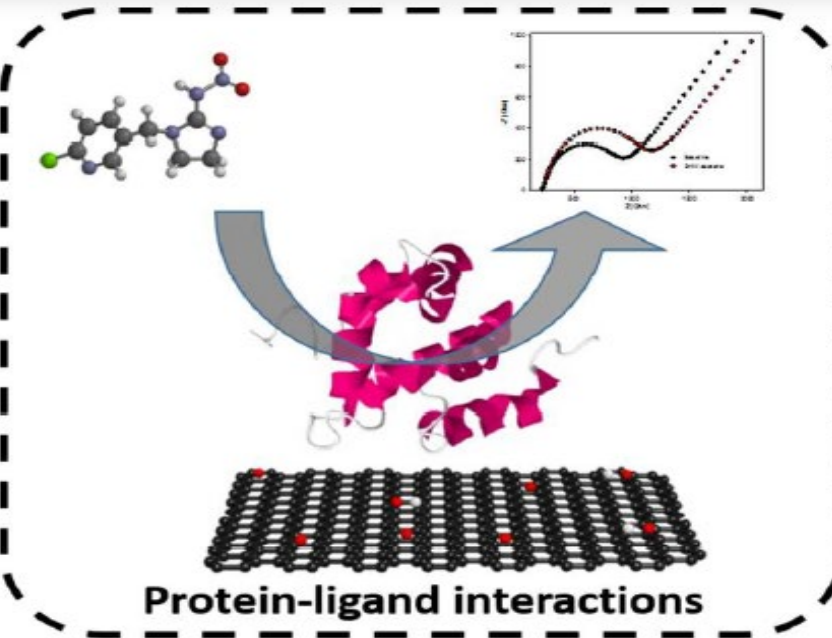
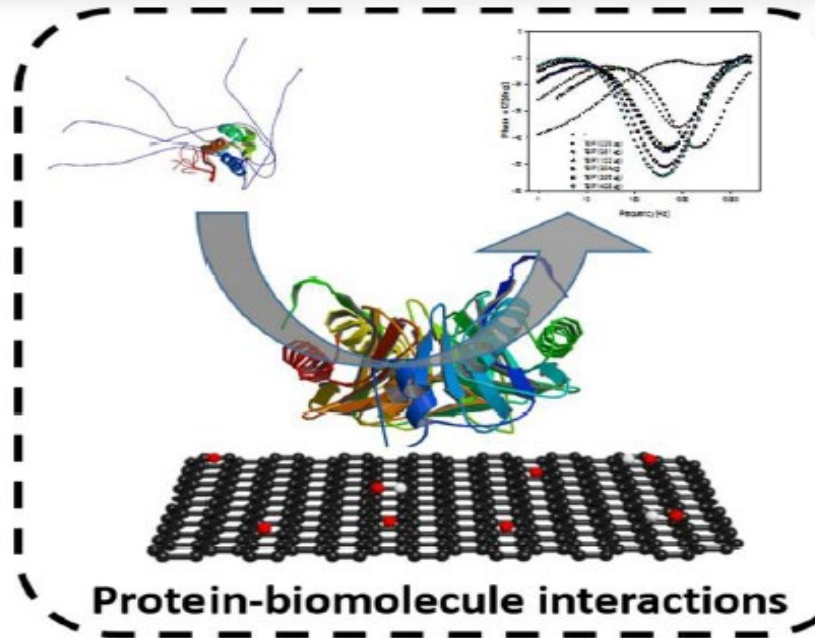
Has sensor engineering evolved with digital transformation



Original innovation



Water Polluted by Mercury (Hg)



Microbial Contamination of Water

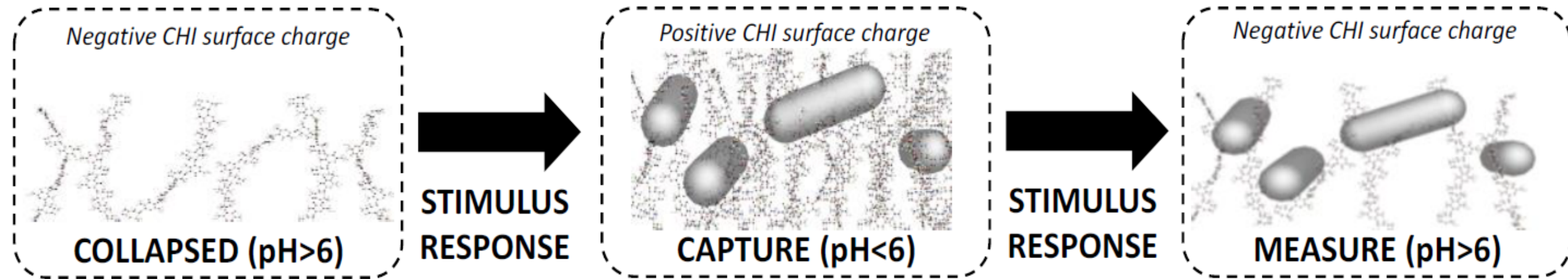
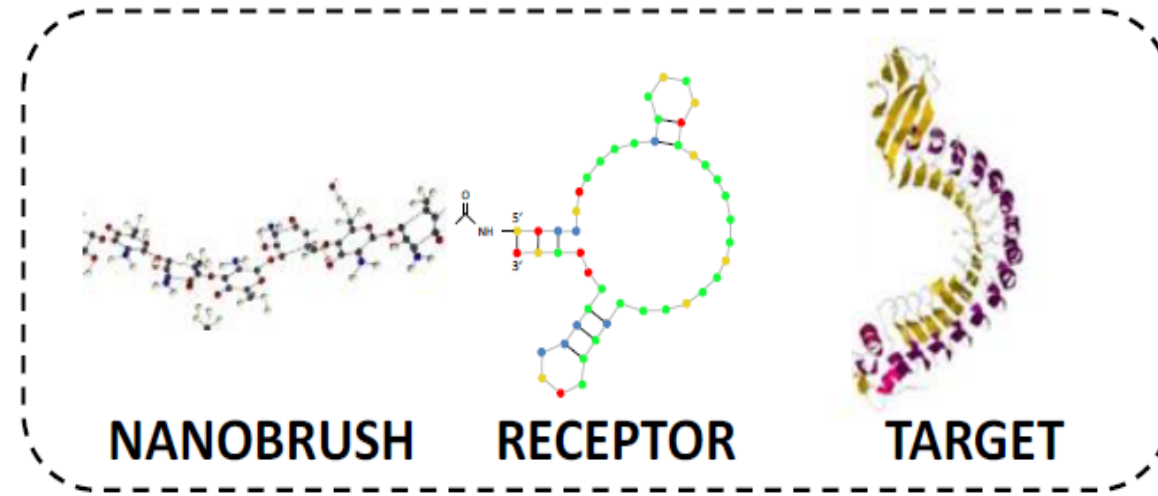
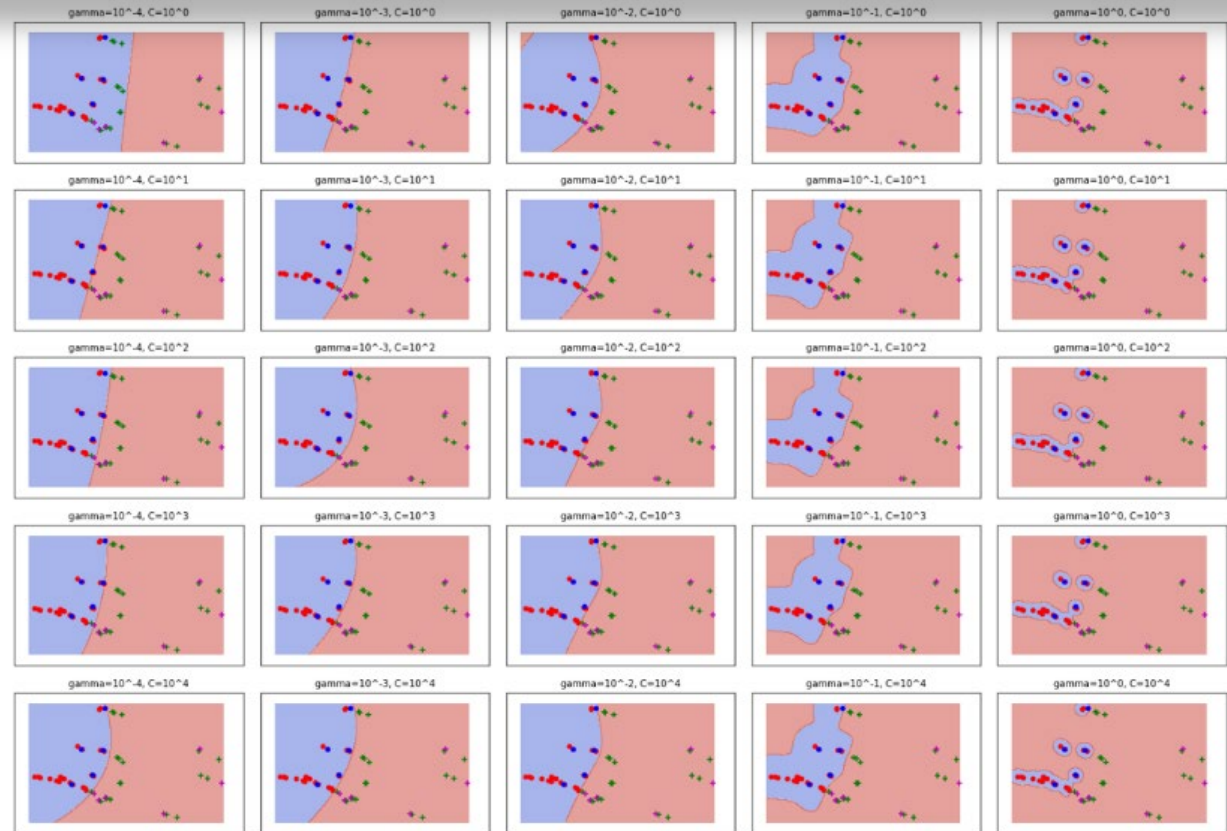


Image courtesy of [Hills et al \(2018\), Analyst](#), 143(7): 1650-1661.

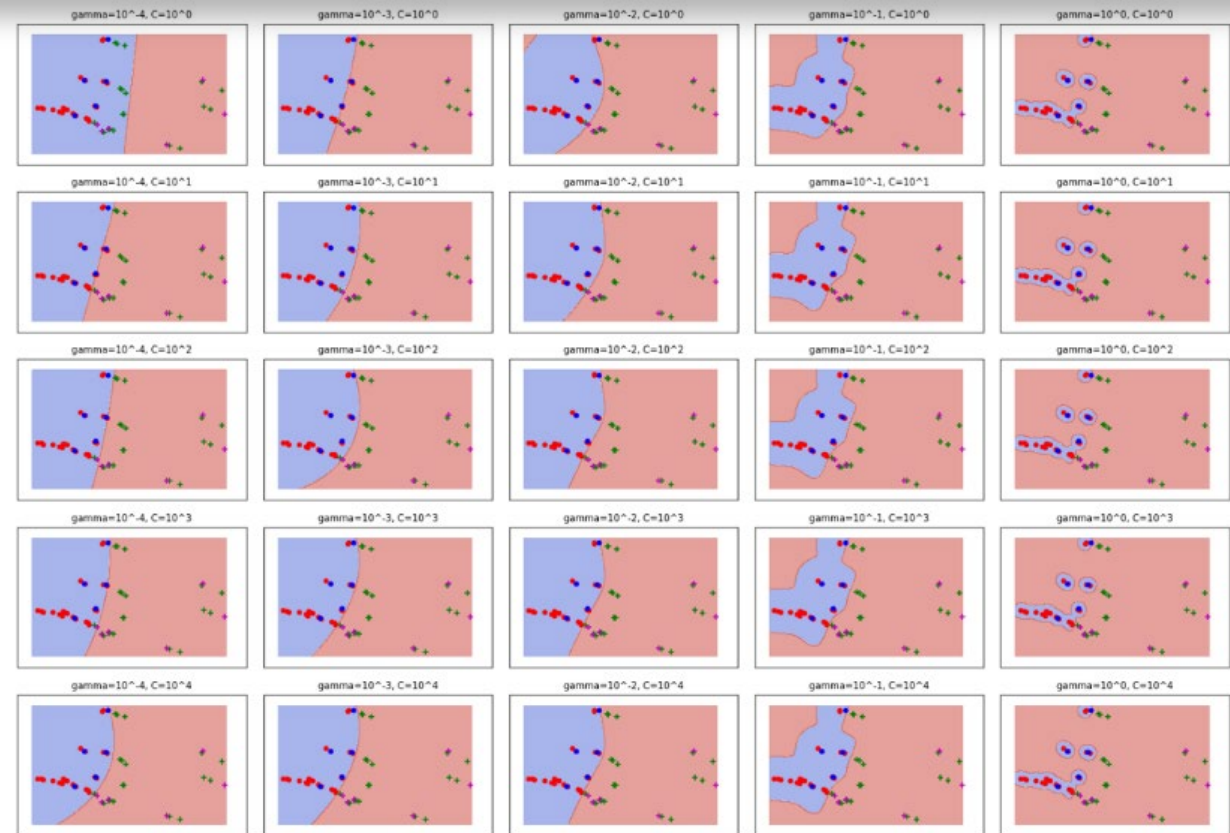
Water Contamination Data Analysis

Prior to running the support vector machine (SVM) algorithm, PCA (principal component analysis) was applied through singular value decomposition (SVD) to reduce 152 features to 2 principal components. PCA was used to reduce the dimension of 152 features in the raw EIS data to a two-dimensional principal components matrix. Depending on number of components to extract, full or randomized truncated SVD was used. To ensure general applicability across other application-specific biosensors, code screens were prepared for four types of SVM: kernels (linear, sigmoidal, radial basis function, polynomial) to identify which approach best segregates the training data.

Tuning of Gaussian radial base function (RBF) hyper-parameters (C and gamma) for chemo-sensory proteins (CSP) acetone interactions. Recombinant insect chemosensory proteins (CSP) derived from *Glossina morsitans* (Gmm, tsetse fly) were heterologously expressed and purified from *E. coli* hosts. Representative support vector machine (SVM) classification results for one training and testing set show the effects of parameters C and g in the output of the RBF kernels. Red and blue circles represent the baseline samples in training and testing sets; green and purple plus symbols represent the positive signals in training and testing sets. The background blue and red region indicated the classifier decision surface, where all data fall into the red region are predicted as positive.

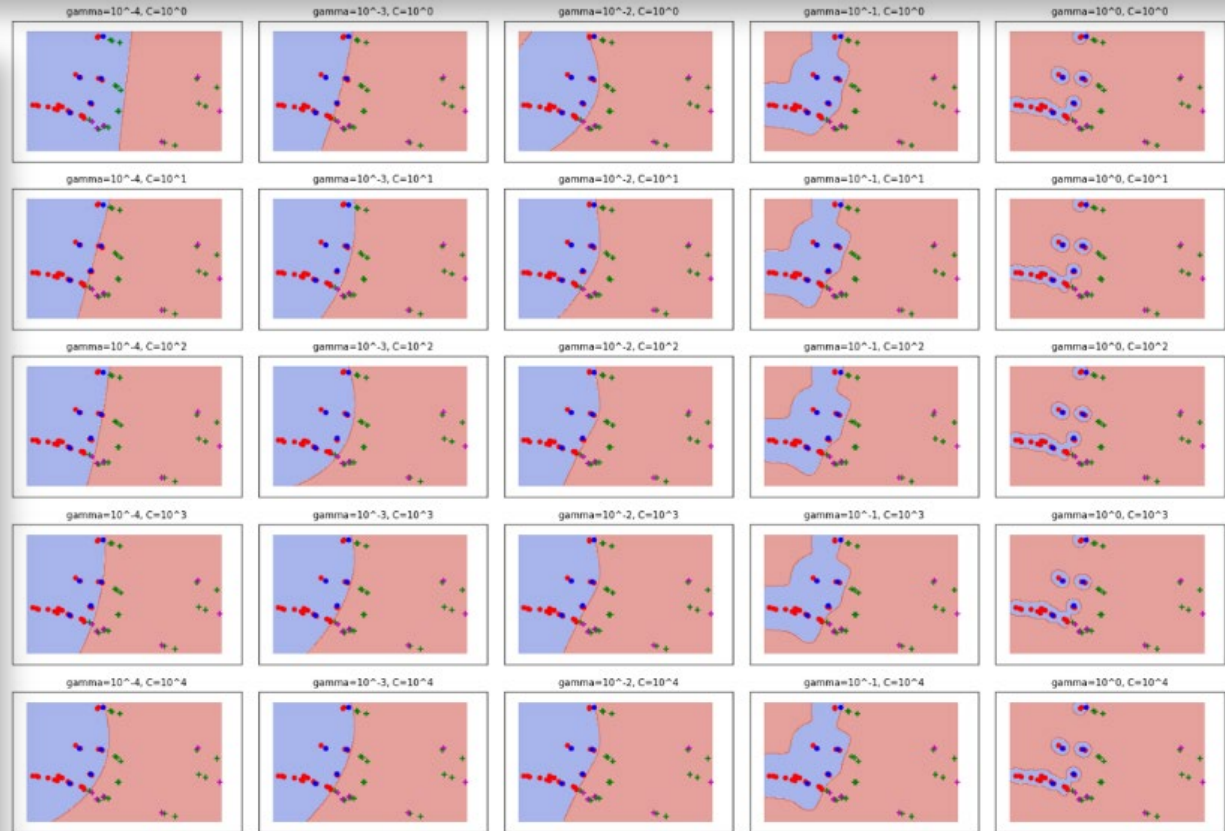


What is the value of this data analysis to the user ?



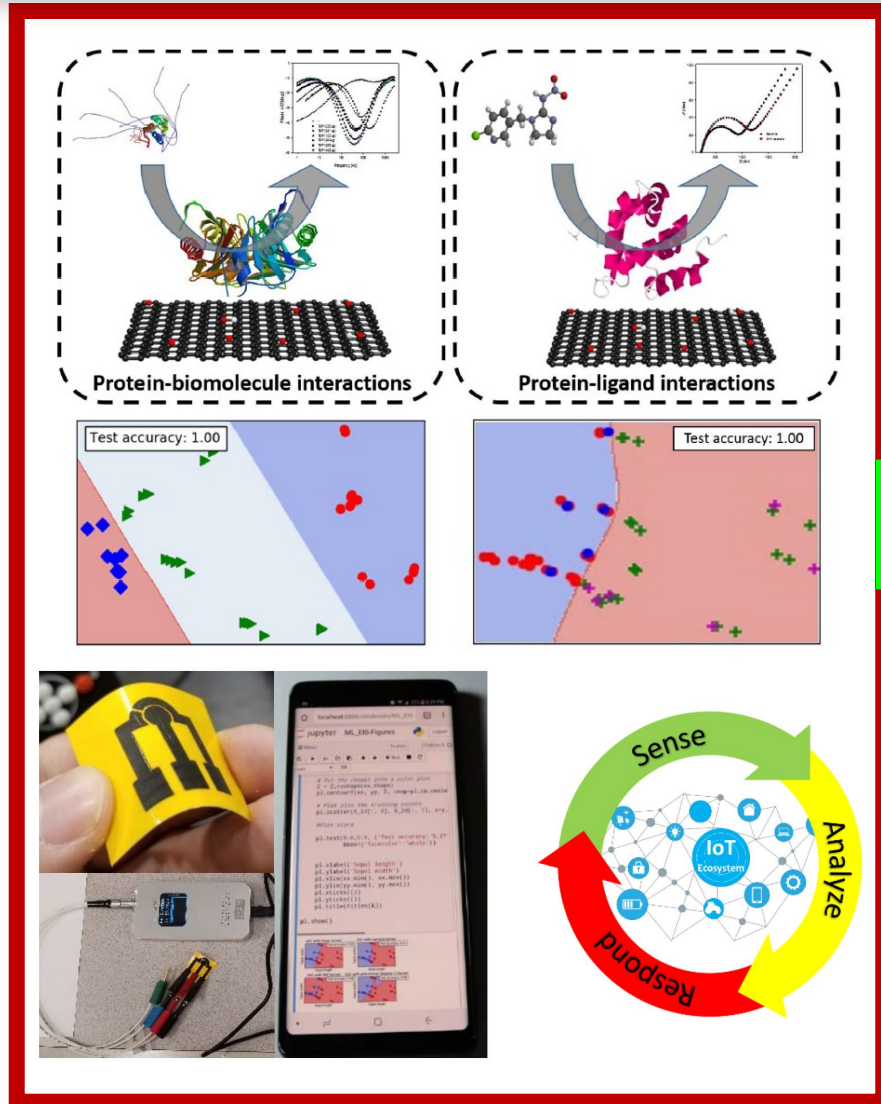
What is the value of this data analysis to the user ?

0

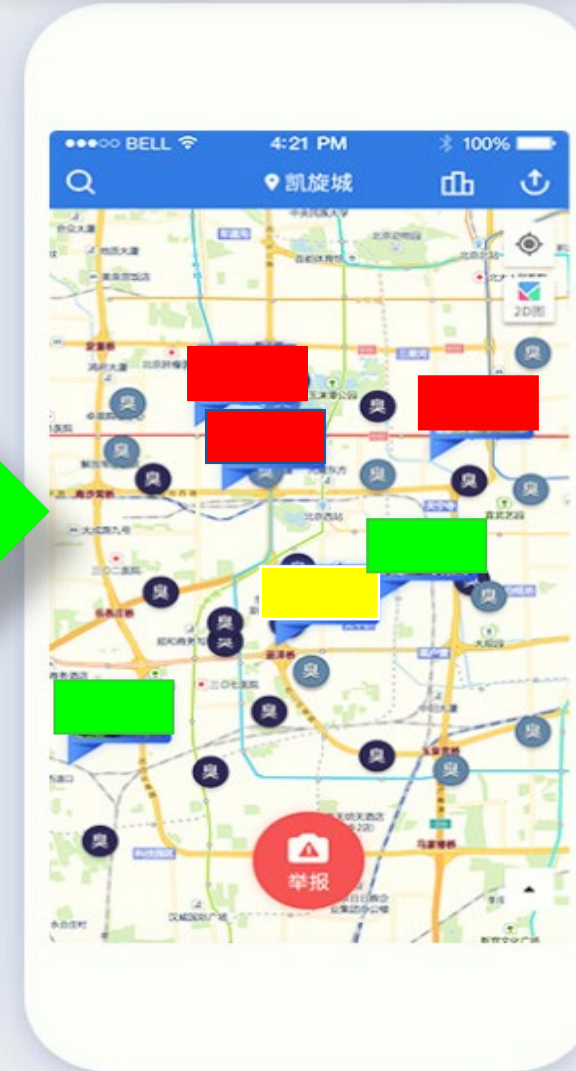


ZERO

IoT-by-design: Data Analytics of Value to End-User



VALUE

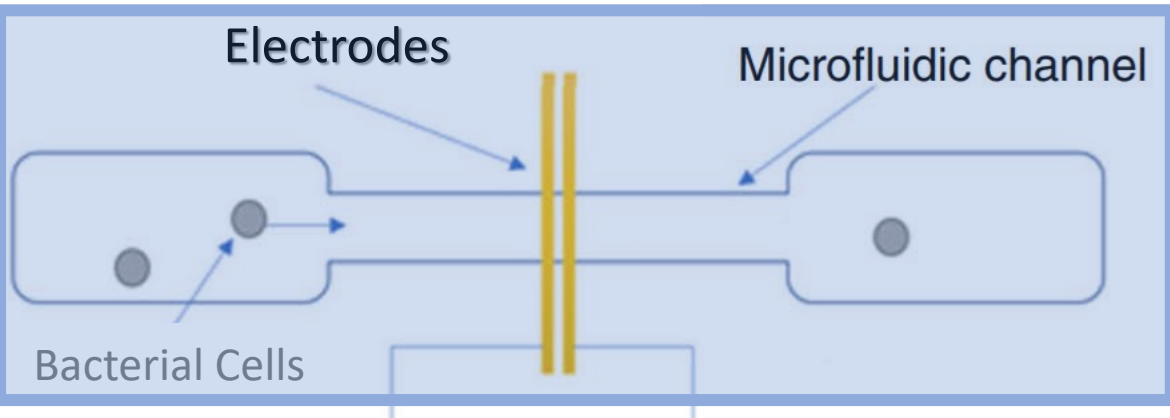


Near Real-Time Analytics: Data-Informed Services at the Edge

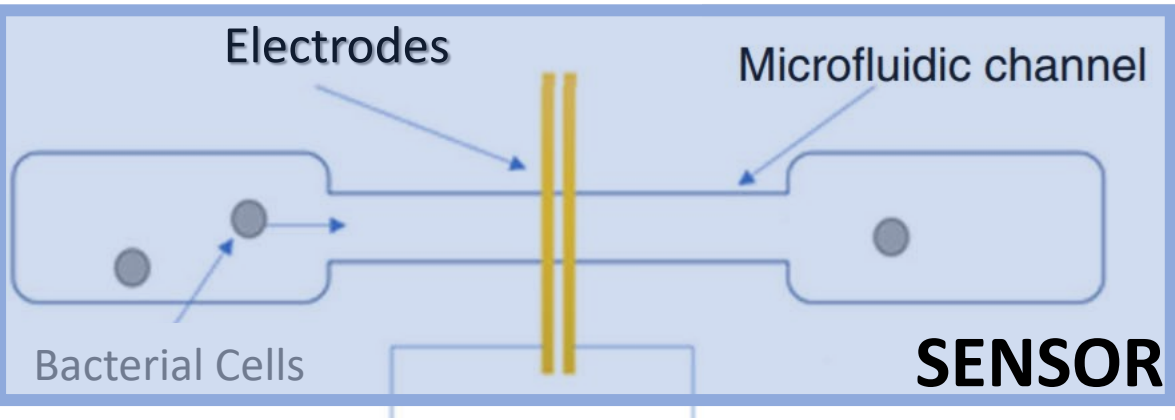
**Bacterial
Cells**

IoT-by-design: Data Analytics of Value to End-User

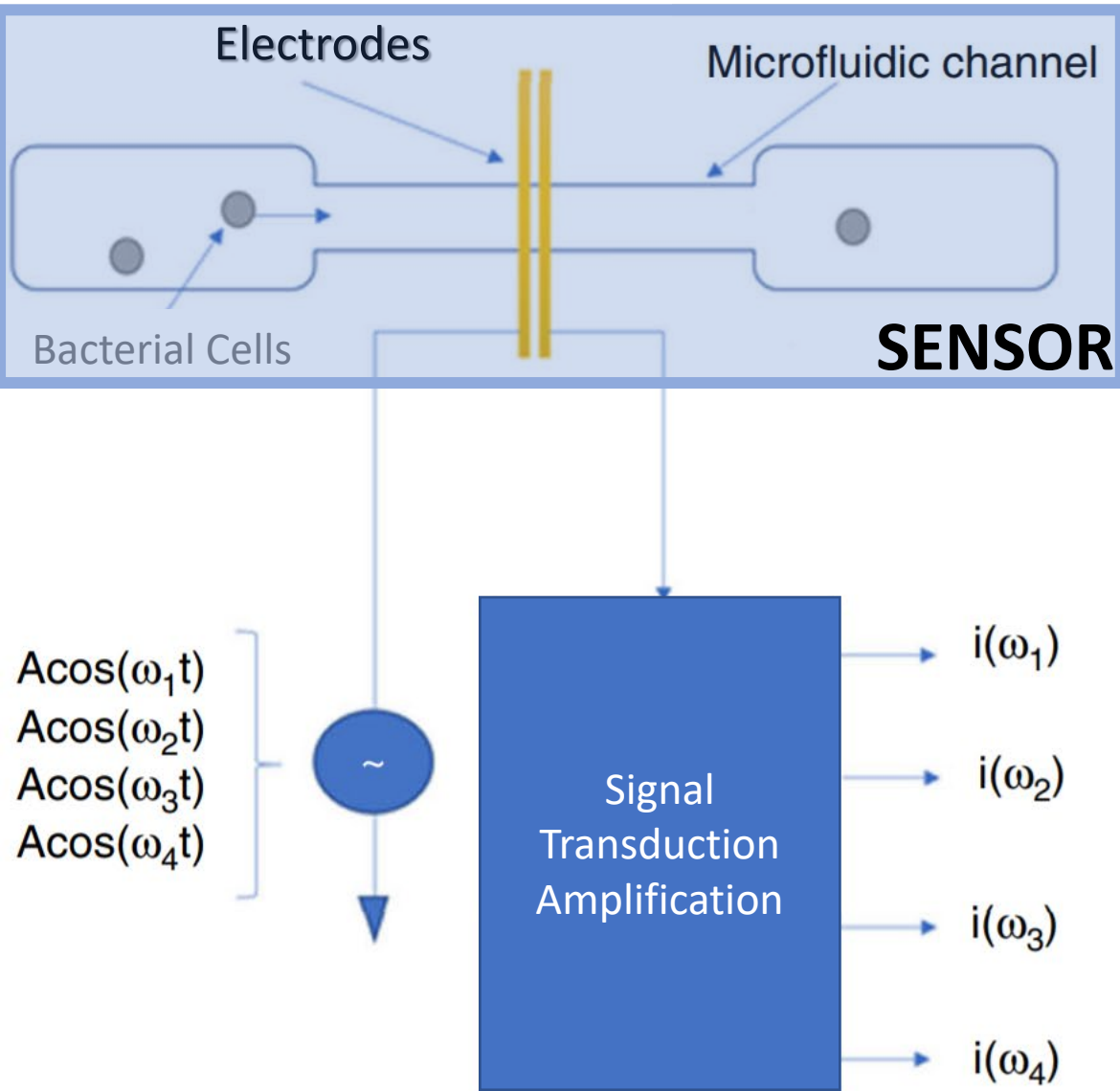
Near Real-Time Analytics: Data-Informed Services at the Edge



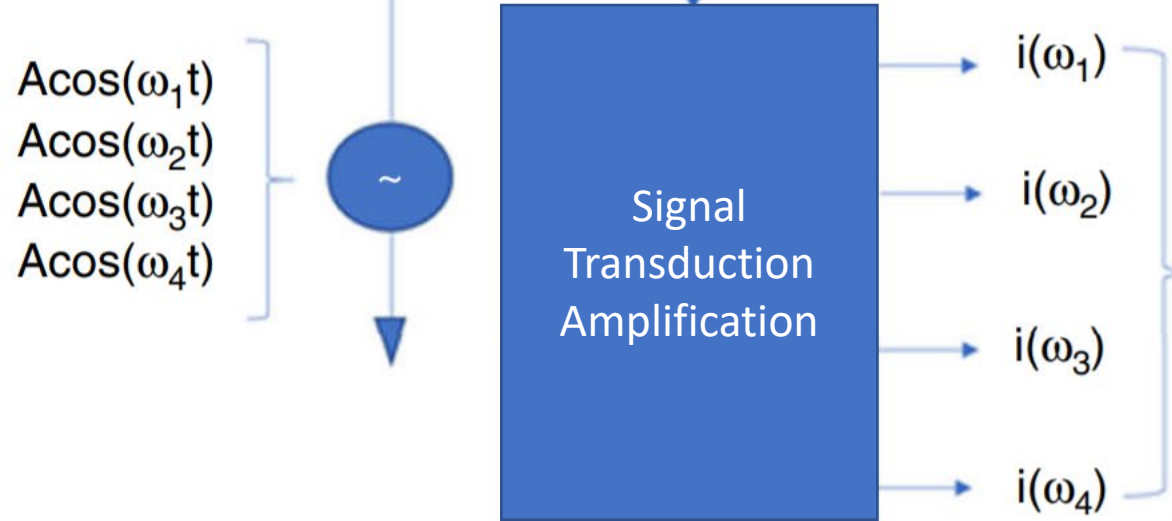
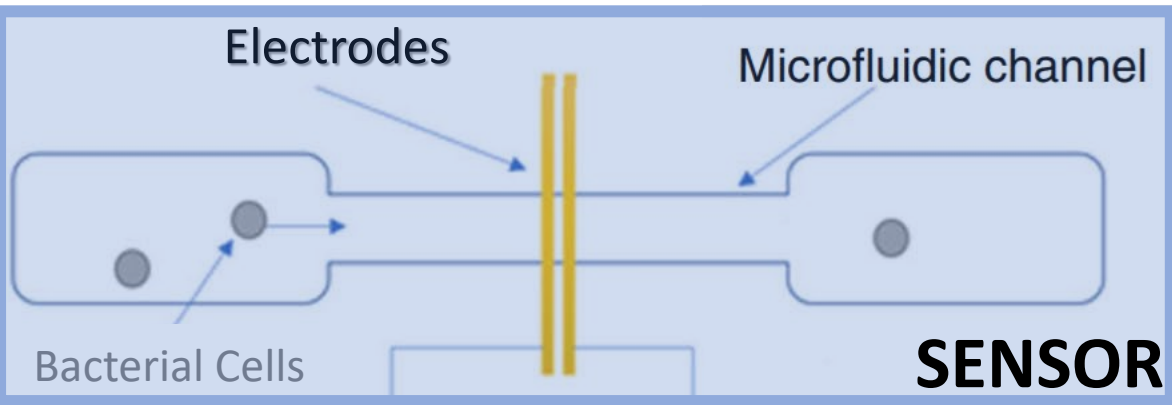
Near Real-Time Analytics: Data-Informed Services at the Edge



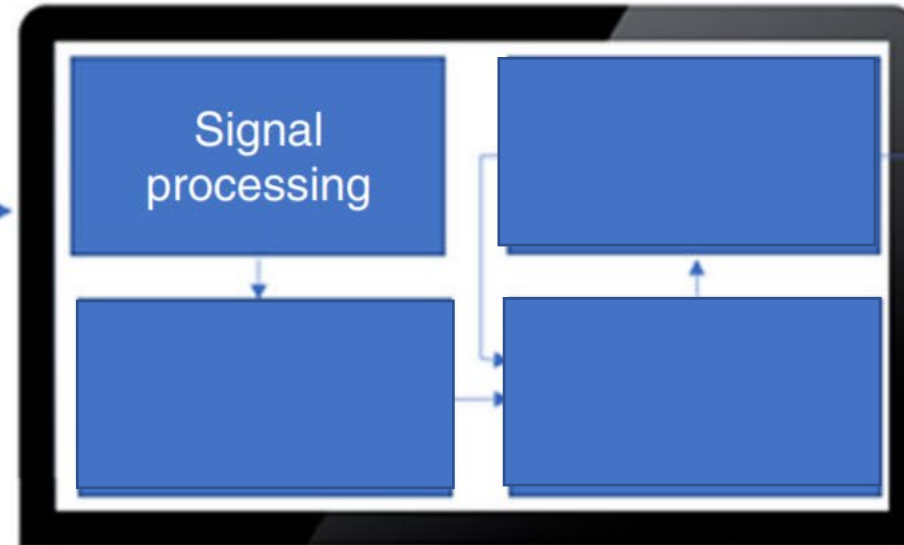
Near Real-Time Analytics: Data-Informed Services at the Edge



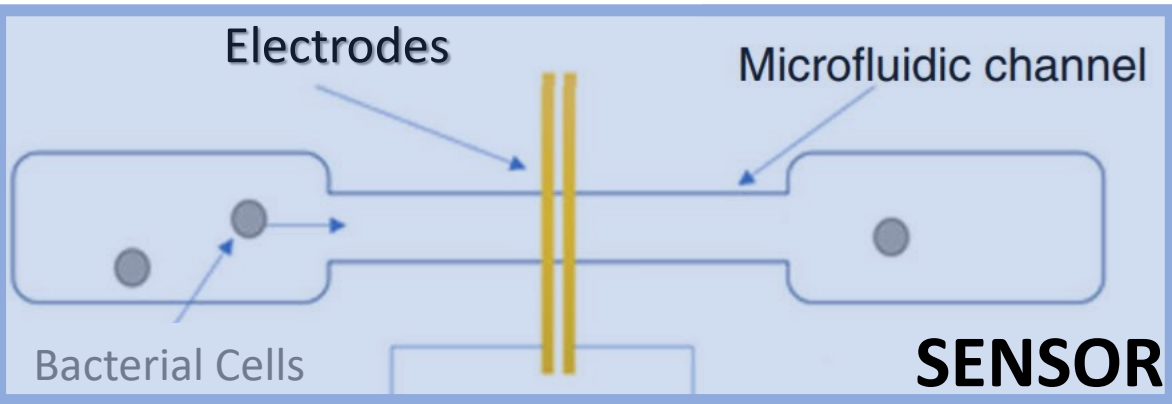
Near Real-Time Analytics: Data-Informed Services at the Edge



Mobile Device Tool-Kit at Point of Use



Near Real-Time Analytics: Data-Informed Services at the Edge

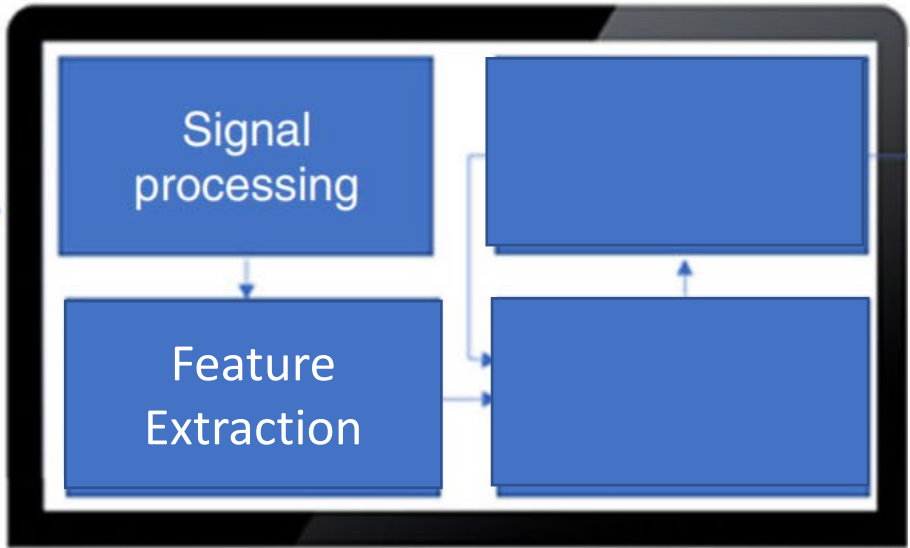


$A\cos(\omega_1 t)$
 $A\cos(\omega_2 t)$
 $A\cos(\omega_3 t)$
 $A\cos(\omega_4 t)$

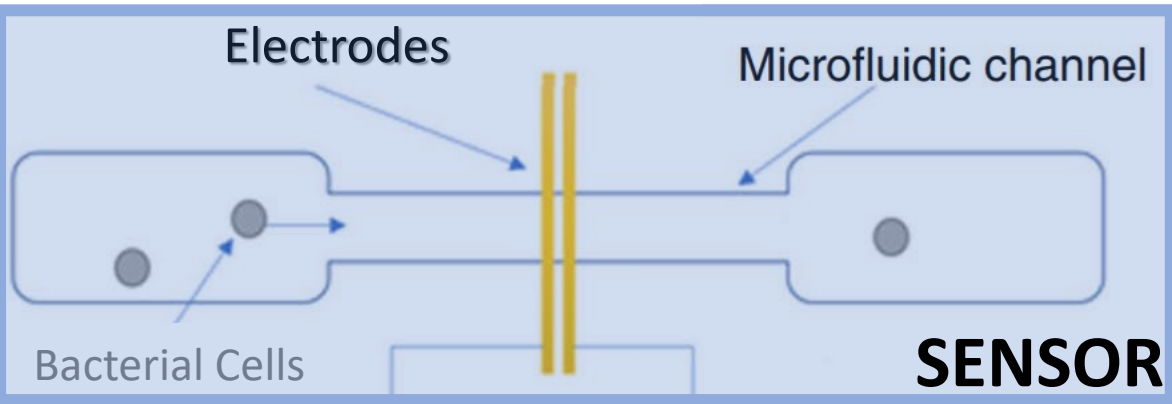


$i(\omega_1)$
 $i(\omega_2)$
 $i(\omega_3)$
 $i(\omega_4)$

Mobile Device Tool-Kit at Point of Use



Near Real-Time Analytics: Data-Informed Services at the Edge

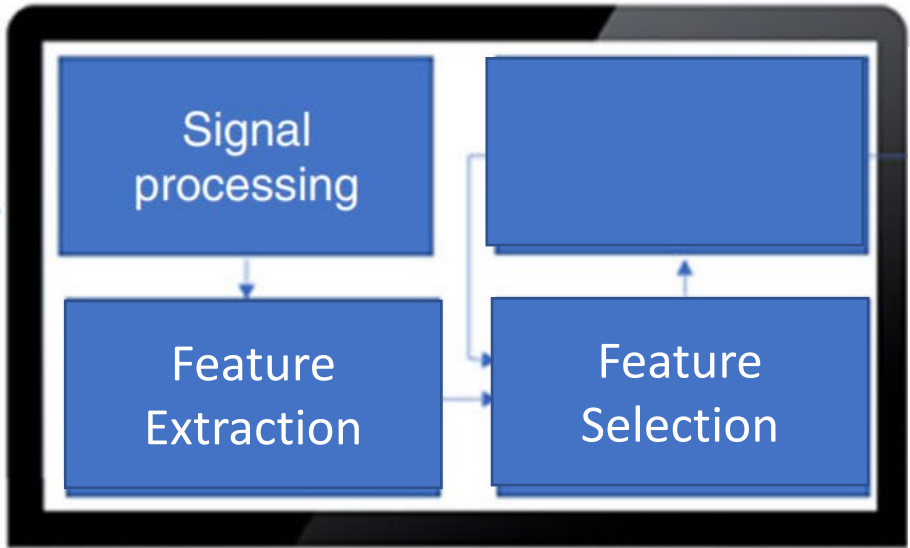


$A\cos(\omega_1 t)$
 $A\cos(\omega_2 t)$
 $A\cos(\omega_3 t)$
 $A\cos(\omega_4 t)$

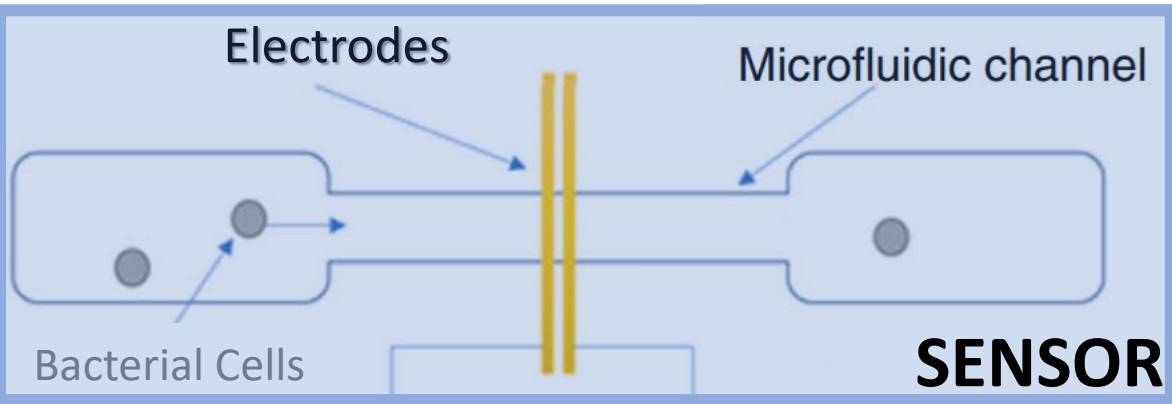


$i(\omega_1)$
 $i(\omega_2)$
 $i(\omega_3)$
 $i(\omega_4)$

Mobile Device Tool-Kit at Point of Use



Near Real-Time Analytics: Data-Informed Services at the Edge

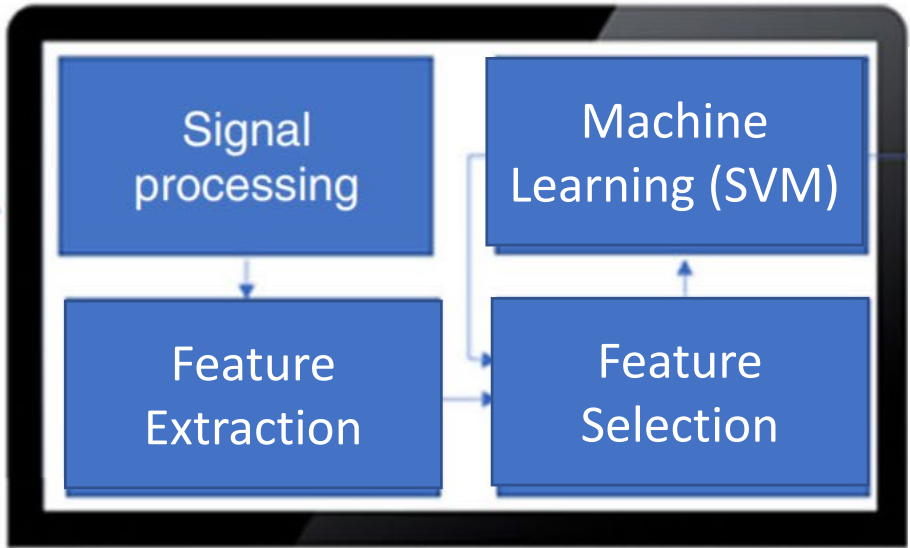


$A\cos(\omega_1 t)$
 $A\cos(\omega_2 t)$
 $A\cos(\omega_3 t)$
 $A\cos(\omega_4 t)$

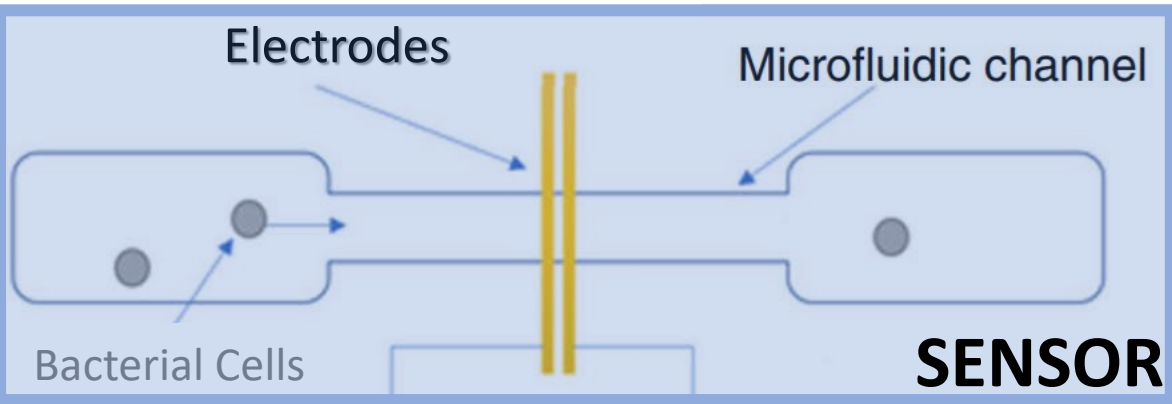


$i(\omega_1)$
 $i(\omega_2)$
 $i(\omega_3)$
 $i(\omega_4)$

Mobile Device Tool-Kit at Point of Use



Near Real-Time Analytics: Data-Informed Services at the Edge

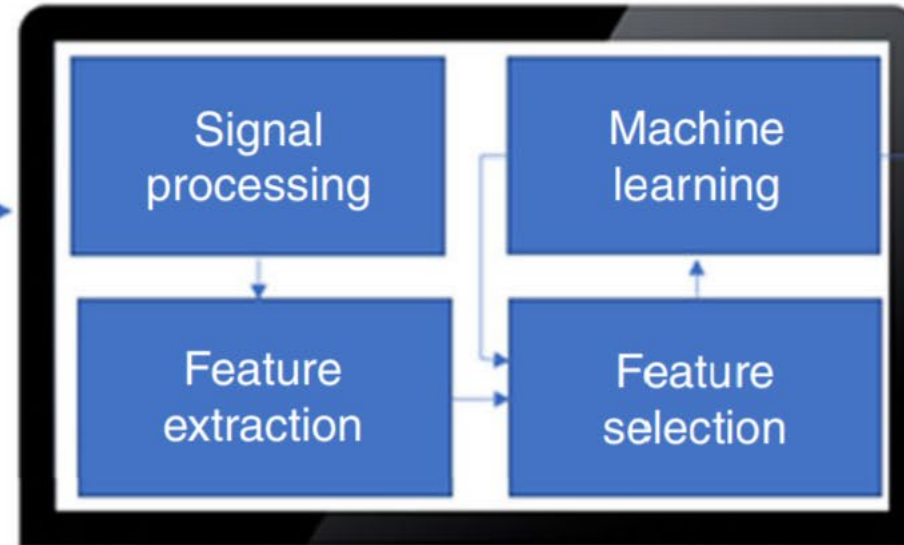


$A\cos(\omega_1 t)$
 $A\cos(\omega_2 t)$
 $A\cos(\omega_3 t)$
 $A\cos(\omega_4 t)$



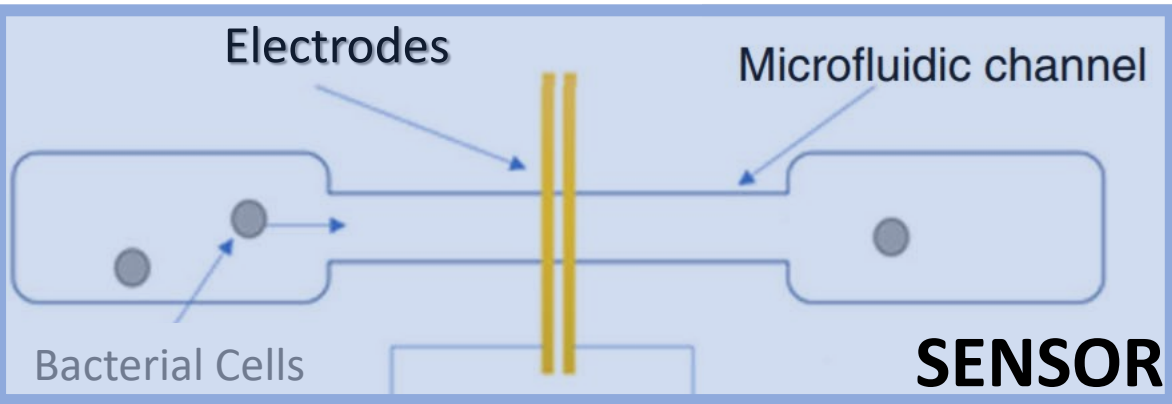
$i(\omega_1)$
 $i(\omega_2)$
 $i(\omega_3)$
 $i(\omega_4)$

Mobile Device Tool-Kit at Point of Use



OUTCOME

Near Real-Time Analytics: Data-Informed Services at the Edge

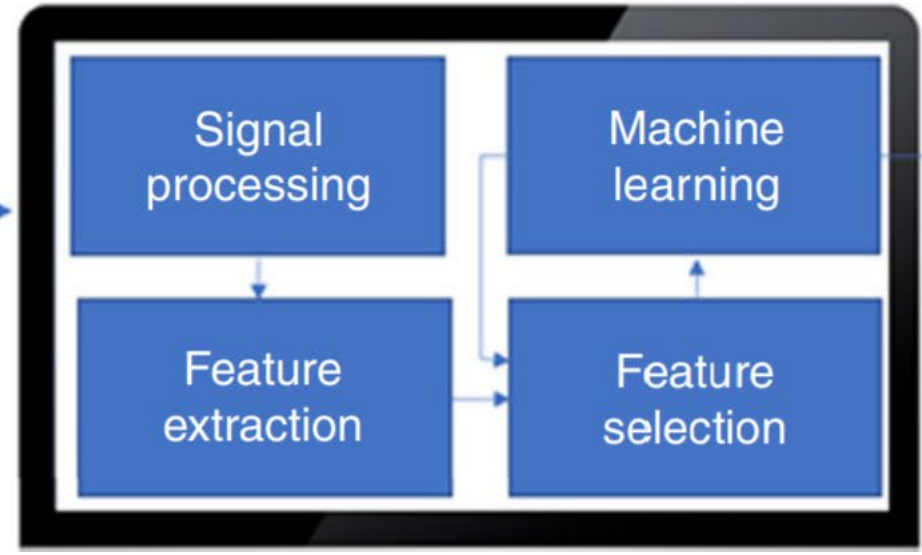


$A\cos(\omega_1 t)$
 $A\cos(\omega_2 t)$
 $A\cos(\omega_3 t)$
 $A\cos(\omega_4 t)$

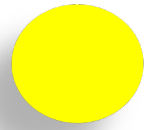


$i(\omega_1)$
 $i(\omega_2)$
 $i(\omega_3)$
 $i(\omega_4)$

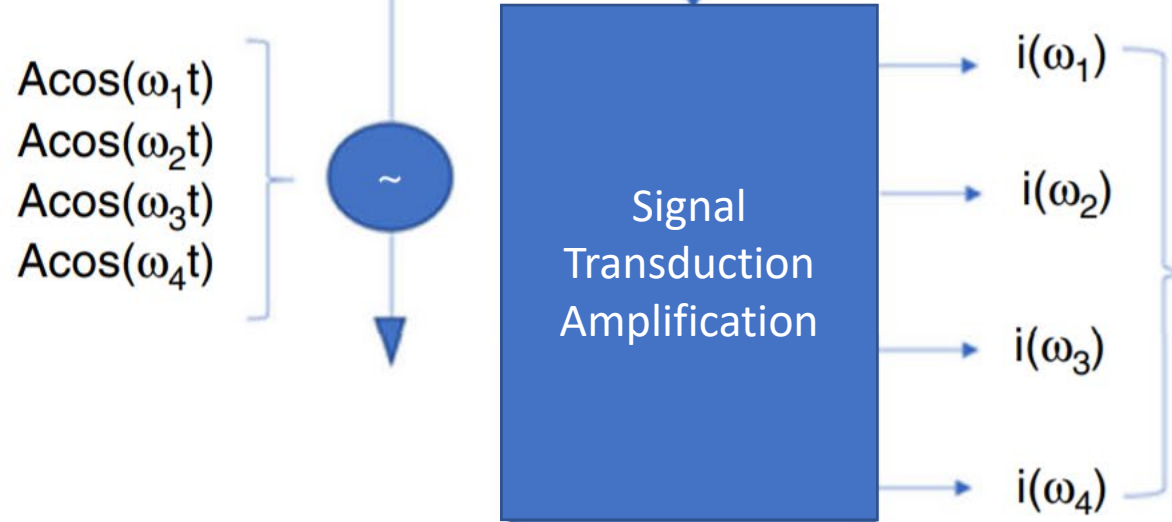
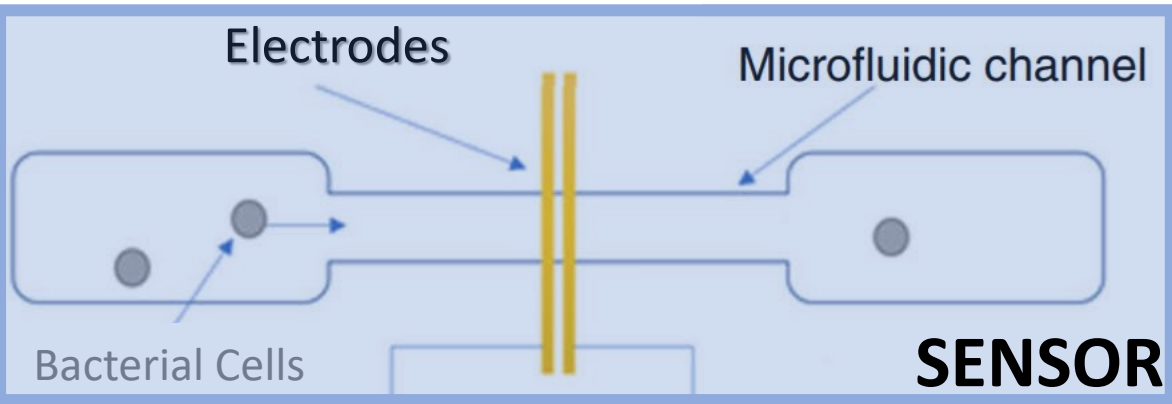
Mobile Device Tool-Kit at Point of Use



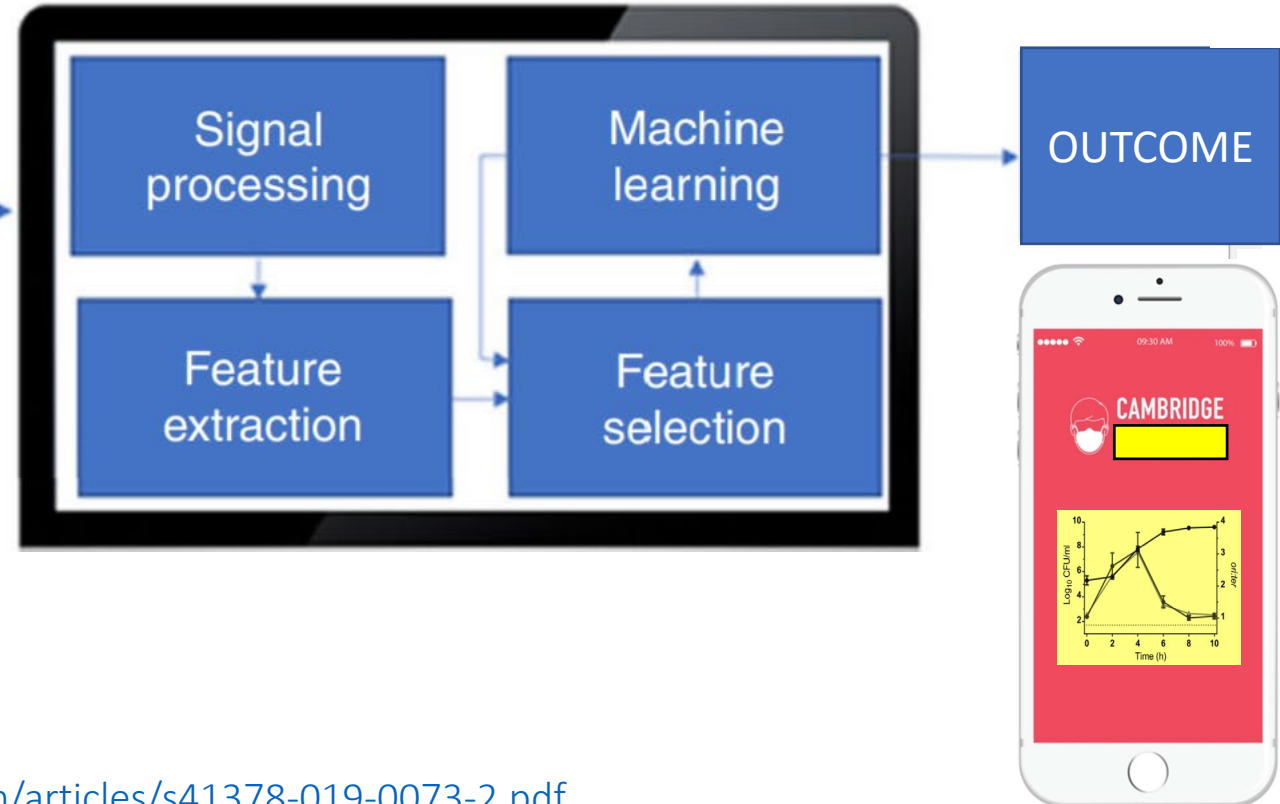
OUTCOME



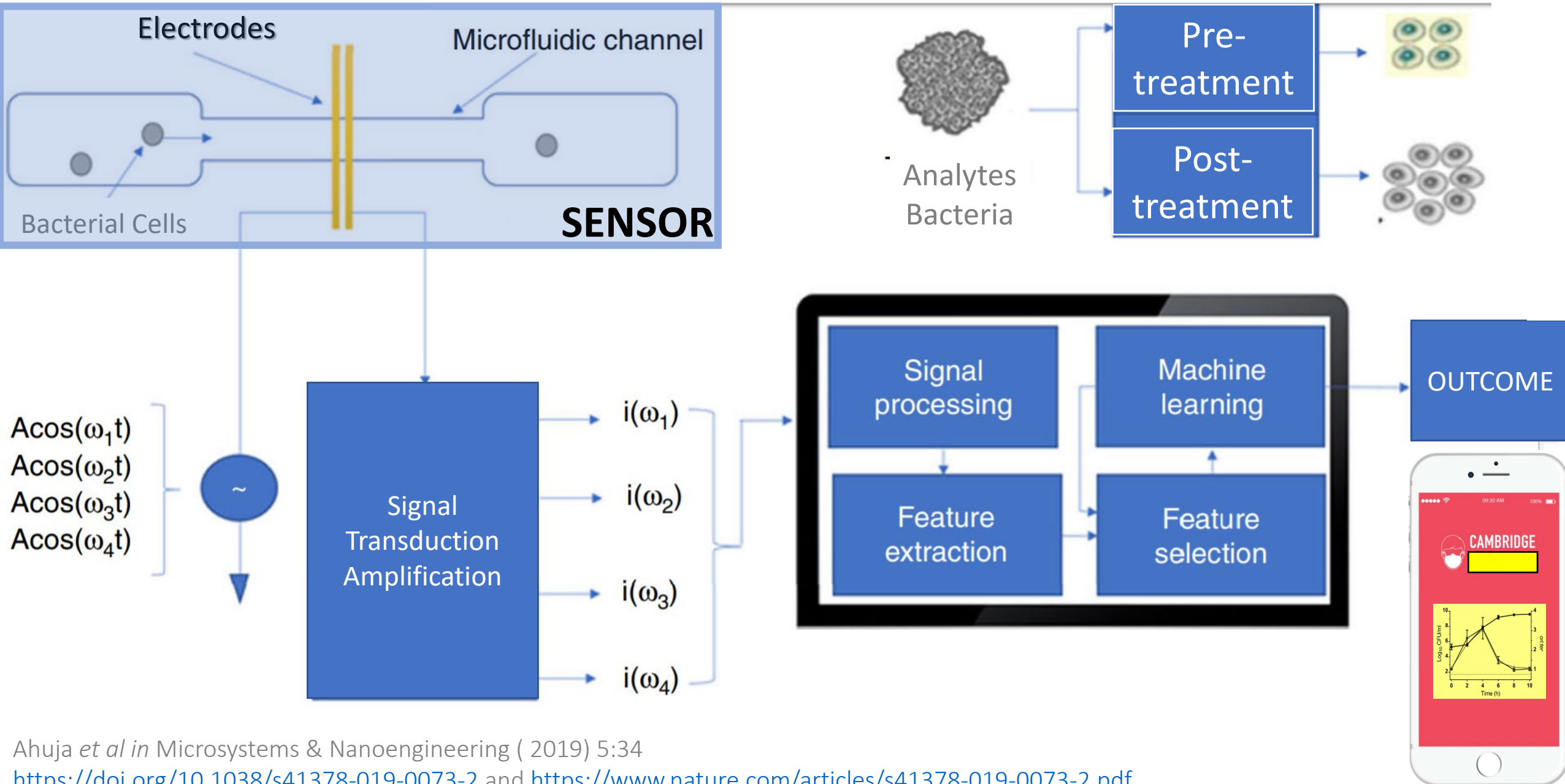
Near Real-Time Analytics: Data-Informed Services at the Edge



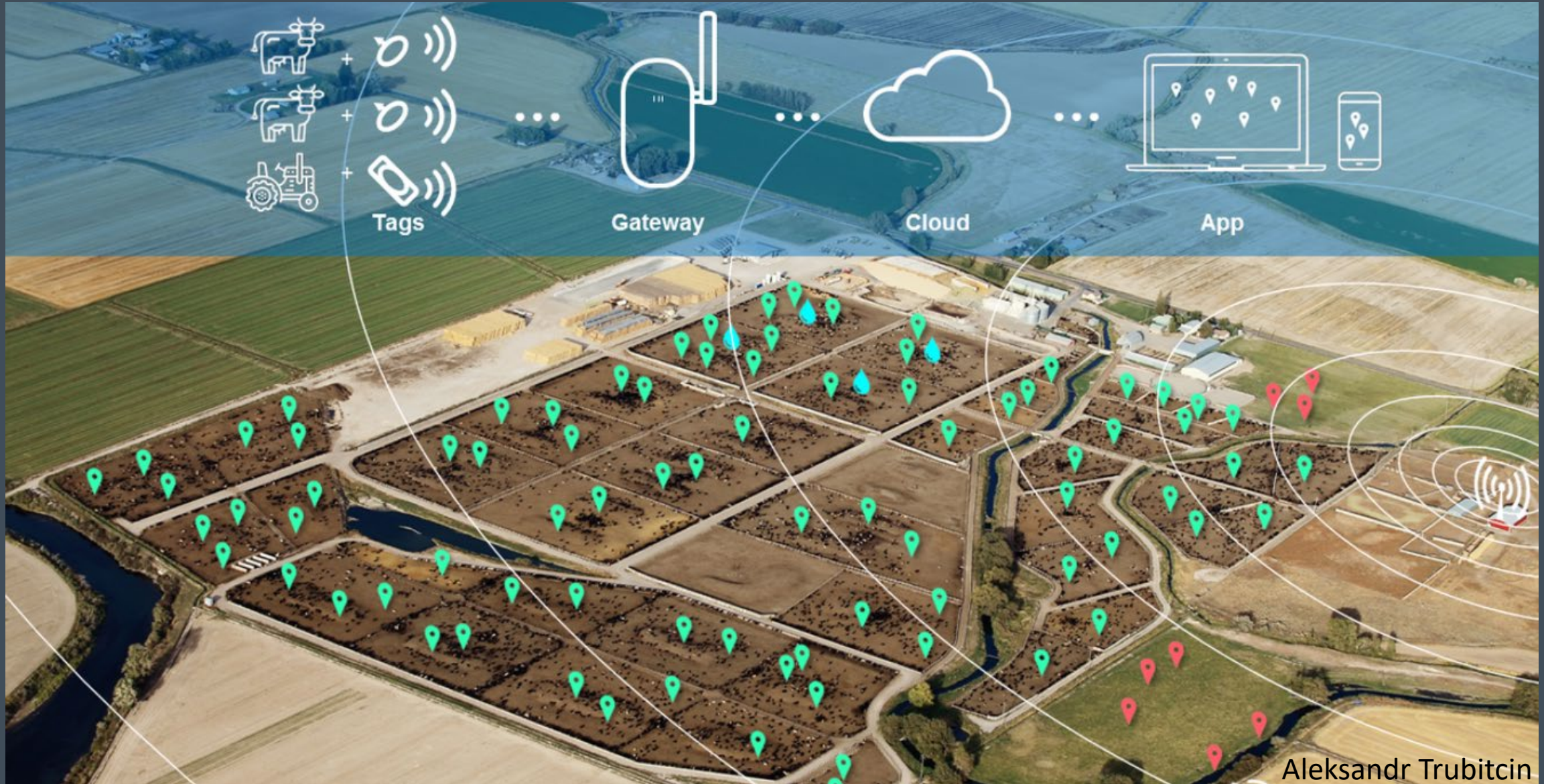
Mobile Device Tool-Kit at Point of Use



Near Real-Time Analytics: Data-Informed Services at the Edge



IoT-by-design: Data Analytics of Value to End-User



See SIGNALS - <https://dspace.mit.edu/handle/1721.1/1111021>

LoRaWAN Cattle Ear Tags: 200 acre feed-lot for 10,000 cows

IoT-BY-DESIGN: PAY A PENNY PER UNIT (PAPPU) PARADIGM ?

Fill in the details of your deployment.

Install Address

421 N 3200 E, Lewisville, ID 8343

Install Environment

Rural

Gateway Height

50 ft

Select Gateway

Field 64c

SF 7 | SF 8 | SF 9 | SF 10

Sensor Placement

Outdoor

Sensor Height

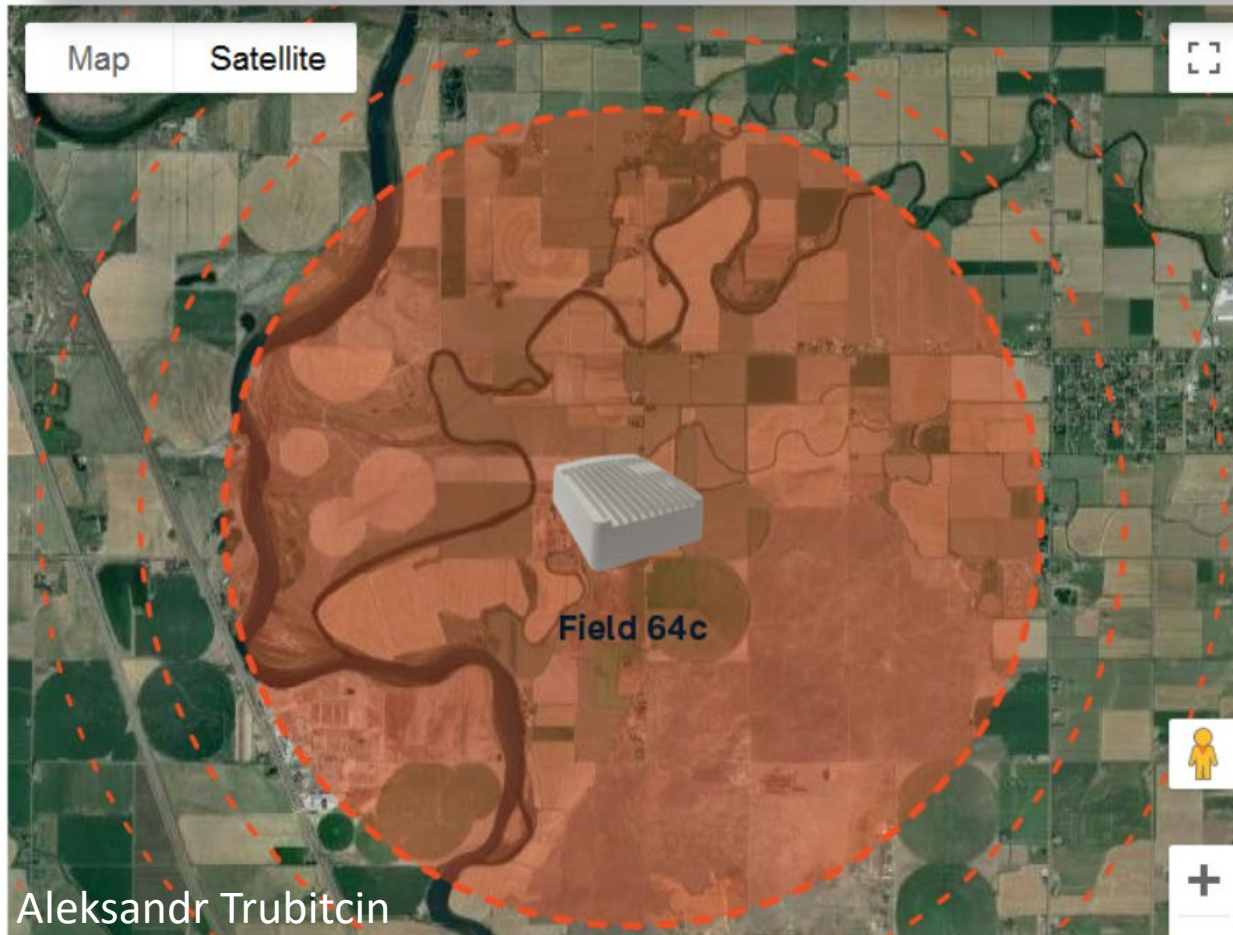
1 ft

Sensor Tx Power

14 dBm

Estimated Gateway Range
3.5 miles

CONNECTIVITY costs \$0.00137 per cow per day



Field 64c gateway with 64 channels of LoRaWAN connectivity and Ethernet/cellular backhaul manufactured by Tektelic, Canada.

MachineQ prices:

Gateway Field 64c \$2800 (CAPEX)

Software License \$4979 pa (OPEX)

Cell \$119 per gateway pa (OPEX)

Connectivity fee per animal (10,000)

US \$0.50 per year (50 cents pa)

**0.001
cents**

LoRaWAN Cattle Ear Tags: 200 acre feed-lot for 10,000 cows

IoT SYSTEMS: HOW NANO-FEES MAY GENERATE MEGA-MILLIONS

The user will also need access to the cattle tracking and monitoring web application. For example, the cost of an annual subscription to the Cattle Tags Technologies app will be \$5 per animal.



**0.12
cents**

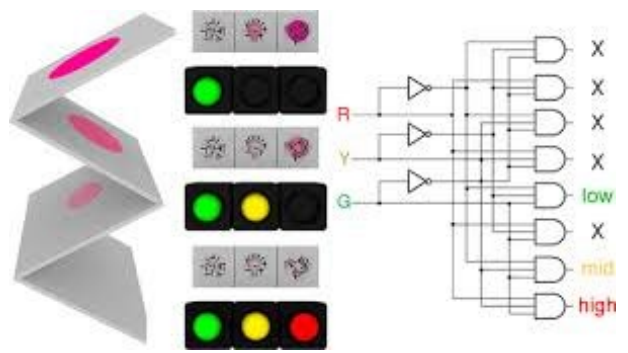
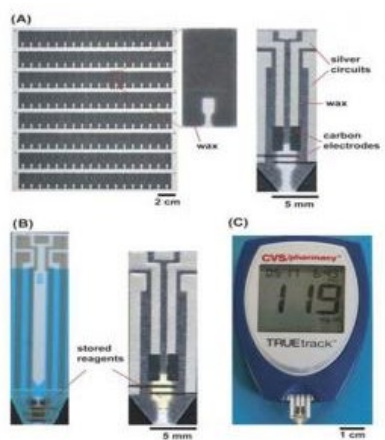
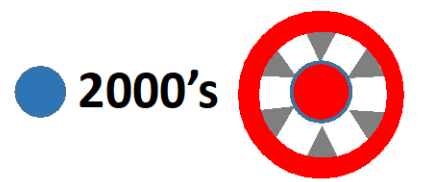
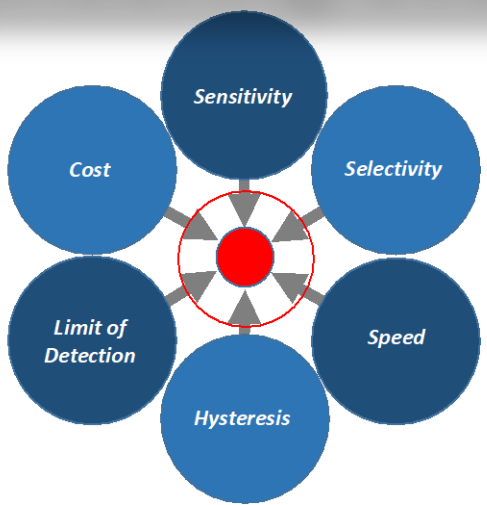
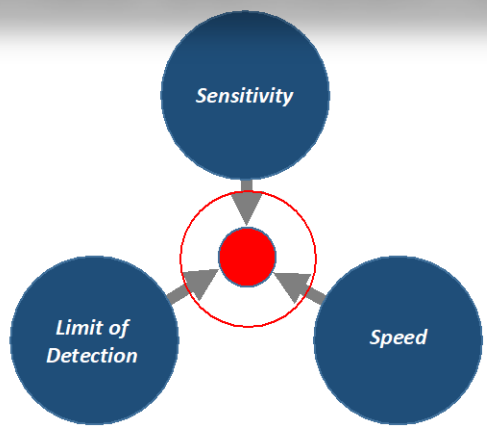
Software subscription cost \$0.0137 per cow per day



LoRaWAN ear tag from Cattle Tags Technologies starts from \$39. Tags have embedded GPS receiver, accelerometer, temperature sensor and replaceable battery. Operator reads RFID-tag with Bluetooth reader (ID sent to ERP system). Installation of activated LoRaWAN ear tag follows. alex.trubitcin@gmail.com

Digital Transformation (Connectivity+App+Tag) Cost \$0.12 per cow per day

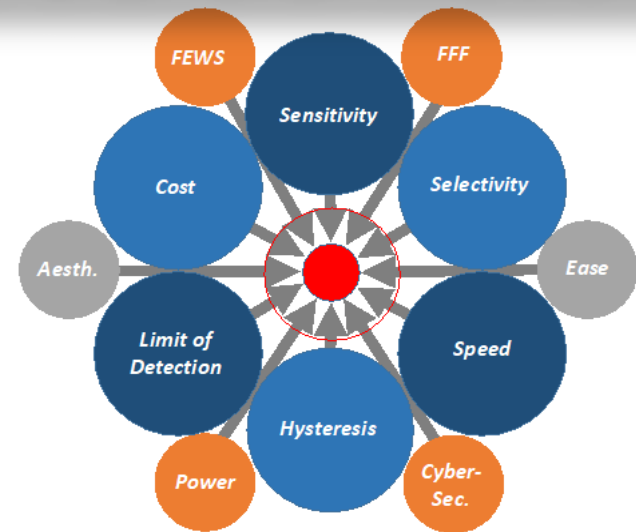
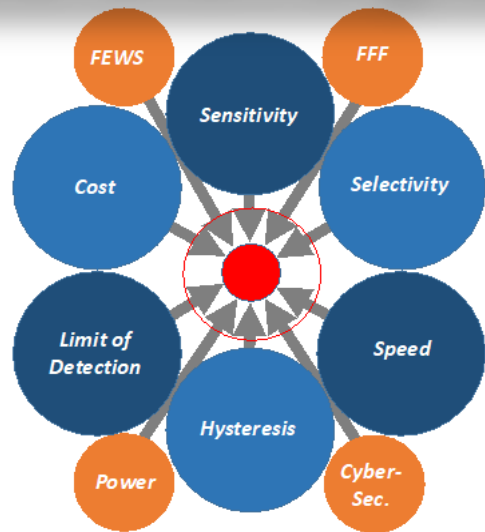
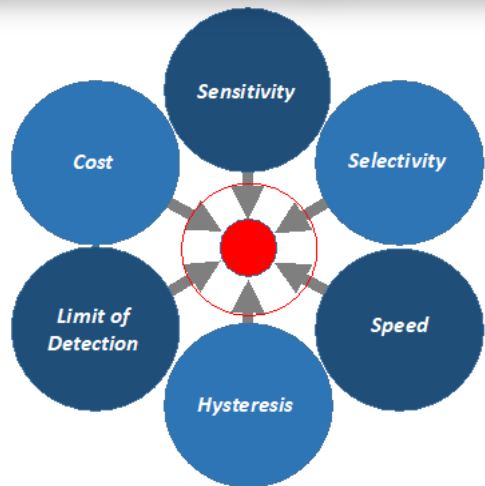
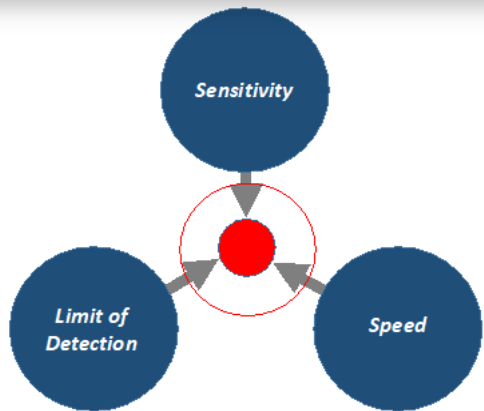
Has sensor engineering evolved with digital transformation



Original innovation



Has sensor engineering evolved with digital transformation

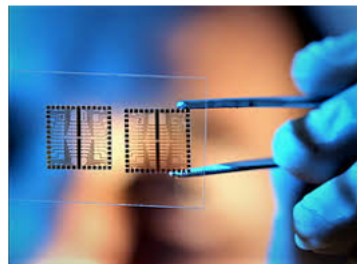
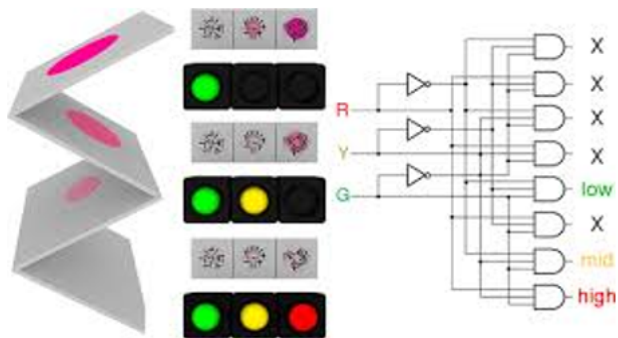
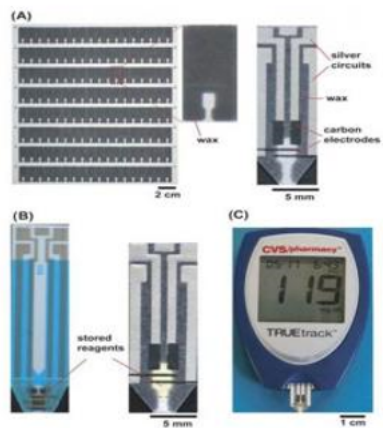


● 1990's

● 2000's

● 2010's

● 2020's

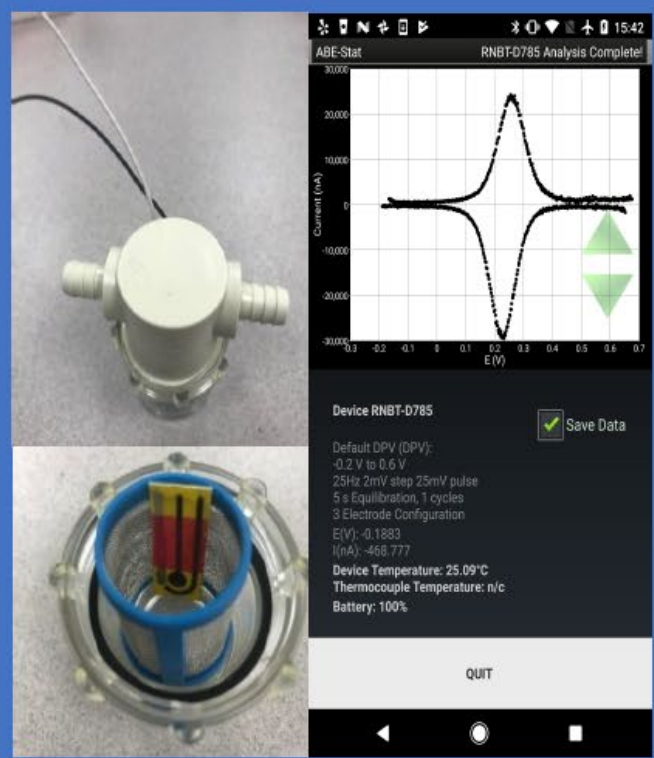


Original innovation

Digital transformation

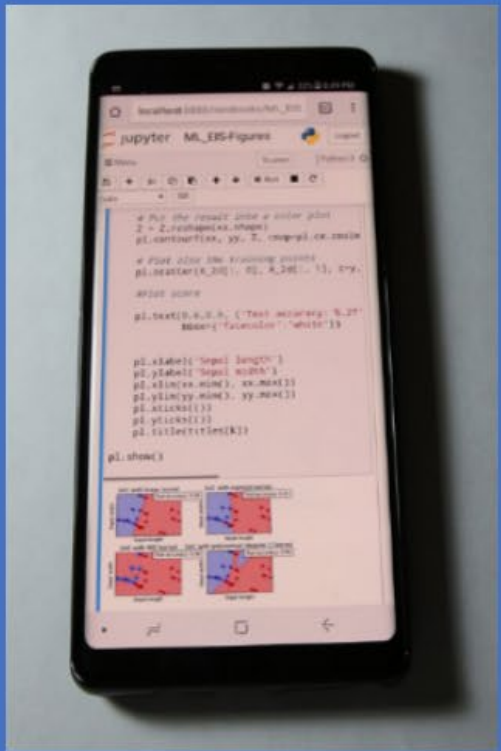
Sensor engineering has evolved with digital transformation

Sense



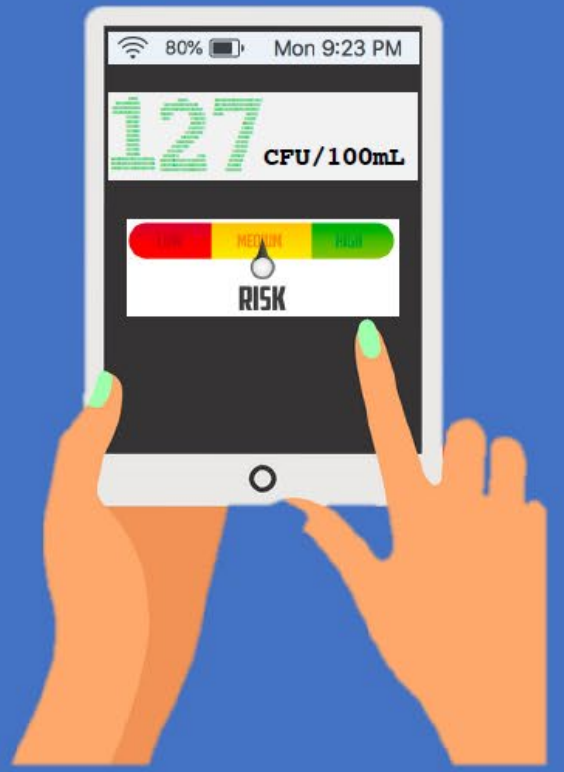
E. coli sensor

Analyze



Analysis

Respond



ART feature

SENSE, ANALYZE, RESPONSE SYSTEMS – SARS

Convergence of



DATA from SENSORS

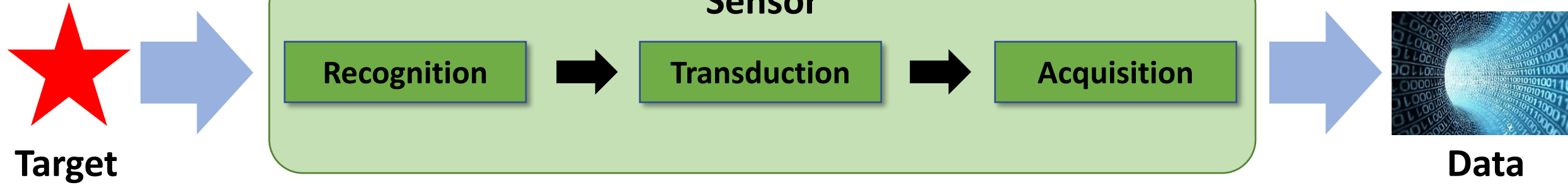
Role of Sensors and Sensor Data in Decision as a Service



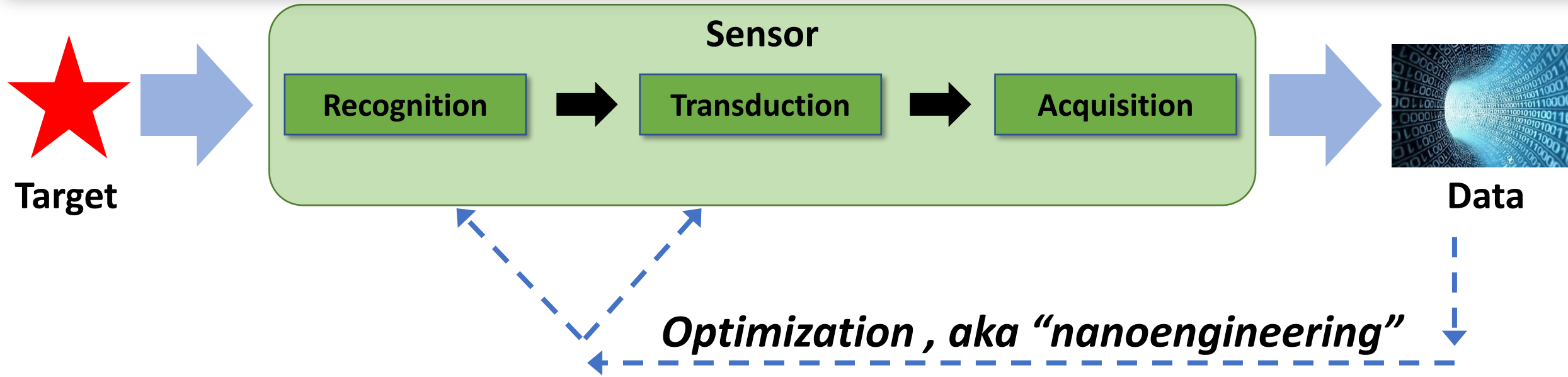
Target

Sensor

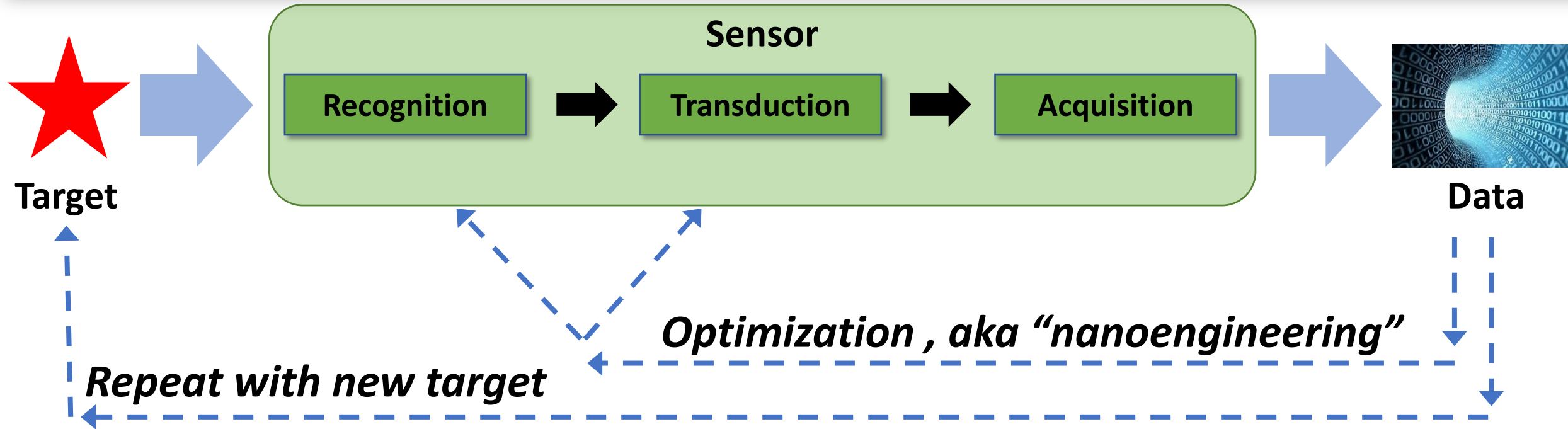
Role of Sensors and Sensor Data in Decision as a Service



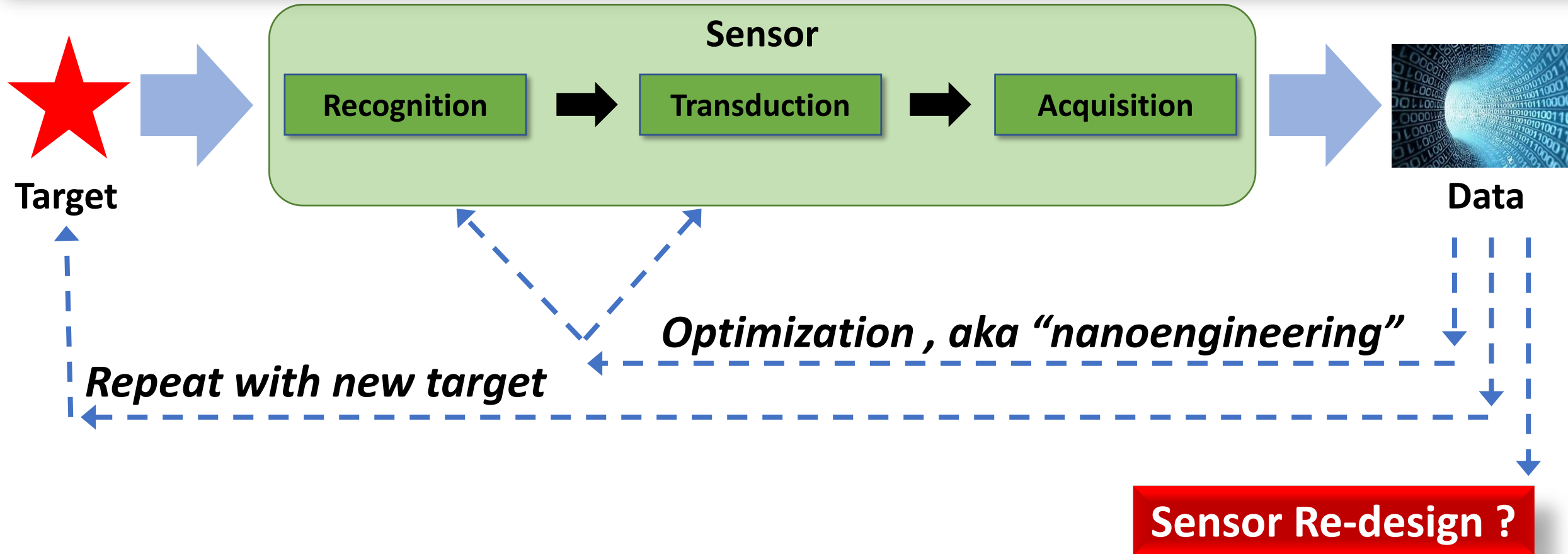
Role of Sensors and Sensor Data in Decision as a Service



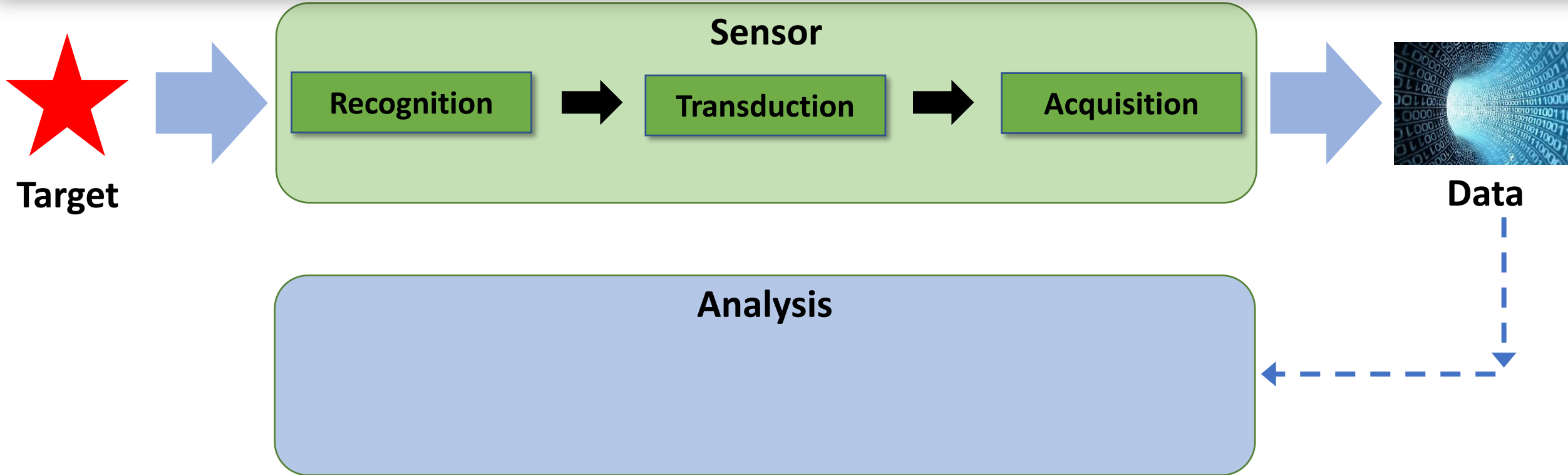
Role of Sensors and Sensor Data in Decision as a Service



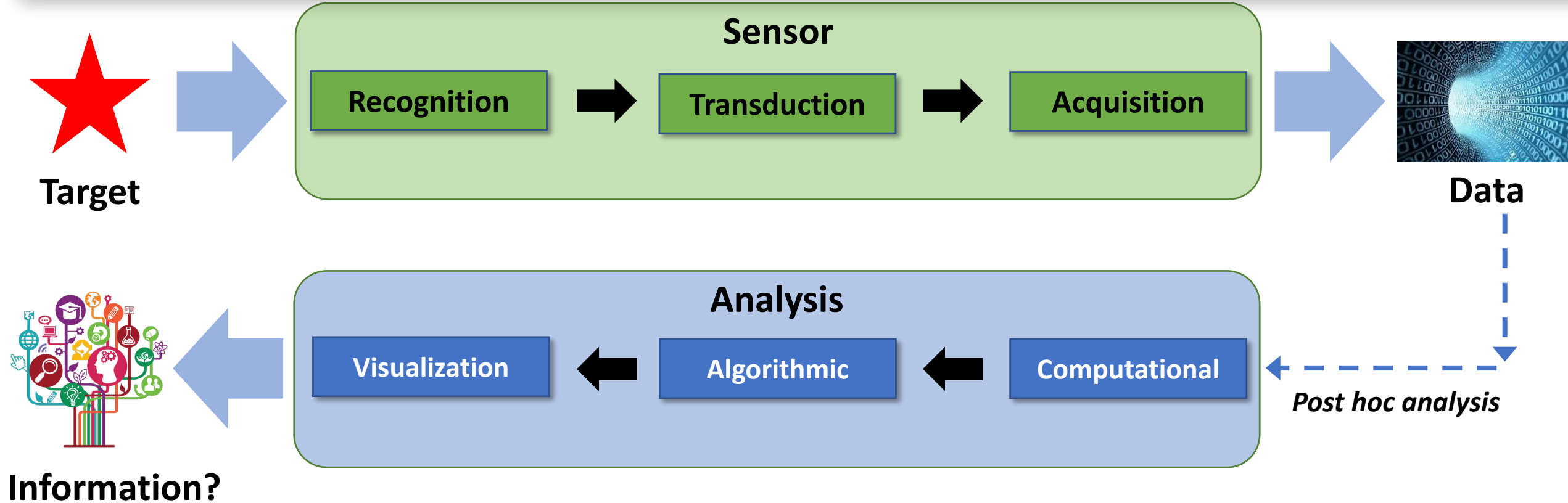
Role of Sensors and Sensor Data in Decision as a Service



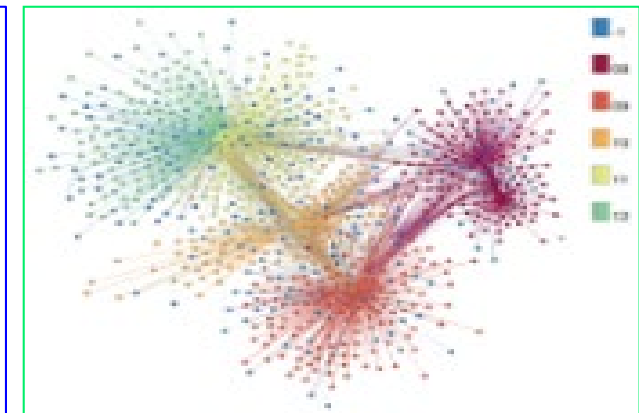
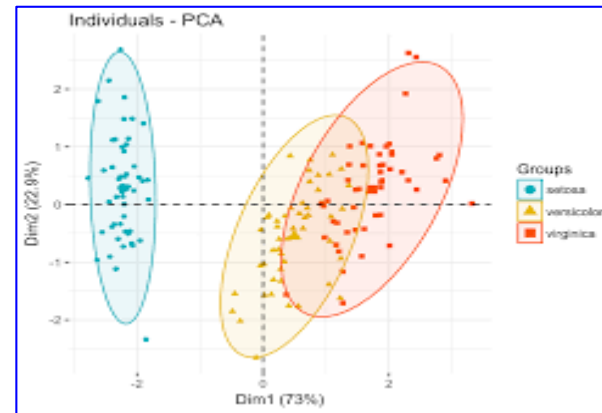
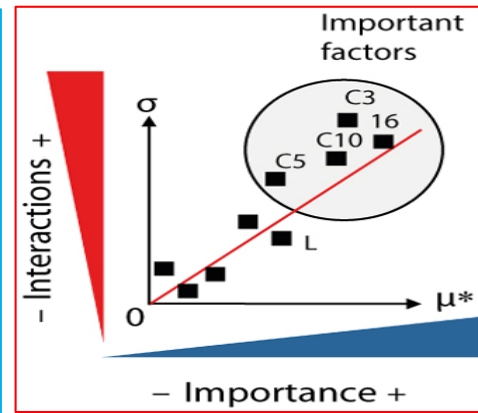
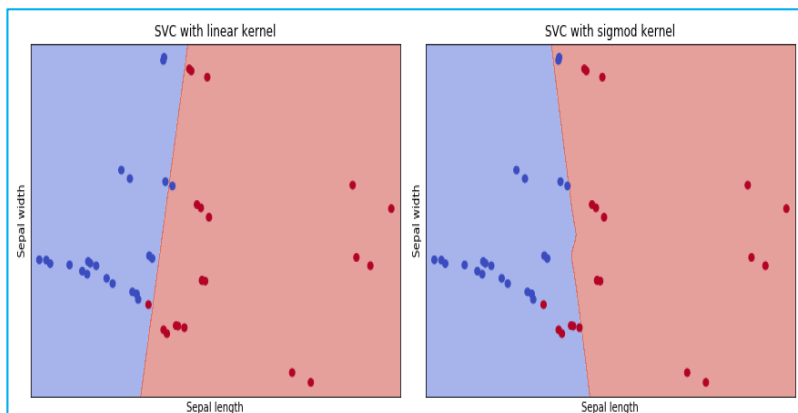
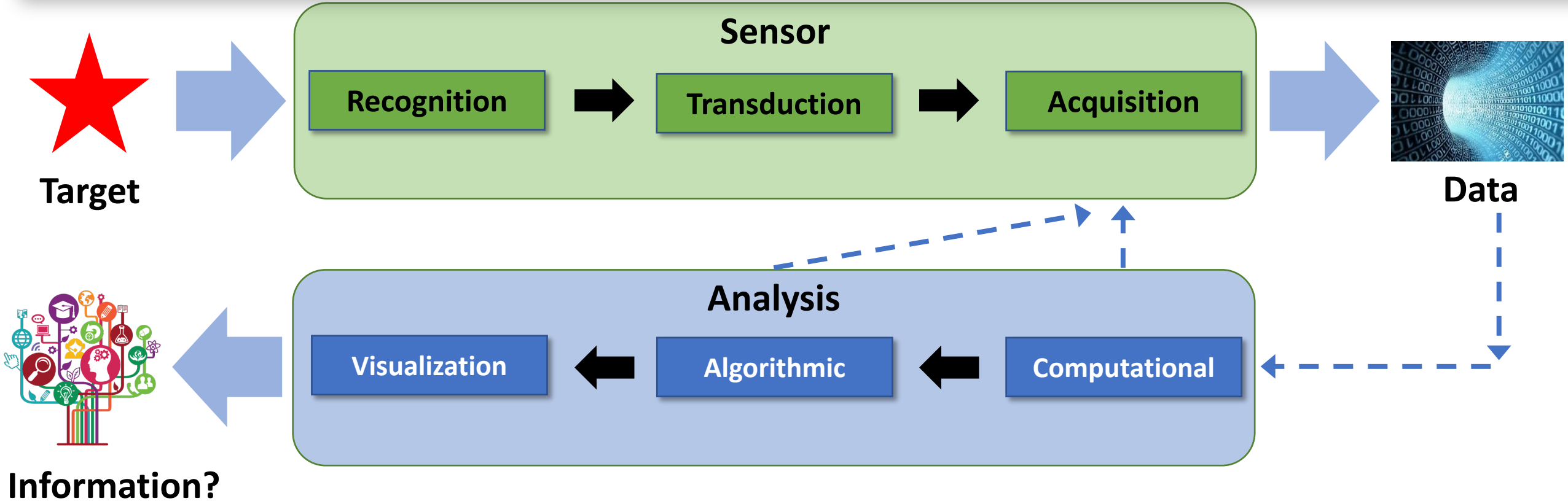
Role of Sensors and Sensor Data in Decision as a Service



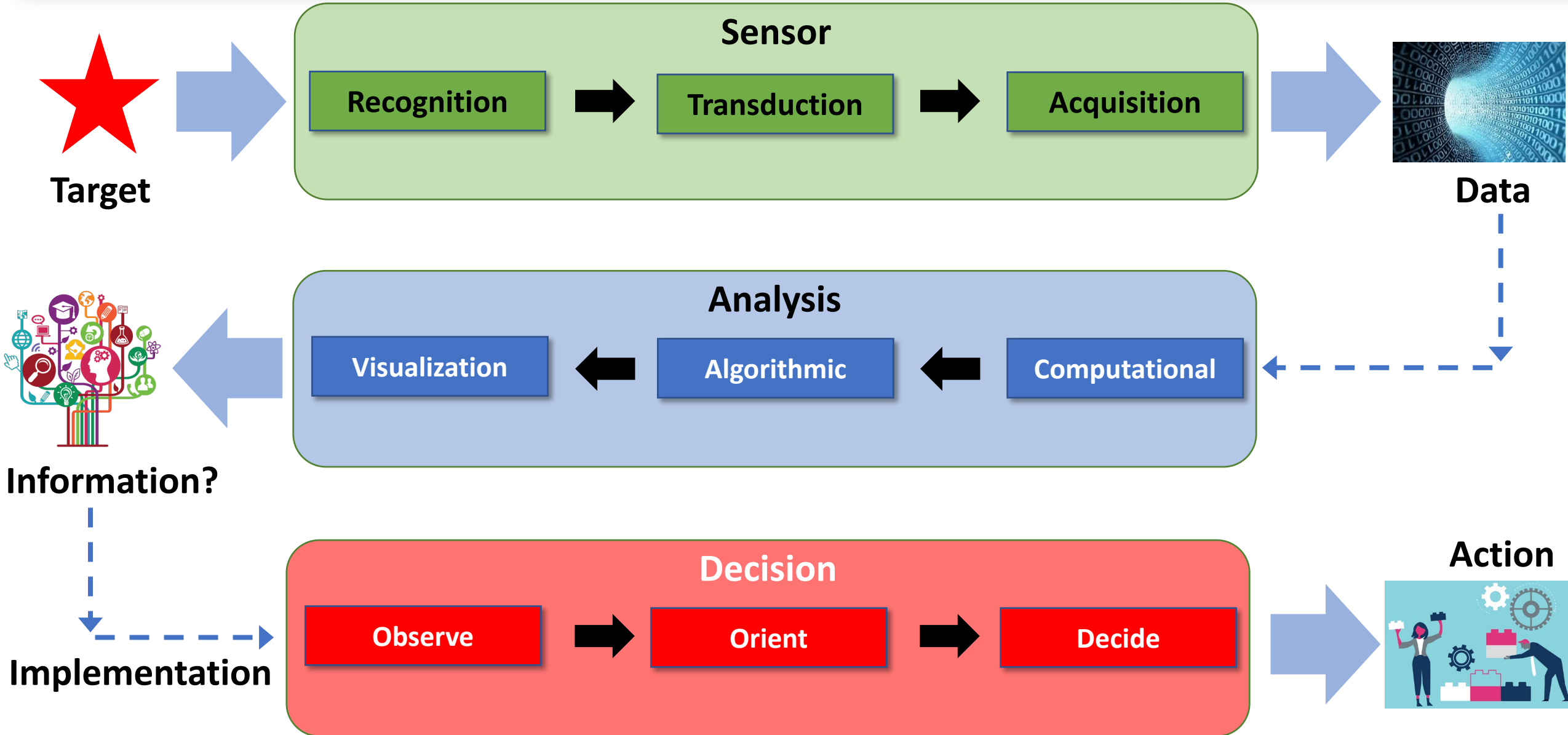
Role of Sensors and Sensor Data in Decision as a Service



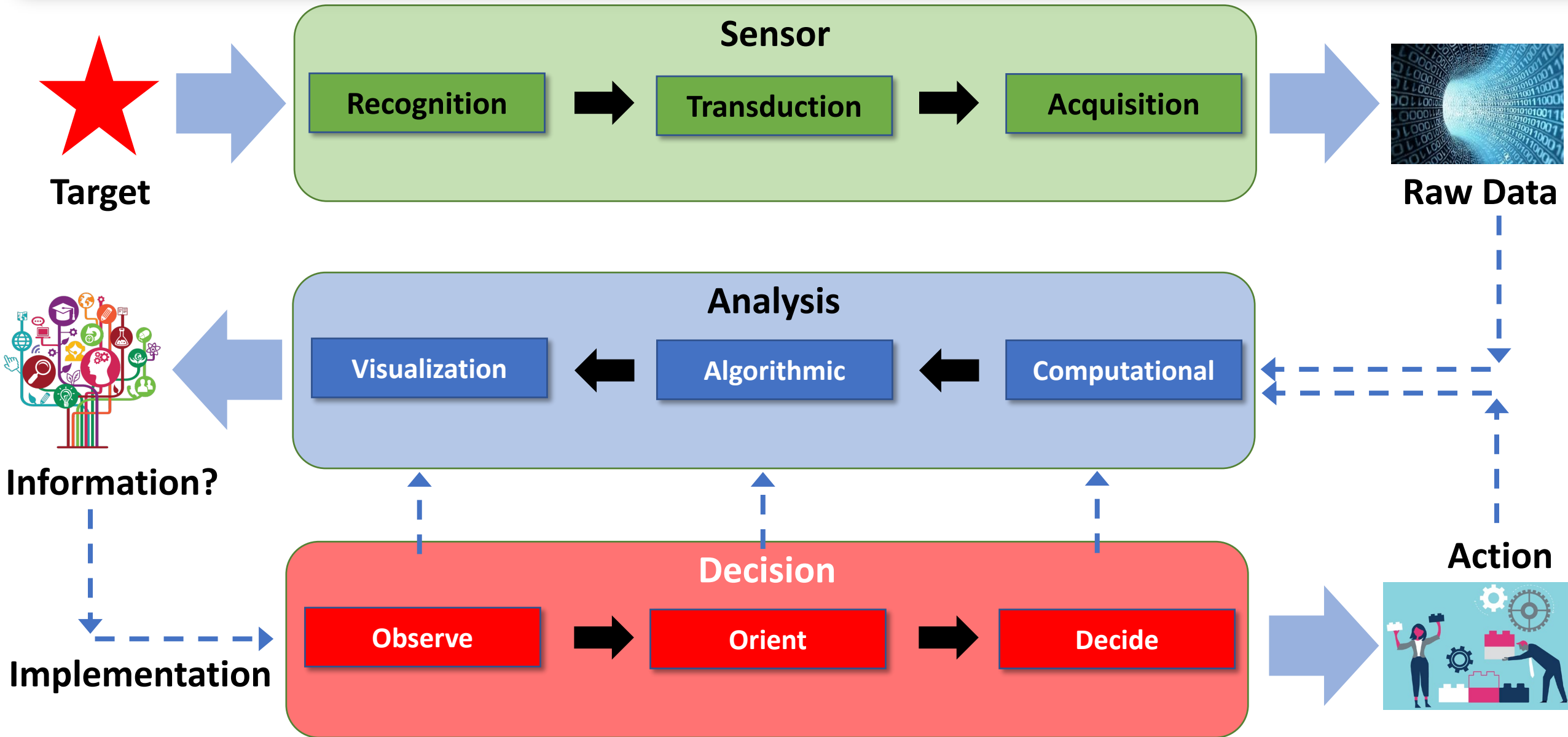
Role of Sensors and Sensor Data in Decision as a Service



Role of Sensors and Sensor Data in Decision as a Service



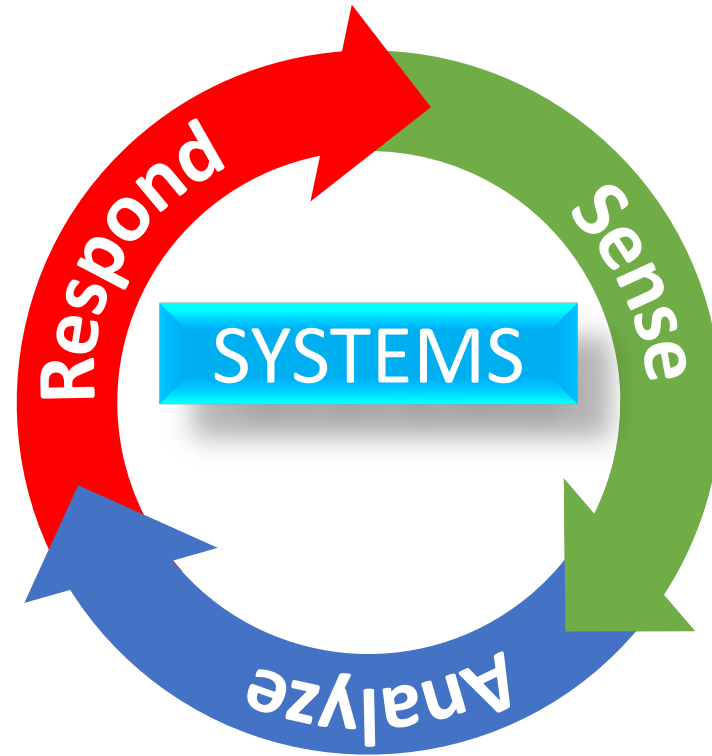
Data-Informed Decision as a Service



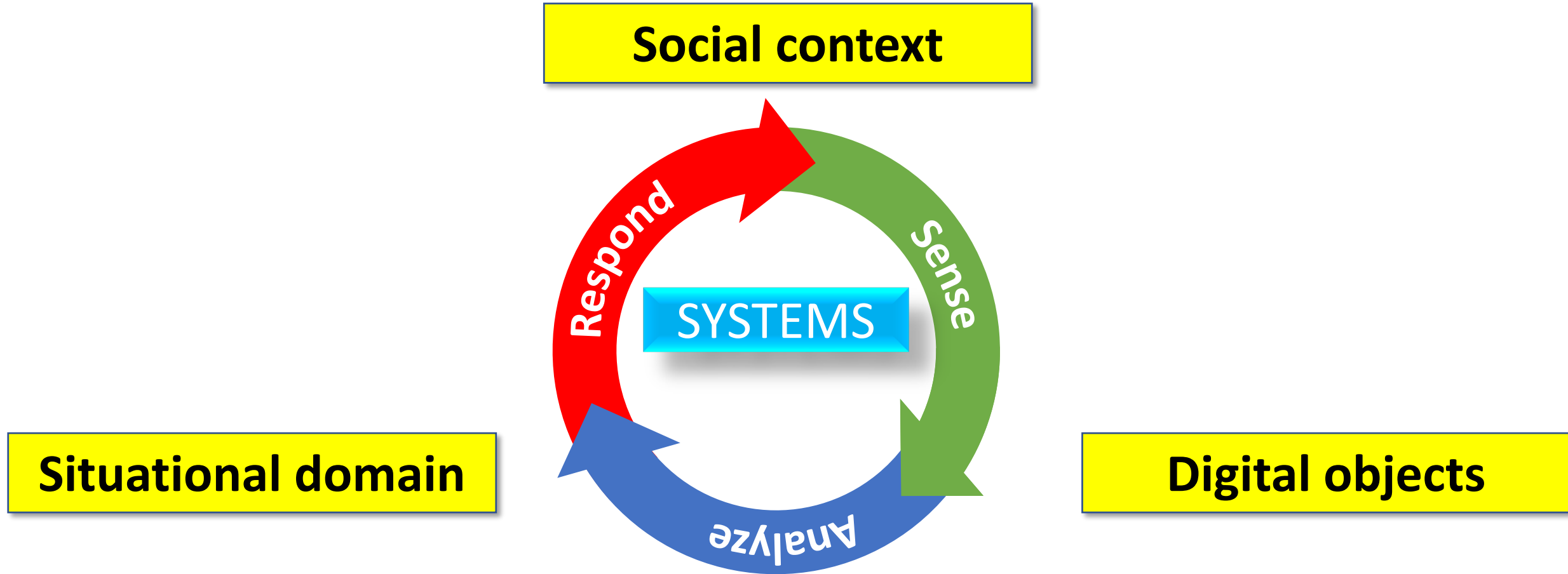
DIDA'S

Data-Informed Decision as a Service

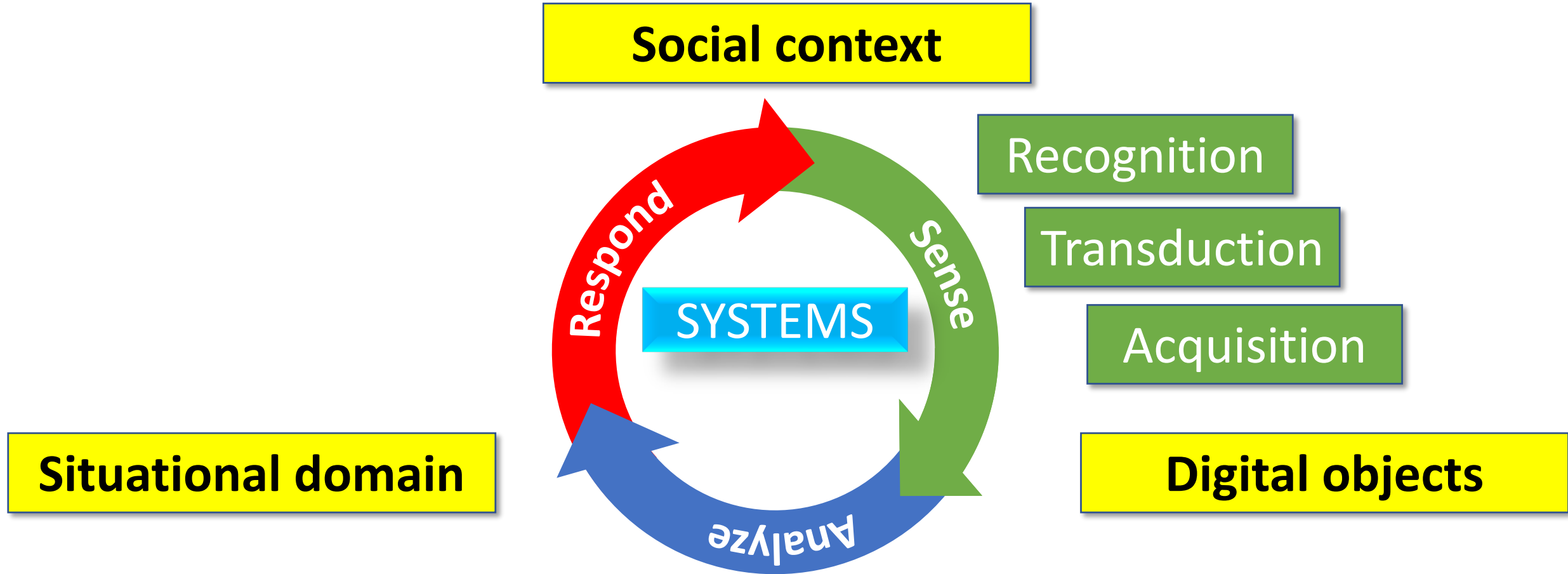
DIDA'S includes Sense, Analyze, Response, Systems (SARS)



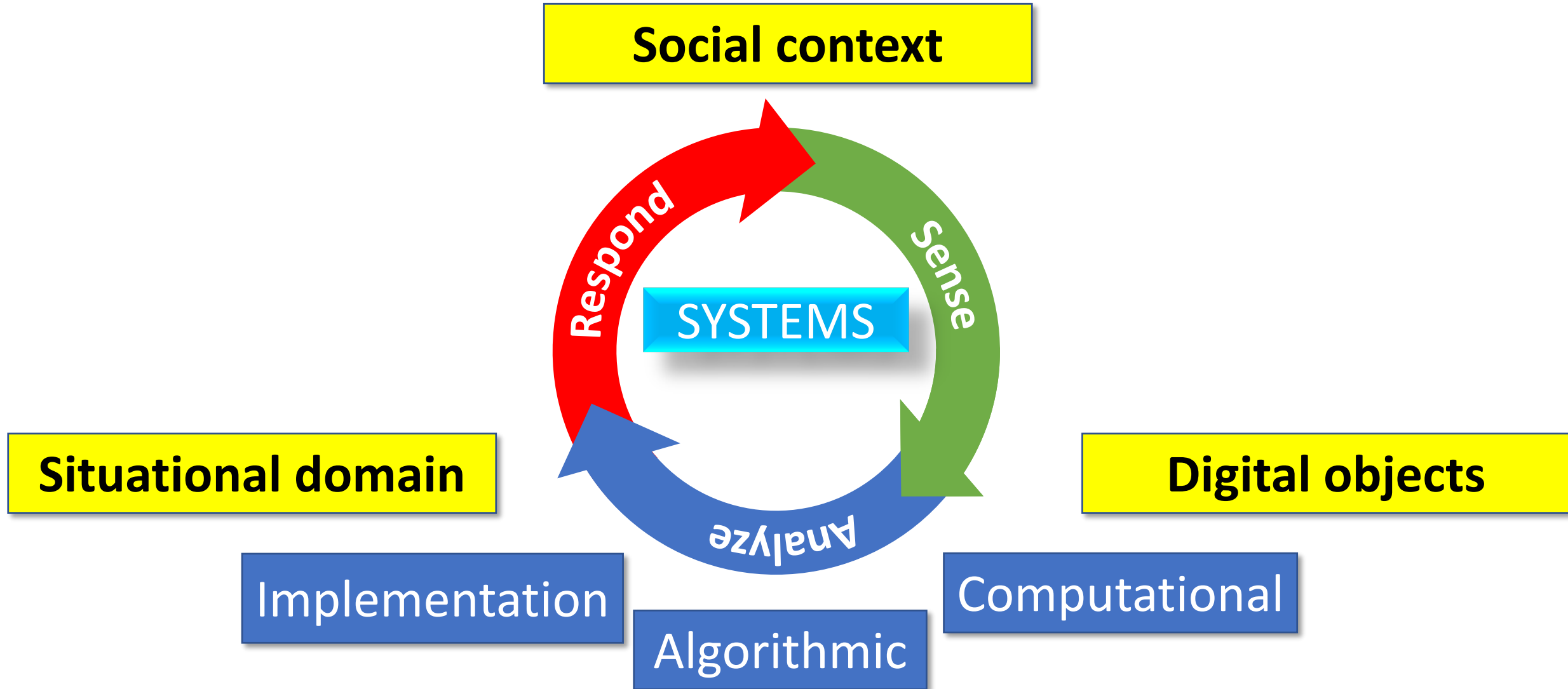
DIDA'S includes SARS context, objects and domains



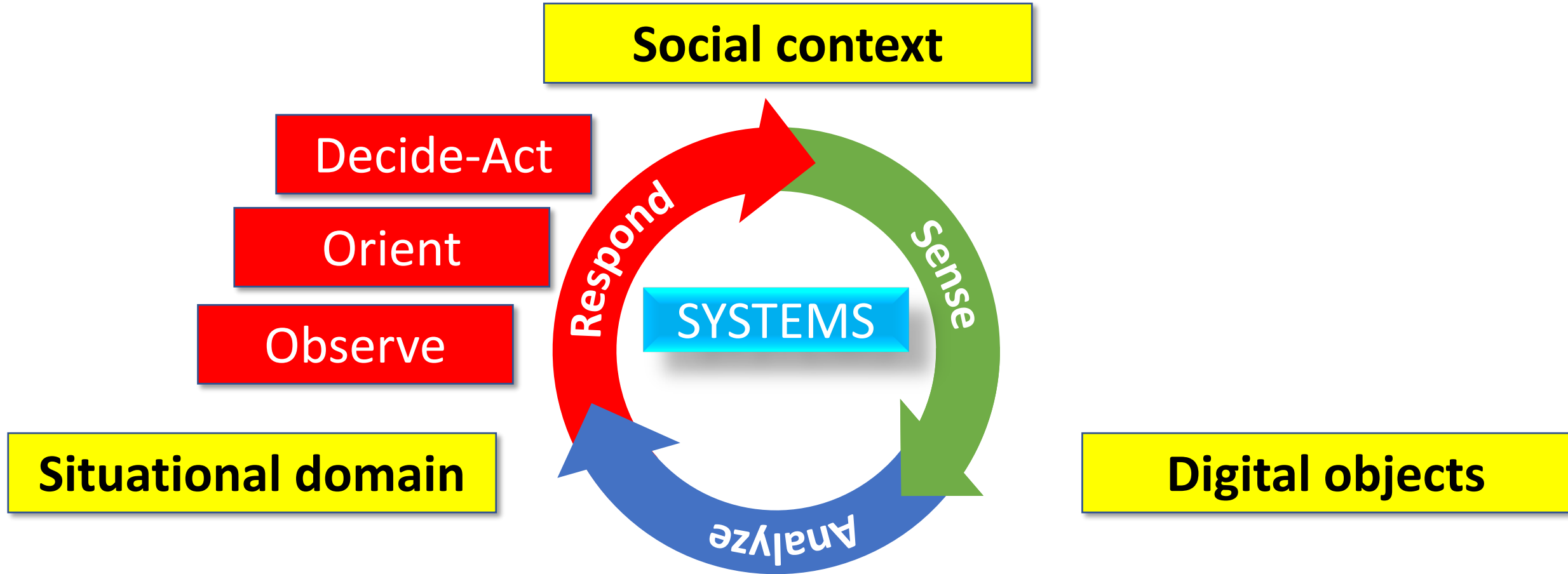
Granularity of the Data-Informed Decision as a Service



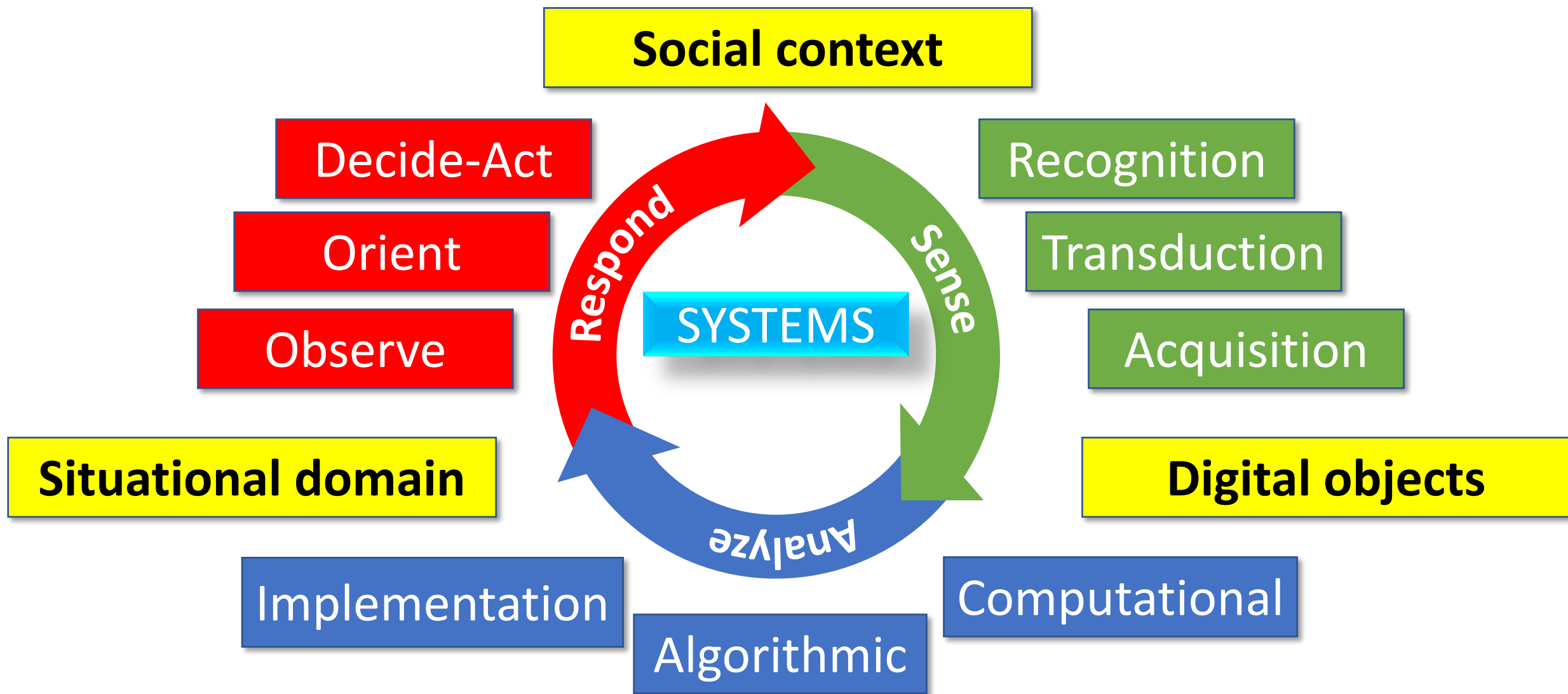
Granularity of the Data-Informed Decision as a Service



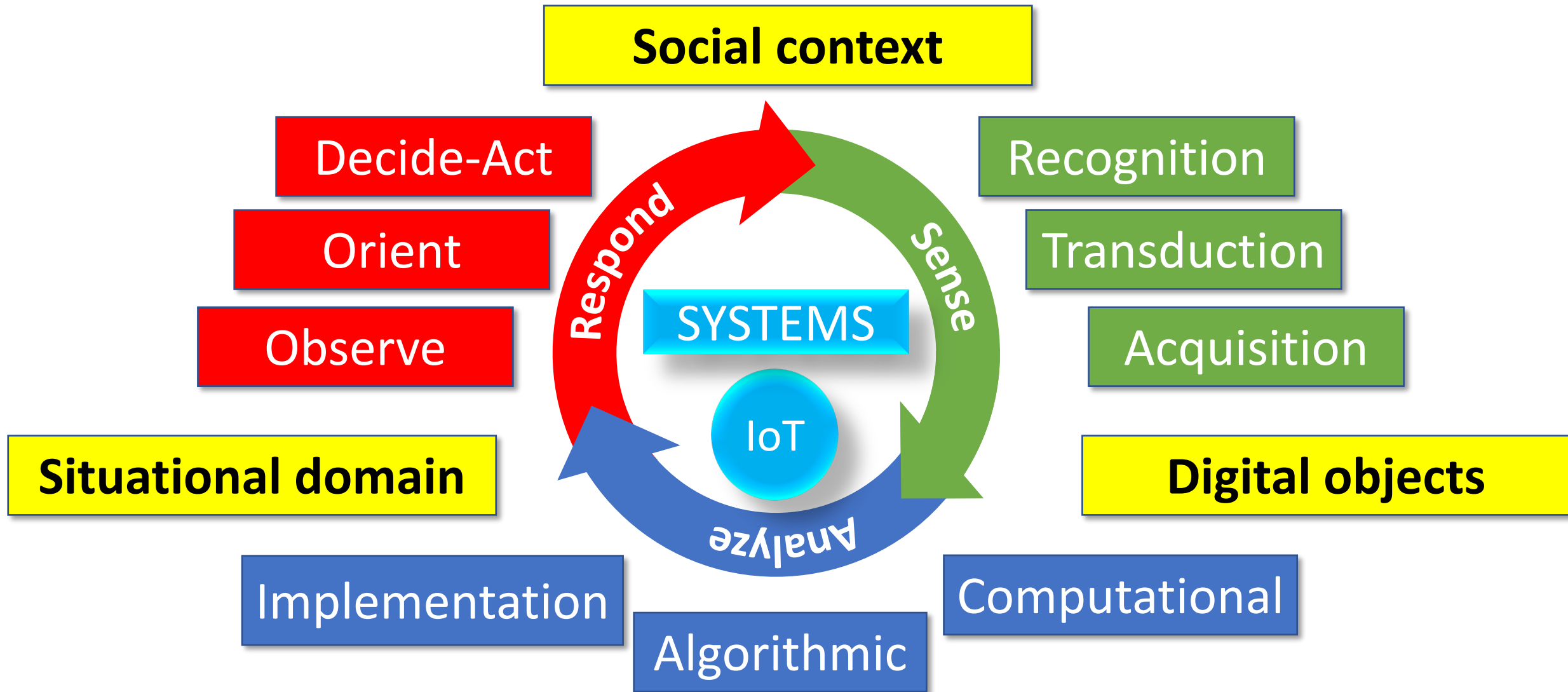
Granularity of the Data-Informed Decision as a Service



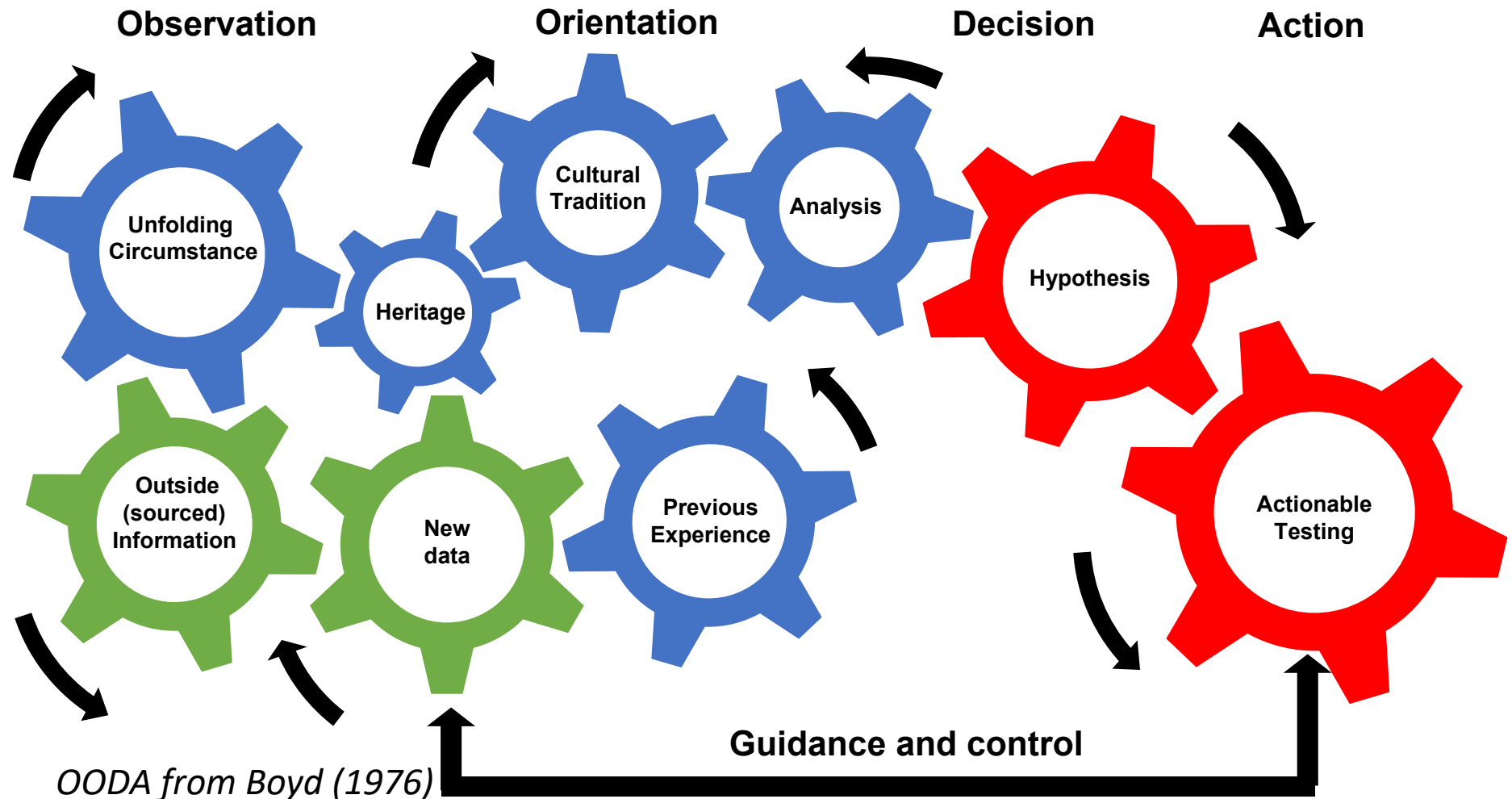
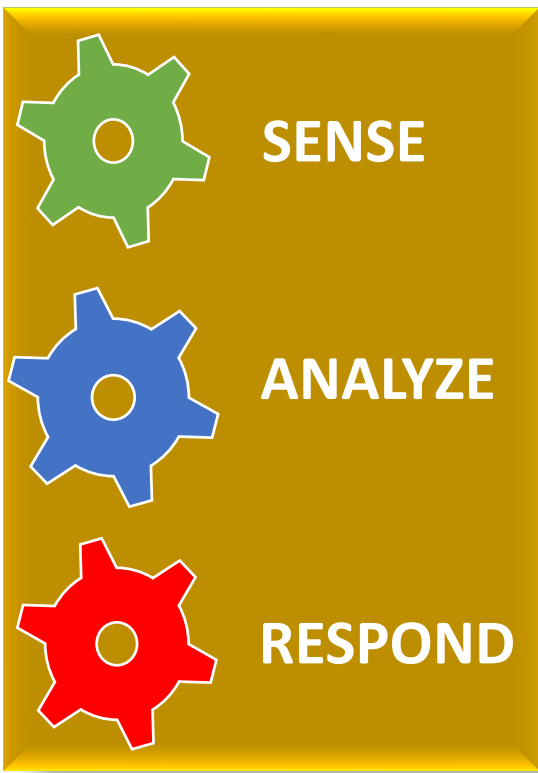
DIDA'S : Data-Informed Decision as a Service with SARS



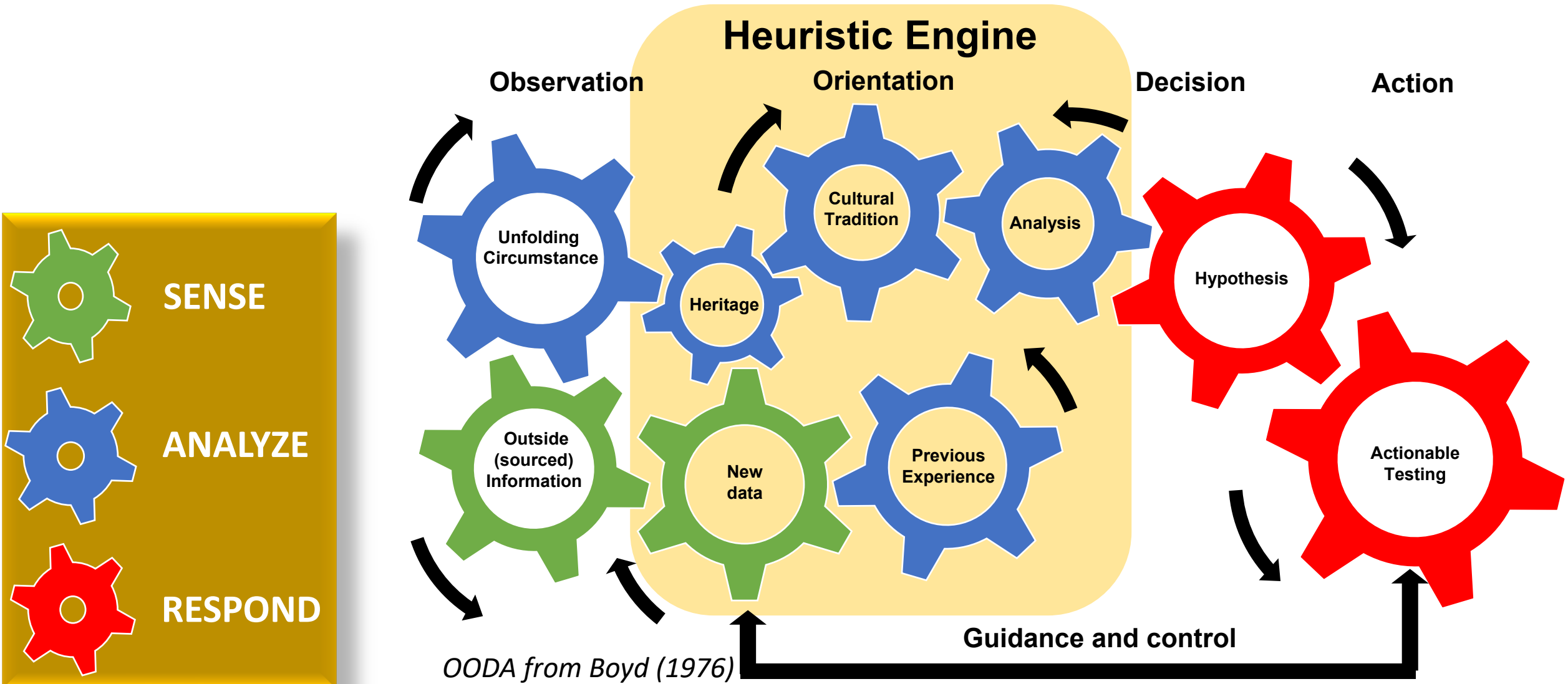
DIDA'S : Data-Informed Decision as a Service



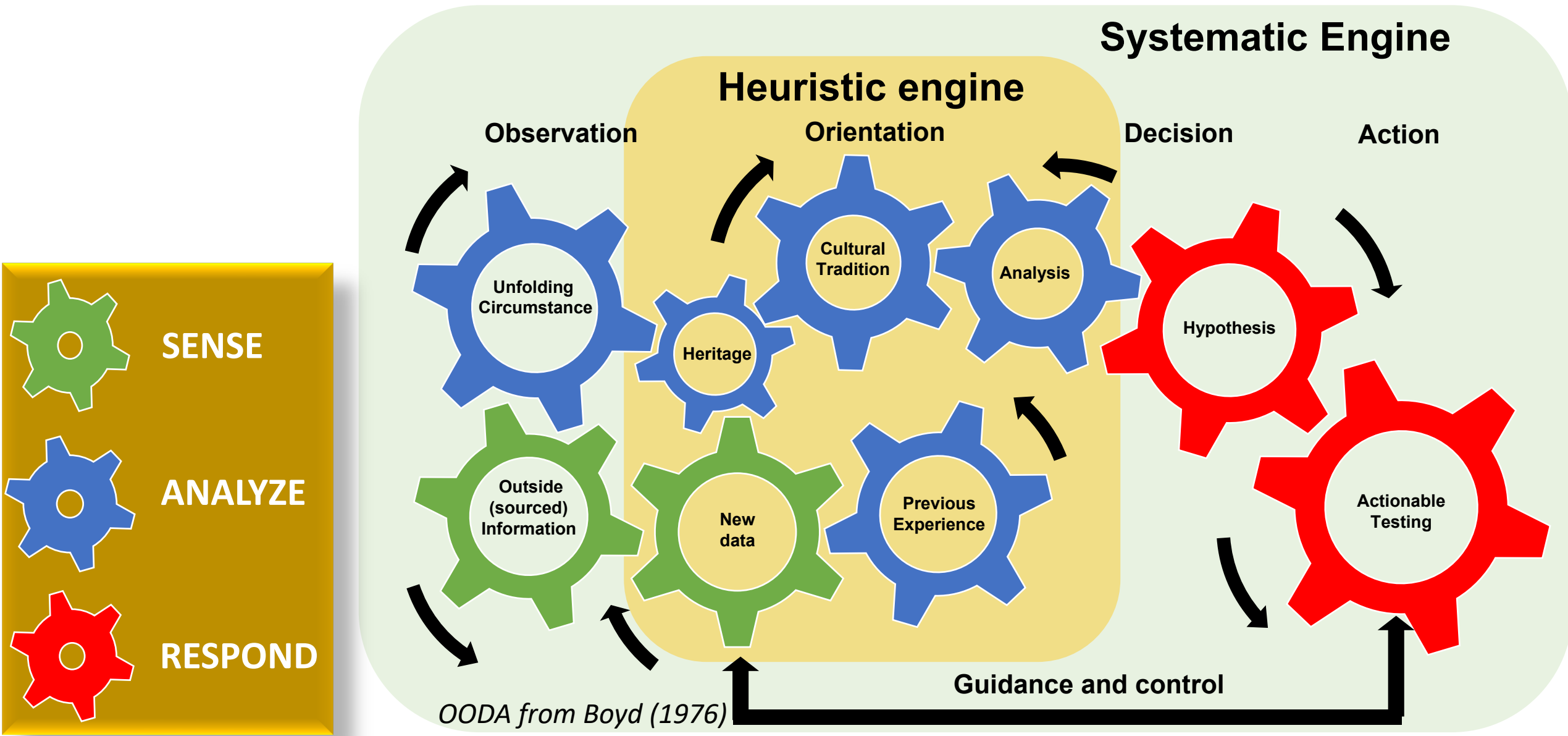
DIDA'S ENGINES : Data-Informed Decision Engines



DIDA'S ENGINES : Data-Informed Decision Engines



DIDA'S ENGINES : Data-Informed Decision Engines



The Value of DIDA'S (Data-Informed Decision as a Service)



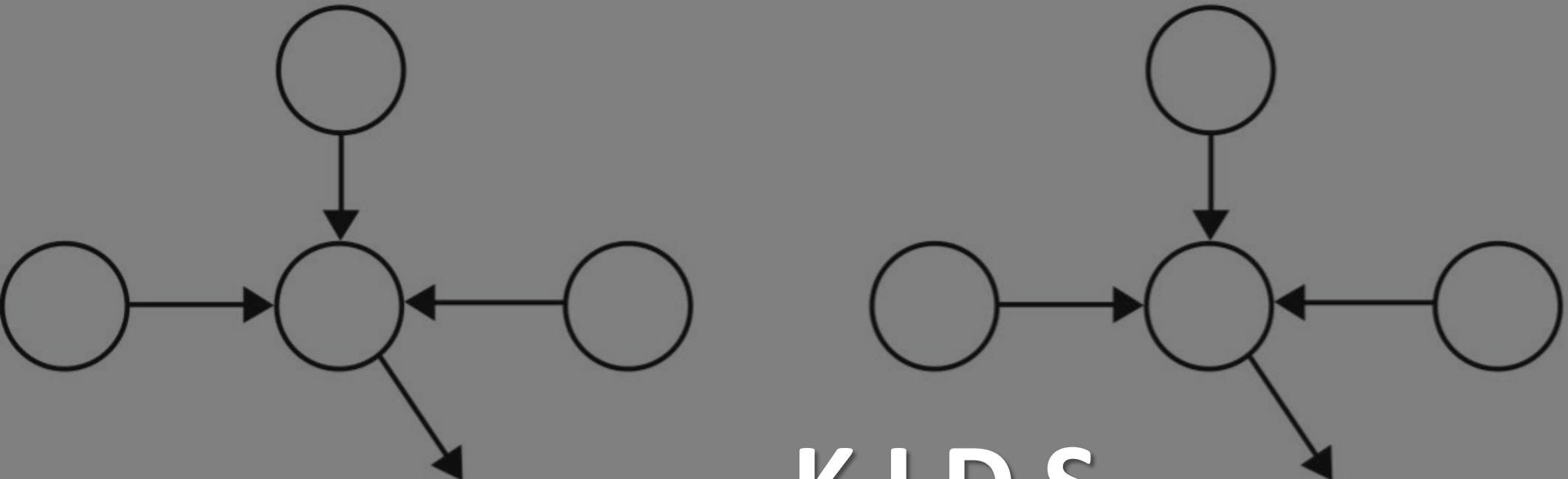
Is there consumer demand for this vegetable?



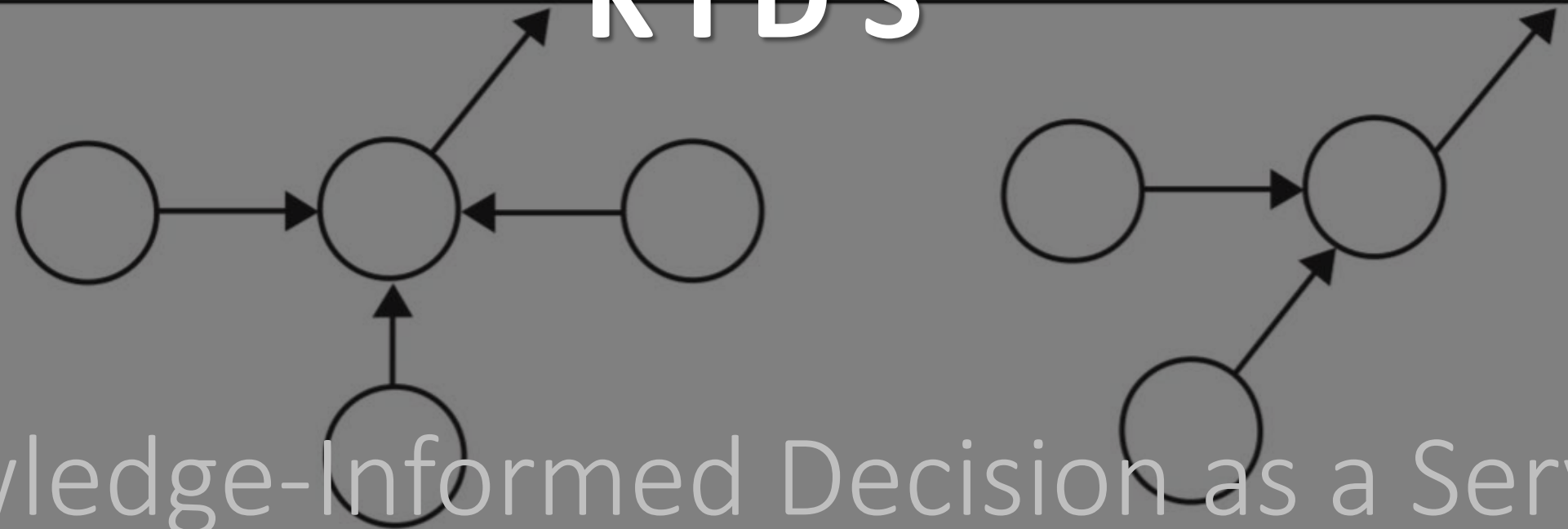
The Value of DIDA'S (Data-Informed Decision as a Service)

To realize the actual value of DIDA'S, the tool must be useful to end-users, if they can use the tool to ask questions and receive actionable information or if it can support the decision making process

The journey to DIDA'S must include and/or create and/or connect a multitude of domains to source data and synthesize relevant information. DIDA'S may lead to knowledge-informed decision as a service.



KIDS

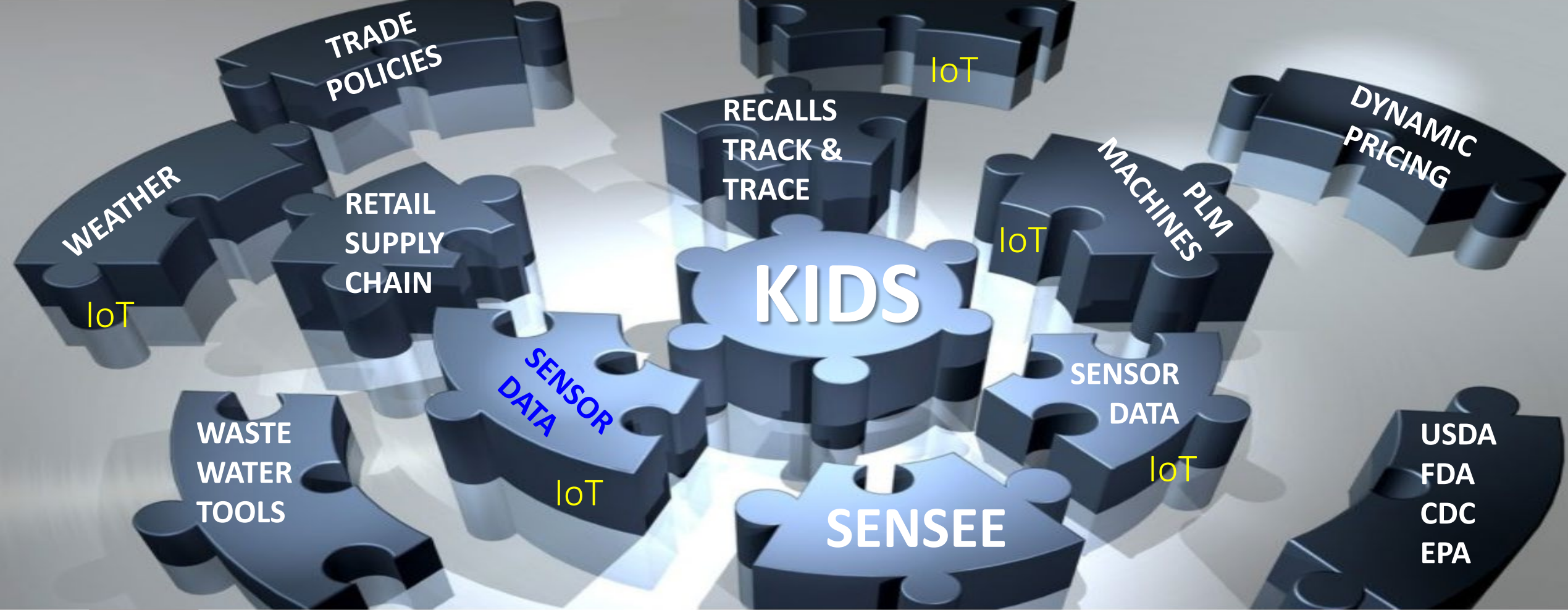


Knowledge-Informed Decision as a Service

KIDS

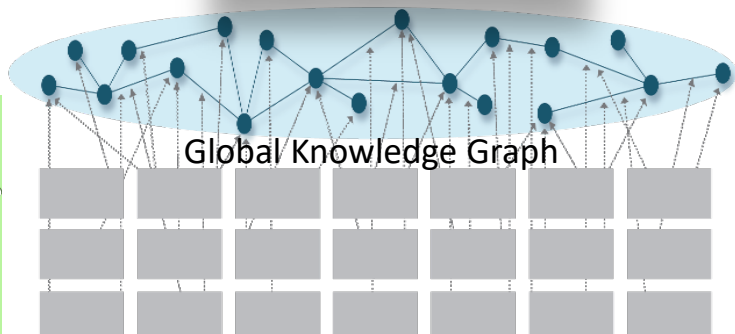
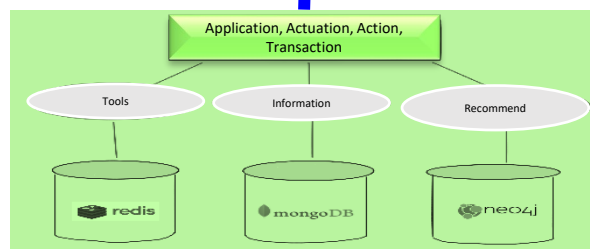
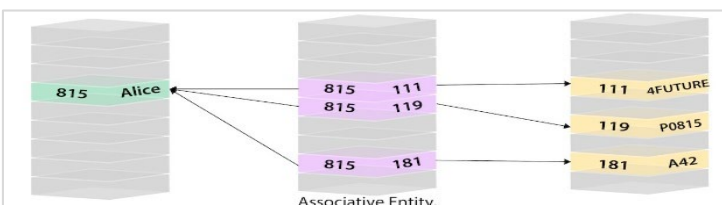
Knowledge-Informed Decision as a Service

KIDS is an open plan platform concept. Platforms are comprised of multiple applications and integrated solutions with embedded tools and databases that function as complete, seamless environments. Product innovation platforms are intended to support groups of users collaborating across various levels, domains, business units, and the ecosystem. These capabilities are increasingly needed throughout the entire extended enterprise in almost every vertical, agnostic of the type of application or function or users, including farmers, meat packers, produce growers, retail stores, customers, suppliers, and business partners. Developing open platform tools and technologies are not limited to any one domain because these modular tools can be applied, used and re-configured for re-use, almost anywhere, for example: error correction, search engine algorithms, NLU/NLP (natural language processing), automated feature engineering, drag and drop functions, analytics, workflows, and services, such as KIDS, where “open” means ‘plug & play’ user friendly human-computer interactions and interoperability between system of systems.

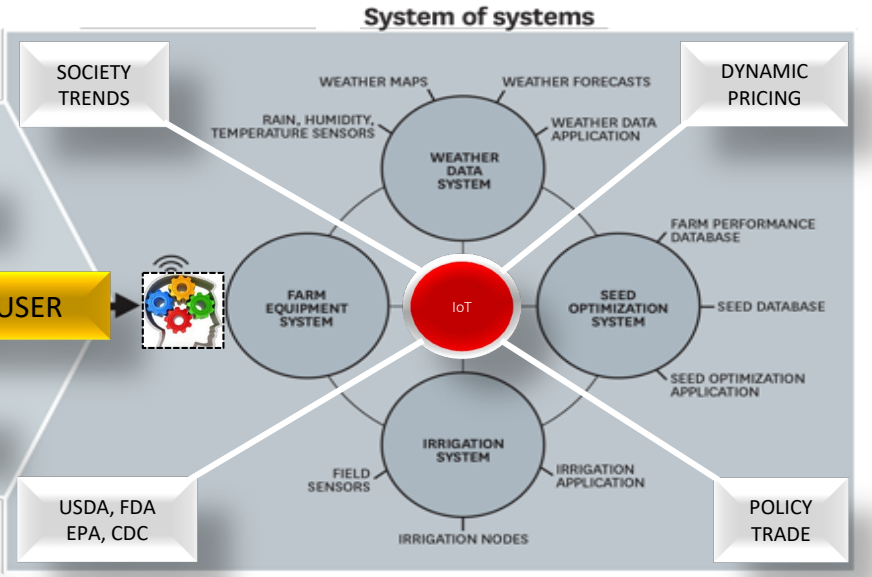
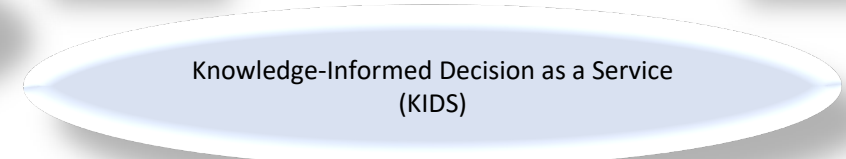
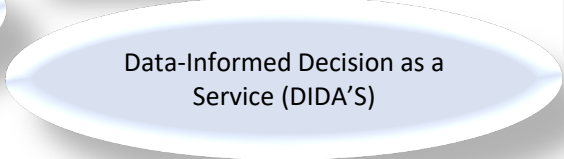
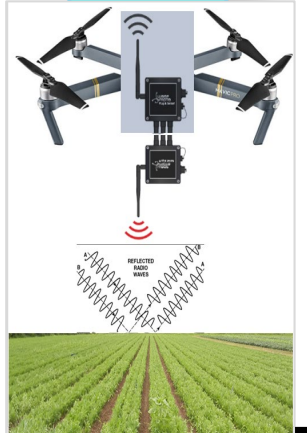
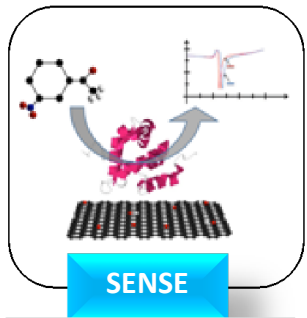


DATA

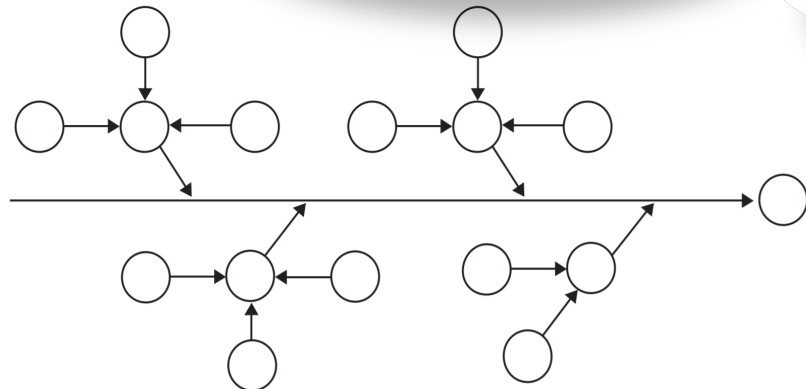
KNOWLEDGE



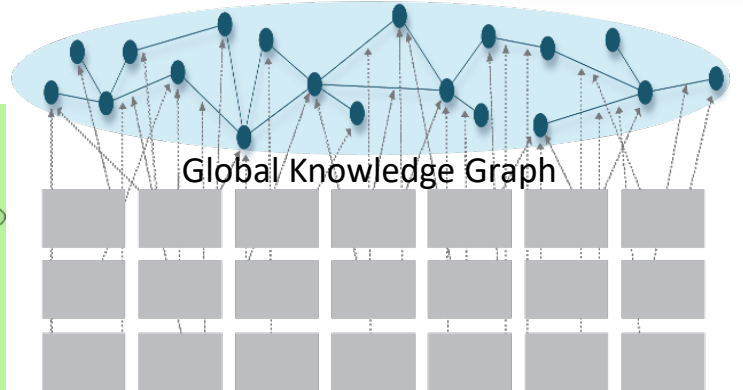
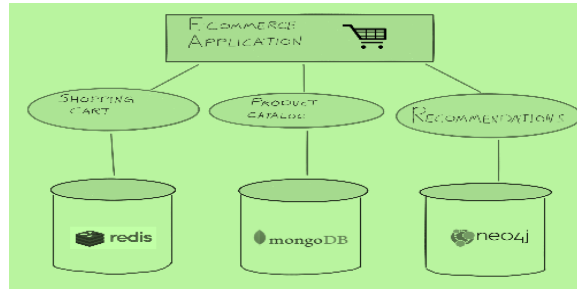
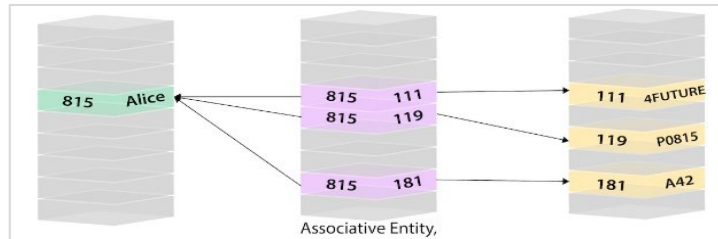
At the end, it is really all about KIDS



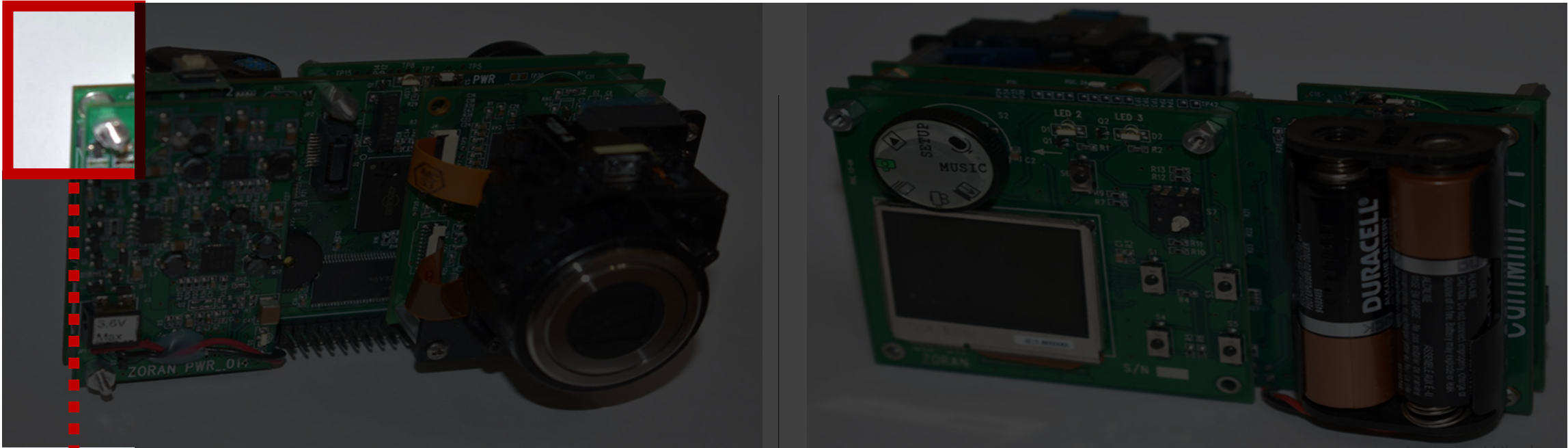
DATA

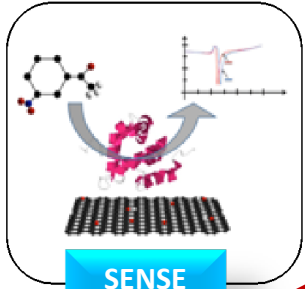


KNOWLEDGE

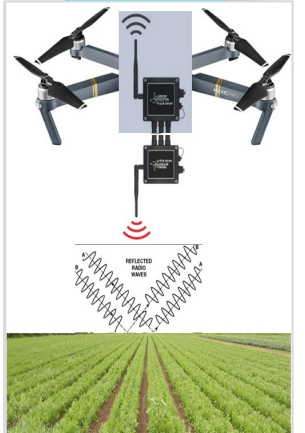


We are not even close



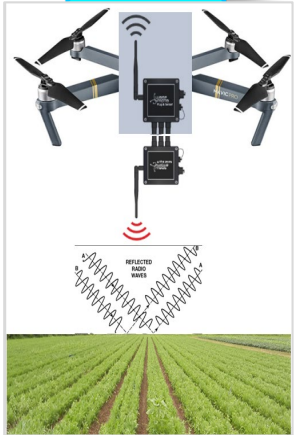
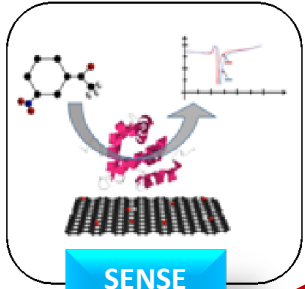


SENSE



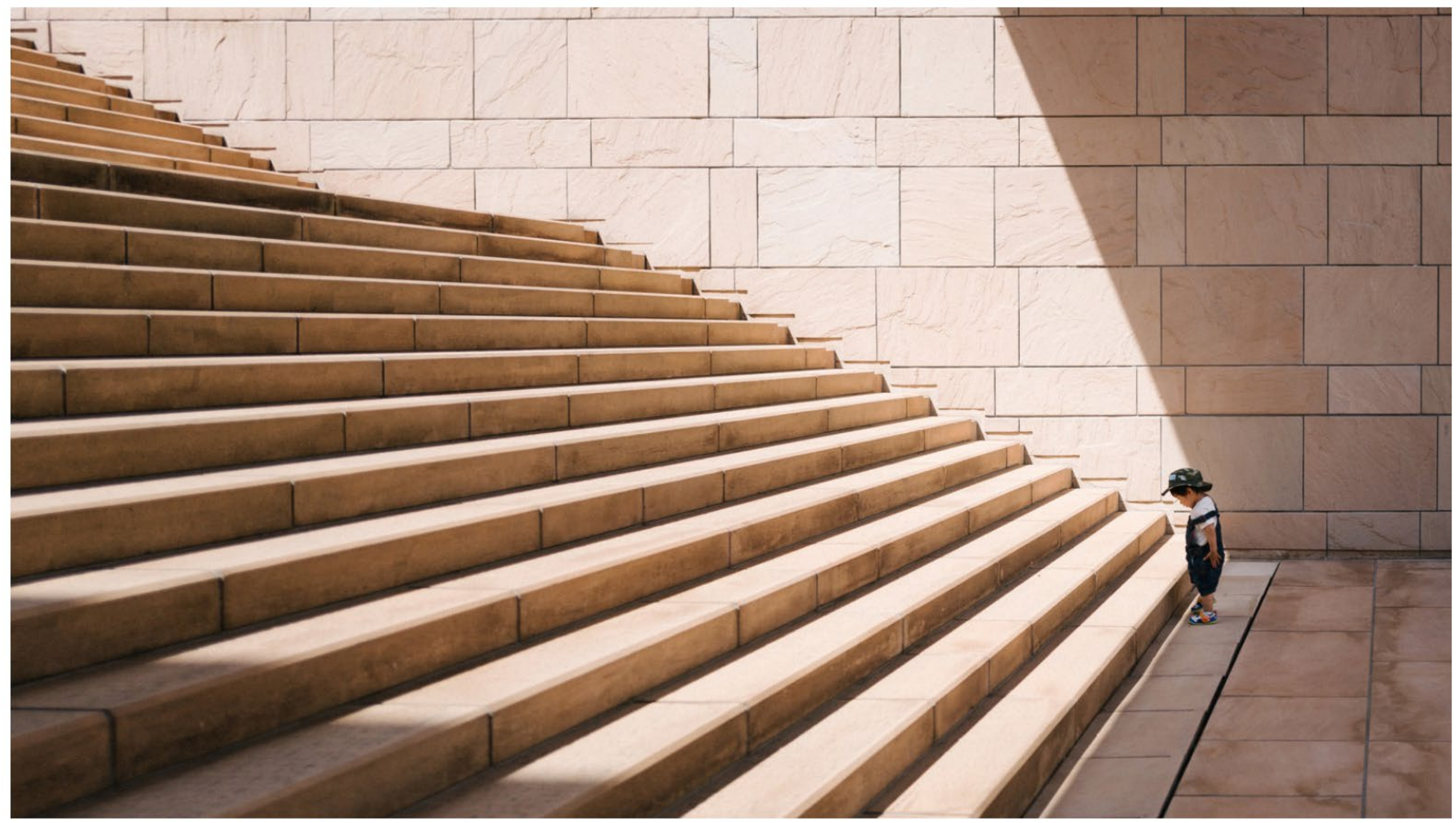
We are just starting here

SENSEE



We are just starting here

SENsor **SE**arch **E**ngine





Data

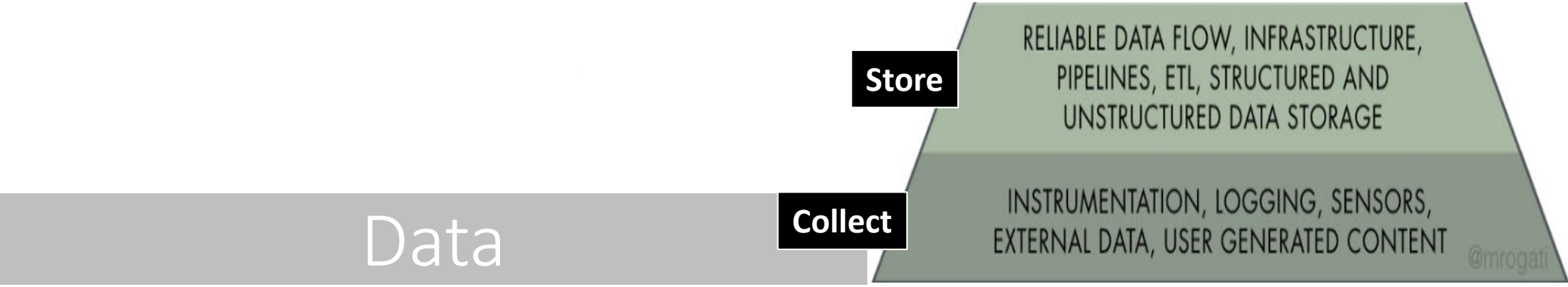


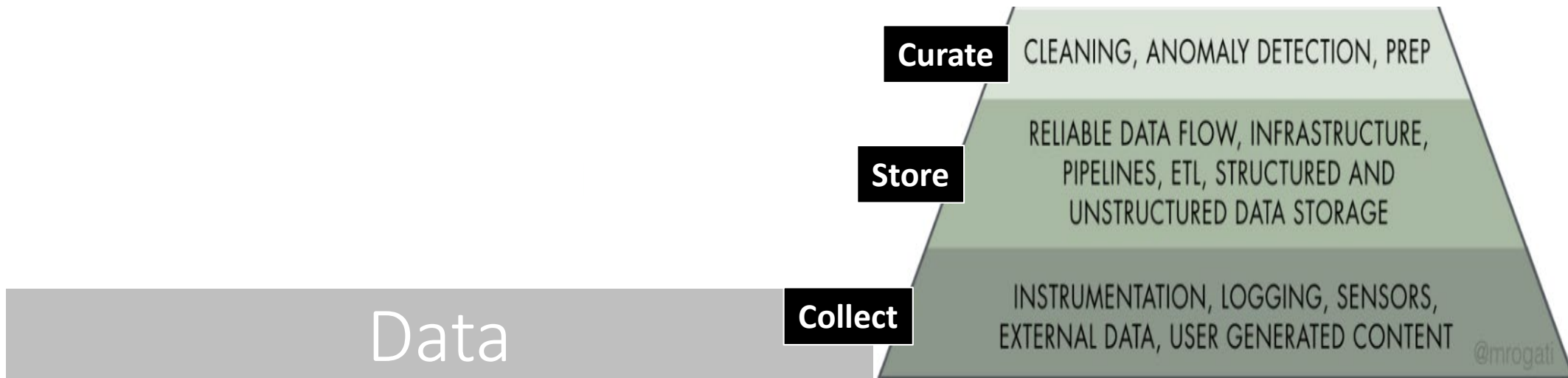
Data

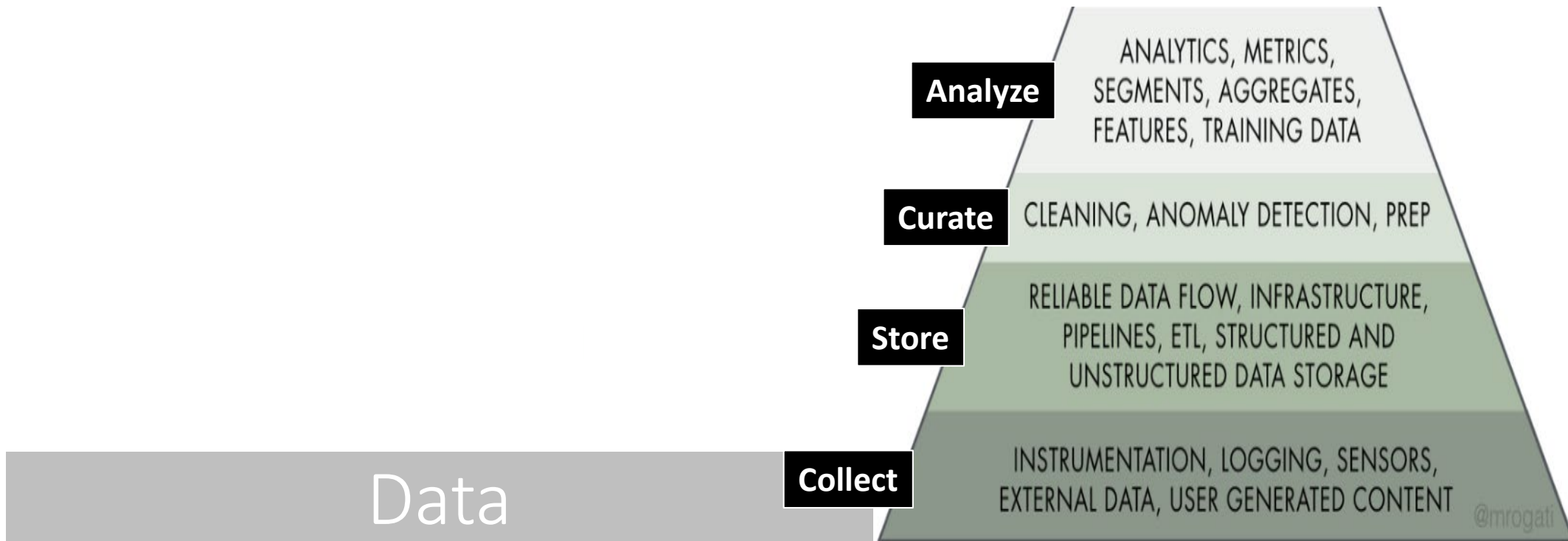
Collect

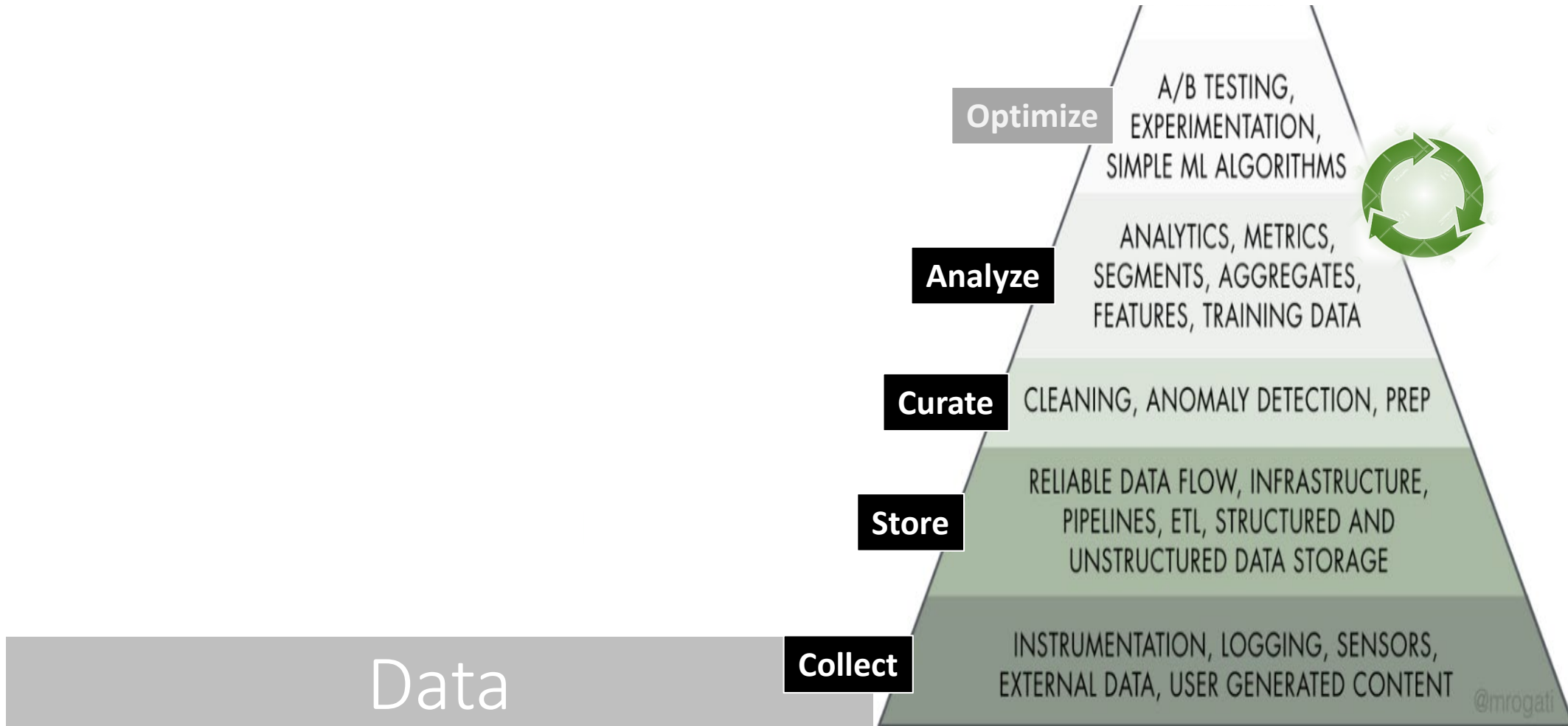
INSTRUMENTATION, LOGGING, SENSORS,
EXTERNAL DATA, USER GENERATED CONTENT

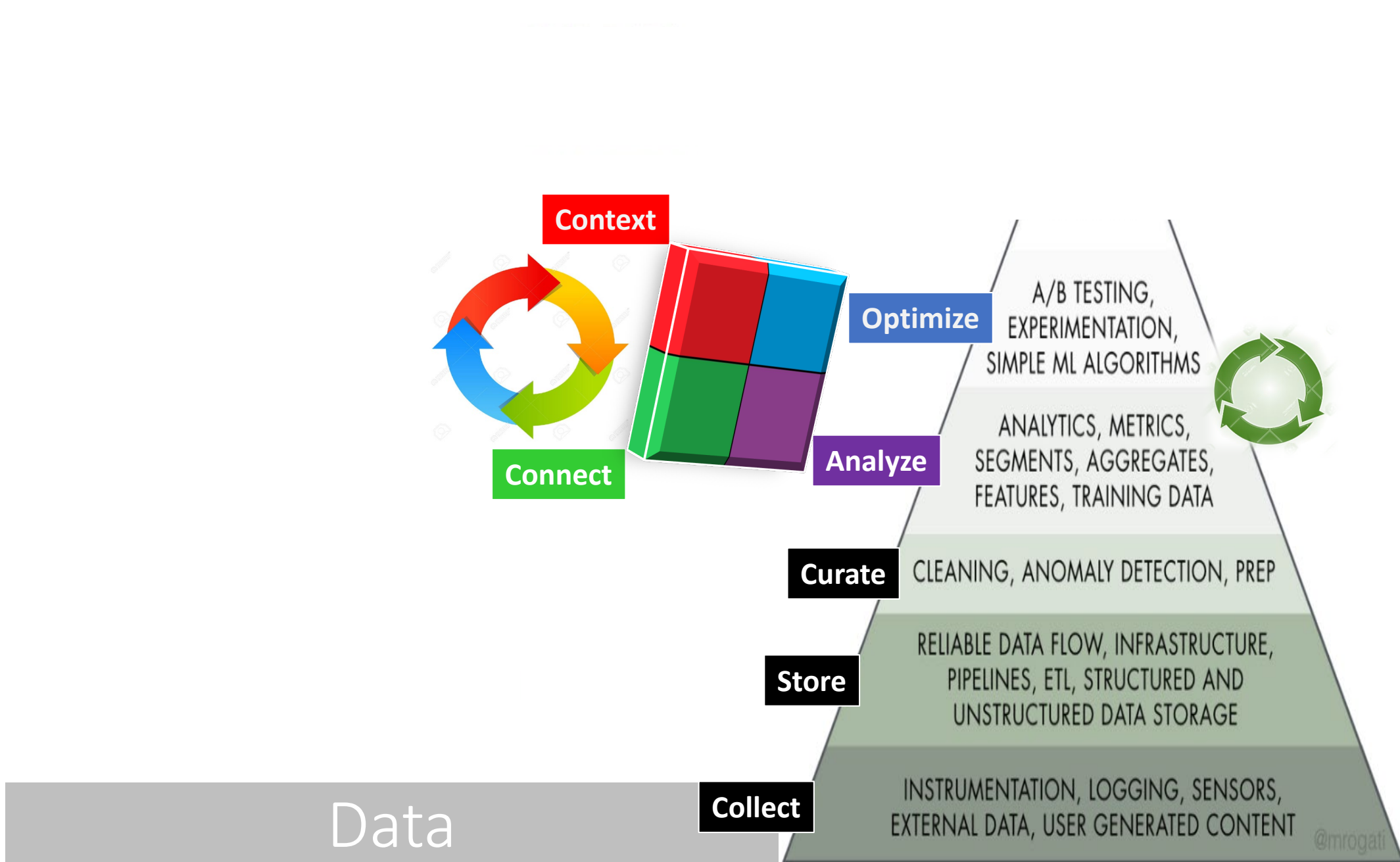
@mrogati

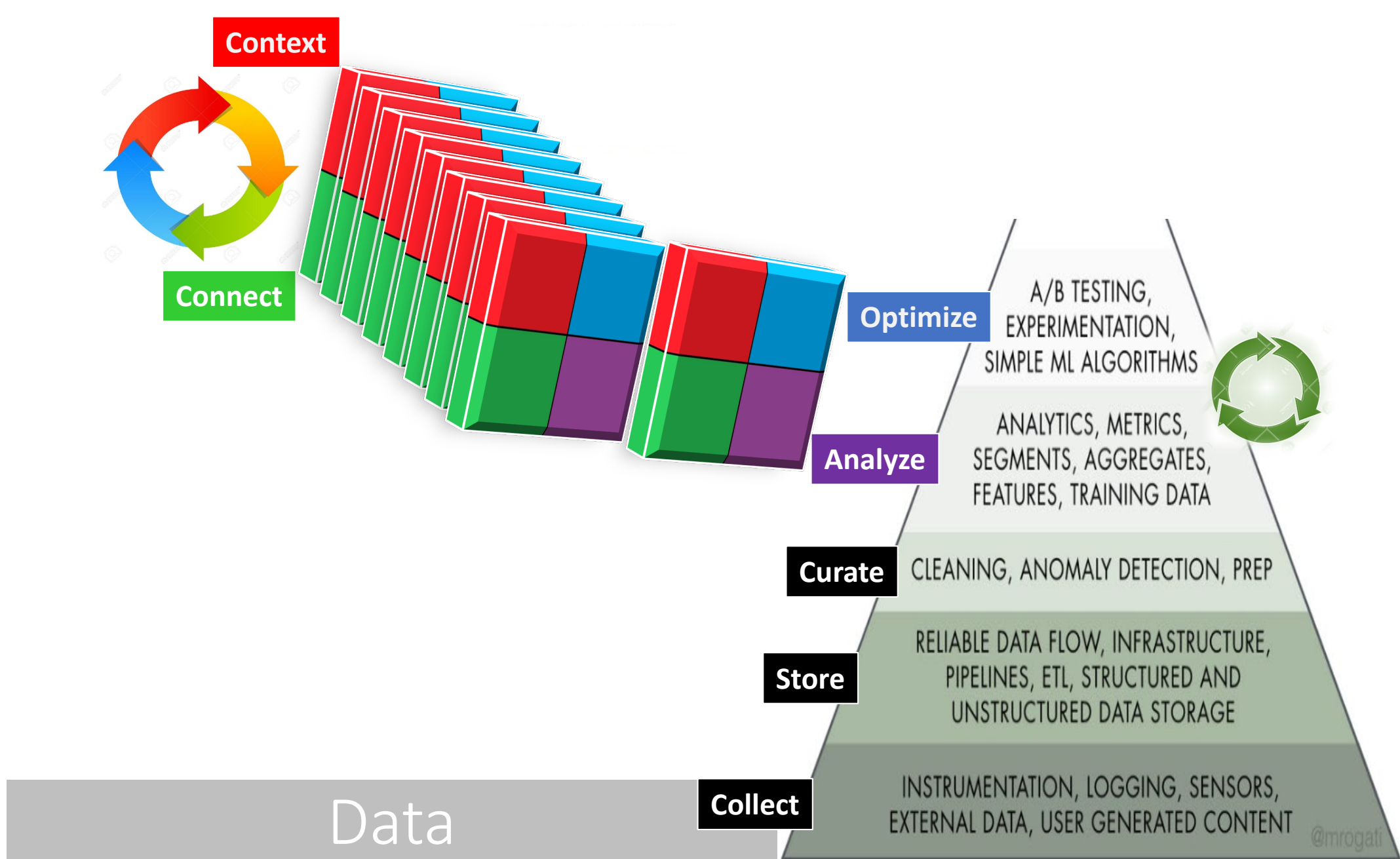


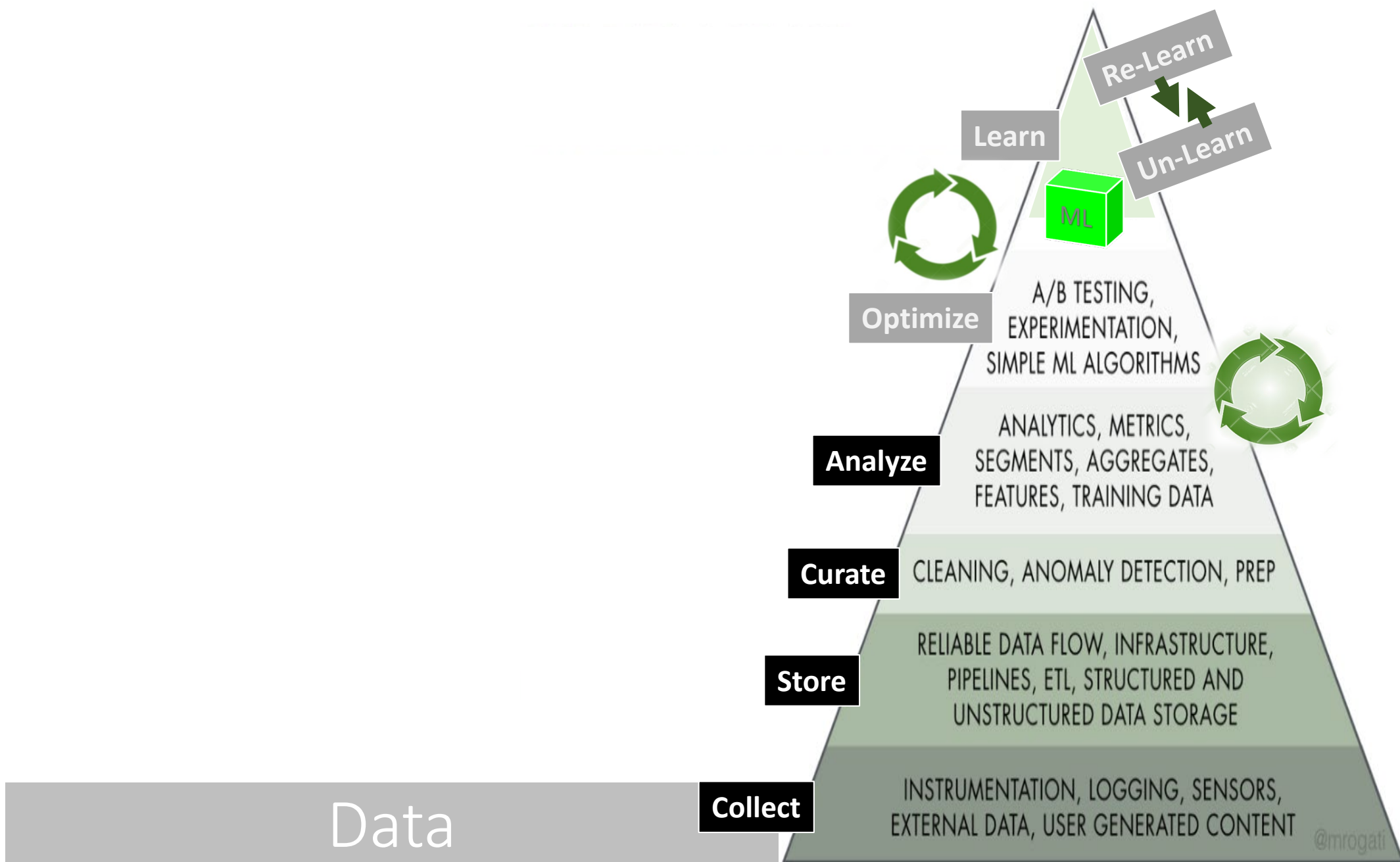


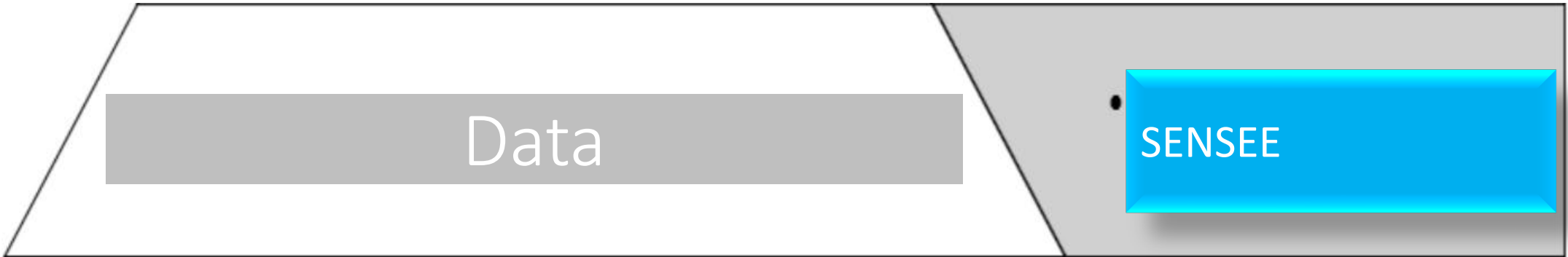






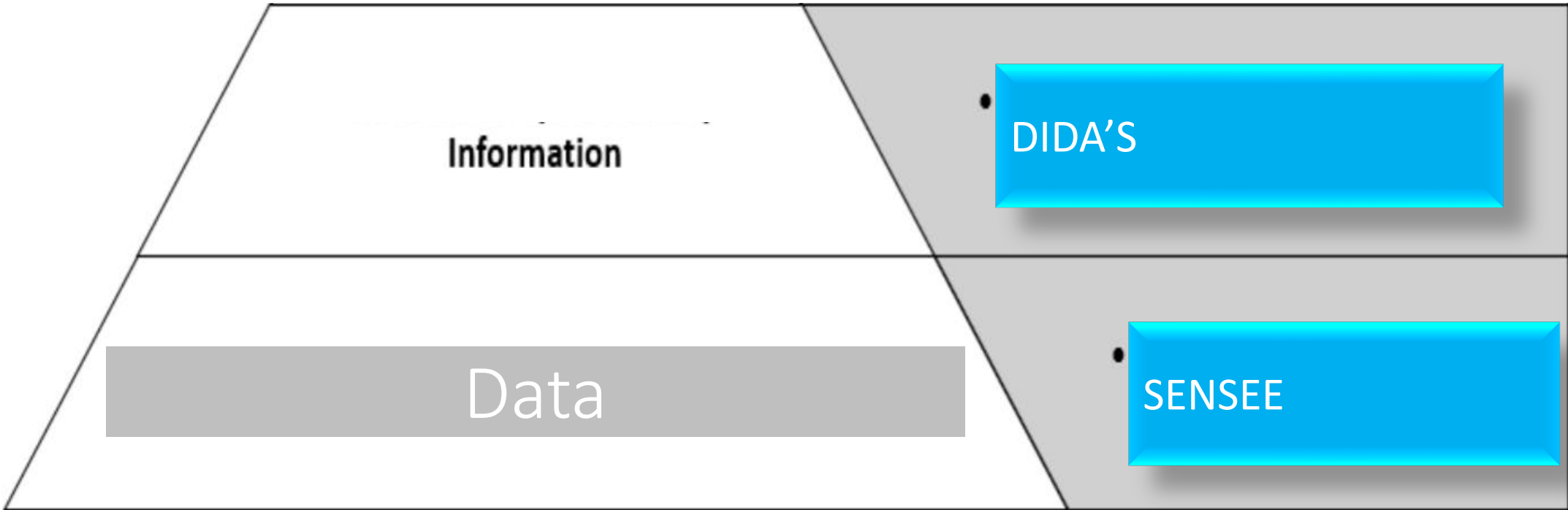






Data

SENSEE

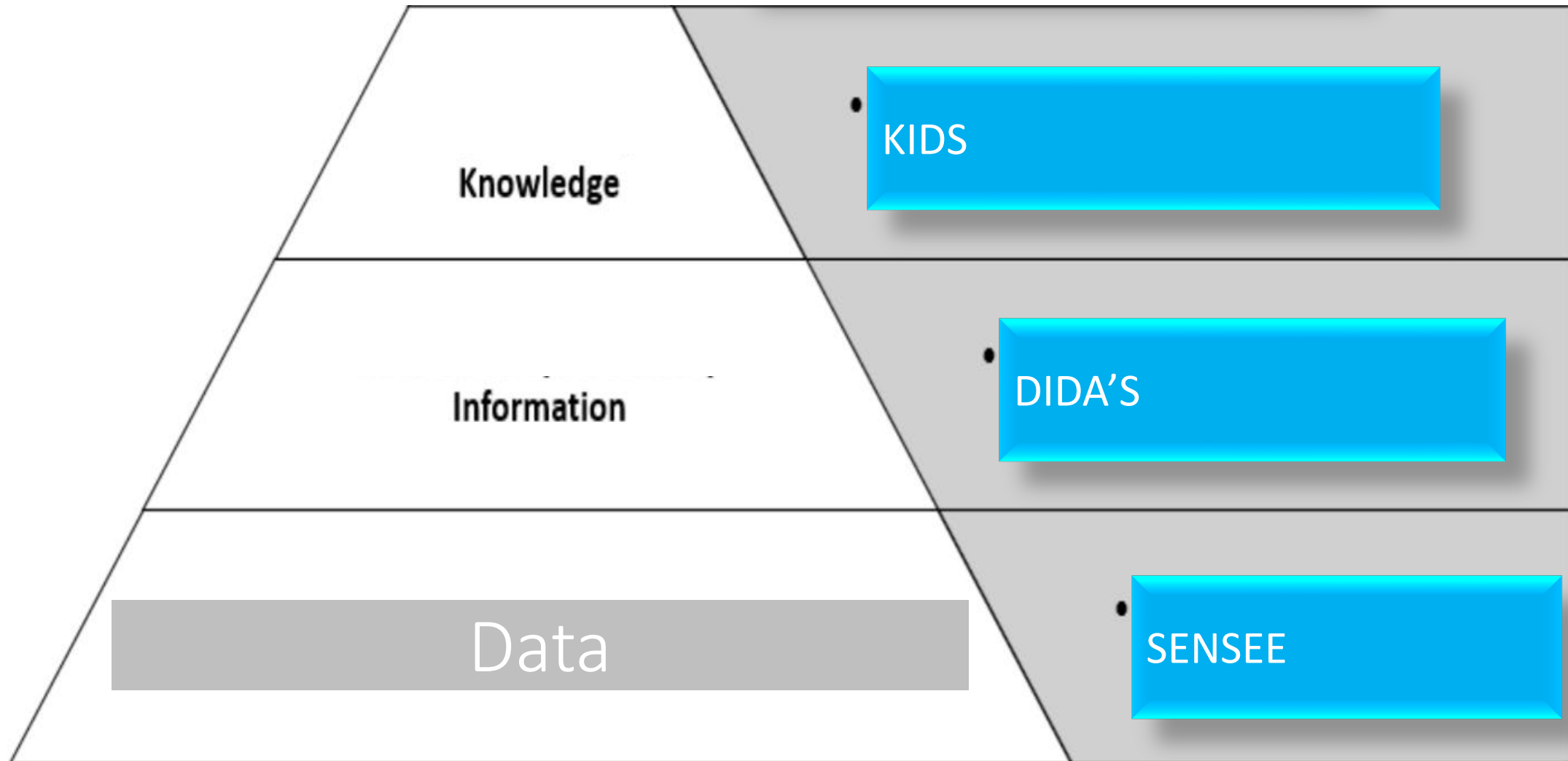


Information

DIDA'S

Data

SENSEE



Knowledge

KIDS

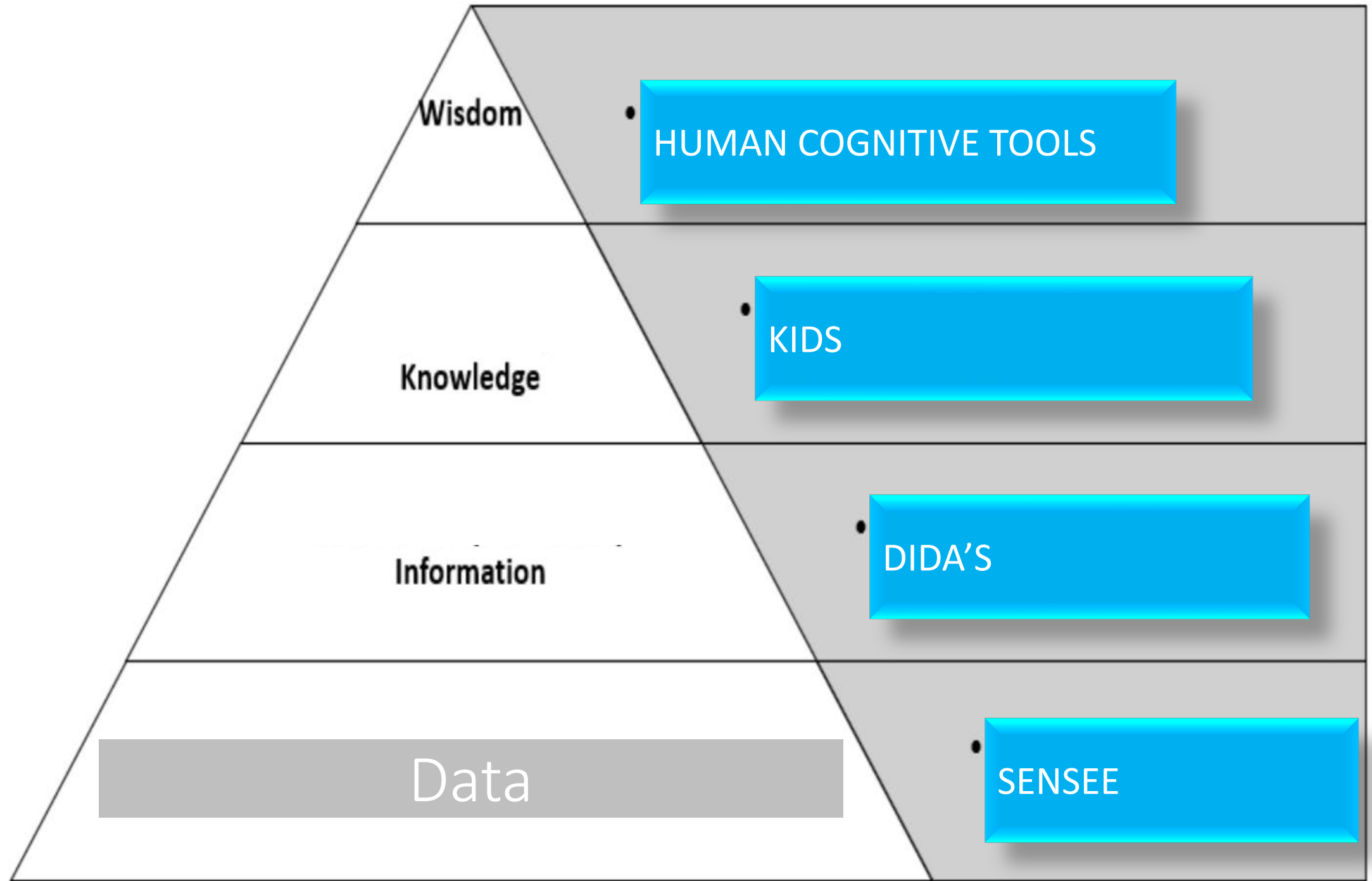
Information

DIDA'S

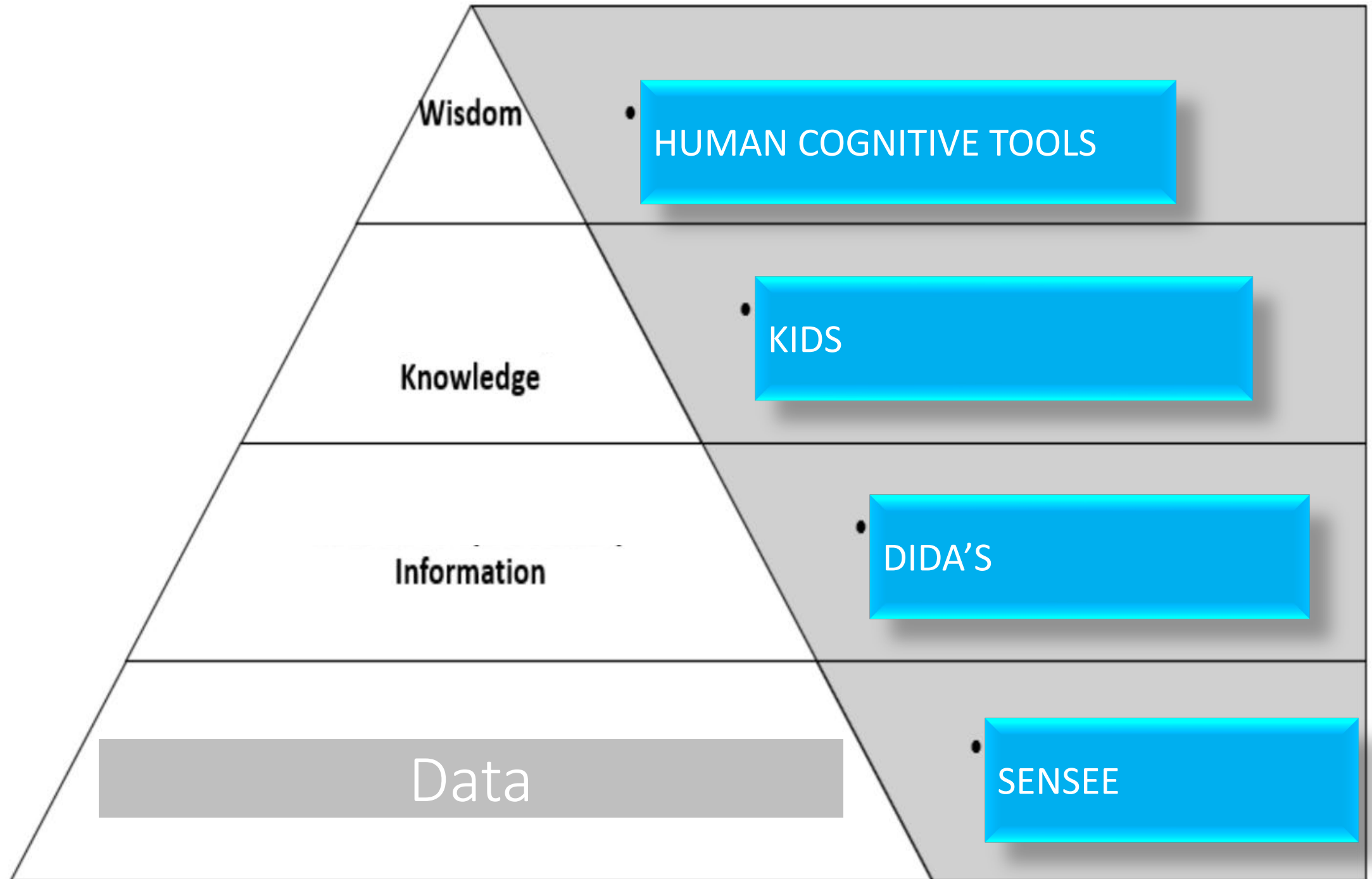
Data

SENSEE

SYNERGISTIC INTEGRATION

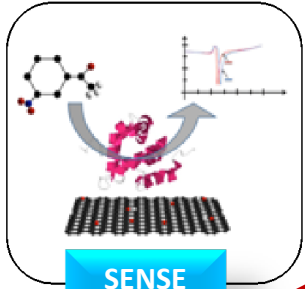


PEAS PLATFORM

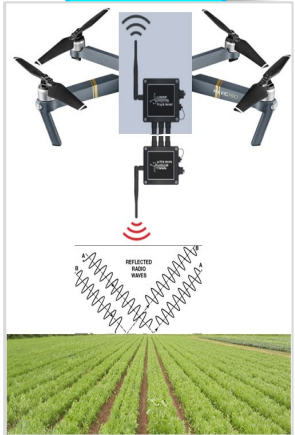


SENSEE

SENsor SEarch Engine



SENSE



Attempt to create an open source curated repository for different types of sensors created by academic and industrial labs, globally. Expect to connect with similar data from sensor manufacturers.

SENSEE

The curated repository containing descriptions of sensors may also serve as an unit or module for the hypothetical open source library to contain information about tools or technologies related to management of agricultural wastewater systems (AWS).

The purpose of the AWS library is to serve end-users (farmers, growers) who may ask questions pertaining to AWS for irrigation. Questions may be related to the detection of heavy metals and microbes (thus, sensors) or waste water treatment technologies (separate module to be developed by USDA SmartPath Project, not a part of SENSEE).

**Development of
an open source
AWS technology
repository (with
mobile access)**

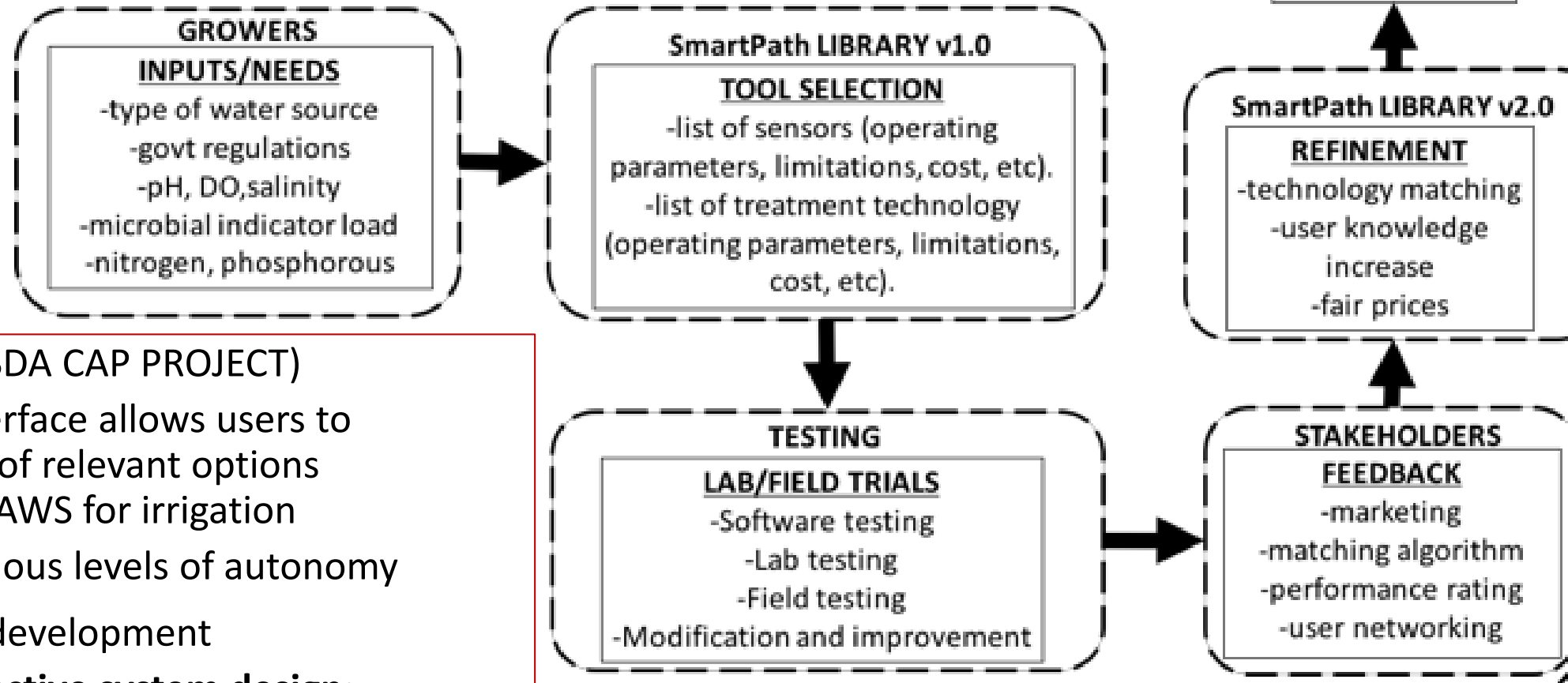


Development of an open source AWS technology repository (with mobile access)

- SmartPath Library (USDA CAP PROJECT)
 - User-friendly interface allows users to explore a variety of relevant options related to use of AWS for irrigation
 - Open source, various levels of autonomy
- Tools/widgets under development
 - Software for **proactive system design**; selection of appropriate technologies (sensors from SENSEE and treatment module)
 - Software for assisting growers with **technology adoption** and assist with trade policies, pricing
 - Software for providing **decision support** for monitoring/treatment (SENSEE, DIDA'S, KIDS)



Development of an open source AWS technology repository (with mobile access)



- SmartPath Library (USDA CAP PROJECT)
 - User-friendly interface allows users to explore a variety of relevant options related to use of AWS for irrigation
 - Open source, various levels of autonomy
- Tools/widgets under development
 - Software for **proactive system design**; selection of appropriate technologies (sensors from SENSEE and treatment module)
 - Software for assisting growers with **technology adoption** and assist with trade policies, pricing
 - Software for providing **decision support** for monitoring/treatment (SENSEE, DIDA'S, KIDS)



SENSEE

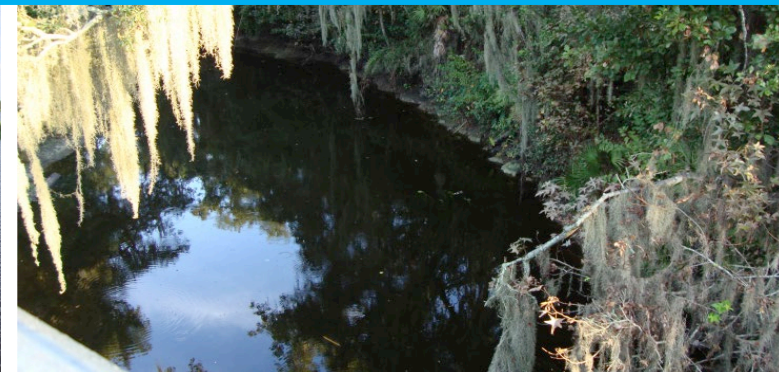
Expert users (academics, students, industrial labs) may be the short term beneficiary from the curated descriptions of sensors, if SENSEE contains a critical mass of sensor descriptions (expectation: sensor descriptions from 1,000 to 10,000 labs, globally).

Google search may reveal millions of documents. SENSEE presents a curated list.

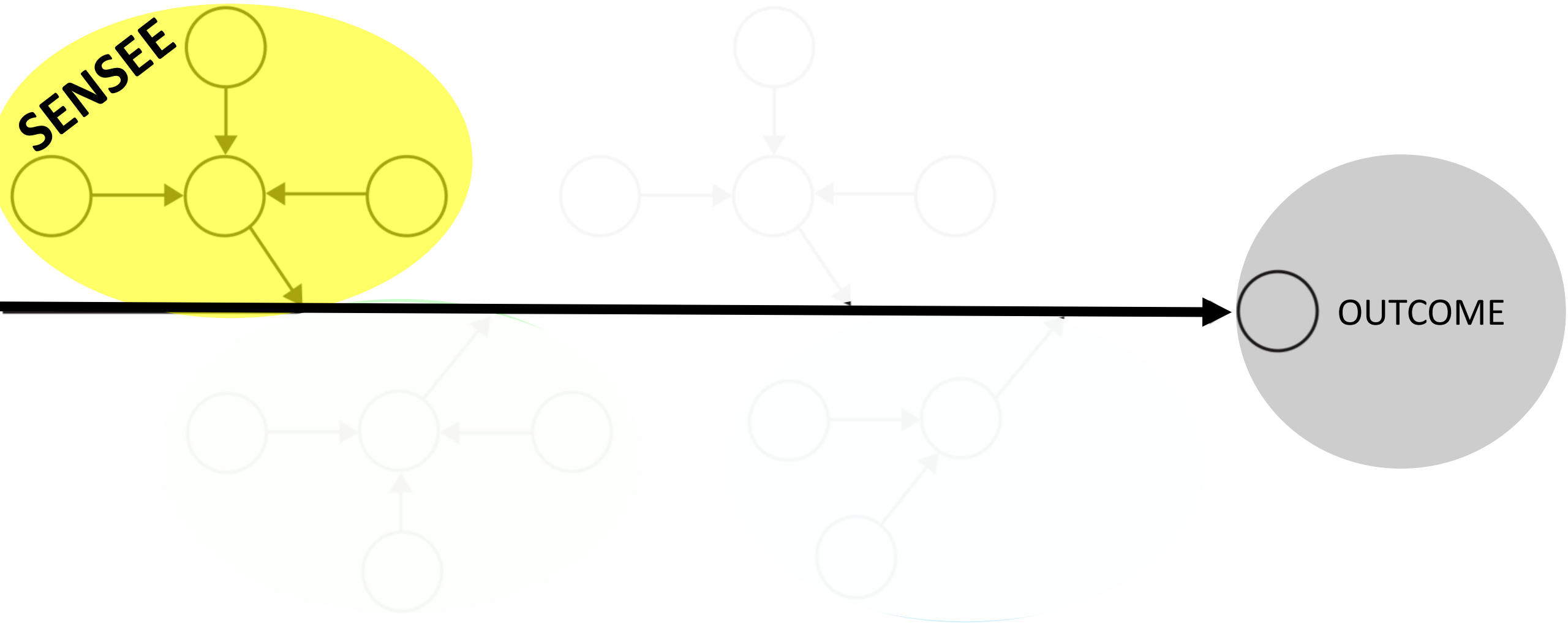
In the future, SENSEE will contain sensor descriptions (categories, attributes) **and** select data from specific sensors. Sensor data ingested in SENSEE will be determined by use cases for specific end-users (farms, grocery stores, food warehouse, food processing plant, packaging operations, retail distribution, food logistics, global transportation).

SENSEE is a start ... but woefully inadequate as a solution

- End-user perspective and questions from the field (agro-ecosystem) are complex:
 - Is my **water quality in compliance** with FSMA produce safety rule (PSR)?
 - What are the **costs** associated with agricultural wastewater (AWS) reuse?
 - Does reuse of AWS add excessive **management** issues?
 - **Who monitors** return flows, aquifer recharge, and water quality?
 - What are the perceived and real **health risks** associated with AWS for irrigation?
 - Can **technologies** (sensors + treatment systems) add **quantifiable** value?
 - Are there **legal implications** of real time water quality data acquisition?
 - Are there **economic penalties** for buyers if data log shows poor water quality?



SENSEE is a start ... but woefully inadequate as a solution



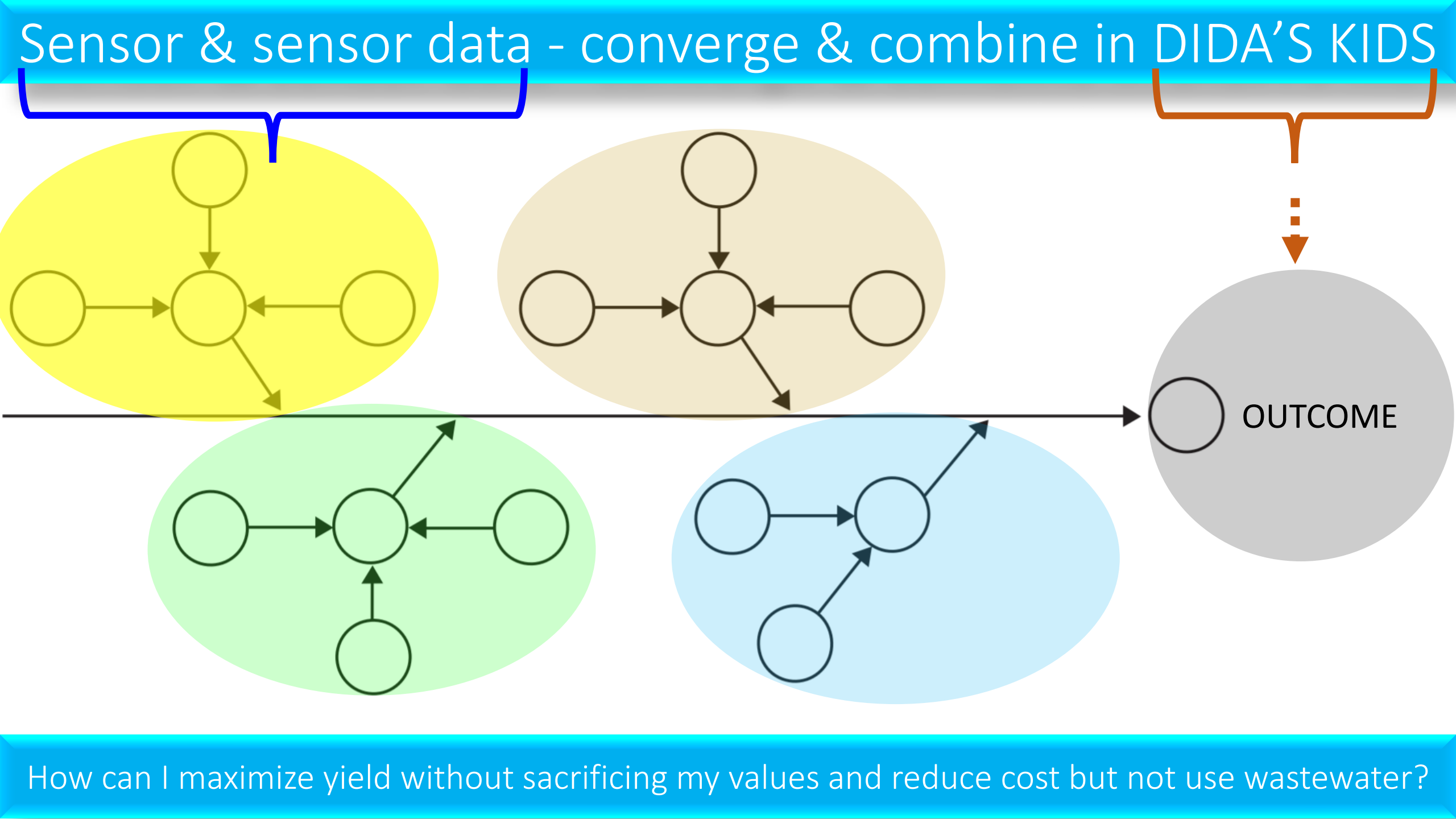
How can I maximize yield without sacrificing my values and reduce cost but not use wastewater?

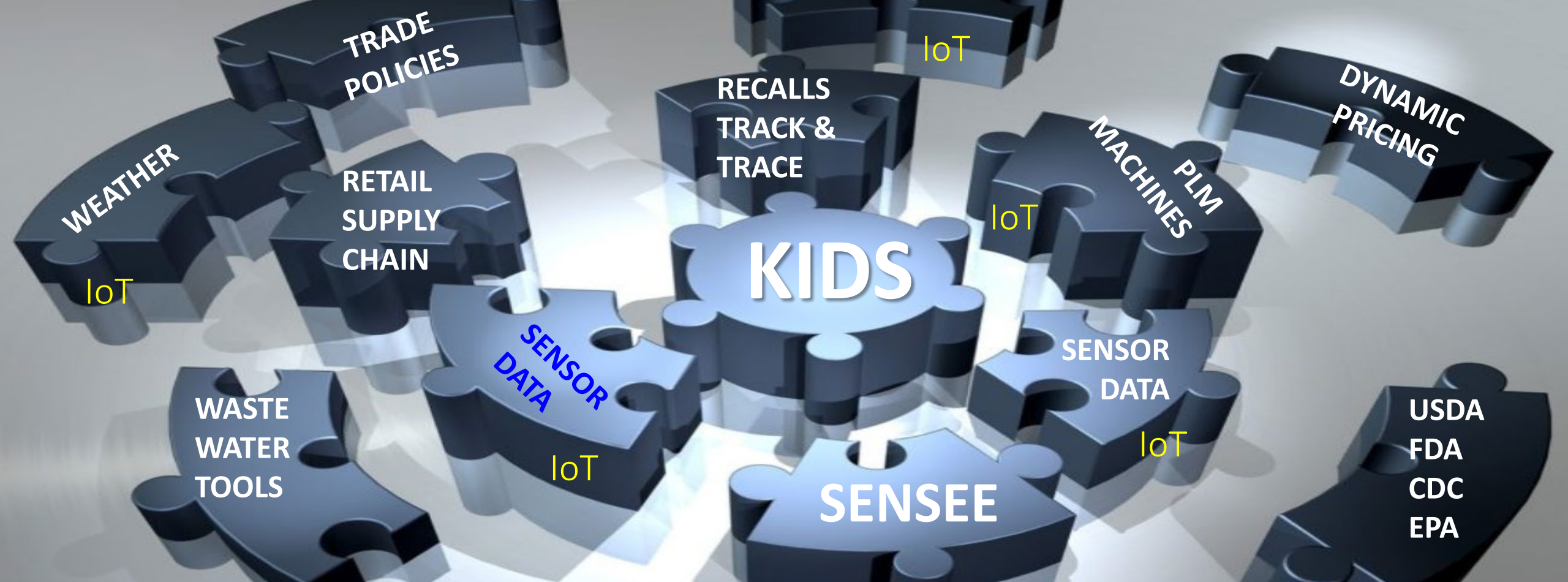
End-user perspective and questions from the field (agro-ecosystem) are complex

KIDS

Do you sense the convergence?

WHY SENSEE IS JUST A TINY STEP IN OUR JOURNEY TO KNOWLEDGE-INFORMED DECISIONS (KIDS)

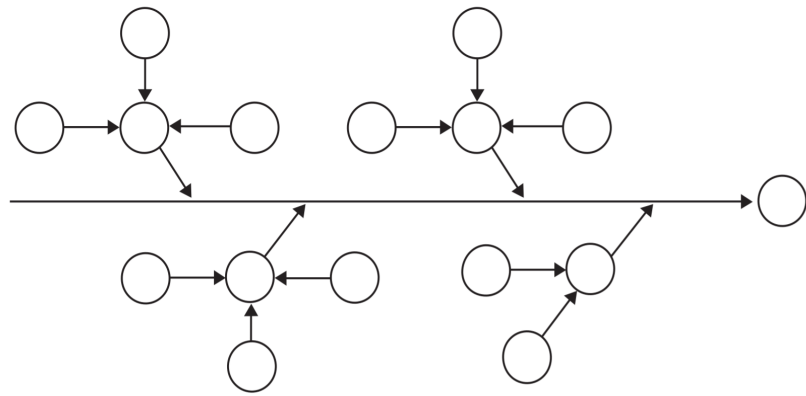


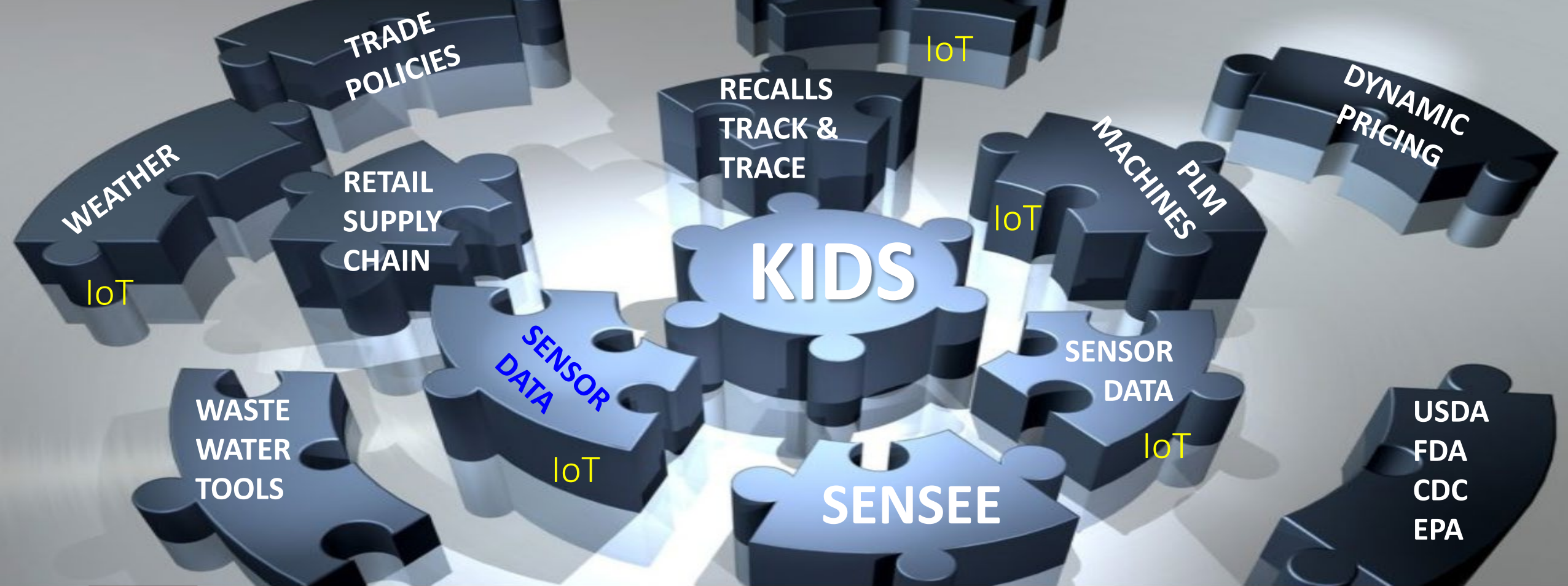


DATA



KNOWLEDGE





DATA

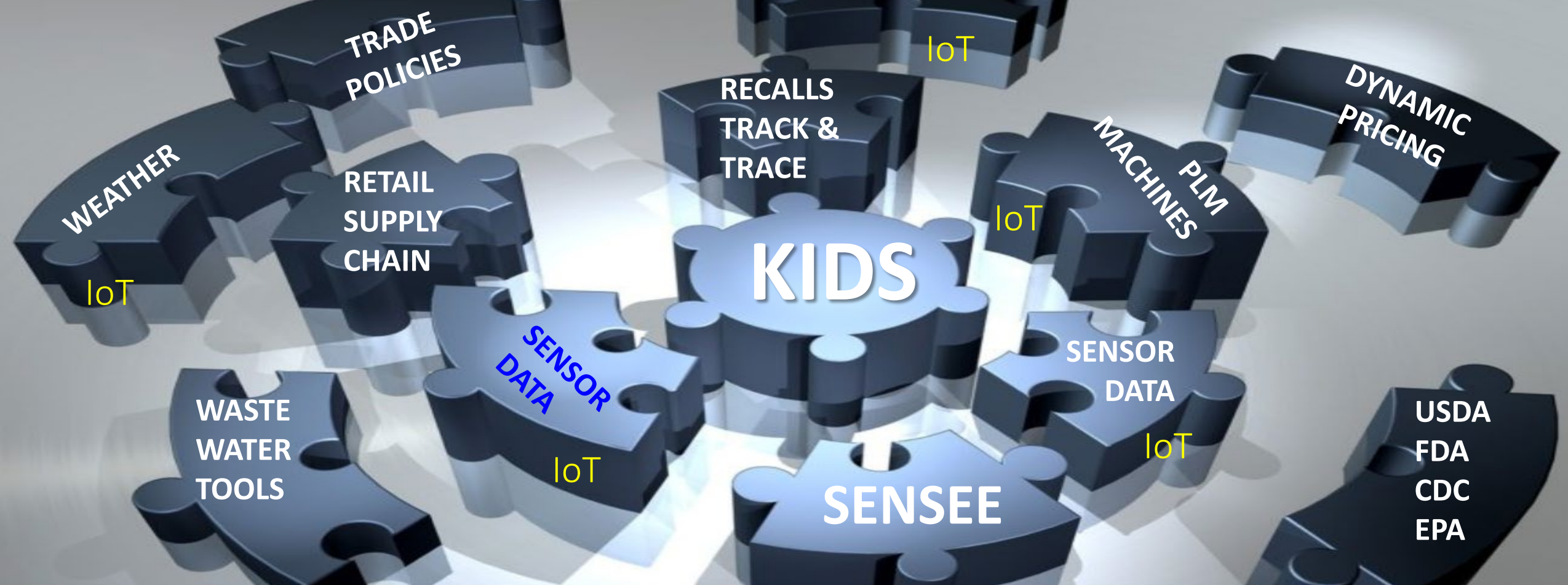
KNOWLEDGE

KIDS IS NOT A "THING"

ONE SIZE WILL NOT FIT ALL

KIDS IS A CONCEPTUAL DESIGN METAPHOR

KIDS IS A SYNERGISTIC KNOWLEDGE INTEGRATION PLATFORM



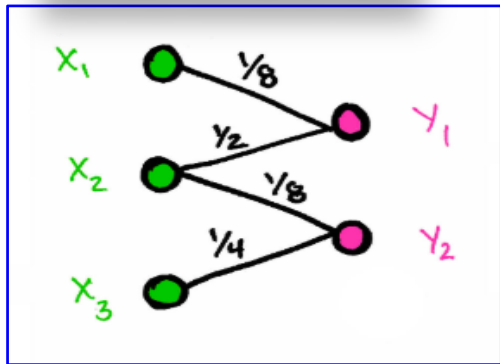
DATA



End-user perspective and questions from the field (agro-ecosystem) are complex:

- Is my **water quality in compliance** with FSMA produce safety rule (PSR)?
- What are the **costs** associated with agricultural wastewater (AWS) reuse?
- Does reuse of AWS add excessive **management** issues?
- Who monitors** return flows, aquifer recharge, and water quality?
- What are the perceived and real **health risks** associated with AWS for irrigation?
- Can **technologies** (sensors + treatment systems) add **quantifiable** value?
- Are there **legal implications** of real time water quality data acquisition?
- Are there **economic penalties** for buyers if data log shows poor water quality?

KNOWLEDGE



WHY SENSEE IS A TINY PART OF A SYSTEM

It may not be difficult to grasp that the questions from field users demand immense cross-pollination of data and information to converge with knowledge, logic and reasoning, to generate even a basic response.

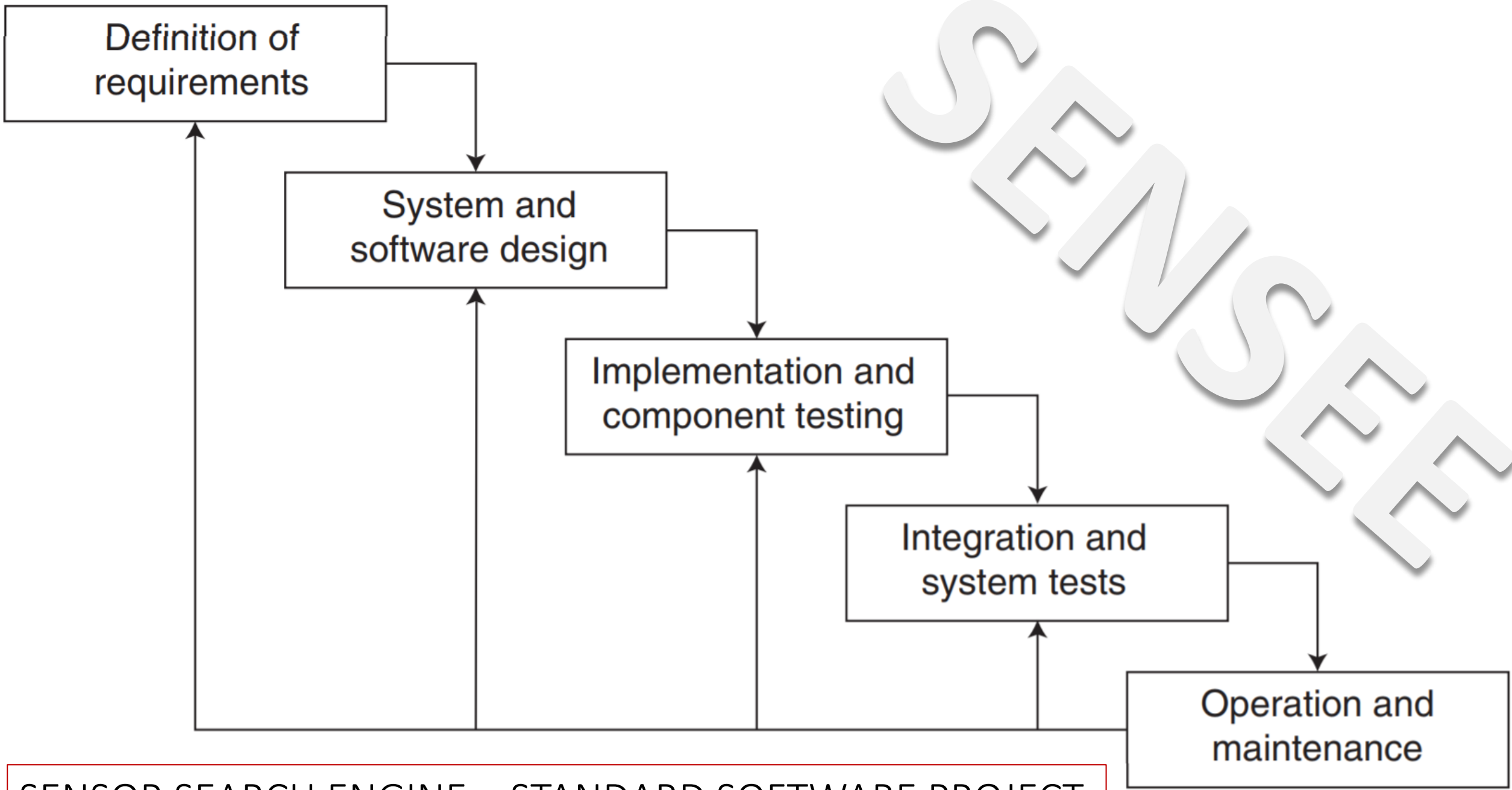
SENSEE

AT THIS TIME, SENSEE 1.0 CONTAINS ONLY SENSOR DESCRIPTIONS (CATEGORIES, ATTRIBUTES). SENSEE CAN ANSWER SELECT QUESTIONS.

Expert users (academics, students, industrial labs) may benefit from the curated descriptions of sensors. In future, SENSEE may contain a critical mass of sensor descriptions. Google search reveal millions of docs but SENSEE is a curated list.

In the future, SENSEE will contain sensor descriptions (categories, attributes) **and** select **data** from specific sensors. Sensor data ingested in SENSEE will be determined by use cases for specific end-users (farms, grocery stores, food warehouse, food processing, packaging, retail distribution, logistics, agri-business, machine tools, supply chain).

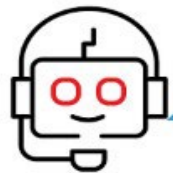
SENSOR SEARCH ENGINE



SENSOR SEARCH ENGINE – STANDARD SOFTWARE PROJECT

Experts can query SENSEE and perhaps receive a decent answer, in the near future

SENSEE



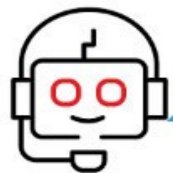
Show 3 molecules (10Da, 100Da and 200Da)
for which there are sensors on LSG platform

Submit

SENSEE WEB SERVICE (MOBILE APP EQUIVALENT)

Experts can query SENSEE and perhaps receive a decent answer, in the near future

SENSEE

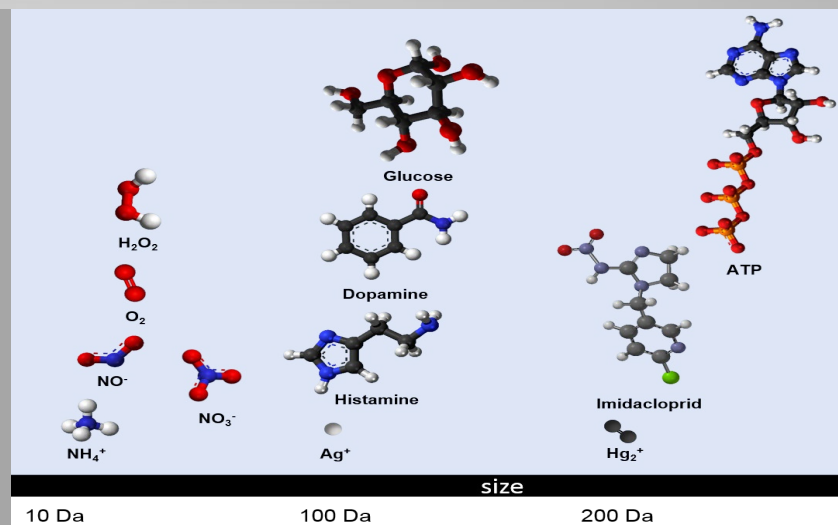


I found 3 classes of molecules. See results.



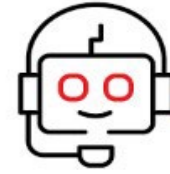
Show 3 molecules (10Da, 100Da and 200Da) for which there are sensors on LSG platform

Submit



Experts can query SENSEE and perhaps receive a decent answer, in the near future

SENSEE

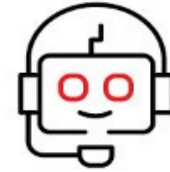


Which types of microbes are most used by sensor labs to create lectin based recognition?

Submit

Experts can query SENSEE and perhaps receive a decent answer, in the near future

SENSEE



I found two types of bacteria. See display.

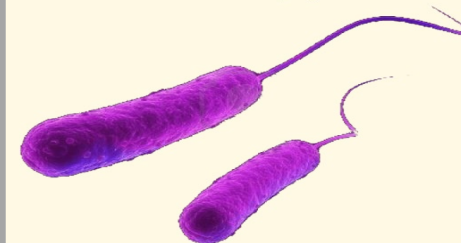


Which types of microbes are most used by sensor labs to create lectin based recognition?

Submit



Listeria monocytogenes



Escherichia coli

Experts may query SENSEE but is SENSEE capable of facing complex questions?

SENSEE

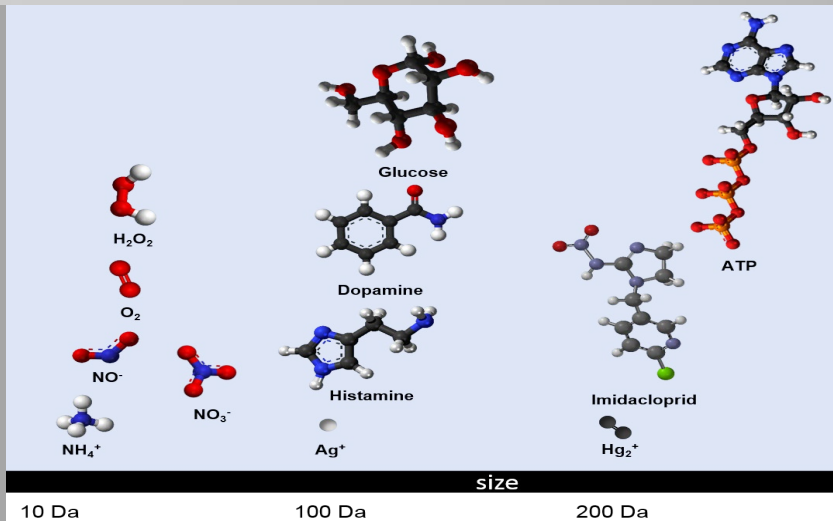


I found 3 classes of molecules. See results.

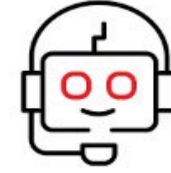


Show 3 molecules (10Da, 100Da and 200Da) for which there are sensors on LSG platform

Submit



SENSEE

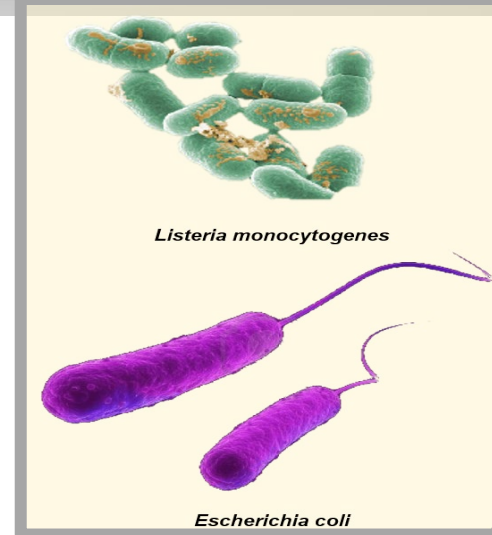


I found two types of bacteria. See display.




Which types of microbes are most used by sensor labs to create lectin based recognition?


Submit



End-user perspective and questions from the field (agro-ecosystem) are complex

SENSEE




 How can I maximize yield without sacrificing my values & reduce cost without using wastewater?

Submit




End-user perspective and questions from the field (agro-ecosystem) are complex

SENSEE



This question does not exist. I am not able to understand the query.



How can I maximize yield without sacrificing my values & reduce cost without using wastewater?

Submit





SENSEE 1.0 CANNOT HELP

CAN ART HELP? CAN KIDS HELP?

End-user perspective and questions from the field (agro-ecosystem) are complex

SENSEE




 How can I disseminate the health benefit of our fresh cilantro sauce for lowering blood pressure?


Submit



End-user perspective and questions from the field (agro-ecosystem) are complex

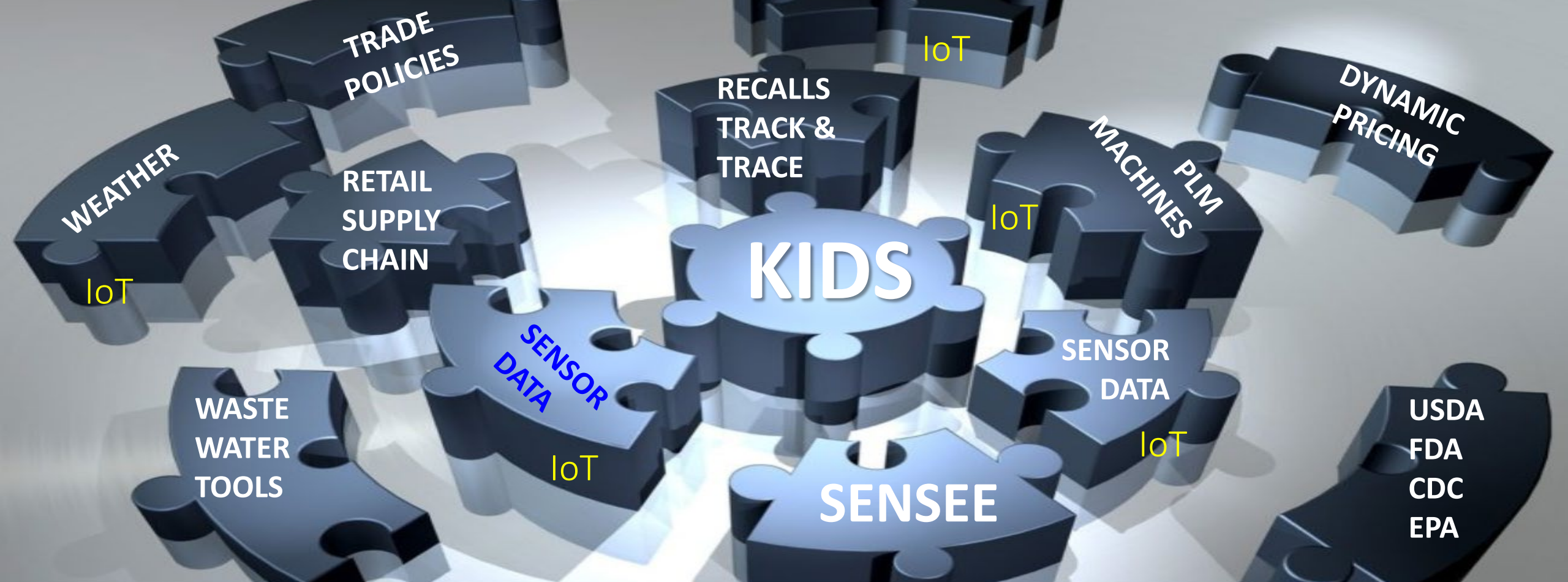
SENSEE

 Go to KIDS to request Agent to connect with Citizen Science Service

 How can I disseminate the health benefit of our fresh cilantro sauce for lowering blood pressure?

Submit





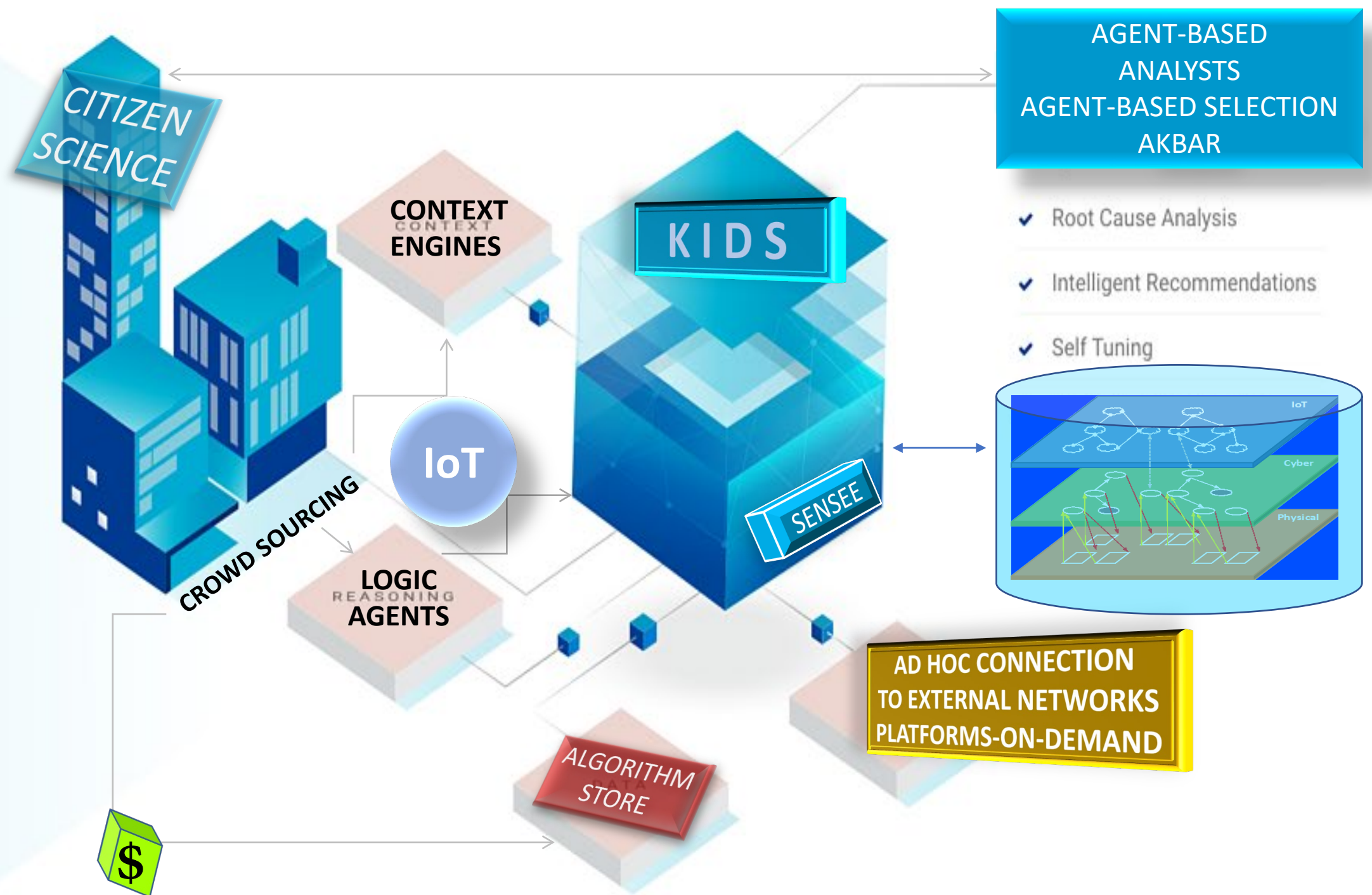
DATA



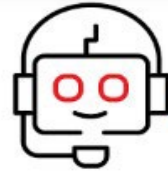
KNOWLEDGE

HOW KIDS IS DESIGNED TO ADDRESS COMPLEXITY. LET US TAKE ANOTHER LOOK.

KIDS



KIDS

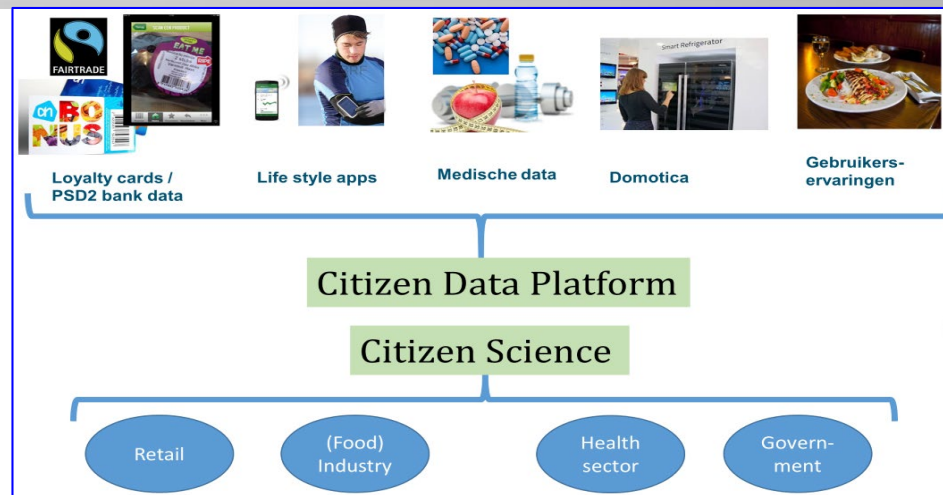


Referring you to Agent Analyst working with Citizen Science Service



How can I disseminate the health benefit of our fresh cilantro sauce for lowering blood pressure?

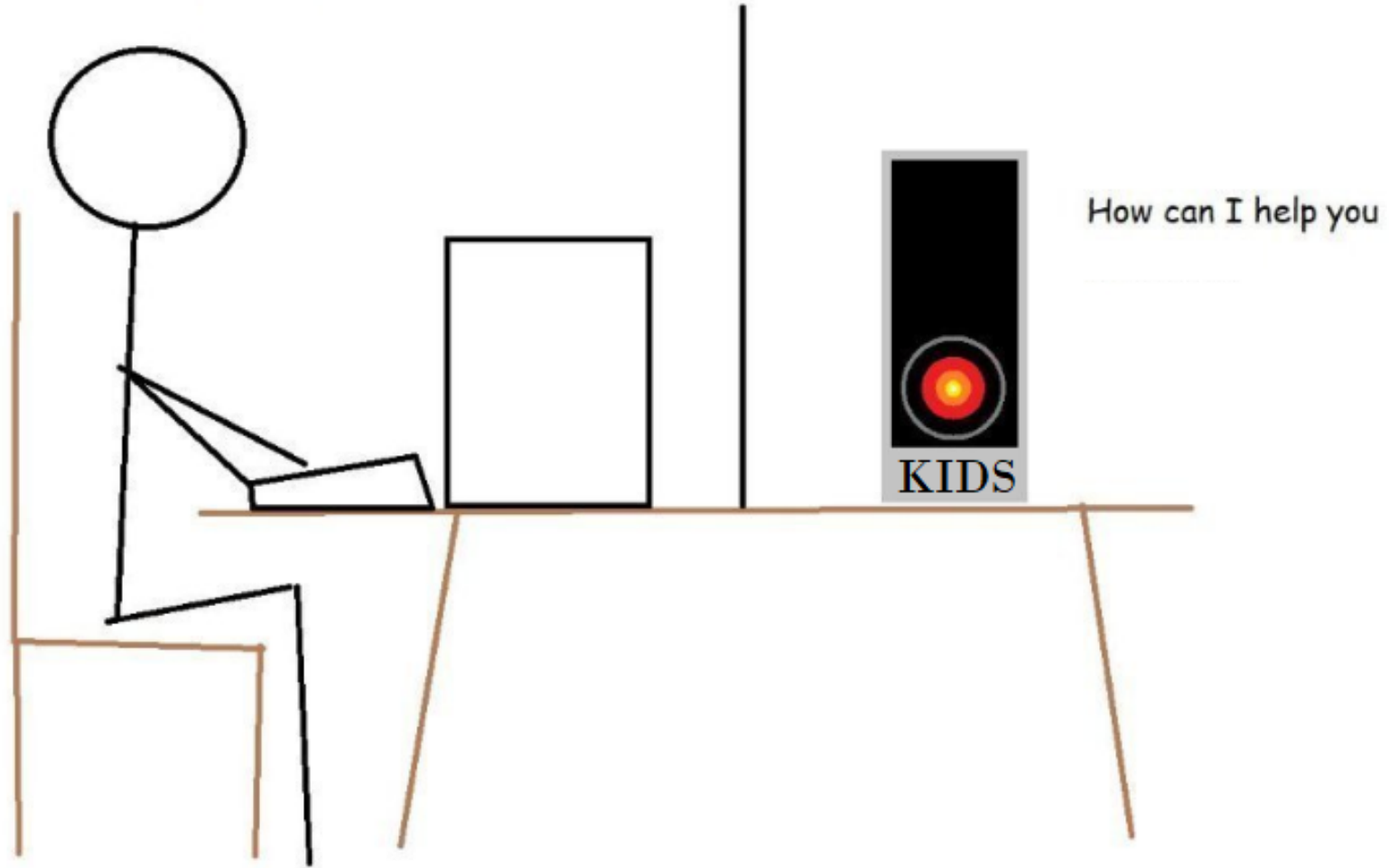
Submit



CITIZEN SCIENCE

The use of Agents as virtual chat bots are common and may be modified for the agro-ecosystem.

K
I
D
S



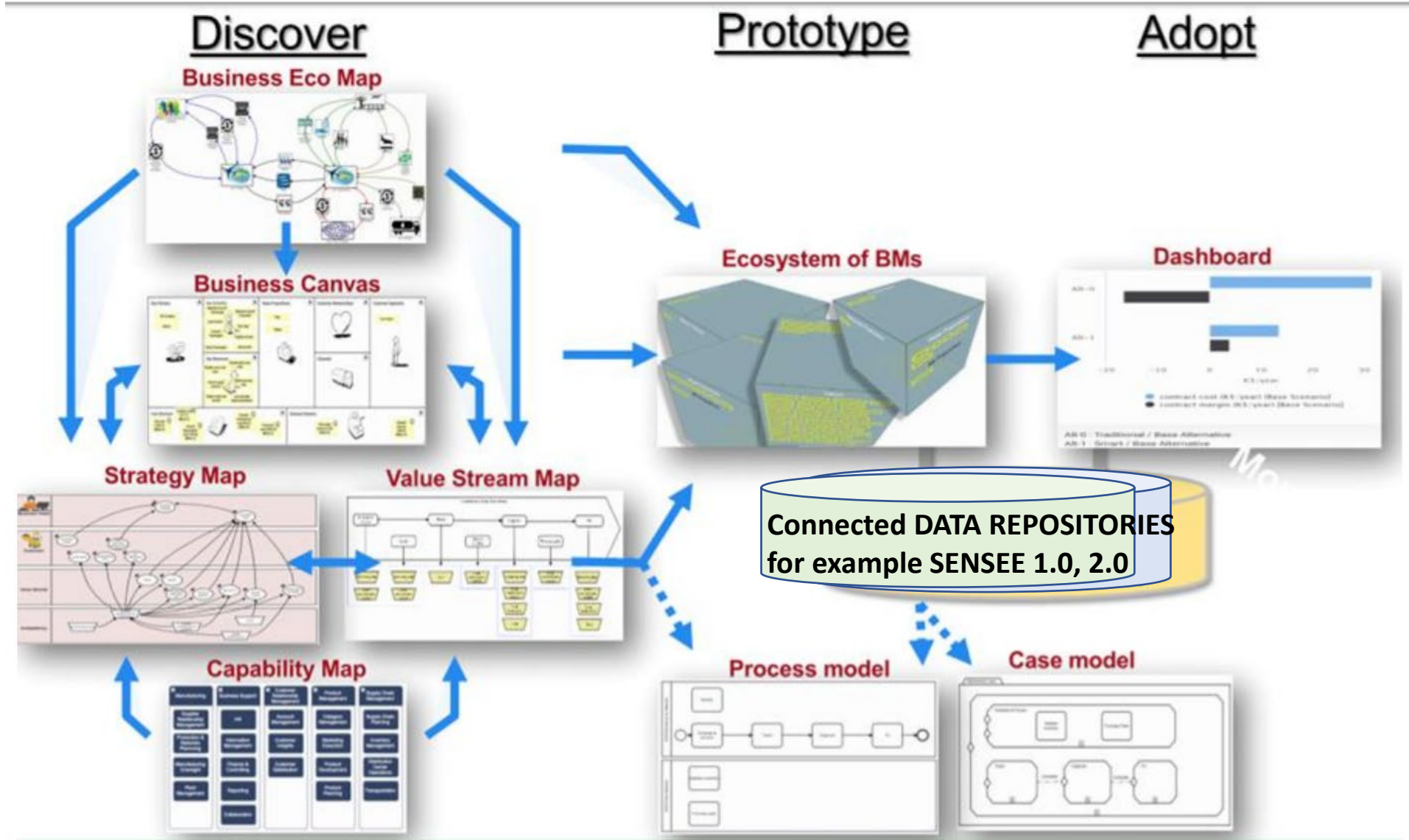
Microsoft Virtual Agent and Dynamics 365 for Finance and Operations

K

I

D

S

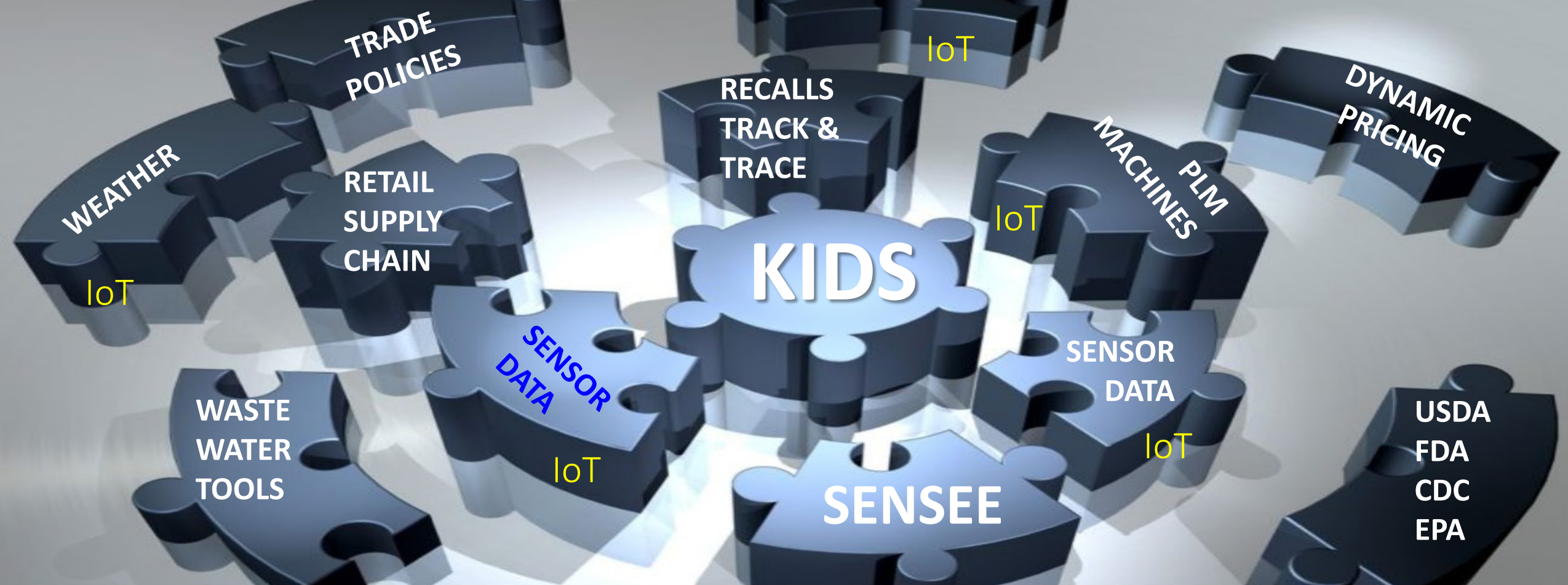


End-user perspective and questions from the field (agro-ecosystem) are complex

PEAS, KIDS

makes sense?

WHY SENSEE IS JUST A TINY STEP IN OUR JOURNEY TO KNOWLEDGE-INFORMED DECISIONS (KIDS)



DATA



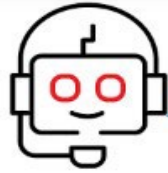
KNOWLEDGE



How can I maximize yield without sacrificing my values and reduce cost but not use wastewater?

Can KIDS answer end-user questions? We don't know but that is the expectation.

KIDS



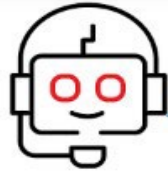
How can I maximize yield without sacrificing my values and reduce cost but not use wastewater?

Submit



Can KIDS answer end-user questions? We don't know but that is the expectation.

KIDS



Explore CropX system.
Monitor soil nitrogen
& moisture every day.



How can I maximize yield without sacrificing my values and reduce cost but not use wastewater?

Submit



SENSEE

A journey of a thousand miles begins with a single step.

Developing SENSEE 1.0

Development of SENSEE 1.0 (**SEN**sor **SE**arch **E**ngine)

Spreadsheet

Sensor Properties

Library
PoC
DB

Development of SENSEE 1.0 (SENsor SEArch Engine)

Spreadsheet

Sensor Properties

	A	B	C	D	E	F	G	H	I	J	K	L
1	MW [Da]	Category	Target	Recognition-transduction scheme	Platform	LOD [M]	Max range [M]	Selectivity (interferent species tested)	Response time [sec]	Durability	USECAT1	Link to paper(s)
2	1	small molecule	H+	H+ ionophore (liquid)	glass capillary	1.00E-13	1.00E-04	excellent (K+, Na+, Ca2+, Mg2+)	2	High	hydroponics	https://www.ncbi.nlm.nih.gov/pubmed/26088926
3	1	small molecule	H+	anthocyanin/nanocellulose	paper filter	1.00E-15	1.00E-02	excellent	2	high	irrigation water	https://www.ncbi.nlm.nih.gov/pubmed/28884510
4	18	small molecule	Ammonium	NH4+ ionophore (liquid)	glass capillary	5.00E-09	1.00E-01	excellent	5	medium	wastewater	http://www.allelopathyjournal.org/archives/?Year=2016&Vol=37&Issue=2&Month=3
5	18	small molecule	Ammonium	NH4+ ionophore (solid)	LSG	2.80E-05	5.00E-01	excellent	2	medium	wastewater	https://pubs.acs.org/doi/10.1021/acsami.8b10991
6	30	small molecule	N/O radicals	nanoplatinum/nanoceria	Pt electrode	1.00E-08	3.00E-06	medium	1	medium	ocean water	https://pubs.rsc.org/en/Content/ArticleLanding/2017/AY/C7AY01964F#divAbstract
7	32	small molecule	DO	Pt porphyrin-nTiO2	fiber optic	1.00E-06	5.00E-06	excellent, temp sens	1	High	hydroponic media	https://www.sciencedirect.com/science/article/pii/S09255400514001117
8	32	small molecule	DO	Pt porphyrin	96 well	1.00E-06	5.00E-06	excellent, temp sens	45	low	hydroponic media	https://www.sciencedirect.com/science/article/pii/S016770121300331X
9	32	small molecule	DO	Pt porphyrin	glass vial	1.00E-06	5.00E-06	excellent, temp sens	45	low	hydroponic media	
10	34	small molecule	H2O2	fractal nPt	Pt electrode	5.00E-09	5.00E-05	excellent	1	high	ocean water	https://www.ncbi.nlm.nih.gov/pubmed/27121177
11	39	small molecule	K+	K+ ionophore (liquid)	glass capillary	1.00E-06	2.50E-01	excellent	2	low	wastewater	https://www.ncbi.nlm.nih.gov/pubmed/24961073
12	41	small molecule	Ca2+	Ca2+ ionophore (liquid)	glass capillary	1.00E-06	5.00E-01	excellent	1	low	Hoaglands media	https://onlinelibrary.wiley.com/doi/full/10.1002/jipln.201700319
13	58	small molecule	acetone	chemosensory proteins-nPt	Pt electrode	5.00E-06	1.00E-05	high	10	low	buffer	https://pubs.rsc.org/en/content/articlelanding/2018/an/c8an00065d#divAbstract
14	62	small molecule	Nitrate	NO3- ionophore (liquid)	glass capillary	1.00E-06	2.00E-01	excellent	2	medium	wastewater	https://www.ncbi.nlm.nih.gov/pubmed/18985610
15	62	small molecule	Nitrate	NO3- ionophore (solid)	LSG	2.00E-05	1.50E-01	excellent	2	medium	wastewater	https://pubs.acs.org/doi/10.1021/acsami.8b10991
16	108	small molecule	Ag+	Ag+ ionophore (liquid)	glass capillary	1.00E-06	5.00E-02	excellent	2	high	wound dressing	https://link.springer.com/article/10.1007/s11356-014-3058-6
17	111	small molecule	histamine	diamine oxidase-nCu	LSG	6.30E-05	1.00E-03	excellent	2	medium	fermented fish	https://www.mdpi.com/2079-6374/8/2/42
18	147	small molecule	Glutamate	CNT/nPt/GlOx	Pt electrode	1.00E-06	1.00E-03	excellent	2	low	INS1 tissue culture	https://www.sciencedirect.com/science/article/pii/S0165027010001196
19	147	small molecule	Glutamate	CNT/nPt/GlOx	Si biochip	1.00E-06	5.00E-01	excellent	2	low	INS1 tissue culture	https://pubs.rsc.org/en/content/articlelanding/2011/im/c1im11561h#divAbstract
20	154	small molecule	catecholamines	nPt	LSG	5.00E-07	3.00E-03	excellent	2	high	ocean water	
21	154	small molecule	catecholamines	graphene anchored nCuO	LSG	3.00E-07	3.00E-03	high	2	medium	buffer	https://pubs.acs.org/doi/abs/10.1021/acssuschemeng.8b02510
22	176	small molecule	indole acetic acid	fractal nPt	Pt/Ir microwire	1.00E-06	1.00E-03	high	1	high	root growth media	https://link.springer.com/article/10.1007/s00344-017-9688-4
23	181	small molecule	Glucose	nPt/GOx	graphene paper	8.00E-08	1.00E-03	excellent	2	medium	buffer	https://www.ncbi.nlm.nih.gov/pubmed/27209574
24	181	small molecule	Glucose	nPt/GOx	Pt/Ir microwire	1.00E-07	5.00E-06	excellent	1	medium	blood	https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0166557
25	181	small molecule	Glucose	nPt/nCe/GOx	Pt electrode	1.00E-07	3.00E-06	excellent	1	medium	buffer	https://www.sciencedirect.com/science/article/pii/S0956566314000992

Development of SENSEE 1.0 (SENsor SEArch Engine)

Spreadsheet

Sensor Properties

	A	B	C	D	E	F	G	H	I	J	K	L
1	MW [Da]	Category	Target	Recognition-transduction scheme	Platform	LOD [M]	Max range [M]	Selectivity (interferent species tested)	Response time [sec]	Durability	USECAT1	Link to paper(s)
2	1	small molecule	H+	H+ ionophore (liquid)	glass capillary	1.00E-13	1.00E-04	excellent (K+, Na+, Ca2+, Mg2+)	2	High	hydroponics	https://www.ncbi.nlm.nih.gov/pubmed/26088926
3	1	small molecule	H+	anthocyanin/nanocellulose	paper filter	1.00E-15	1.00E-02	excellent	2	high	irrigation water	https://www.ncbi.nlm.nih.gov/pubmed/28884510
4	18	small molecule	Ammonium	NH4+ ionophore (liquid)	glass capillary	5.00E-09	1.00E-01	excellent	5	medium	wastewater	http://www.allelopathyjournal.org/archives/?Year=2016&Vol=37&Issue=2&Month=3
5	18	small molecule	Ammonium	NH4+ ionophore (solid)	LSG	2.80E-05	5.00E-01	excellent	2	medium	wastewater	https://pubs.acs.org/doi/10.1021/acsami.8b10991
6	30	small molecule	N/O radicals	nanoplatinum/nanoceria	Pt electrode	1.00E-08	3.00E-06	medium	1	medium	ocean water	https://pubs.rsc.org/en/Content/ArticleLanding/2017/AY/C7AY01964E#divAbstract
7	32	small molecule	DO	Pt porphyrin-nTiO2	fiber optic	1.00E-06	5.00E-06	excellent, temp sens	1	High	hydroponic media	https://www.sciencedirect.com/science/article/pii/S0925400514001117
8	32	small molecule	DO	Pt porphyrin	96 well	1.00E-06	5.00E-06	excellent, temp sens	45	low	hydroponic media	https://www.sciencedirect.com/science/article/pii/S016770121300331X
9	32	small molecule	DO	Pt porphyrin	glass vial	1.00E-06	5.00E-06	excellent, temp sens	45	low	hydroponic media	
10	34	small molecule	H2O2	fractal nPt	Pt electrode	5.00E-09	5.00E-05	excellent	1	high	ocean water	https://www.ncbi.nlm.nih.gov/pubmed/27121177
11	39	small molecule	K+	K+ ionophore (liquid)	glass capillary	1.00E-06	2.50E-01	excellent	2	low	wastewater	https://www.ncbi.nlm.nih.gov/pubmed/24961073
12	41	small molecule	Ca2+	Ca2+ ionophore (liquid)	glass capillary	1.00E-06	5.00E-01	excellent	1	low	Hoaglands media	https://onlinelibrary.wiley.com/doi/full/10.1002/jpln.201700319
13	58	small molecule	acetone	chemosensory proteins-nPt	Pt electrode	5.00E-06	1.00E-05	high	10	low	buffer	https://pubs.rsc.org/en/content/articlelanding/2018/an/c8an00065d#divAbstract
14	62	small molecule	Nitrate	NO3- ionophore (liquid)	glass capillary	1.00E-06	2.00E-01	excellent	2	medium	wastewater	https://www.ncbi.nlm.nih.gov/pubmed/18985610
15	62	small molecule	Nitrate	NO3- ionophore (solid)	LSG	2.00E-05	1.50E-01	excellent	2	medium	wastewater	https://pubs.acs.org/doi/10.1021/acsami.8b10991
16	108	small molecule	Ag+	Ag+ ionophore (liquid)	glass capillary	1.00E-06	5.00E-02	excellent	2	high	wound dressing	https://link.springer.com/article/10.1007/s11356-014-3058-6
17	111	small molecule	histamine	diamine oxidase-nCu	LSG	6.30E-05	1.00E-03	excellent	2	medium	fermented fish	https://www.mdpi.com/2079-6374/8/2/42
18	147	small molecule	Glutamate	CNT/nPt/GlOx	Pt electrode	1.00E-06	1.00E-03	excellent	2	low	INS1 tissue culture	https://www.sciencedirect.com/science/article/pii/S0165027010001196
19	147	small molecule	Glutamate	CNT/nPt/GlOx	Si biochip	1.00E-06	5.00E-01	excellent	2	low	INS1 tissue culture	https://pubs.rsc.org/en/content/articlelanding/2011/im/c1im11561h#divAbstract
20	154	small molecule	catecholamines	nPt	LSG	5.00E-07	3.00E-03	excellent	2	high	ocean water	
21	154	small molecule	catecholamines	graphene anchored nCuO	LSG	3.00E-07	3.00E-03	high	2	medium	buffer	https://pubs.acs.org/doi/abs/10.1021/acssuschemeng.8b02510
22	176	small molecule	indole acetic acid	fractal nPt	Pt/Ir microwire	1.00E-06	1.00E-03	high	1	high	root growth media	https://link.springer.com/article/10.1007/s00344-017-9688-4
23	181	small molecule	Glucose	nPt/GOx	graphene paper	8.00E-08	1.00E-03	excellent	2	medium	buffer	https://www.ncbi.nlm.nih.gov/pubmed/27209574
24	181	small molecule	Glucose	nPt/GOx	Pt/Ir microwire	1.00E-07	5.00E-06	excellent	1	medium	blood	https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0166557
25	181	small molecule	Glucose	nPt/nCe/GOx	Pt electrode	1.00E-07	3.00E-06	excellent	1	medium	buffer	https://www.sciencedirect.com/science/article/pii/S0956566314000992

Library
PoC
DB

Development of SENSEE 1.0 (**SEN**sor **SE**arch **E**ngine)

Sensor R&D
Community

Spreadsheet

High Quality Description

Sensor Properties

Contributed by
Experts

Library
PoC
DB

Development of SENSEE 1.0 (**SEN**sor **SE**arch Engine)

Sensor R&D
Community

Spreadsheet

High Quality Description

Basic Search, DB Tools

Sensor Properties

Contributed by
Experts

Elasticsearch, UI
DevOps, Web Host



SENSEE



Response time for
superoxide dismutase is
1200 seconds

what is the response time for superoxide dismutase?

Submit

<http://139.162.7.63/SENSEE/>

Library
PoC
DB

Development of SENSEE 1.0 (**SEN**sor **SE**arch **E**ngine)

Sensor R&D
Community

Spreadsheet

High Quality Description

Search Tools

Training



Sensor Properties

Contributed by
Experts

Elasticsearch, UI
DevOps, Web Host

NLU – BERT NLP
Error Correction

Library
PoC
DB

Development of SENSEE 1.0 (**SEN**sor **SE**arch **E**ngine)

Sensor R&D
Community

Spreadsheet

High Quality Description

Search Tools

Training

Scaling



Sensor Properties

Contributed by
Experts

Elasticsearch, UI
DevOps, Web Host

NLU – BERT NLP
Error Correction

Auto-upload,
Auto-config, Check

Library
PoC
DB

Development of SENSEE 1.0 (**SEN**sor **SE**arch **E**ngine)

Sensor R&D
Community

Spreadsheet

High Quality Description

Search Tools

Training

Scaling



Sensor Properties

Contributed by
Experts

Elasticsearch, UI
DevOps, Web Host

NLU – BERT NLP
Error Correction

Auto-upload,
Auto-config, Check

Users

Library
PoC
DB

SENSEE 1.0 PROOF OF CONCEPT – TEST QUESTIONS

- 155) What molecules can be detected in breast milk using biosensors?
- 156) What is the difference in sensitivity between glucose biosensors based on graphene or platinum foil?
- 157) What is the most sensitive biosensor based on carbon nanotubes?
- 158) How many biosensors have been proposed for glucose determination?
- 159) Anthocyanin is used as a target for which biosensor?
- 160) Which biosensors can be used for hydroponic medium?
- 161) In which samples, glutamate and/or glutamine was determined using biosensors?
- 162) Which biosensors were proposed for catecholamine determination?
- 163) What is the lowest limit of detection for graphene-based biosensors?
- 164) What is the maximal range for nitrate biosensors?
- 165) What platforms can be used for ammonium detection and mercury detection?
- 166) Most durable recognition-transduction scheme for interferon gamma biosensors?
- 167) Best limit of detection achieved with phosphotriesterase-based biosensors?
- 168) How many biosensors were described for ATP determination?
- 169) What platforms were proposed for ATP-sensitive biosensors?
- 170) What is the average LOD of K⁺ sensors?
- 171) Which platform could be used for selective glutamate analysis?
- 172) What is largest analyte/molecule for which there is a sensor in the database?
- 173) Is there any cost associated with any type of sensor?
- 174) How many labs are making sensors to detect lead in water?
- 175) Are there sensors to detect air-borne viruses in the air?

Development of SENSEE 1.0 (SENsor SEarch Engine)

Sensor R&D
Community

Spreadsheet

High Quality Description

Search Tools

Training

Scaling

Sensor Properties

Contributed by
Experts

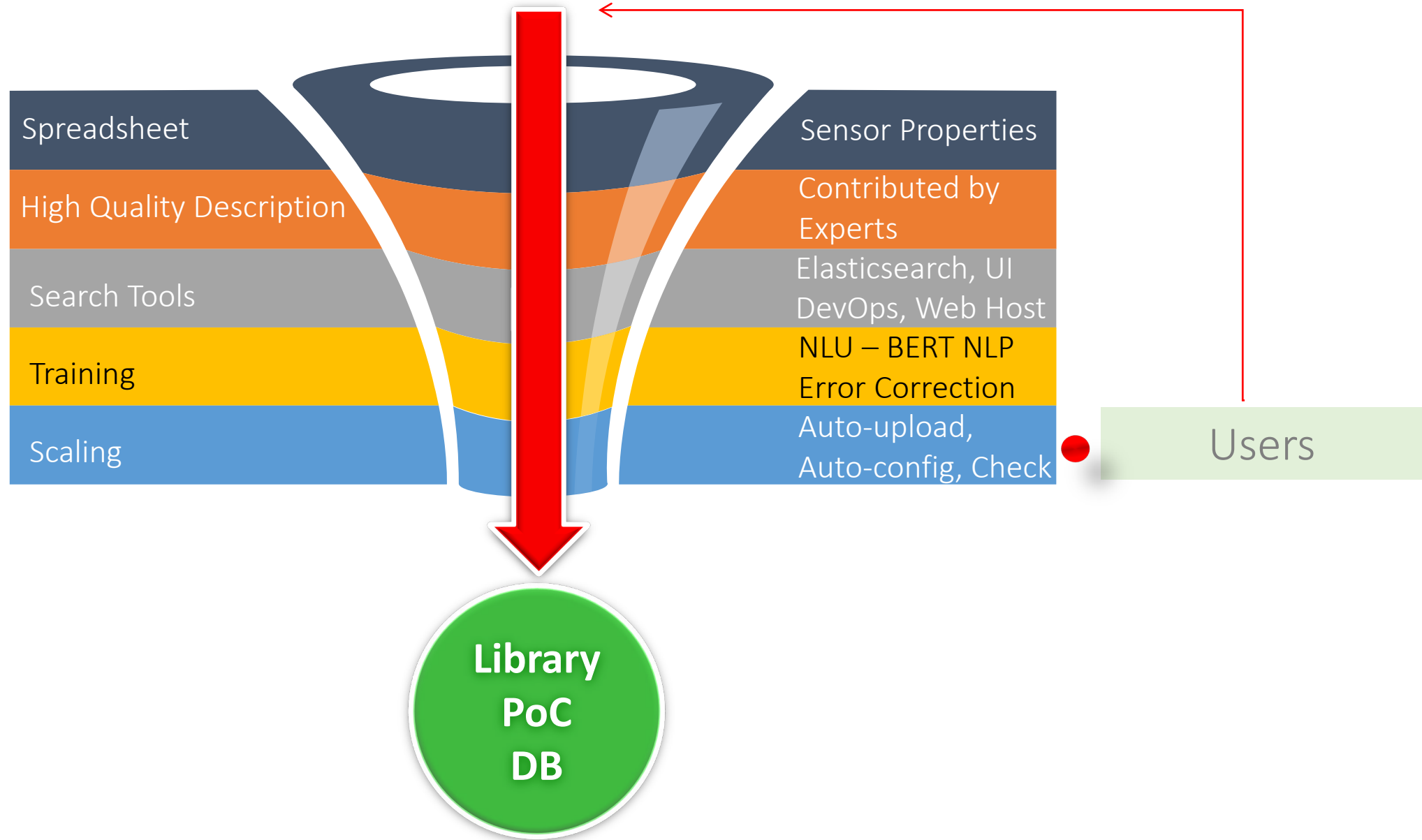
Elasticsearch, UI
DevOps, Web Host

NLU – BERT NLP
Error Correction

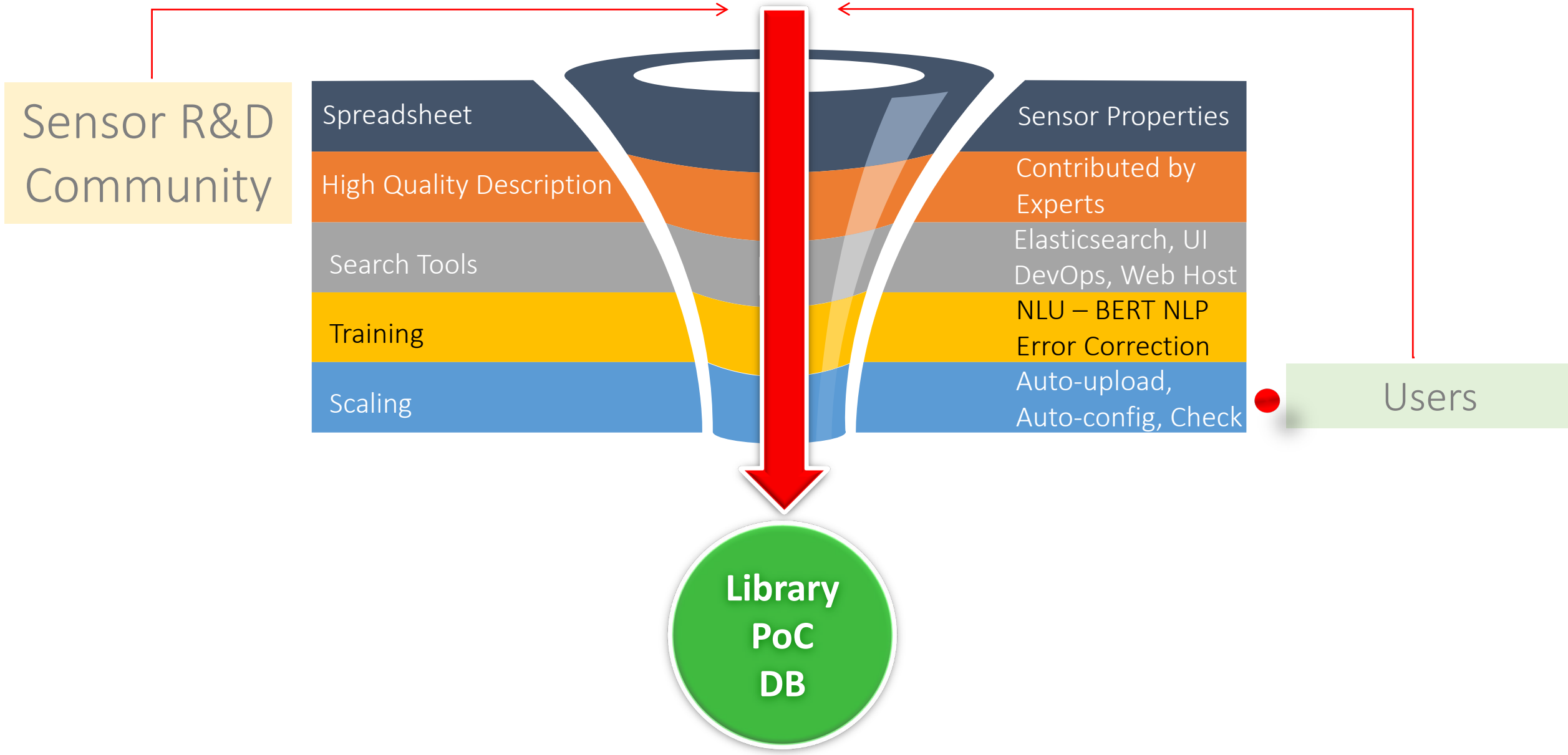
Auto-upload,
Auto-config, Check

Users

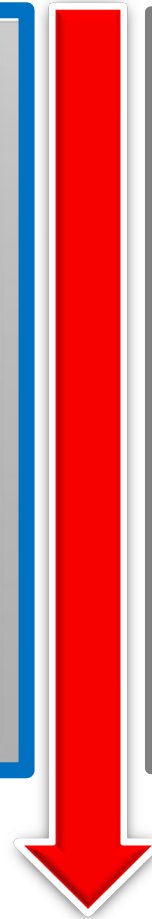
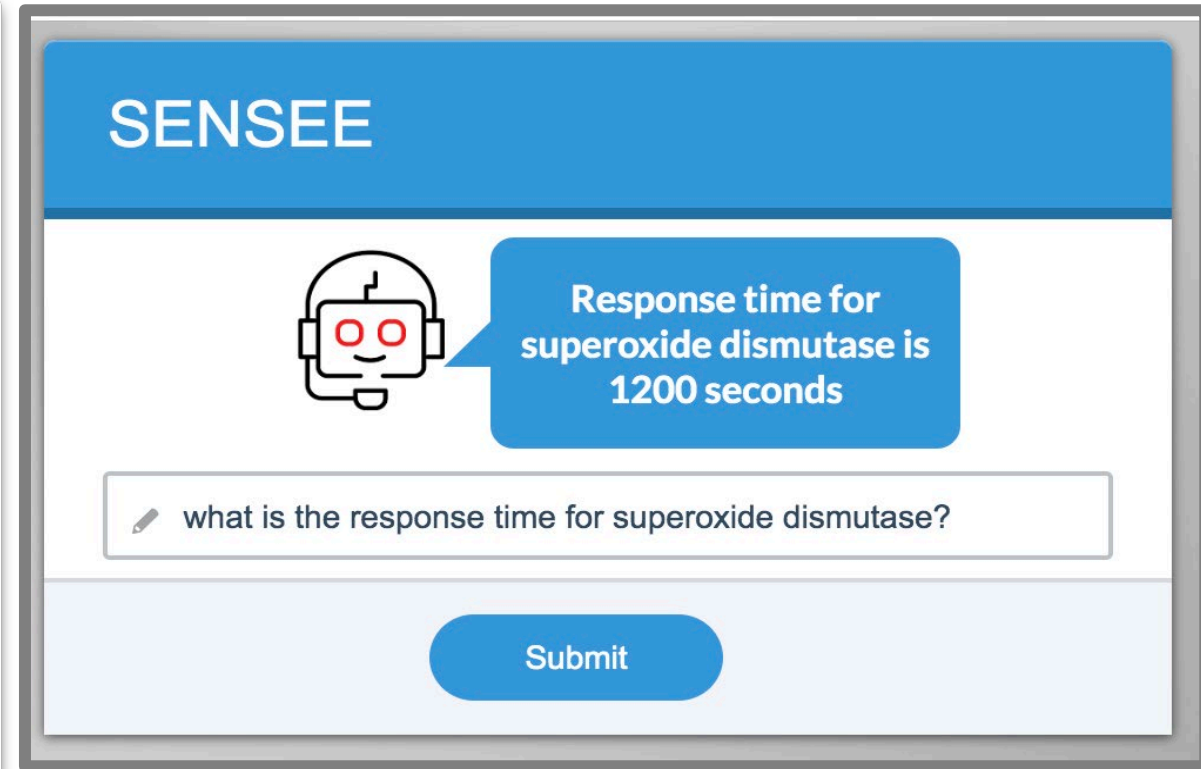
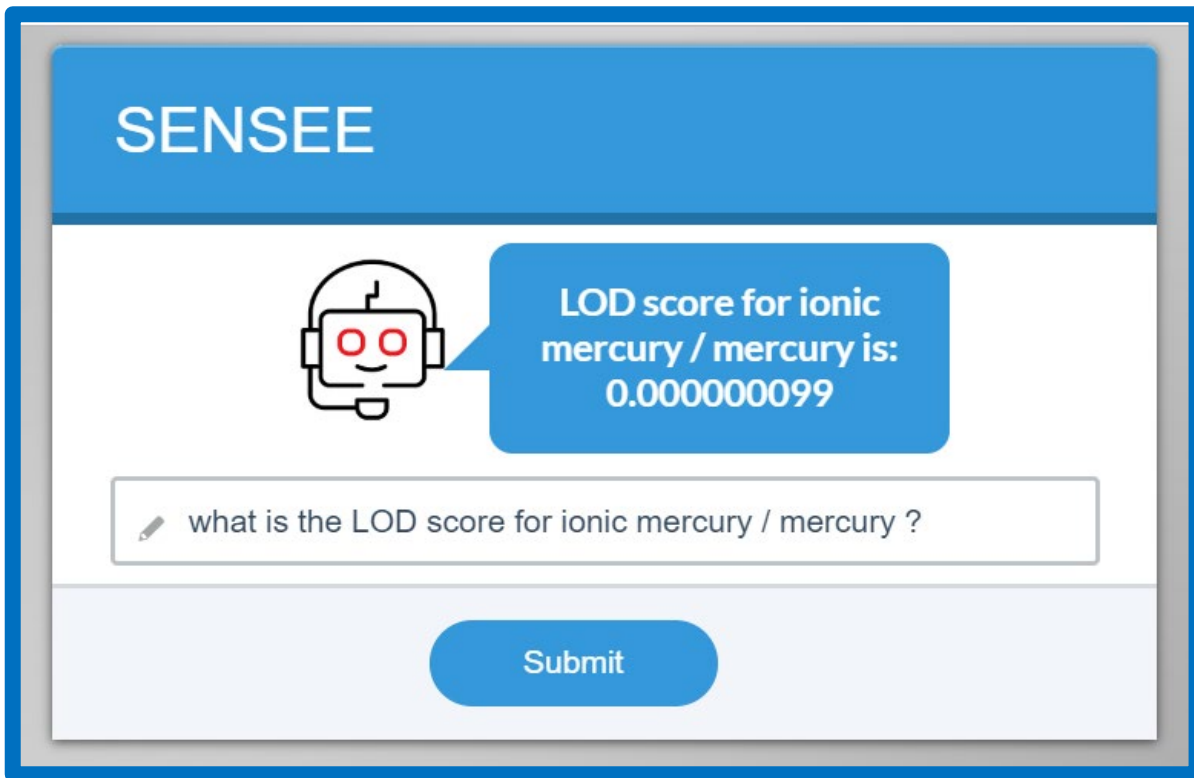
Library
PoC
DB



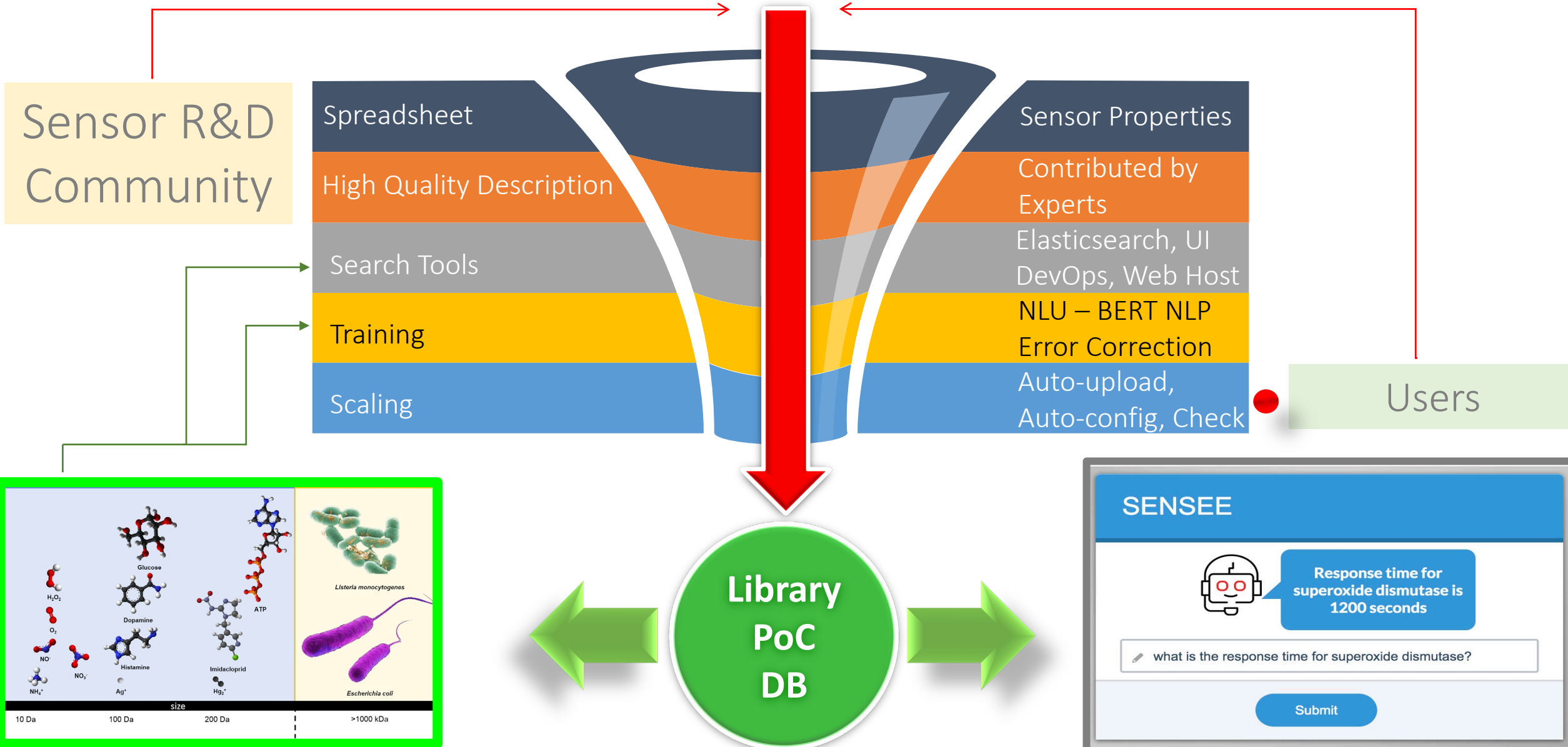
Development of SENSEE 1.0 (**SEN**sor **SE**arch Engine)



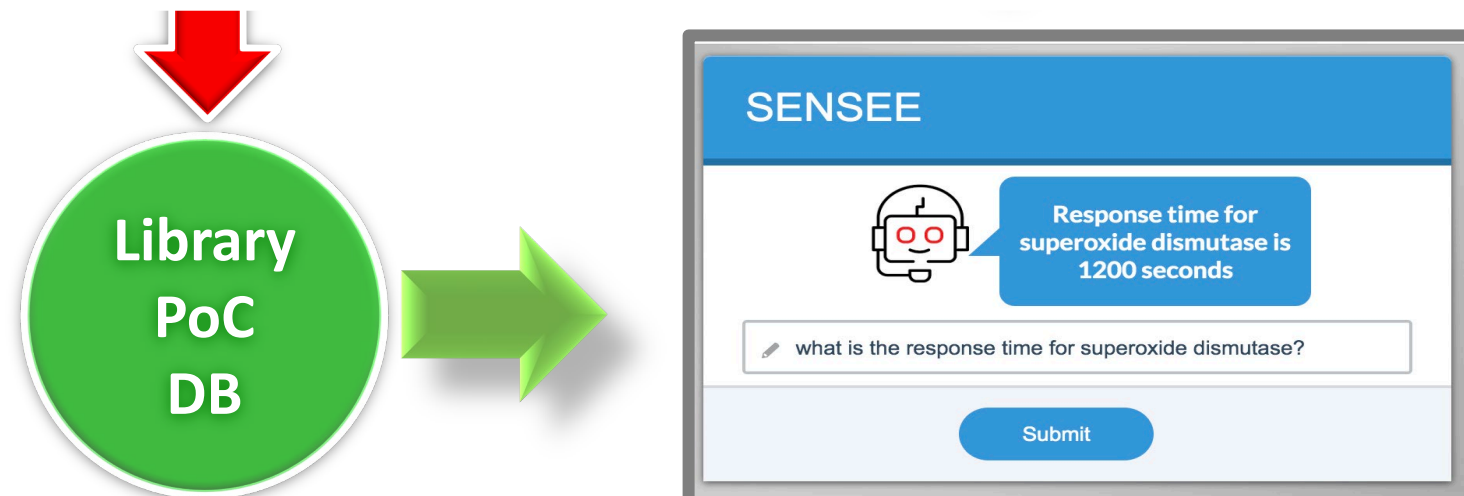
SENSEE 1.0 PROOF OF CONCEPT – DIALOG BOX APP



Development of SENSEE 1.0 (SENsor SEArch Engine)



This is where we are ...

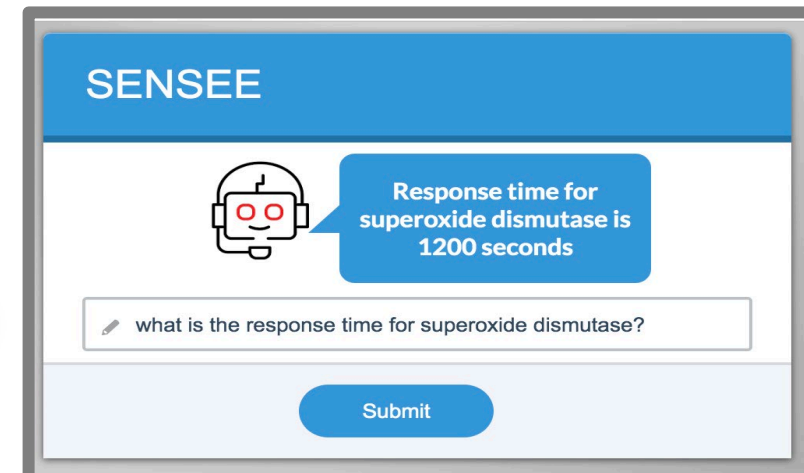
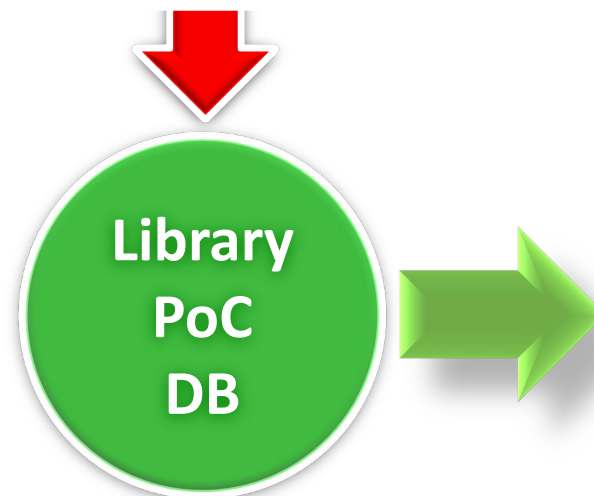


Development of SENSEE 1.0 – This is where we are



To move forward ...

<http://bit.ly/SUBSCRIBE-TO-SENSEE>



Research Community we need your help

Scaling

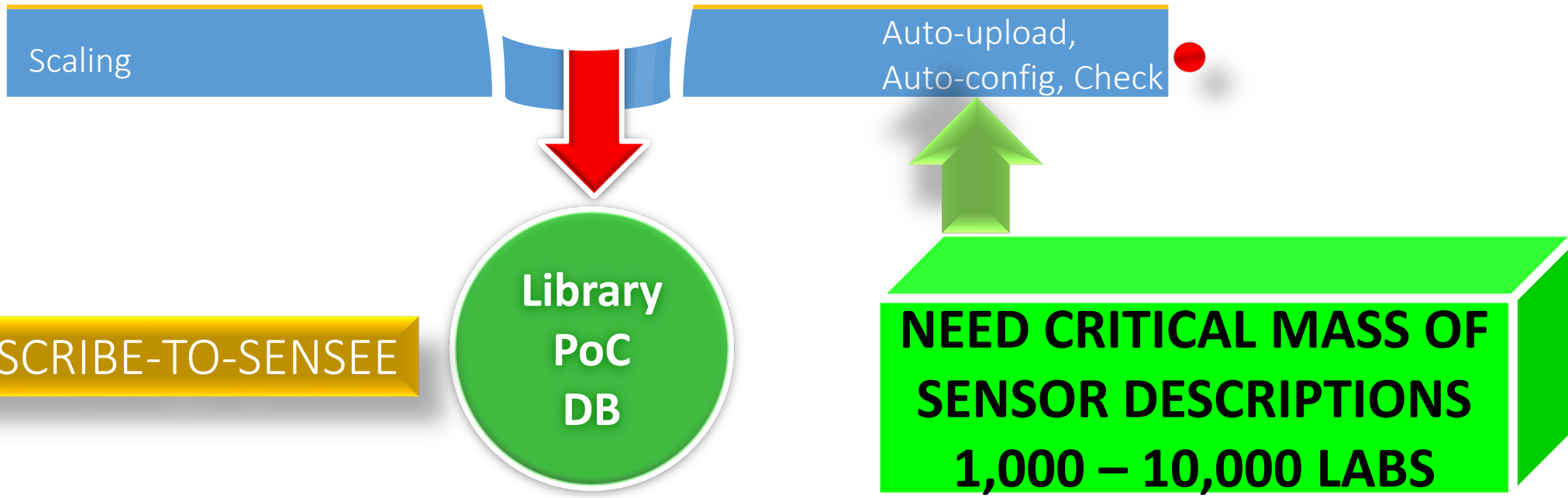
Auto-upload,
Auto-config, Check

Library
PoC
DB

**NEED CRITICAL MASS OF
SENSOR DESCRIPTIONS
1,000 – 10,000 LABS**

<http://bit.ly/SUBSCRIBE-TO-SENSEE>

It is useless without sensor descriptions



<http://bit.ly/SUBSCRIBE-TO-SENSEE>

NO sensor data until 2.0

Your sensor descriptions

Scaling

Auto-upload,
Auto-config, Check

Library
PoC
DB

**NEED CRITICAL MASS OF
SENSOR DESCRIPTIONS
1,000 – 10,000 LABS**

<http://bit.ly/SUBSCRIBE-TO-SENSEE>

XL auto-UPLOAD tool for your sensor descriptions

Scaling

Auto-upload,
Auto-config, Check

<http://bit.ly/SUBSCRIBE-TO-SENSEE>

Library
PoC
DB

**NEED CRITICAL MASS OF
SENSOR DESCRIPTIONS
1,000 – 10,000 LABS**

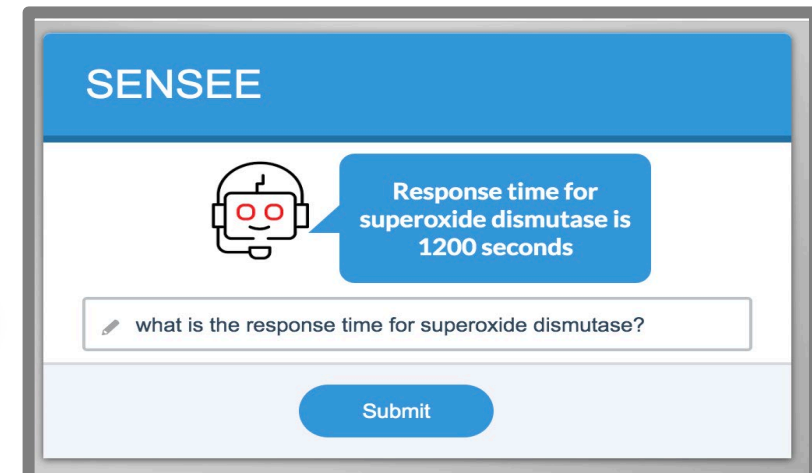
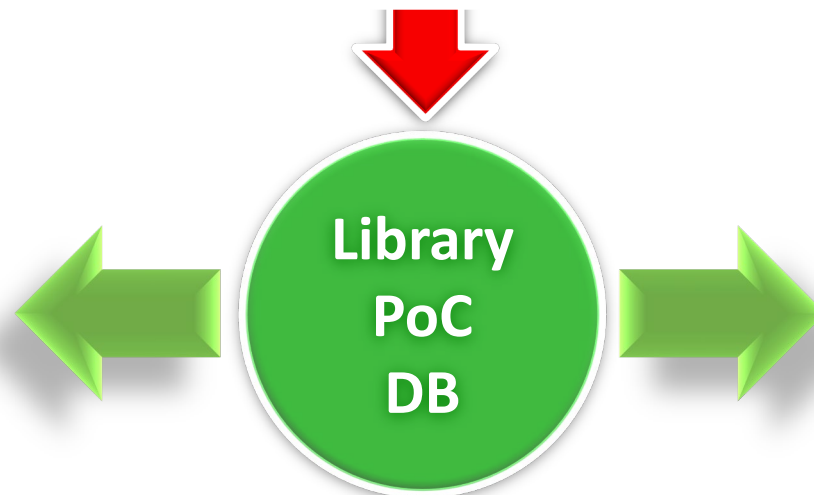
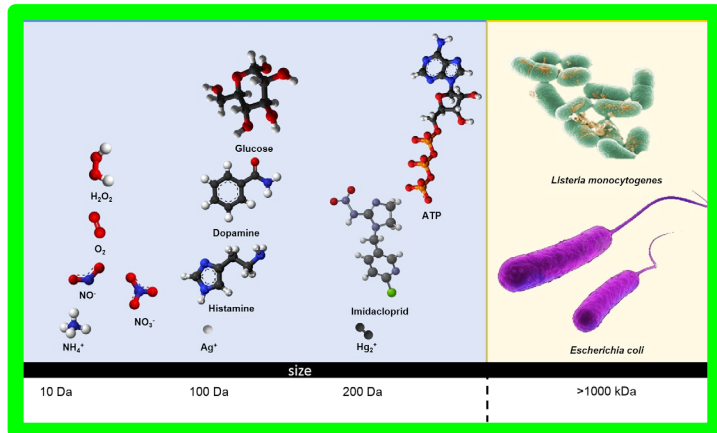
Your Spreadsheet

Sensor Properties

	A	B	C	D	E	F	G	H	I	J	K	L
1	MW [Da]	Category	Target	Recognition-transduction scheme	Platform	LOD [M]	Max range [M]	Selectivity (interferent species tested)	Response time [sec]	Durability	USECAT1	Link to paper(s)
2	1	small molecule	H+	H+ ionophore (liquid)	glass capillary	1.00E-13	1.00E-04	excellent (K+, Na+, Ca2+, Mg2+)	2	High	hydroponics	https://www.ncbi.nlm.nih.gov/pubmed/26088926
3	1	small molecule	H+	anthocyanin/nanocellulose	paper filter	1.00E-15	1.00E-02	excellent	2	high	irrigation water	https://www.ncbi.nlm.nih.gov/pubmed/28884510
4	18	small molecule	Ammonium	NH4+ ionophore (liquid)	glass capillary	5.00E-09	1.00E-01	excellent	5	medium	wastewater	http://www.allelopathyjournal.org/archives/?Year=2016&Vol=37&Issue=2&Month=3
5	18	small molecule	Ammonium	NH4+ ionophore (solid)	LSG	2.80E-05	5.00E-01	excellent	2	medium	wastewater	https://pubs.acs.org/doi/10.1021/acsami.8b10991
6	30	small molecule	N/O radicals	nanoplatinum/nanoceria	Pt electrode	1.00E-08	3.00E-06	medium	1	medium	ocean water	https://pubs.rsc.org/en/Content/ArticleLanding/2017/AY/C7AY01964E#divAbstract
7	32	small molecule	DO	Pt porphyrin-nTiO2	fiber optic	1.00E-06	5.00E-06	excellent, temp sens	1	High	hydroponic media	https://www.sciencedirect.com/science/article/pii/S0925400514001117
8	32	small molecule	DO	Pt porphyrin	96 well	1.00E-06	5.00E-06	excellent, temp sens	45	low	hydroponic media	https://www.sciencedirect.com/science/article/pii/S016770121300331X
9	32	small molecule	DO	Pt porphyrin	glass vial	1.00E-06	5.00E-06	excellent, temp sens	45	low	hydroponic media	
10	34	small molecule	H2O2	fractal nPt	Pt electrode	5.00E-09	5.00E-05	excellent	1	high	ocean water	https://www.ncbi.nlm.nih.gov/pubmed/27121177
11	39	small molecule	K+	K+ ionophore (liquid)	glass capillary	1.00E-06	2.50E-01	excellent	2	low	wastewater	https://www.ncbi.nlm.nih.gov/pubmed/24961073
12	41	small molecule	Ca2+	Ca2+ ionophore (liquid)	glass capillary	1.00E-06	5.00E-01	excellent	1	low	Hoaglands media	https://onlinelibrary.wiley.com/doi/full/10.1002/jpln.201700319
13	58	small molecule	acetone	chemosensory proteins-nPt	Pt electrode	5.00E-06	1.00E-05	high	10	low	buffer	https://pubs.rsc.org/en/content/articlelanding/2018/an/c8an00065d#divAbstract
14	62	small molecule	Nitrate	NO3- ionophore (liquid)	glass capillary	1.00E-06	2.00E-01	excellent	2	medium	wastewater	https://www.ncbi.nlm.nih.gov/pubmed/18985610
15	62	small molecule	Nitrate	NO3- ionophore (solid)	LSG	2.00E-05	1.50E-01	excellent	2	medium	wastewater	https://pubs.acs.org/doi/10.1021/acsami.8b10991
16	108	small molecule	Ag+	Ag+ ionophore (liquid)	glass capillary	1.00E-06	5.00E-02	excellent	2	high	wound dressing	https://link.springer.com/article/10.1007/s11356-014-3058-6
17	111	small molecule	histamine	diamine oxidase-nCu	LSG	6.30E-05	1.00E-03	excellent	2	medium	fermented fish	https://www.mdpi.com/2079-6374/8/2/42
18	147	small molecule	Glutamate	CNT/nPt/GlOx	Pt electrode	1.00E-06	1.00E-03	excellent	2	low	INS1 tissue culture	https://www.sciencedirect.com/science/article/pii/S0165027010001196
19	147	small molecule	Glutamate	CNT/nPt/GlOx	Si biochip	1.00E-06	5.00E-01	excellent	2	low	INS1 tissue culture	https://pubs.rsc.org/en/content/articlelanding/2011/im/c1im11561h#divAbstract
20	154	small molecule	catecholamines	nPt	LSG	5.00E-07	3.00E-03	excellent	2	high	ocean water	
21	154	small molecule	catecholamines	graphene anchored nCuO	LSG	3.00E-07	3.00E-03	high	2	medium	buffer	https://pubs.acs.org/doi/abs/10.1021/acssuschemeng.8b02510
22	176	small molecule	indole acetic acid	fractal nPt	Pt/Ir microwire	1.00E-06	1.00E-03	high	1	high	root growth media	https://link.springer.com/article/10.1007/s00344-017-9688-4
23	181	small molecule	Glucose	nPt/GOx	graphene paper	8.00E-08	1.00E-03	excellent	2	medium	buffer	https://www.ncbi.nlm.nih.gov/pubmed/27209574
24	181	small molecule	Glucose	nPt/GOx	Pt/Ir microwire	1.00E-07	5.00E-06	excellent	1	medium	blood	https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0166557
25	181	small molecule	Glucose	nPt/nCe/GOx	Pt electrode	1.00E-07	3.00E-06	excellent	1	medium	buffer	https://www.sciencedirect.com/science/article/pii/S0956566314000992

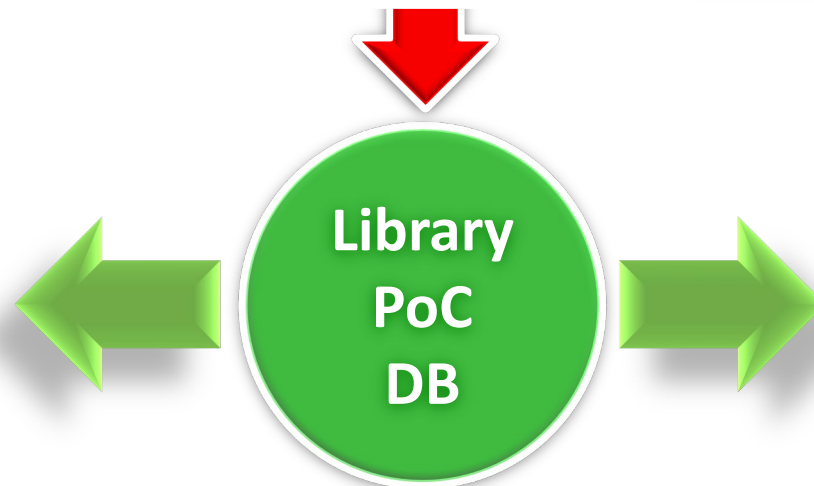
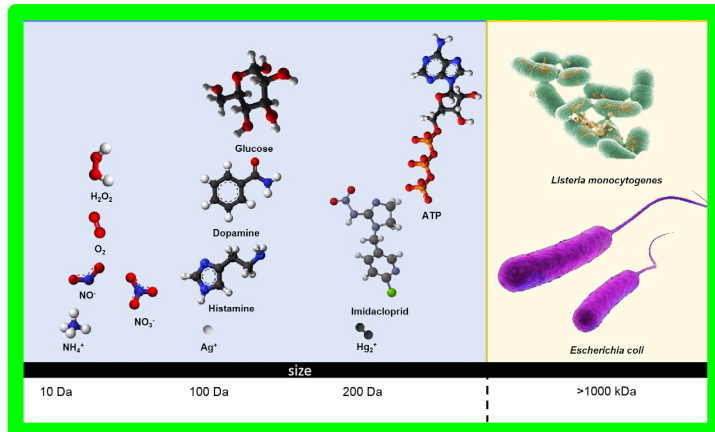
<http://bit.ly/SUBSCRIBE-TO-SENSEE>

We aim to improve visualization tool



What may follow

- ◆ Deploy SENSEE tool. Go live!
 - Automate Feature Engineering
 - Ingest Sensor-specific Data
 - Use cases for DIDA'S PoC
 - Knowledge Graph Algorithms
 - Semantic Data Catalogs
 - User directed search



SENSEE

Response time for superoxide dismutase is 1200 seconds

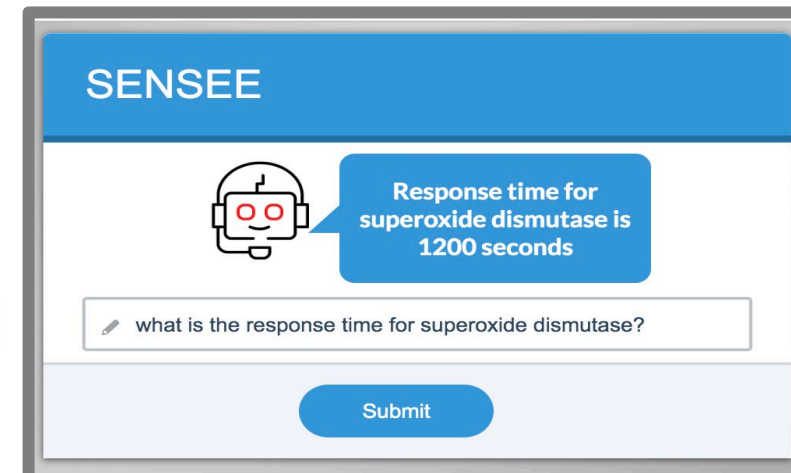
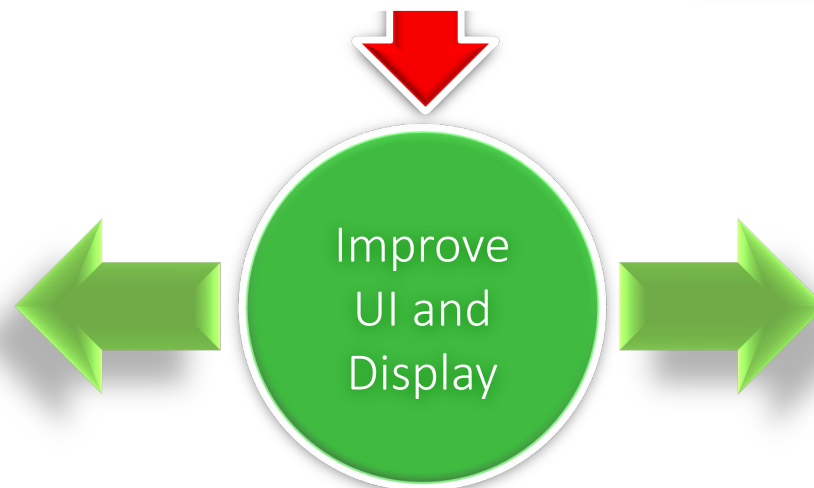
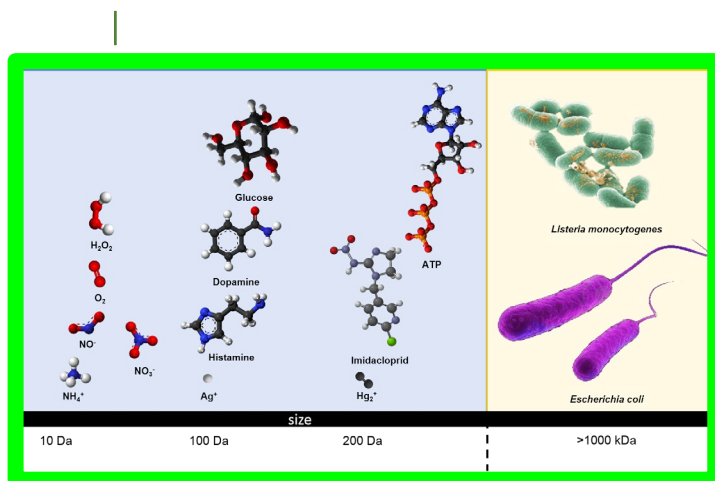
what is the response time for superoxide dismutase?

Submit

Development of SENSEE 1.0 (SENsor SEArch Engine)

Who will use SENSEE 1.0 tool? We anticipate that critical mass of sensor descriptions (categories, attributes) will improve the value of SENSEE 1.0 as a search tool for curated information. Users may be experts in academic and industrial labs. The task of sourcing, uploading, maintaining sensor descriptions may become cost-prohibitive unless a cooperative support structure is implemented to distribute and share the cost of professional services for SENSEE.

◆ Deploy SENSEE 1.0. Go live!



THE
LONGEST
JOURNEY

SENSEE



DIDA'S



KIDS

SENSEE

2.0

THE
LONGEST
JOURNEY

SENSEE



DIDA'S



KIDS

SENSEE

2.0

- Ingest Sensor-specific Data

THE
LONGEST
JOURNEY

SENSEE



DIDA'S



KIDS

SENSEE 2.0 INGESTS SENSOR-SPECIFIC DATA BASED ON USE CASES

The key performance indicator (KPI) for SENSEE will be a measure of its quality of service (QoS metric) with respect to the delivery of precision responses and value of recommendations. Description of sensor types (categories, attributes) in SENSEE 1.0 may enable end-users to choose sensors relative to use cases. But, without sensor-specific data, *relative to the use case of the end-user*, the value of SENSEE diminishes. Acquisition of data from sensors in SENSEE 2.0 will be relative to use case. For example, if Comfrey Farms wishes to optimize quality of meat color in its pork product, the outcome (desired color of pork meat) may need to converge and combine data from ammonia sensors (amount of ammonia in the hog environment), homofermentative microbial species in feed (*Lactobacillus* sp) and colorimetric data from robotic arm involved in meat processing. SENSEE 2.0 aims to acquire end-user case-based sensor data to address problems and questions of pragmatic value. The feasibility of this approach may be challenged by sensor manufacturers (for example, ammonia gas sensor from C2Sense, microbial sensor from Thermo-Fisher and colorimetric sensor from Omron) who may want to aggregate their own data and encrypt data ports and data loggers to prevent data interoperability and distribution. Manufacturer's portals are focused on sensors specific to the manufacturer. SENSEE 2.0 is an open platform, catalyzing synergistic integration of data to synthesize information, with respect to the end-user's problem. The potential for profitability from data fusion followed by synthesis of actionable information, may be an economic incentive for end-users. It may encourage users to support the SENSEE-DIDA'S-KIDS platform approach by uploading sensor data to SENSEE 2.0 directly from their operations. DIDA'S, and in future DIDA'S KIDS, may evolve from data-informed DSS to synthesis of relevant information, followed by the knowledge-informed paradigm in decision science.

<http://bit.ly/PARTNER-WITH-PEAS>

SENSEE 2.0 and DIDA'S

Data-Informed Decision as a Service

Progress of Development – SENSEE 2.0 and DIDA'S

Sensor R&D
Community

Spreadsheet

High Quality Description

Search Tools

Training

Scaling

Sensor Properties

Contributed by
Experts

Elasticsearch, UI
DevOps, Web Host

NLU – BERT NLP
Error Correction

Auto-upload,
Auto-config, Check

Users

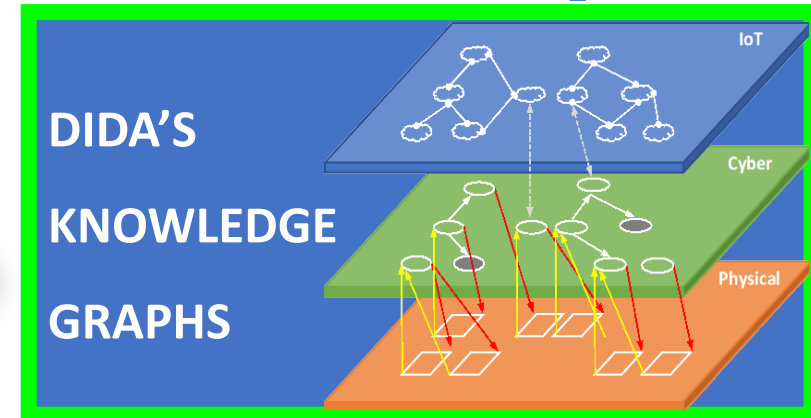
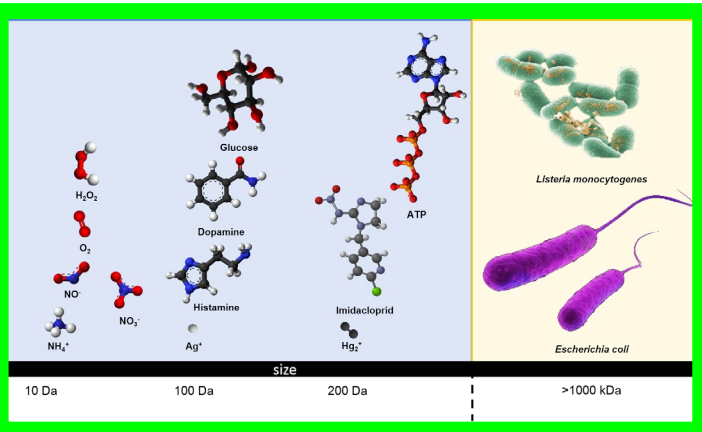
Library
PoC
DB

DIDA'S
KNOWLEDGE
GRAPHS

IoT

Cyber

Physical

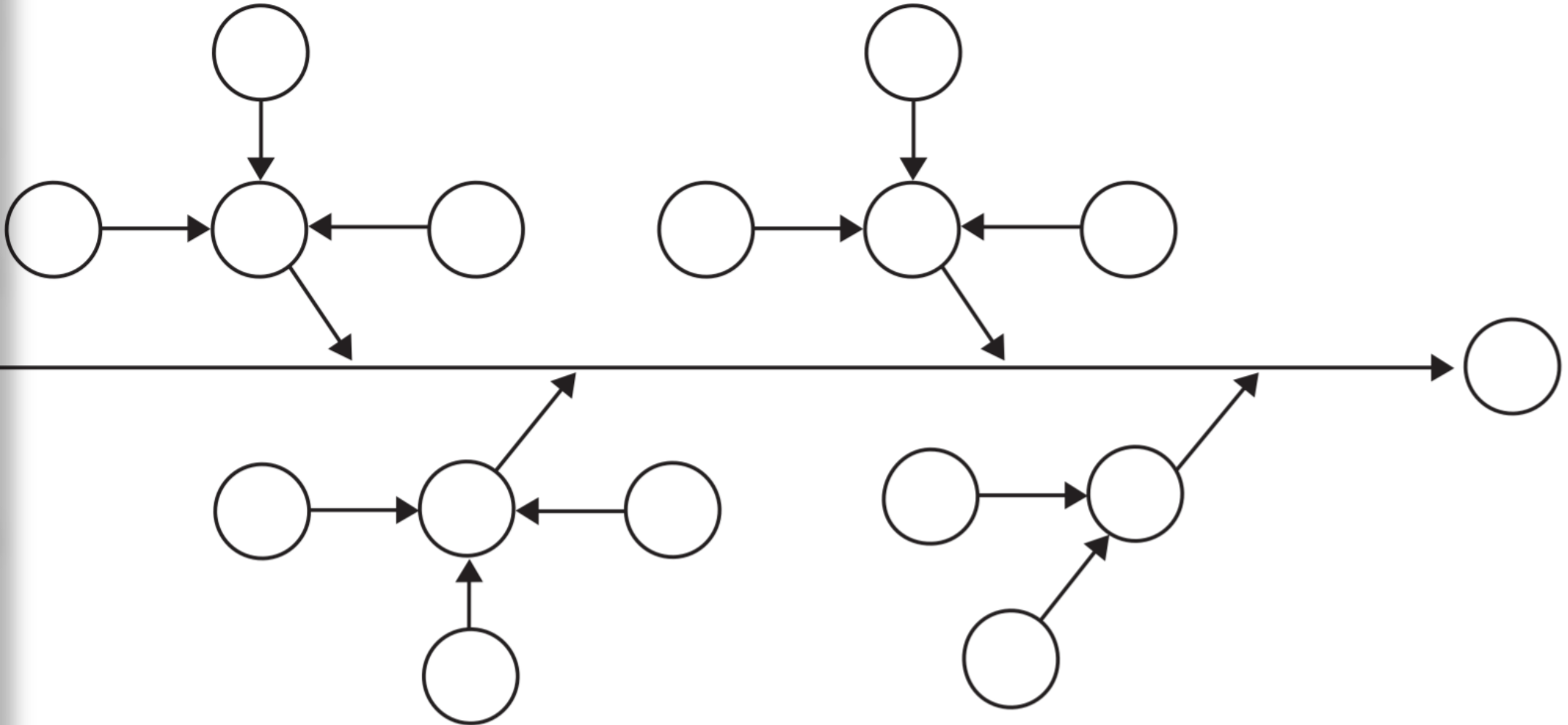


THE
LONGEST
JOURNEY

SENSEE

DIDA'S

KIDS

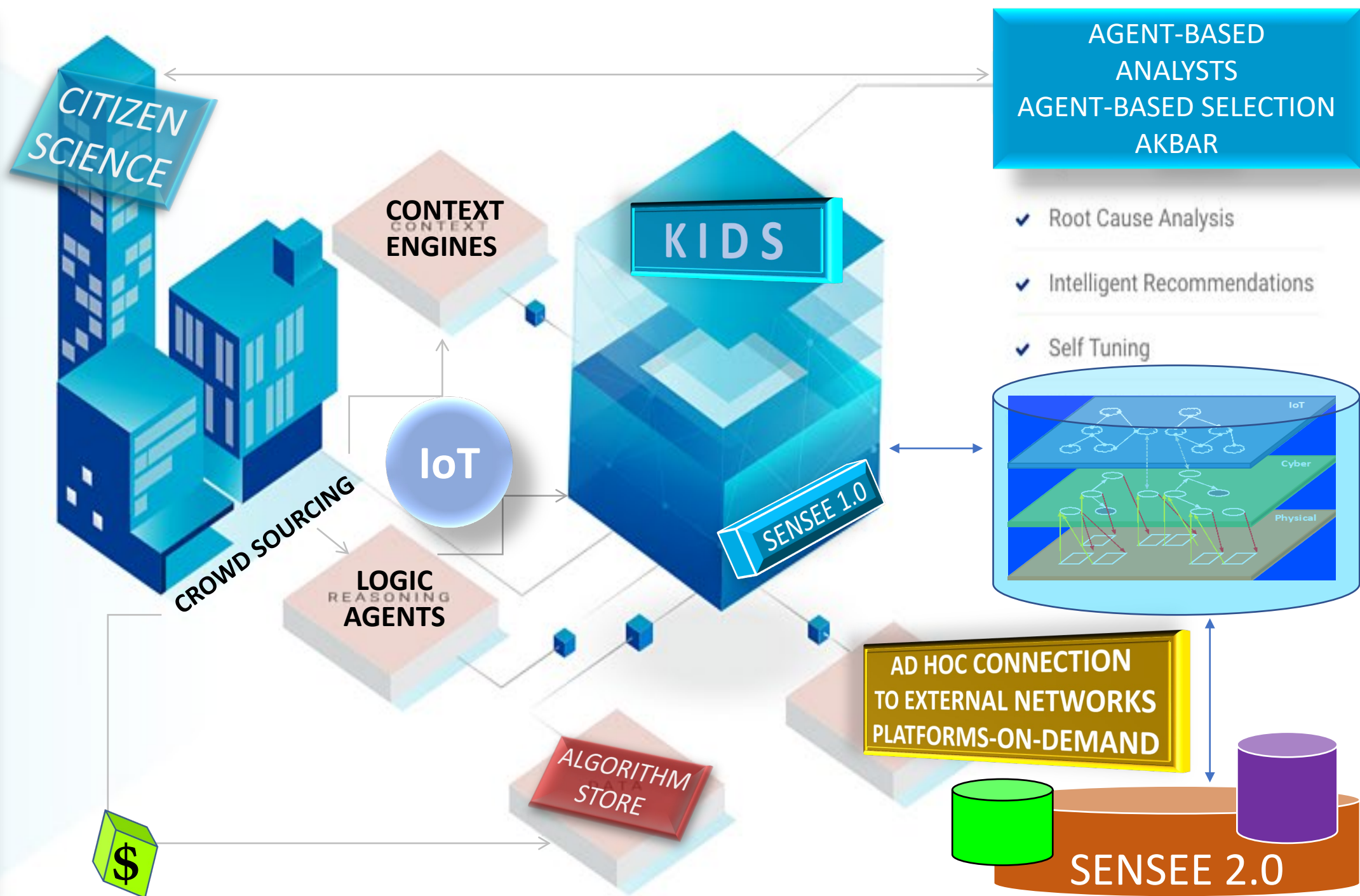


THE
LONGEST
JOURNEY

SENSEE

DIDA'S

KIDS



Anticipate challenges from manufacturers and users

SENSEE

2.0

Unless users allow access to raw data from sensors, the system may be unable to optimize outcomes or minimize risks, for questions which require specific case related data, from relevant sensors. With other general access data, for example, standard protocols for wastewater treatment, it may be possible to offer some degree of information or recommendation but then the value of convergence is limited in its scope.

Anticipated deliverables from SENSEE – Logic Tools?

SENSEE 1.0 (sensor descriptions) and SENSEE 2.0 (sensor-specific data) are tangible pursuits, which can deliver case based solutions, within the scope of [a] data-informed decision support for [b] limited interrelationships in a specific domain [c] restricted to information extraction and recommendation but [d] not approaching the extent of DIDA'S.

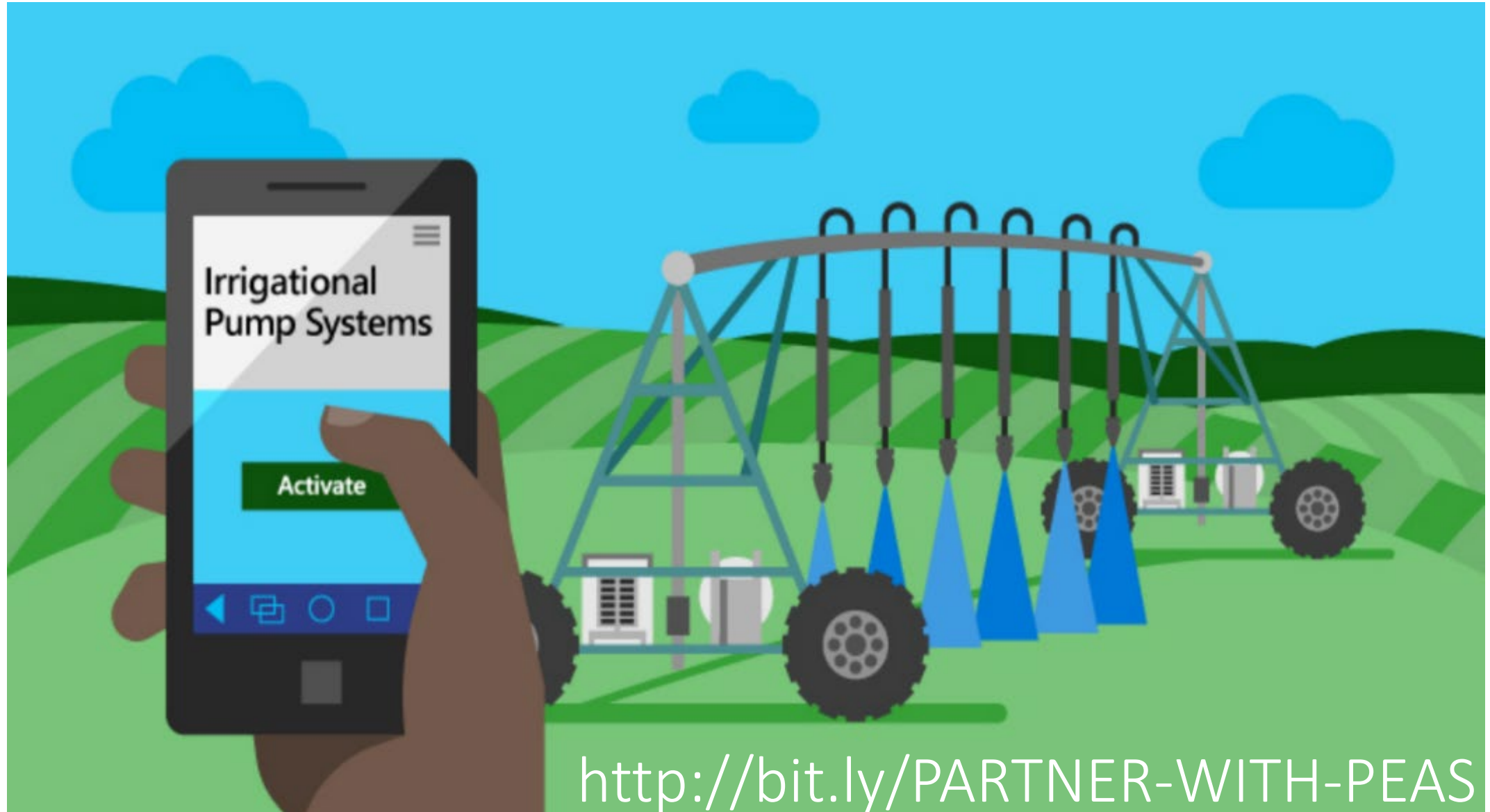
We can use data to create information (thrust of the current state of art with respect to so-called data science) and apply a set of rules and reasoning (logic, dependency, analytics, prior knowledge) to predict known unknowns, in the form of decision support for humans in the loop (recommendation without discovery or actuation) or venture to relinquish control for partial automation (risk-limited actuation) in an IFTTT (workflow) approach to basic service.

This is a form of data-driven, evidence-driven, **reasoning** solution with potential for partially automating workflow. The efficiency gains anticipated from “intelligent” decision support systems lies in our ability to integrate **logic rules**. DIDA'S KIDS includes this format, as the foundation. Logic rules, if understood (semantics), integrated, optimized, and executed, may be the answer to 80% of the global problems, for a tiny fraction of the cost, which may accelerate market adoption and penetration of digital-agro services. Remaining 20% of issues may require DIDA'S KIDS to create dynamic knowledge composable tools embedded with statistical and mathematical modeling based machine learning solutions. These two approaches may be complimentary for 20% of the problems. But, knowledge tools may not be as critical for 80% of our everyday problems, eg, optimizing and actuating (partial automation) of irrigation water pump systems (control volume and distribution of water) based on soil moisture, salinity, ionic content and weather. Thus, we can focus on **logic tools**.

Anticipated deliverables from SENSEE (SENSEE.ES)

SENSEE 1.0 (sensor descriptions) and SENSEE 2.0 (sensor-specific data) repositories, combined with analytics and artificial reasoning, harks back to “expert systems” which preceded the snake oil sales of AI (artificial intelligence) to the stage where hyped-up “AI systems” exploded to near-extinction (1990’s “winter of AI”). The recent re-invention of AI (2010’s) has catalyzed its re-entry into the den of vipers. SENSEE may stay clear of the foggy panache of AI and focus on delivering expert services, in near real-time, which are profitable for users. An expert service requires we create a framework for an expert system to partially mimic the decision-making ability of human experts, who can solve problems by using data and reasoning aided by prior knowledge. The SENSEE concept of expert service (ES) is not the 1980’s version of expert systems. In SENSEE.ES we will use advanced tools: elasticsearch, NLP, semantic catalogs, graph networks, machine learning, and digital-by-design concepts from the internet of things (IoT), using mobile, agile, standards-based tools to optimize data interoperability, semantic intertoperability, technical interoperability (open platform approach) and, ambitious of all, policy interoperability, to be globally adaptable. In the hands of the human analyst, SENSEE 2.0 is the data source to extract evidence and make informed decisions to act on the evidence (SENSEE 2.0 data). The human analyst supplements this decision making logic using domain expertise and experience in the organization (enterprise, farm, factory) to prescribe analytics and orchestrate any necessary course of action based on the data, processes and reasoning. An Agent-based system (ABS) emulating this “human” step (a part of the **logic tools portfolio** of SENSEE.ES) plus IFTTT (if this then that) type workflow based low level decision-driven partial automation, if combined, may suffice to solve many problems, eg, irrigation water flow.

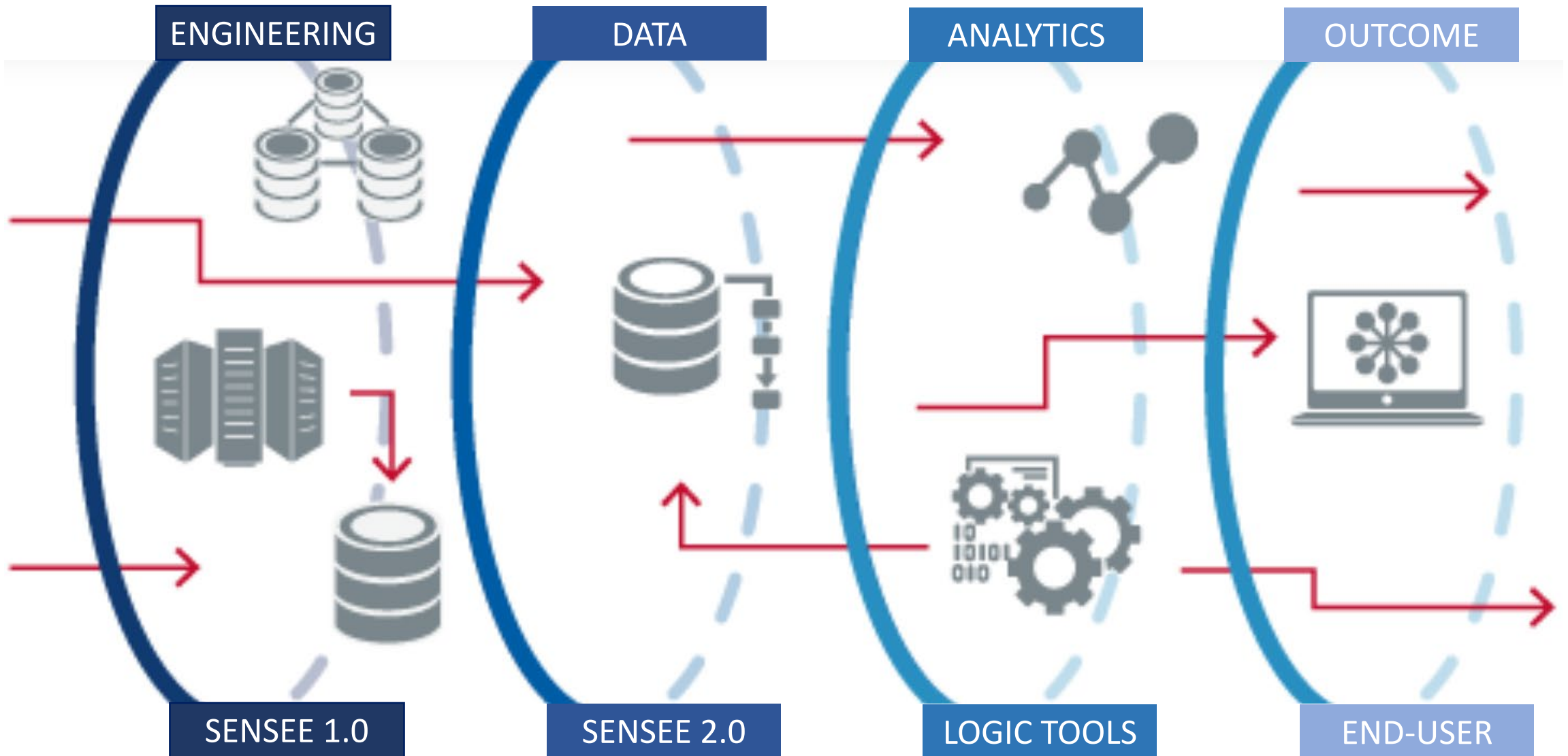
Deliverables from SENSEE – Logic Tools – call it ART ?



<http://bit.ly/PARTNER-WITH-PEAS>

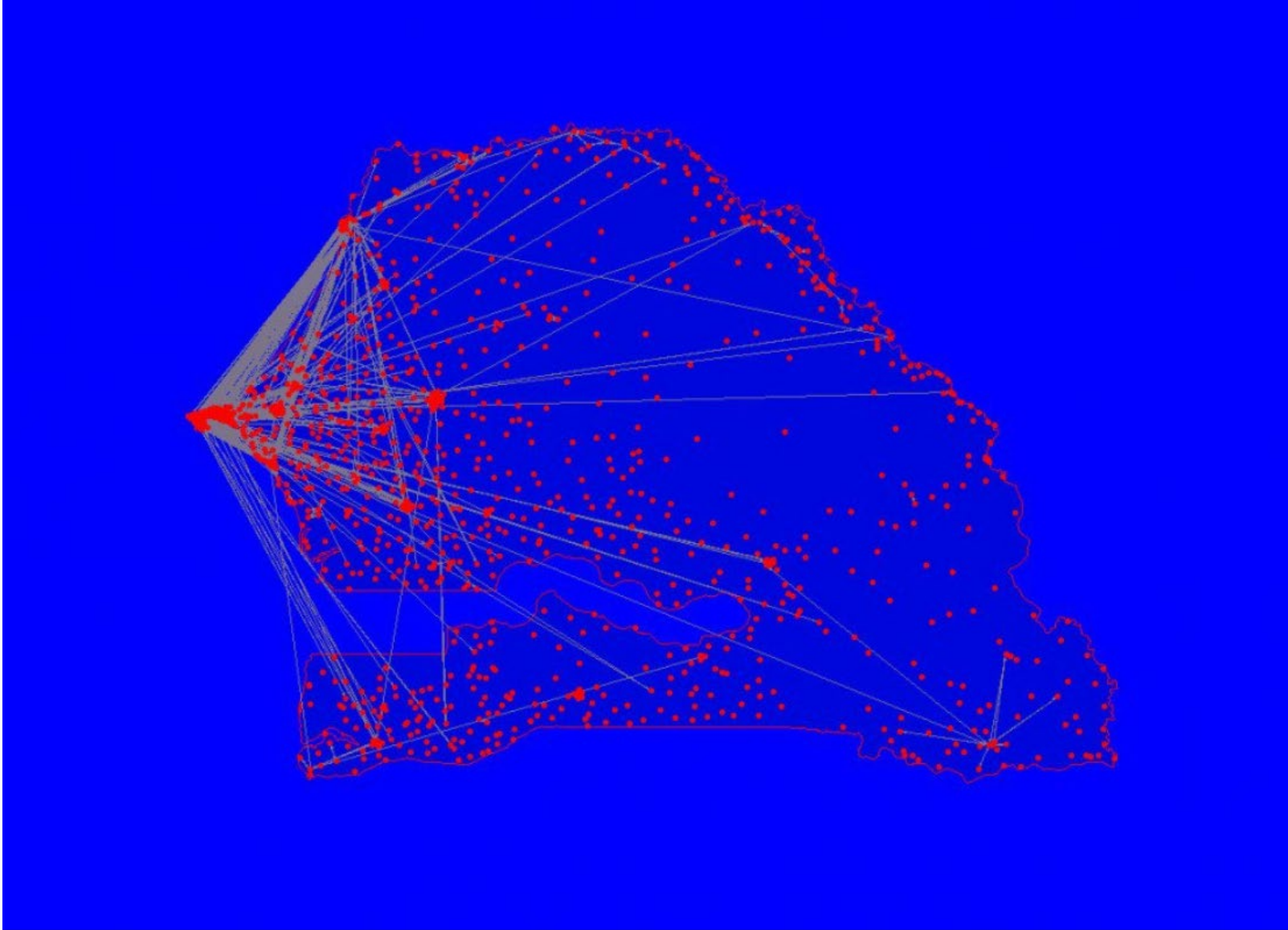
Short-term deliverable from SENSEE? ART of Simplicity

<http://bit.ly/PARTNER-WITH-PEAS>



The nexus of hardware and software lead to the "Plug-n-Play" paradigm. Extending that synergistic simplicity to data and data-informed decision support (DIDA'S) may evolve into DADA ("Drag and Drop Analytics") and the subset SENSOR DADA.

Short-term deliverable from SENSEE? ART of Aggregation



Short-term deliverable from SENSEE? Use natural language

Machine Reading Comprehension (MRC)

uses neural network architecture, Reasoning Network (R-Net), to the mimic inferencing process (constrained by subject/predicate optimization/alignment).

<https://arxiv.org/pdf/1609.05284.pdf>

Another tool is BERT NLP which is also undergoing a series of tests.

<https://arxiv.org/pdf/1810.04805.pdf>

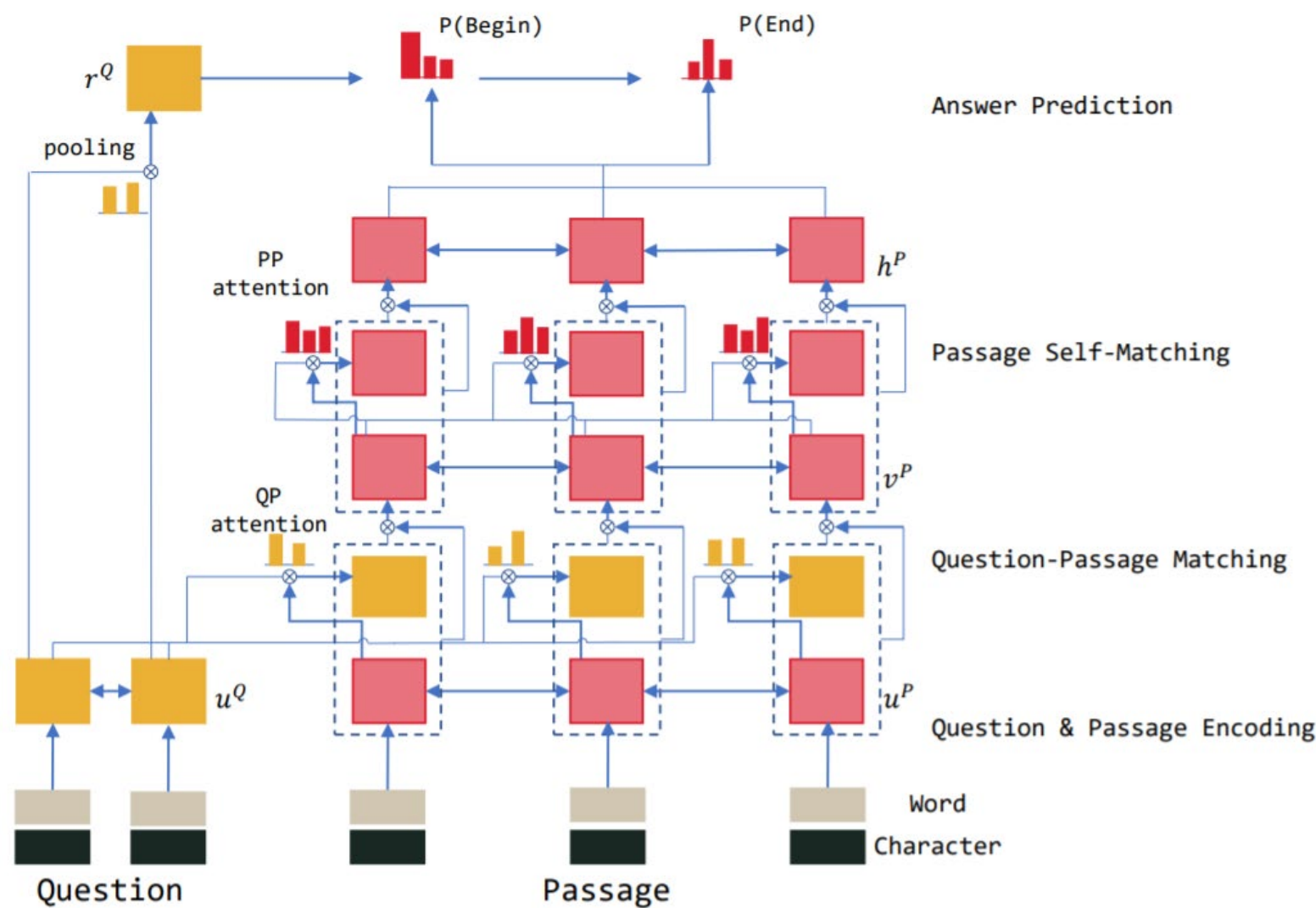
<https://rajpurkar.github.io/SQuAD-explorer/>

Convergence of MRC, R-Net, BERT, XLNet, HAN (hierarchical attention networks), etc, with KG (knowledge graphs) may help to mine contextual word embeddings. It may evolve as a tool not only for Q&A but for non-obvious relationship analysis (NORA) and extraction.

<https://arxiv.org/pdf/1906.08237.pdf>

<https://arxiv.org/pdf/1810.06033.pdf>

www.nature.com/articles/s41586-019-1335-8



https://blogs.microsoft.com/uploads/2018/02/The-Future-Computed_2.8.18.pdf

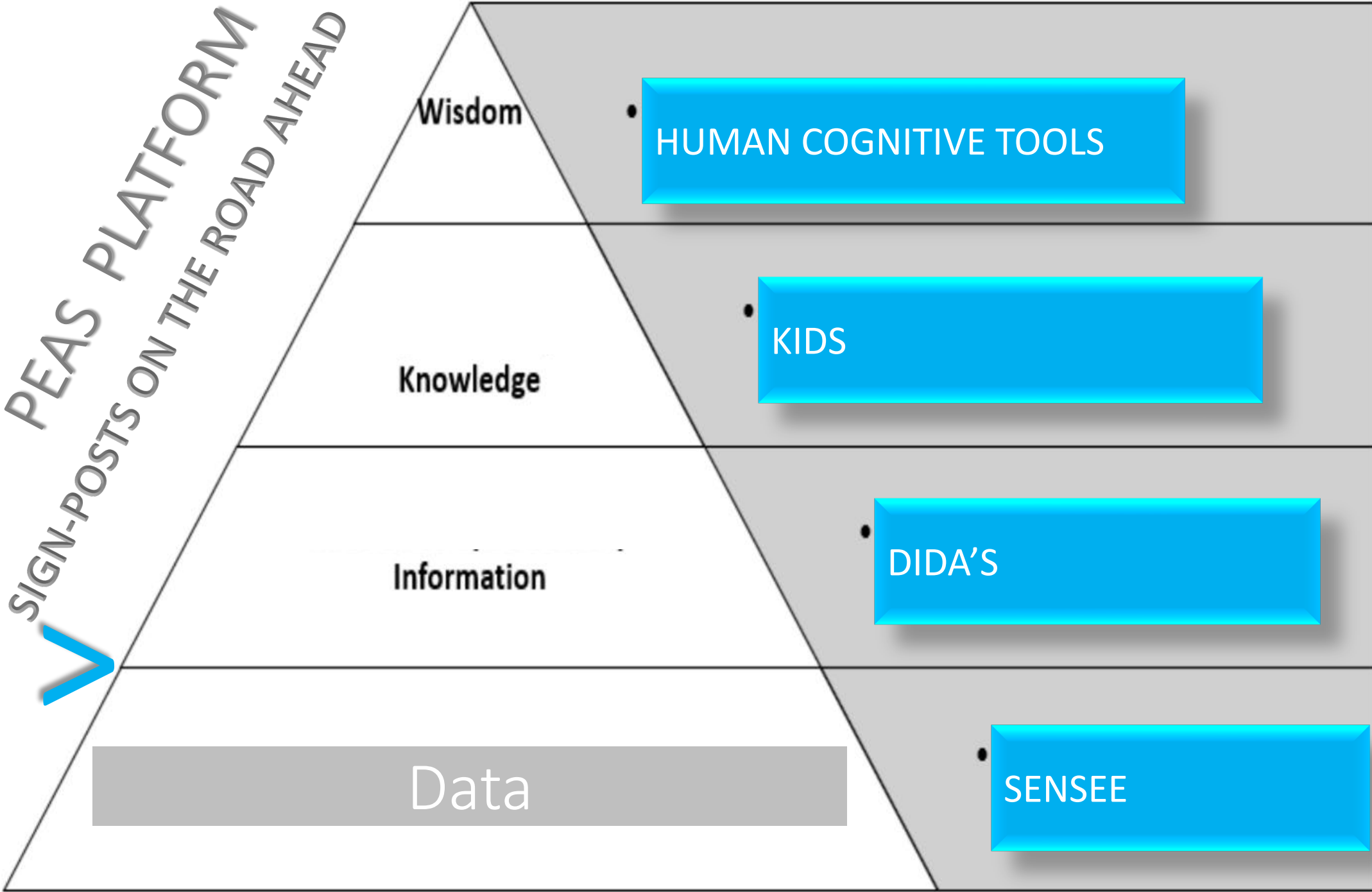
Deliverables from SENSEE – Logic Tools – call it ART ?

ART

Artificial Reasoning Tools

SENSEE leads us to ART, a logical middle ground that may deliver decision tools, as partial solutions for problems bounded by domains (not too expansive in scope) before DIDA'S KIDS.

PEAS PLATFORM
SIGN-POSTS ON THE ROAD AHEAD



< ART

ARTIFICIAL
REASONING
TOOLS (ART)

But, is knowledge still the key performance indicator?

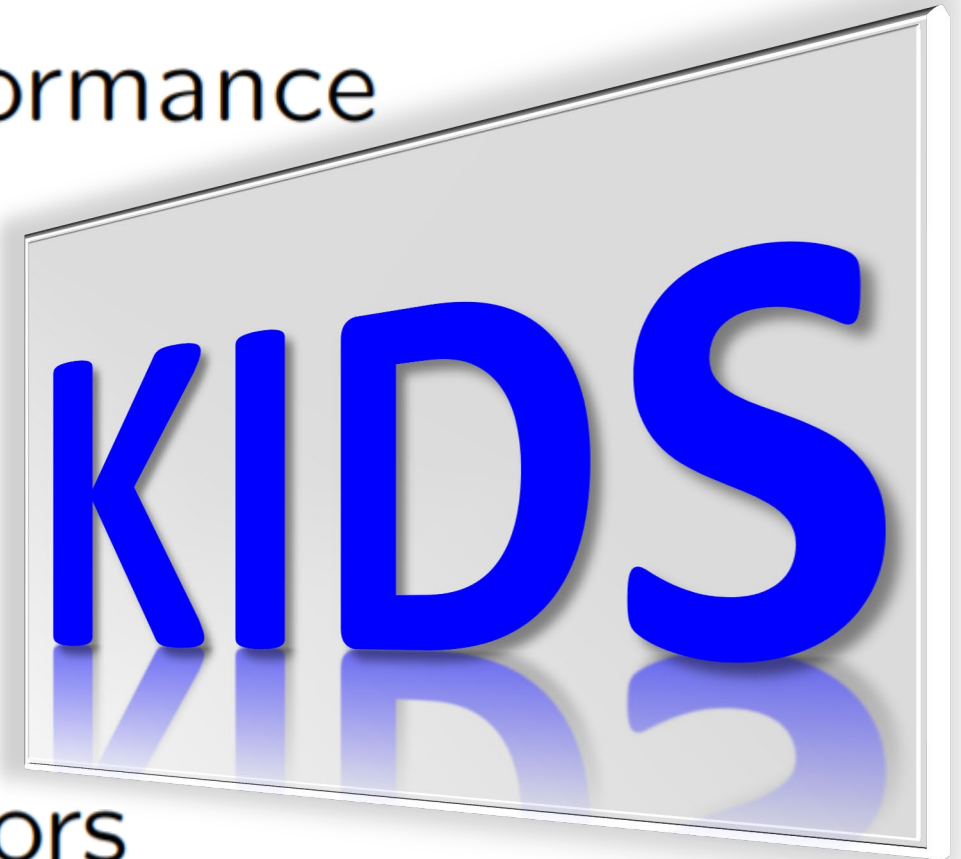
– P

– E

– A

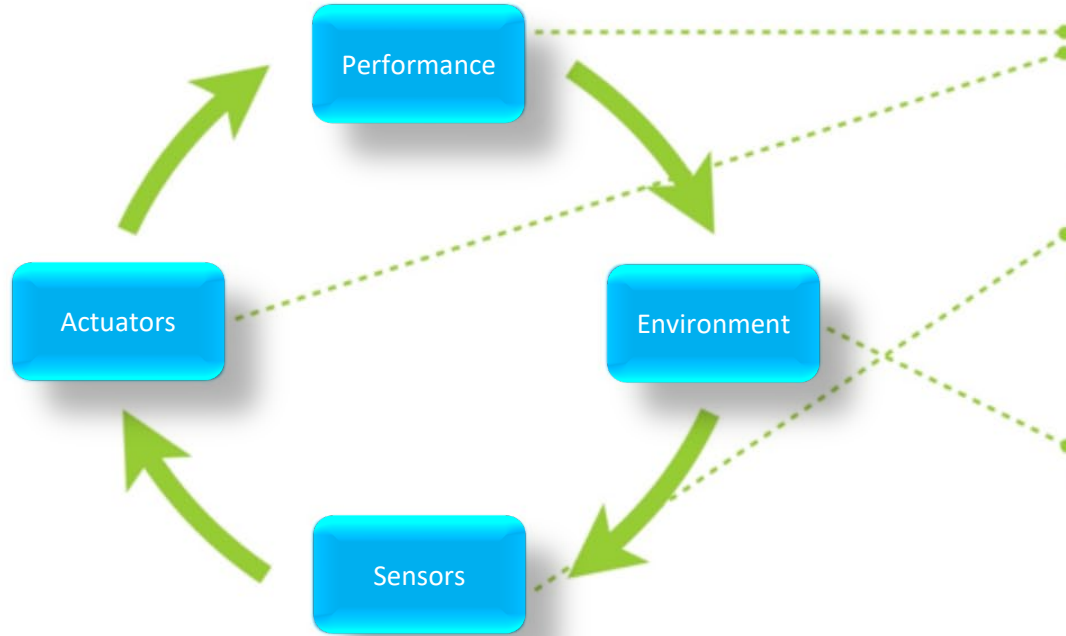
– S

– Performance



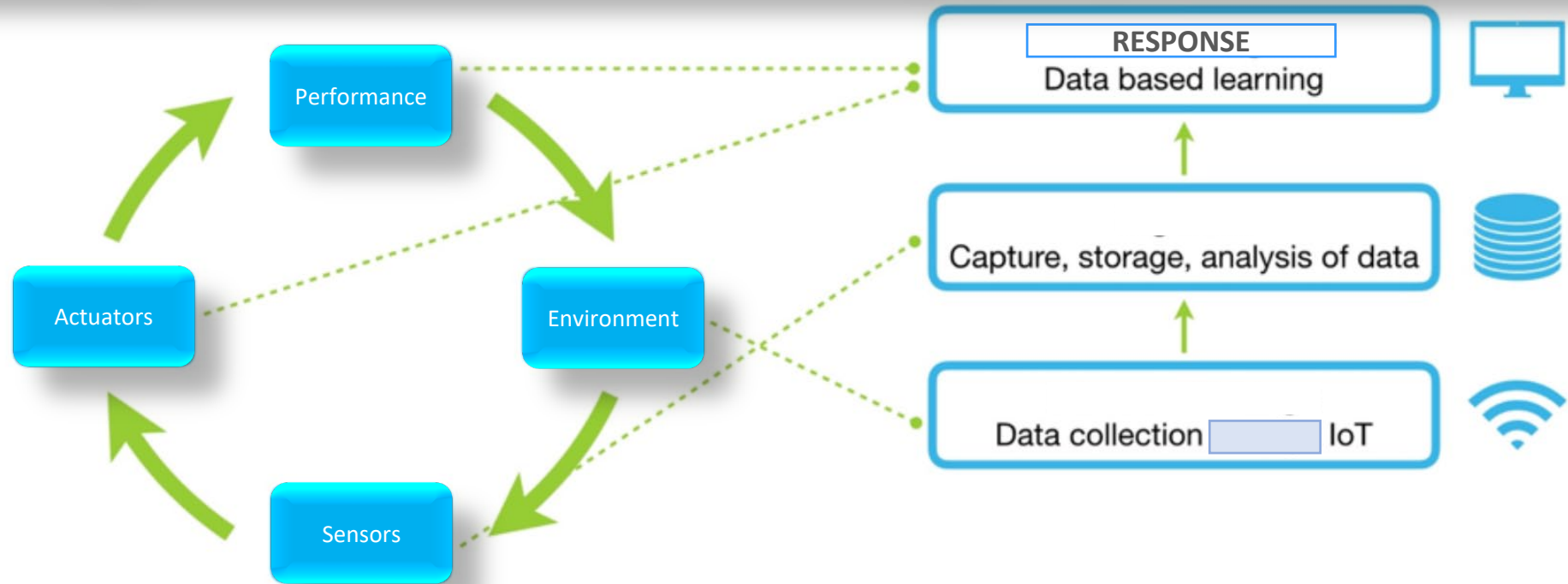
– Sensors

Knowledge is the ultimate key performance indicator



<http://bit.ly/PARTNER-WITH-PEAS>

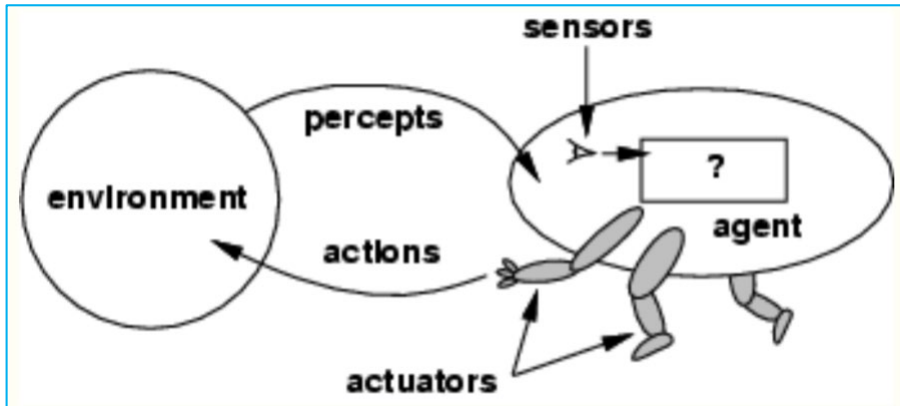
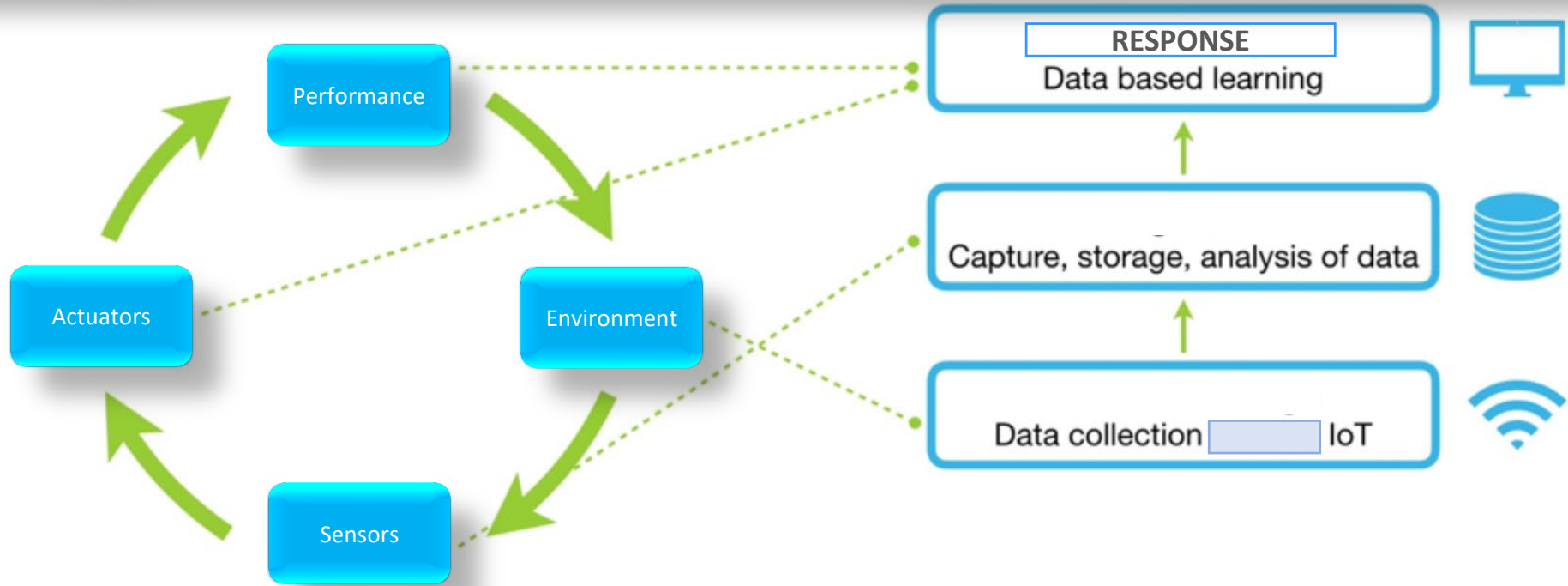
Knowledge is the ultimate key performance indicator



<http://bit.ly/PARTNER-WITH-PEAS>

Knowledge is the ultimate key performance indicator

<http://bit.ly/PARTNER-WITH-PEAS>



<https://www.ics.uci.edu/~welling/teaching/ICS171fall10/Agents171Fall10.pdf>

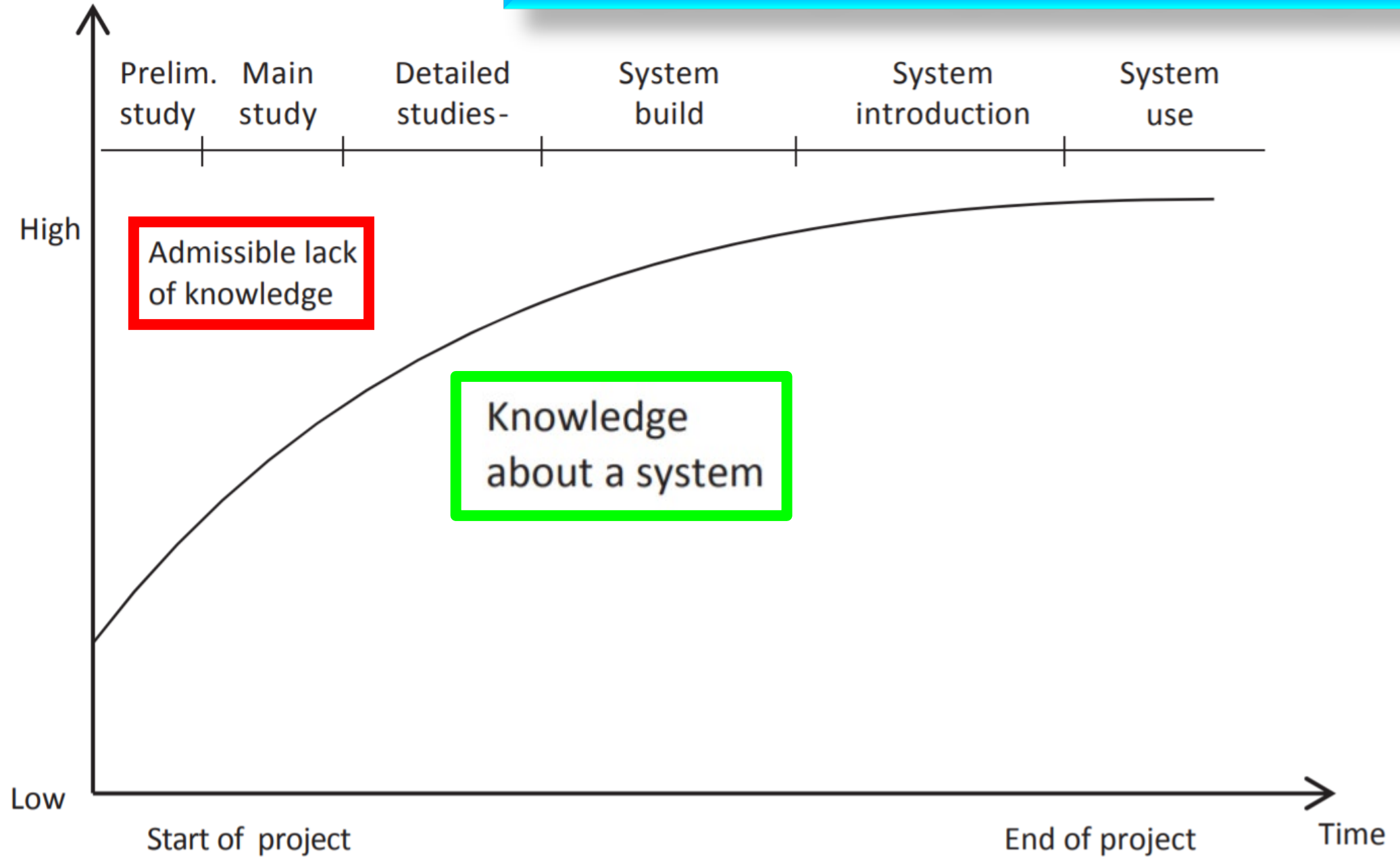
<https://courses.edx.org/asset-v1:ColumbiaX+CSMM.101x+1T2017+type@asset+block@AI+edx+intelligent+agents+new+1+.pdf>

Have we gained *knowledge* from data and decisions?

An open question, for the long run ...

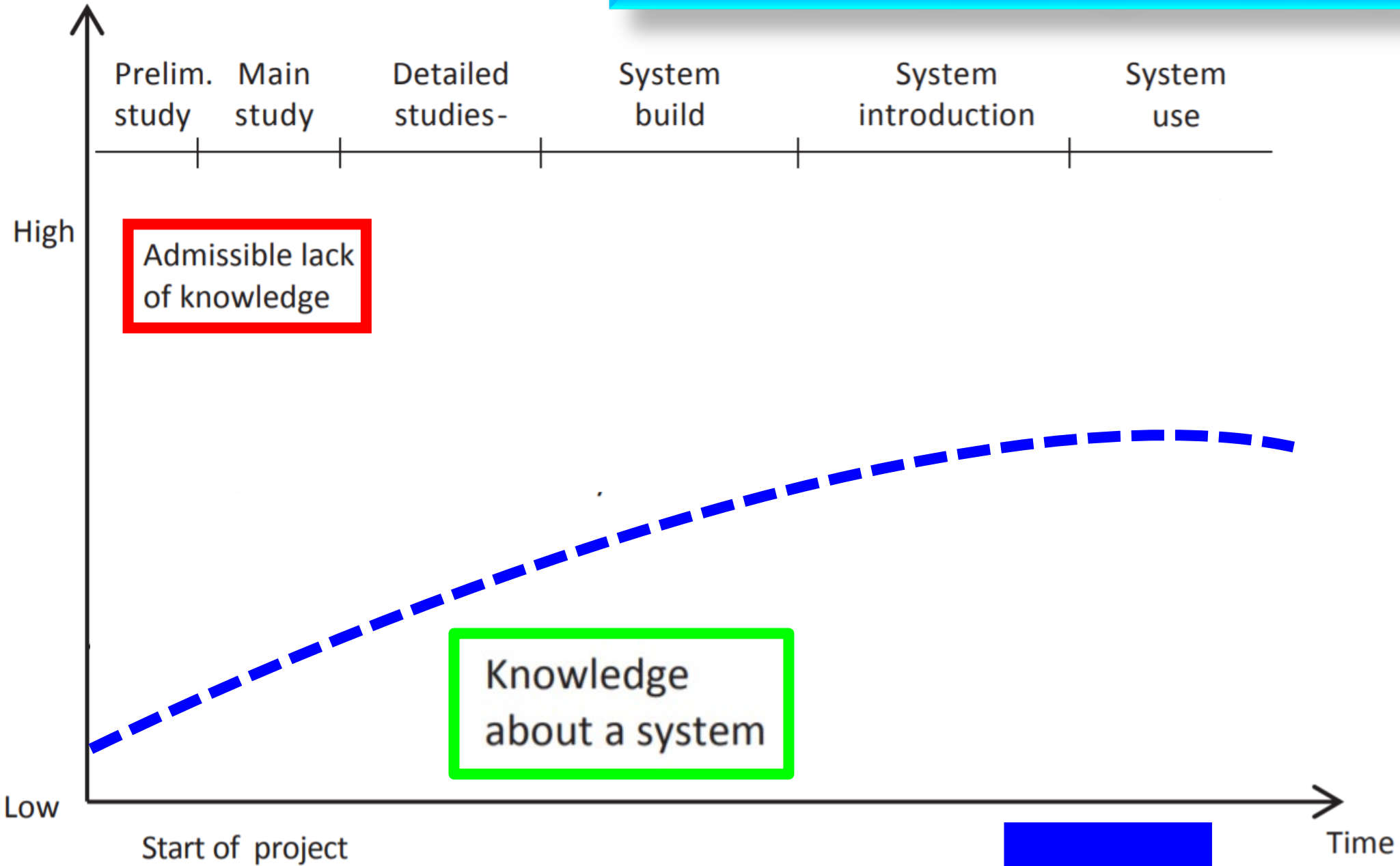
In a systems engineering approach, knowledge increases.

Knowledge

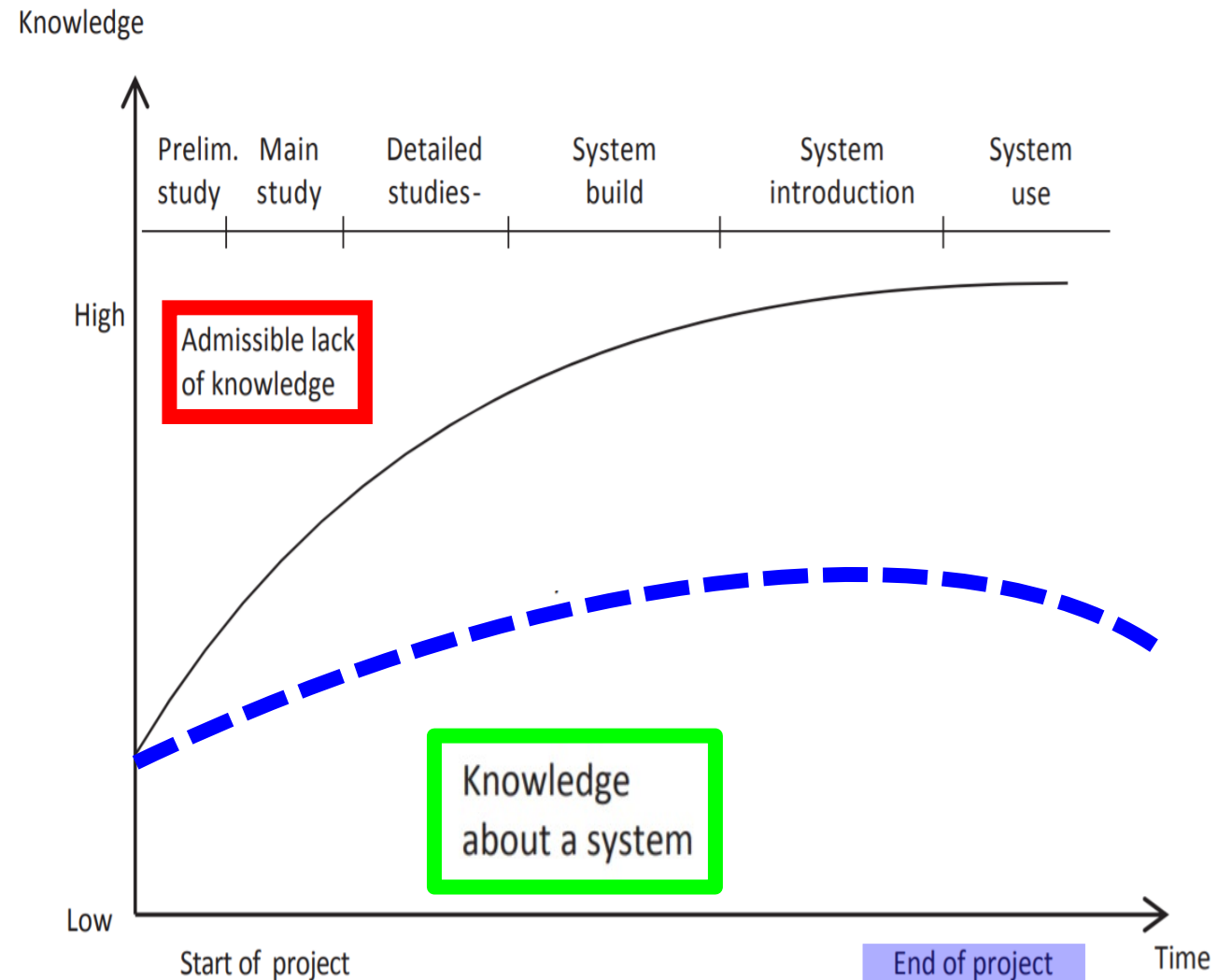
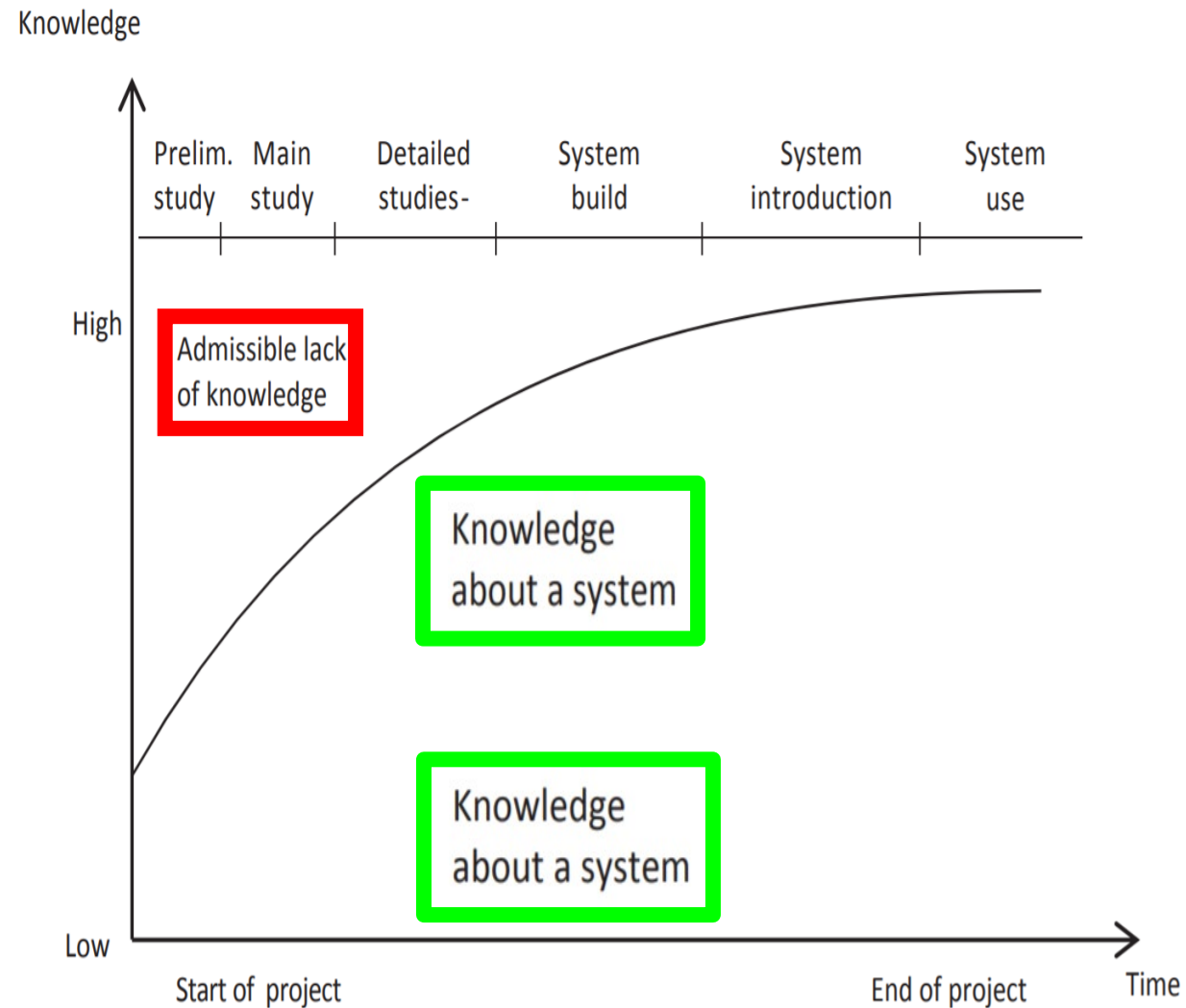


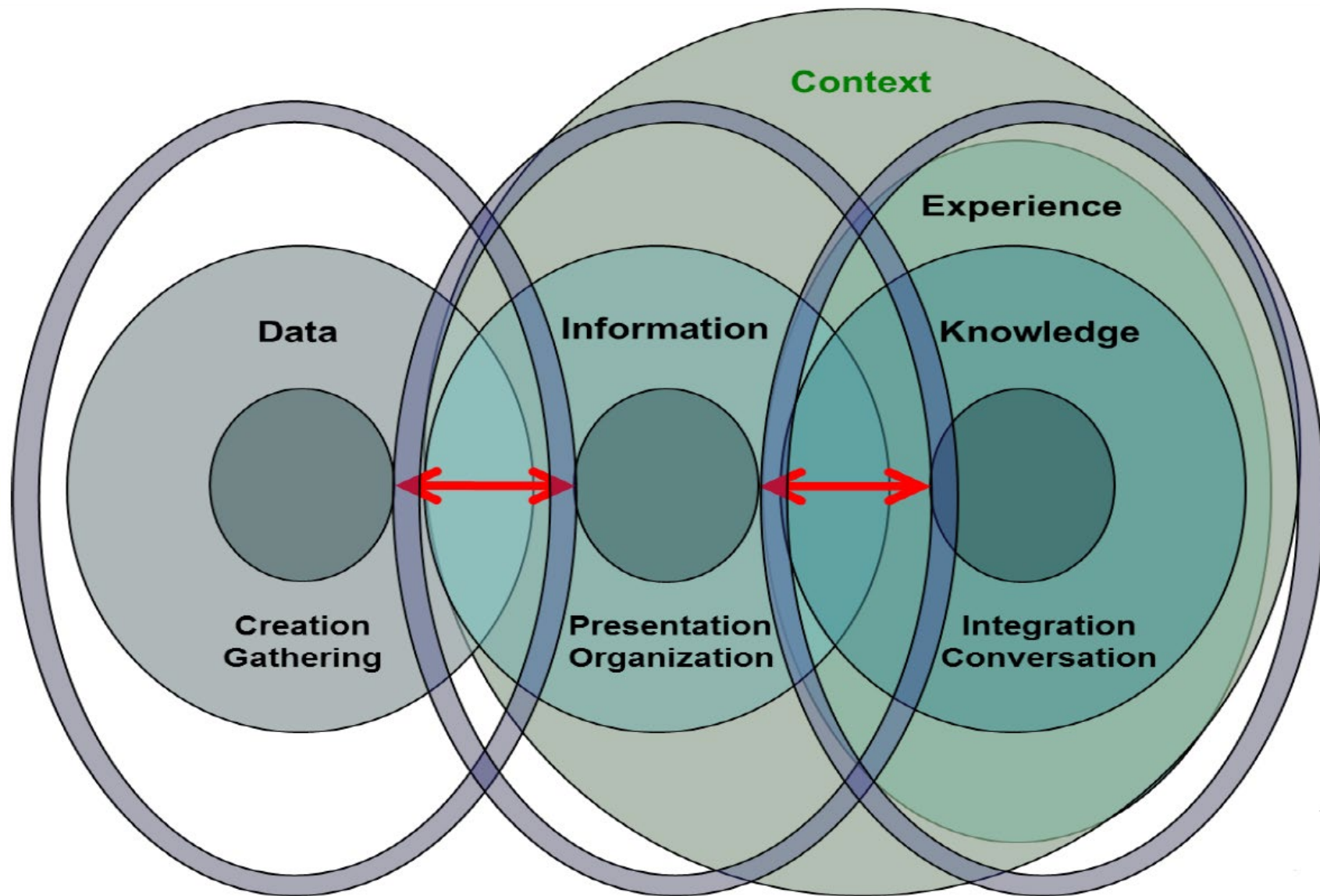
In the real world, knowledge increase may be bit sluggish.

Knowledge

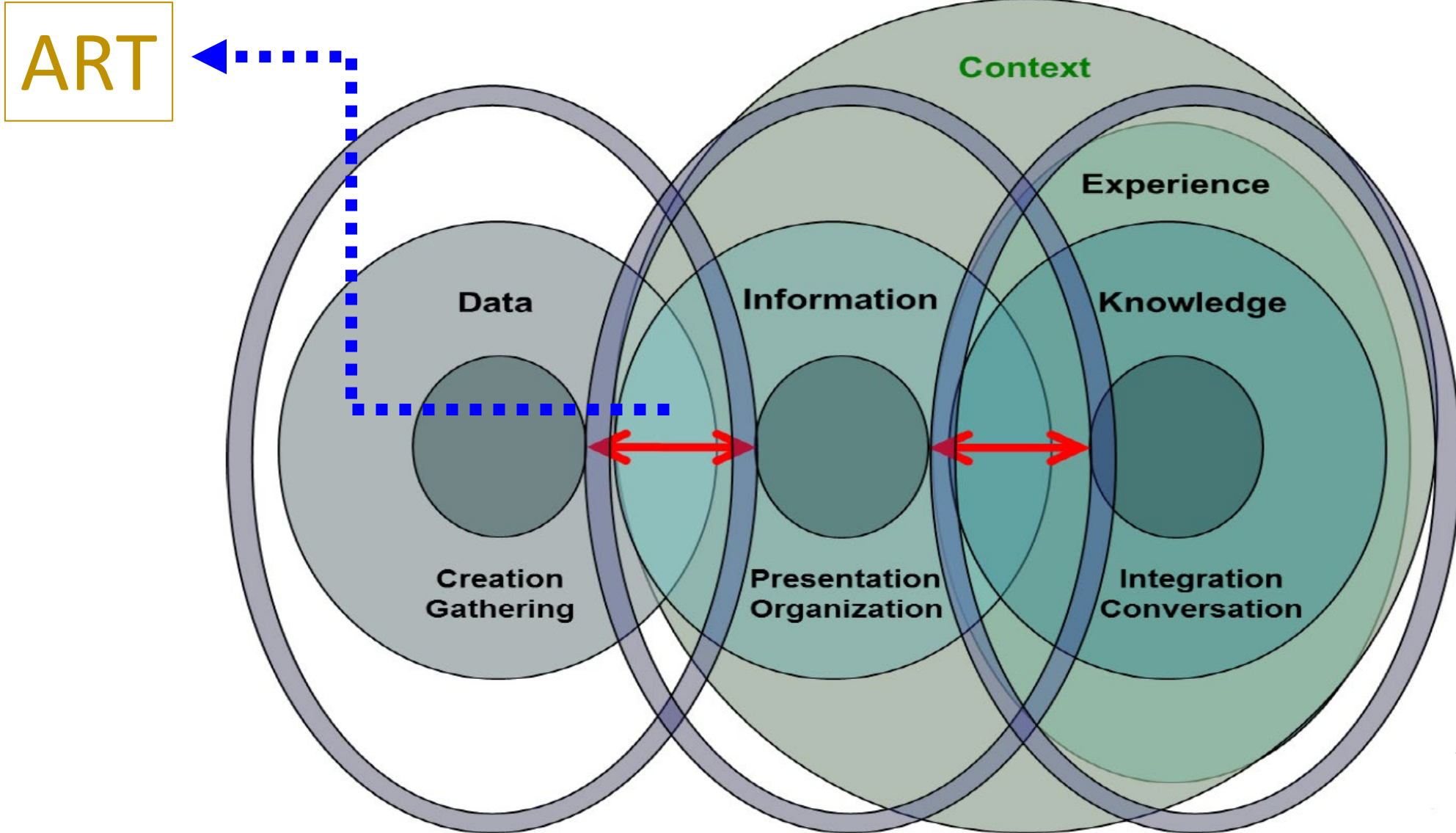


Have we gained knowledge from data and decisions?

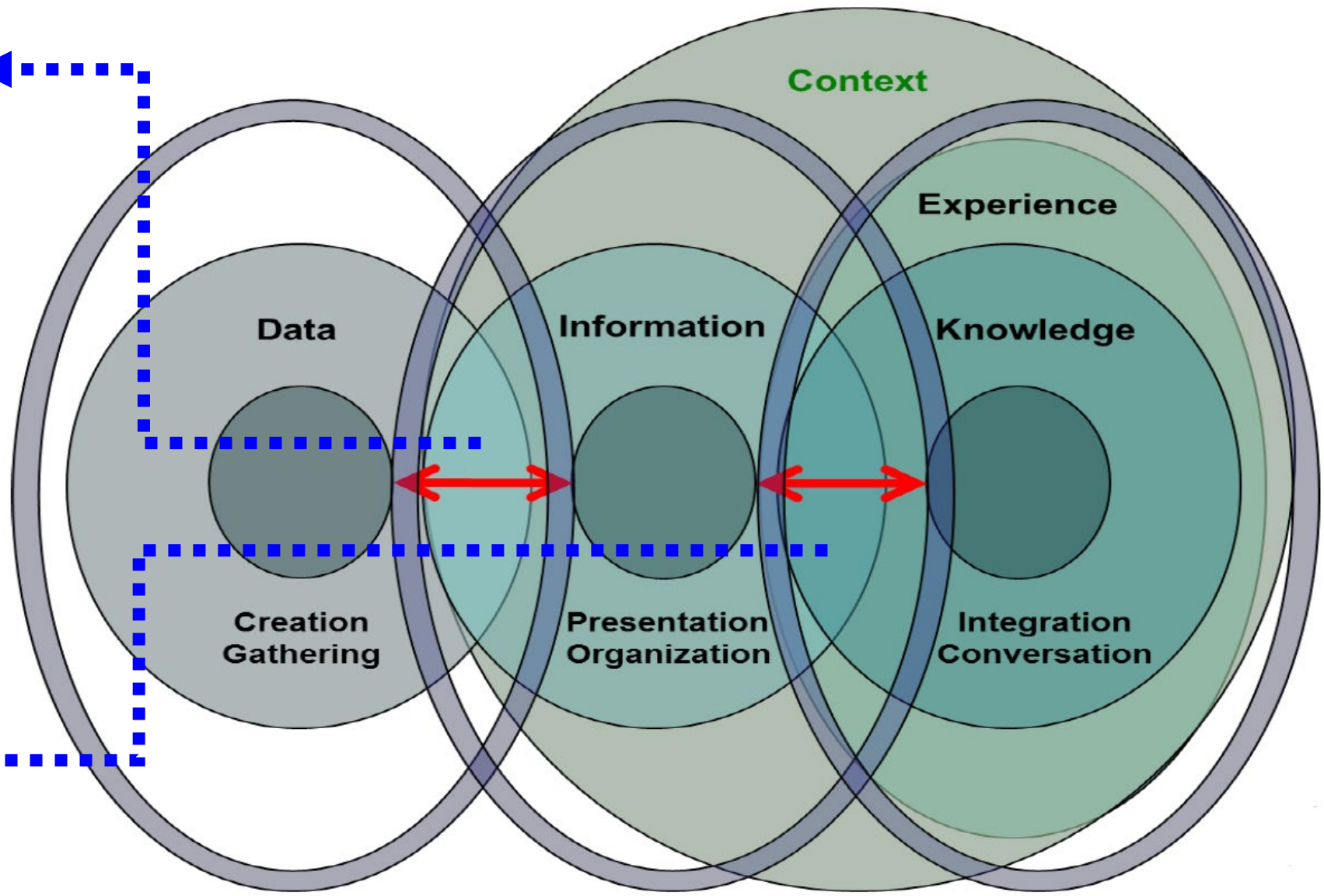




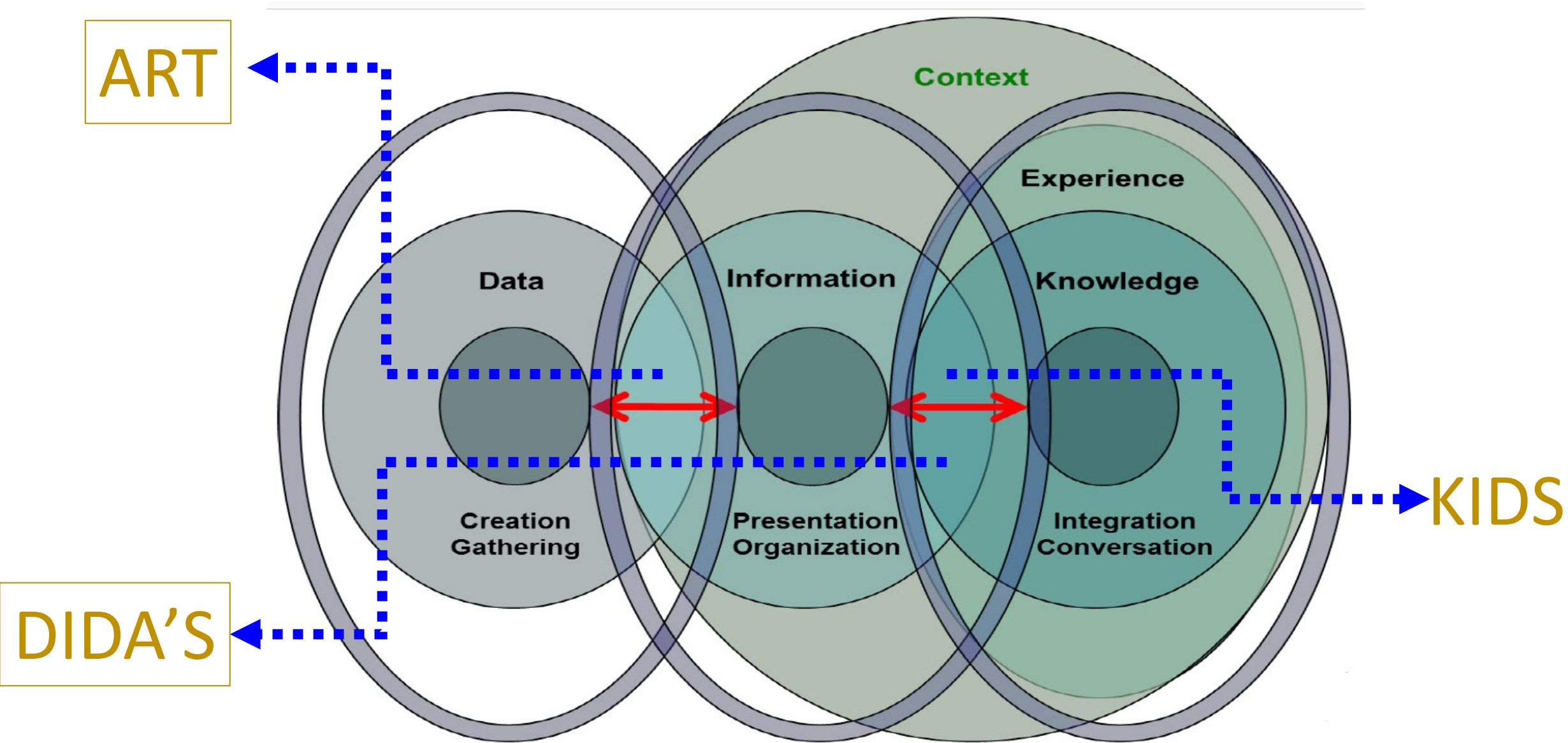
Artificial Reasoning Tools (ART)



ART



DIDA'S



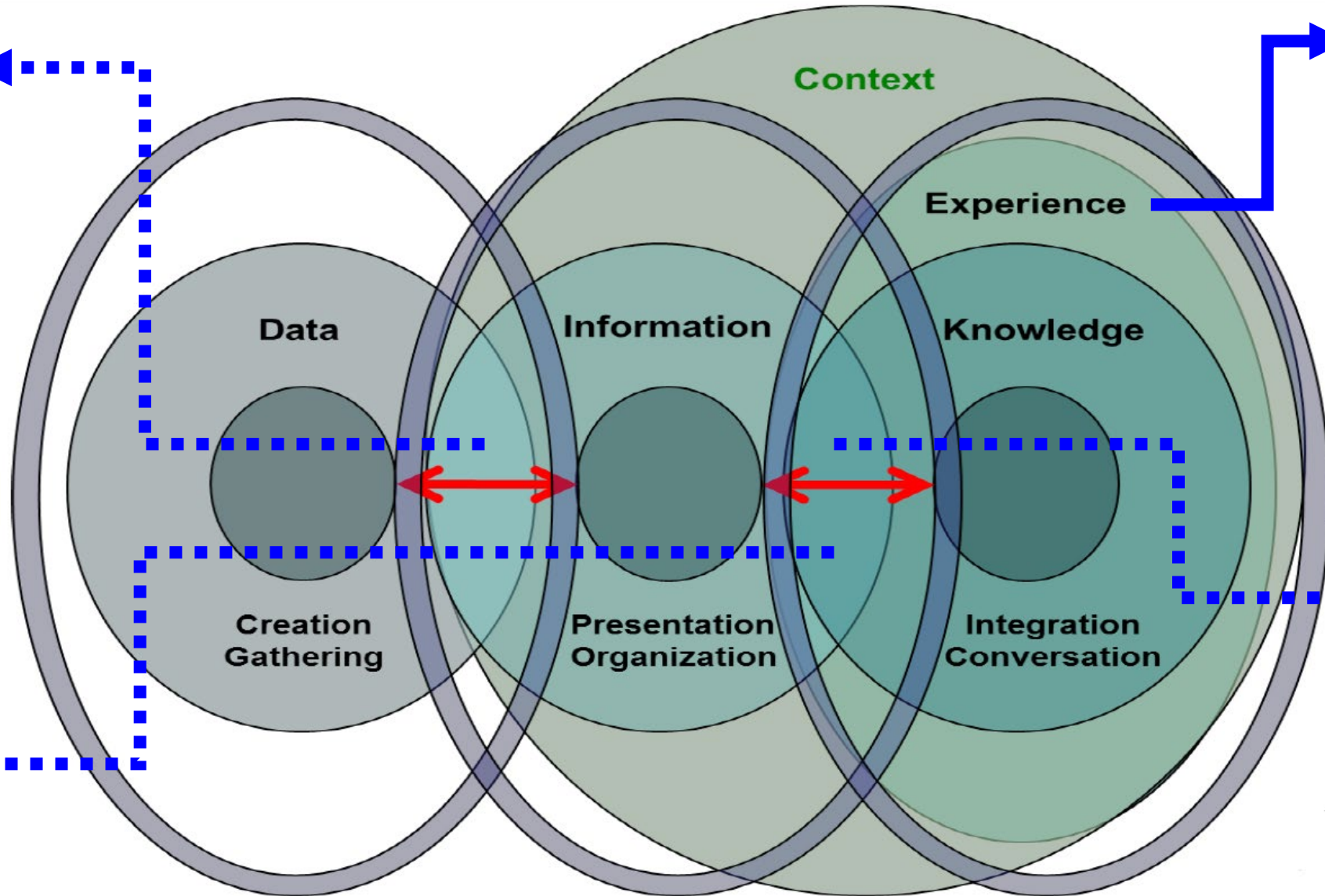
Data-Informed Decision as a Service

Knowledge-Informed Decision as a Service

Beyond knowledge, experience

Realm
of
Experience

ART



KIDS

DIDA'S

NEW YORK TIMES BESTSELLER

TRACY KIDDER

WINNER OF THE PULITZER PRIZE

MOUNTAINS BEYOND MOUNTAINS

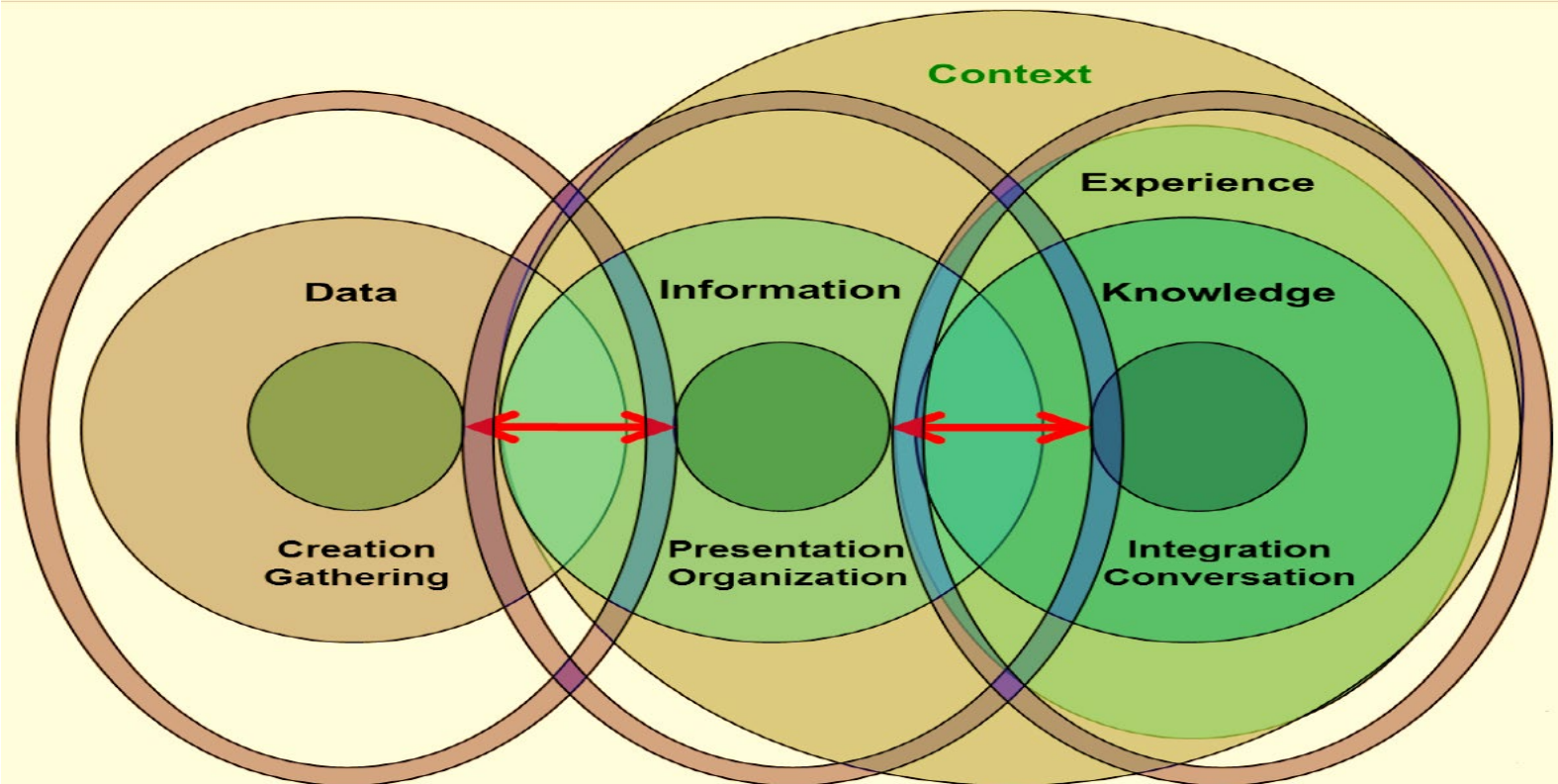
THE QUEST OF DR. PAUL FARMER,
A MAN WHO WOULD CURE
THE WORLD

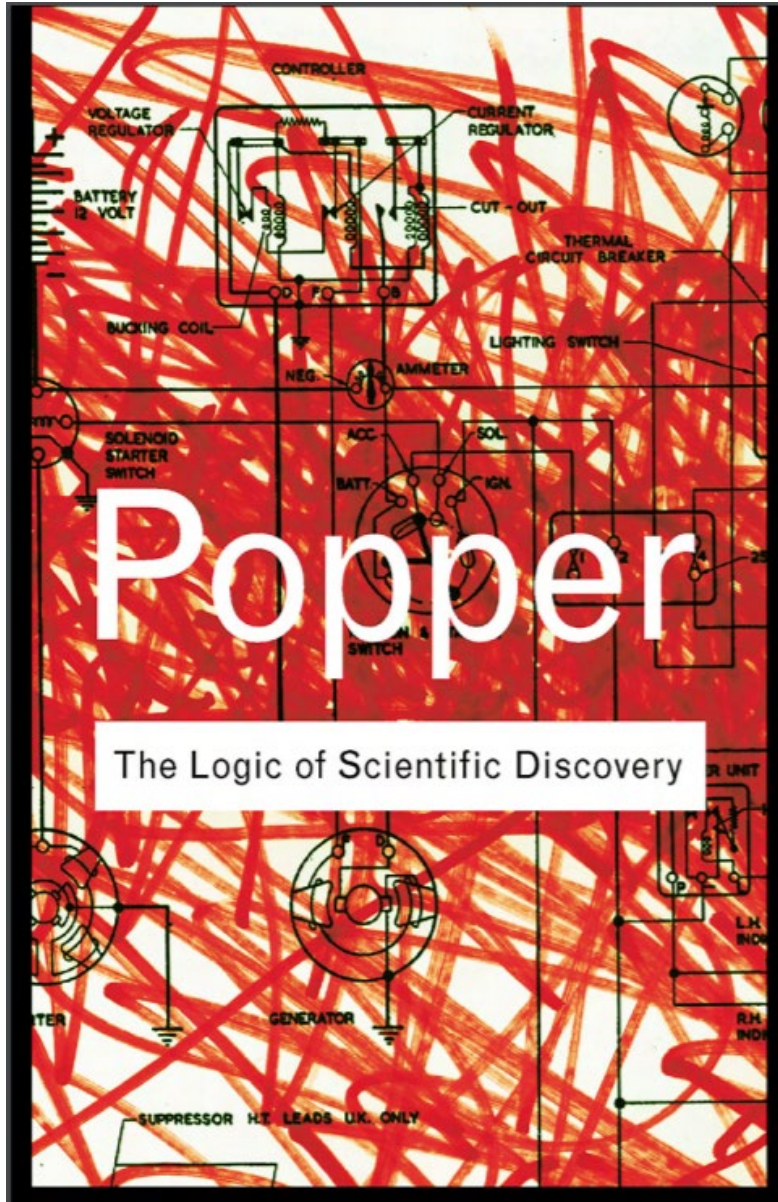


"INSPIRING, DISTURBING, DARING AND COMPLETELY ABSORBING."
—ABRAHAM VERGHESE, THE NEW YORK TIMES BOOK REVIEW

Beyond knowledge, experience

mountains beyond mountains





But how is the system that represents our world of experience to be distinguished? The answer is: by the fact that it has been submitted to tests, and has stood up to tests. This means that it is to be distinguished by applying to it that deductive method which it is my aim to analyse, and to describe.

‘Experience’, on this view, appears as a distinctive method whereby one theoretical system may be distinguished from others; so that empirical science seems to be characterized not only by its logical form but, in addition, by its distinctive method. (This, of course, is also the view of the inductivists, who try to characterize empirical science by its use of the inductive method.)

The theory of knowledge, whose task is the analysis of the method or procedure peculiar to empirical science, may accordingly be described as a theory of the empirical method—a theory of what is usually called ‘experience’.

Elusive Quest for Knowledge

Advanced integration of information, data, decisions

- KIDS may need TWINS

- KIDS may include SARA

KIDS need TWINS

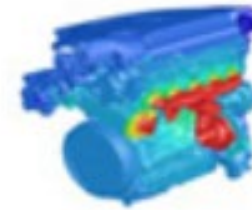
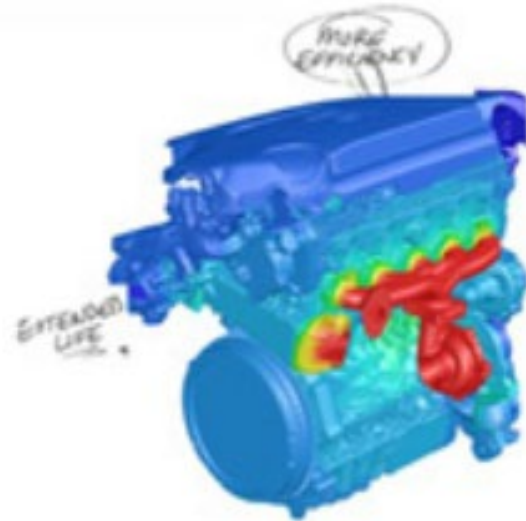
Adding PLM capacity in the form of Digital Twins to DIDA'S and KIDS

Digital Twin -- From Design to Operation

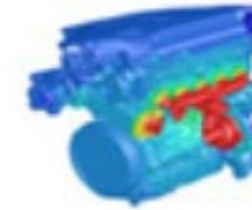
Physical Asset



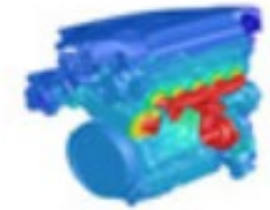
Virtual Prototype



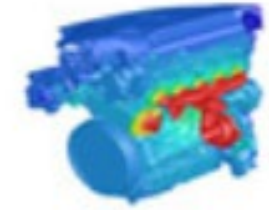
Digital Twin



Digital Twin



Digital Twin



Digital Twin

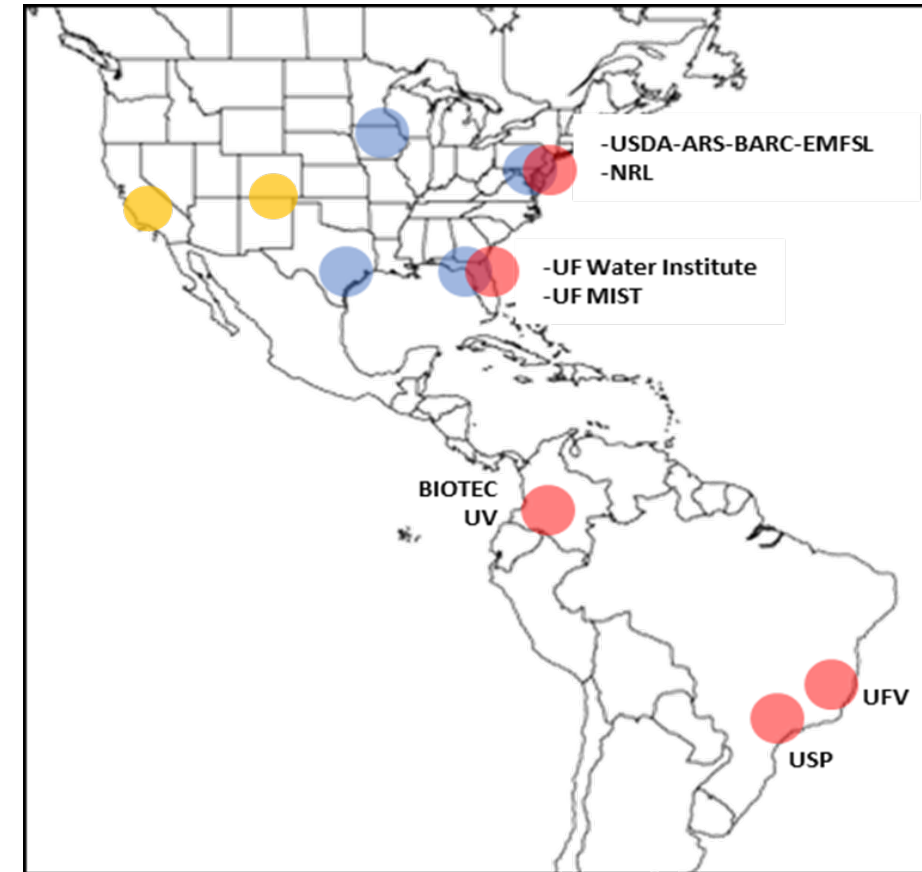
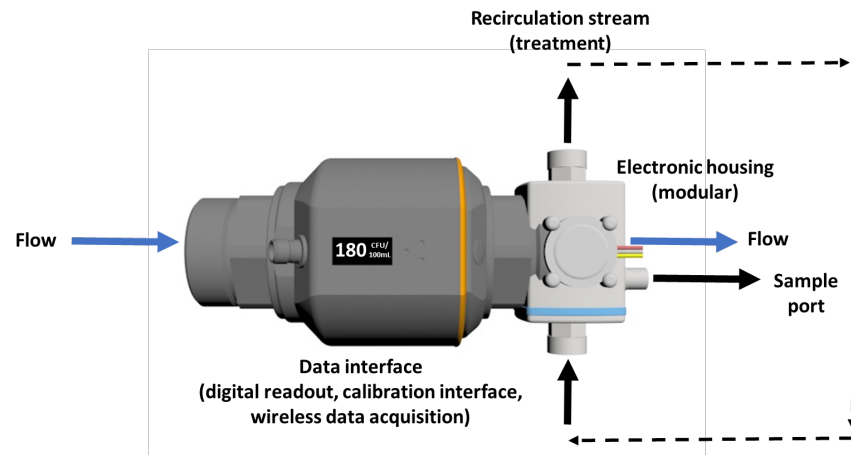
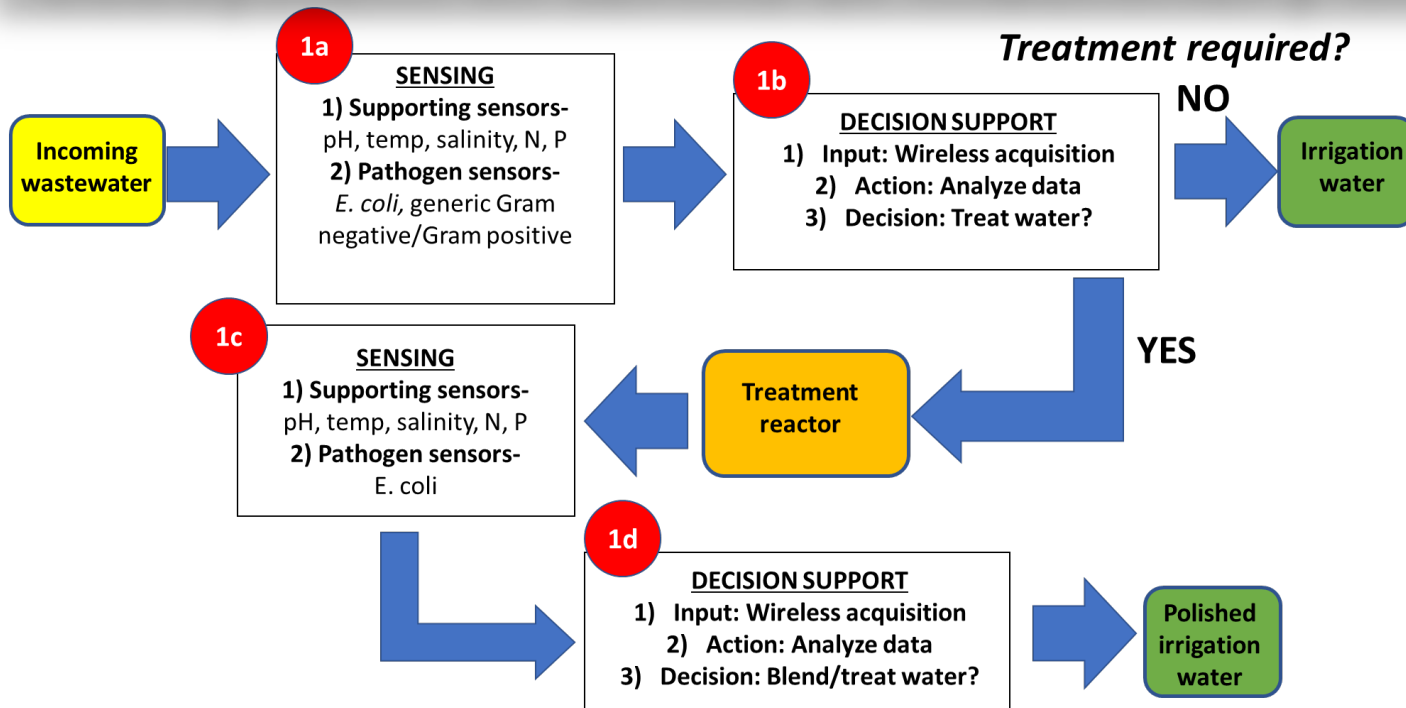


Digital Twin

Physics-based analytics to model the present state of every asset

CAD Courtesy of Volvo Cars

Use case: KIDS integrated with DIGITAL TWINS may improve the ecosystem in terms of machinery lifecycle in the agroecosystem



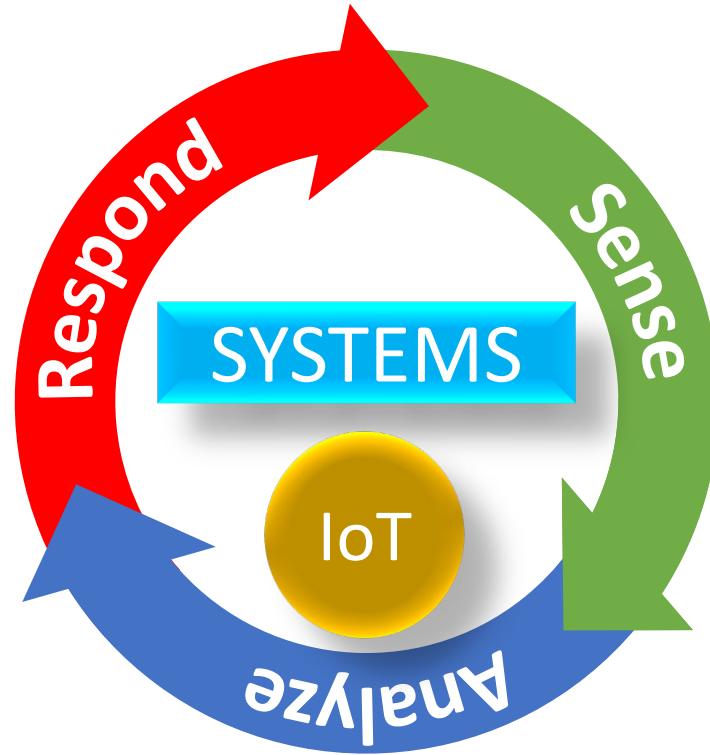
- SmartPath Institute
- Partner Institute
- Collaborator

KIDS to include SARA

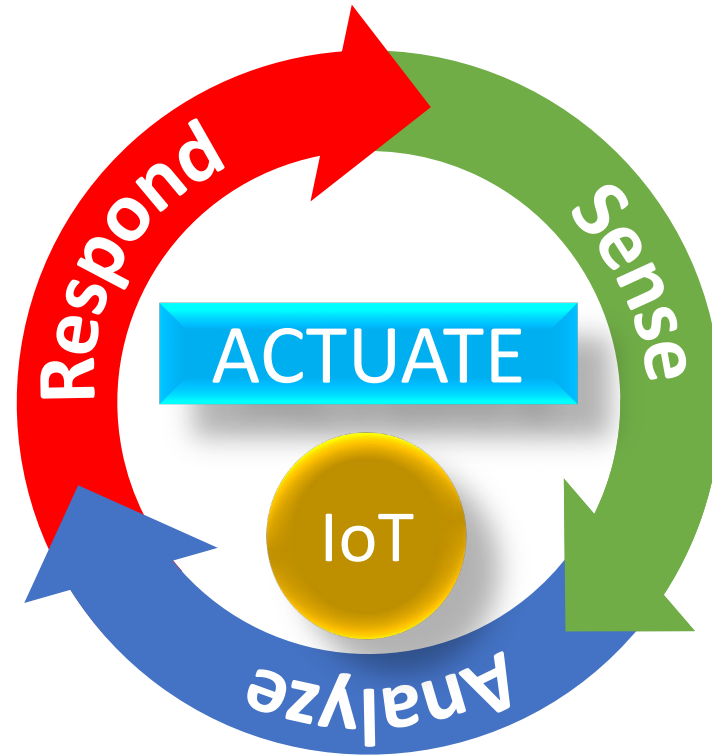
From sense, analyze, response, systems (SARS)

to sense, analyze, response, actuate (SARA)

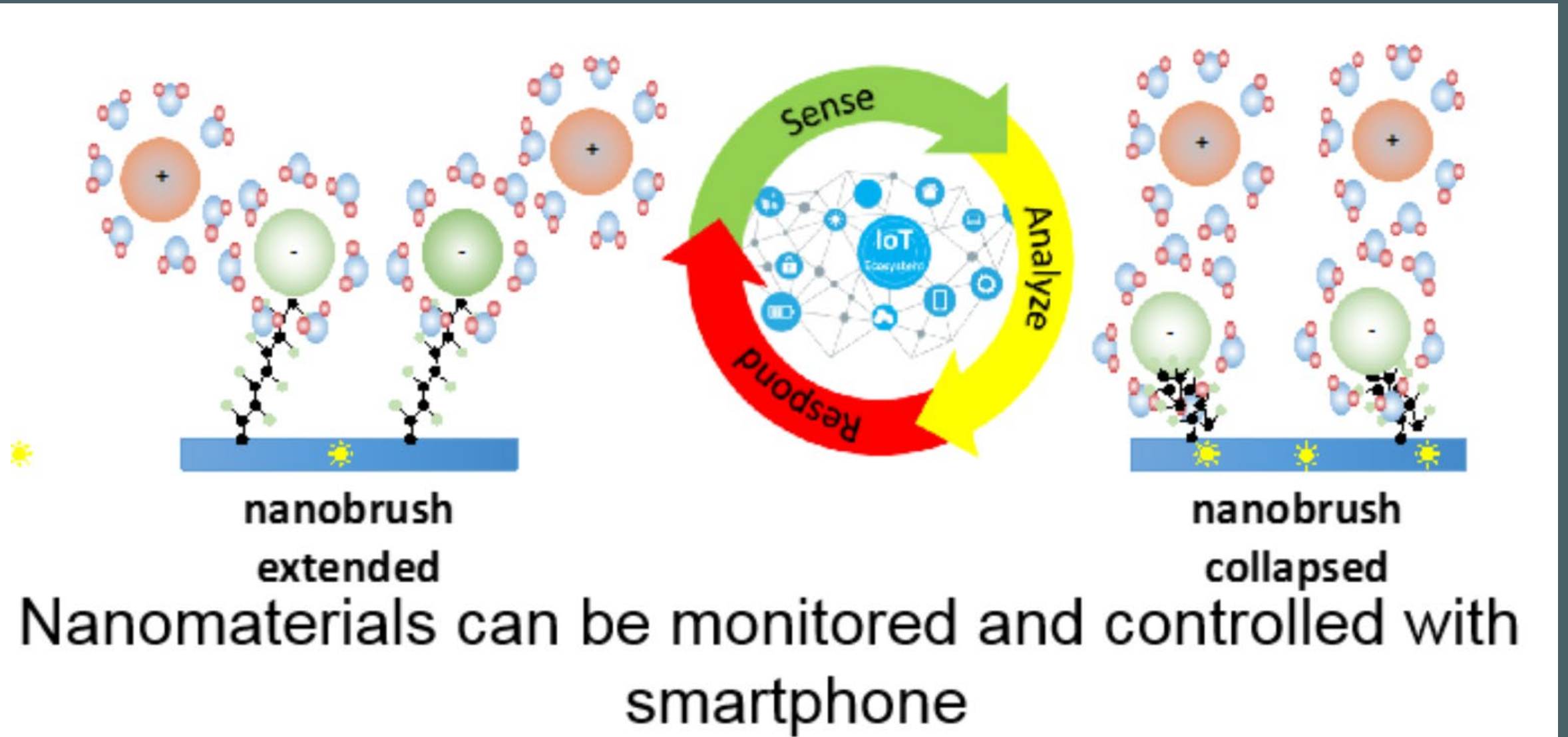
DIDA'S includes Sense, Analyze, Response, Systems (SARS)



KIDS to include Sense, Analyze, Response, Actuate (SARA)



Atoms to Bits - Sense, Analyze, Response, Actuate (SARA) Sensors using Smartphone



Future of digital transformation for the agro-ecosystem and emergence of digital products for traditional agri-businesses.

<https://emclamor.wixsite.com/mclamorelab>

Conventional Wisdom Questions Growth from Digital Transformation:

Conventional Wisdom Questions Growth from Digital Transformation:

BUSINESS
INSIDER

TECH FINANCE POLITICS STRATEGY LIFE ALL

BI PRIME INTELLIGENCE



NASA is opening the space station to \$35,000-a-night visits. A tourist who paid Russia \$30 million to get there a decade ago says it's a 'seismic shift.'

Dave Mosher 2h



NASA plans to open up the International Space Station to tourists and, to an even larger degree, commercial activity. NASA; Alyssa Powell/Business Insider

Conventional Wisdom ?

BUSINESS INSIDER

TECH FINANCE POLITICS STRATEGY LIFE ALL

BI PRIME INTELLIGENCE

NASA is opening the space station to \$35,000-a-night visits. A tourist who paid Russia \$30 million to get there a decade ago says it's a 'seismic shift.'

Dave Mosher 2h



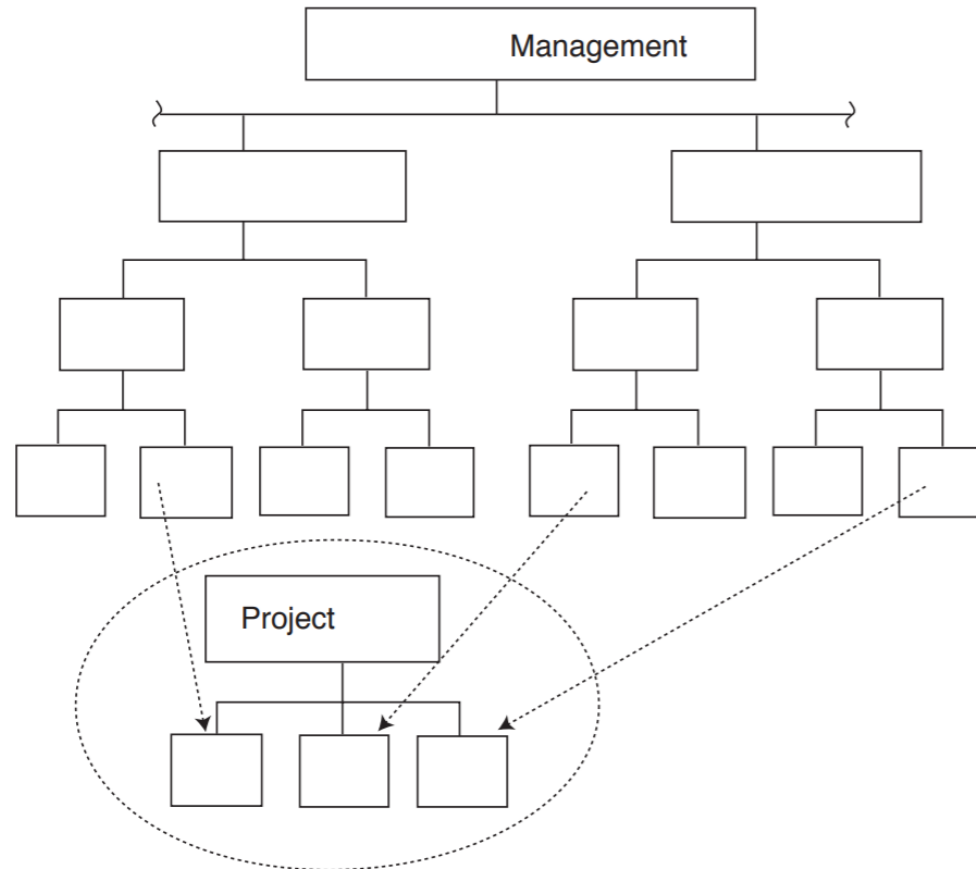
NASA plans to open up the International Space Station to tourists and, to an even larger degree, commercial activity. NASA; Alyssa Powell/Business Insider

Hadoop is sinking
because big data is
bullshit

MARTYN RICHARD JONES
goodstrat.com - THE GOOD STRATEGY COMPANY

martyn.jones@martyn.es

CONVENTIONAL WISDOM



Think different. Think non-linear. Think outside the box. Think beyond boundaries.

Exports from Latin America to India was US\$2 billion in 2000. In 2018, it exceeded US\$25 billion.

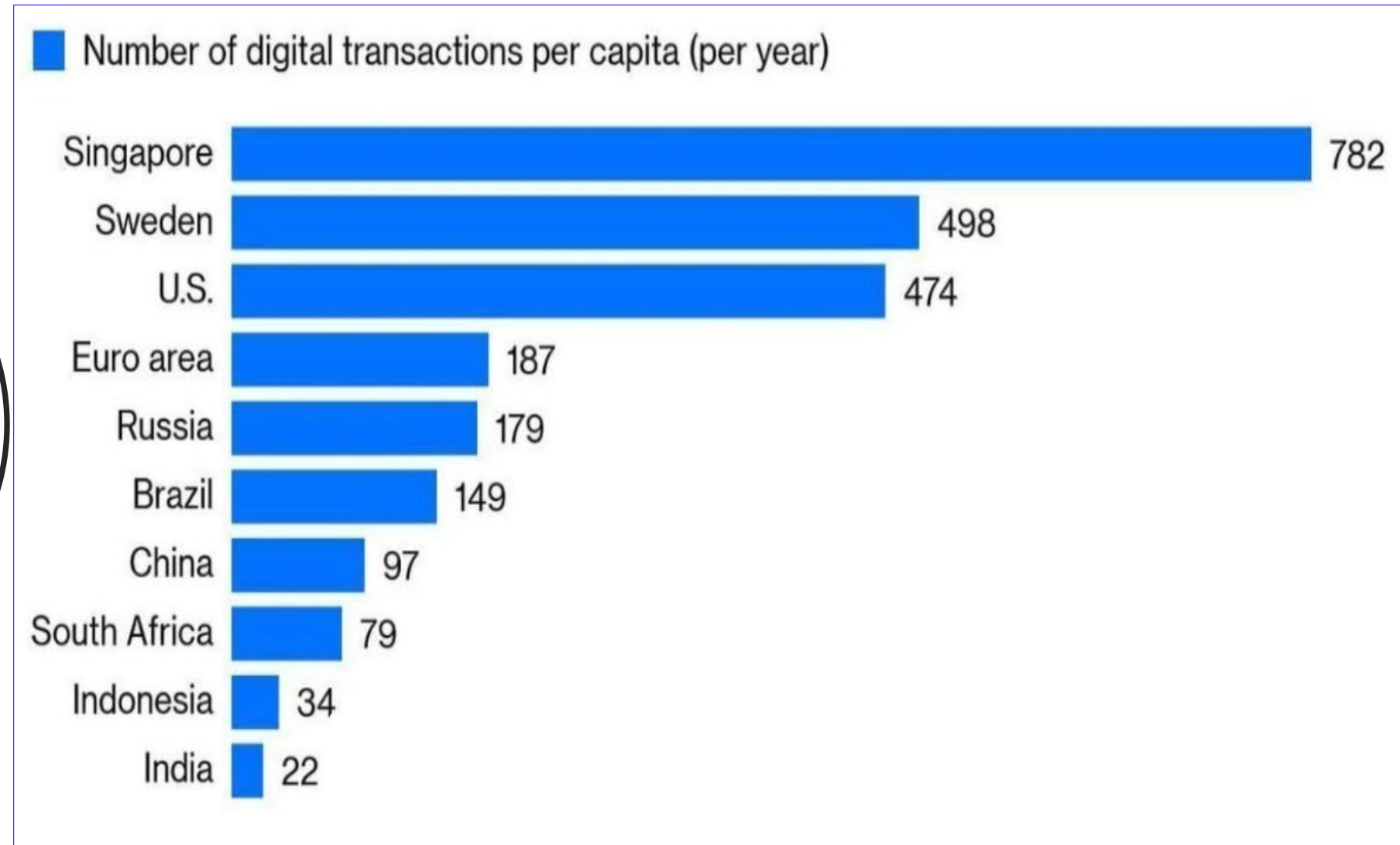
Mayores exportadores a la India

Venezuela, México y Brasil representaron dos tercios de los envíos de la región a la India



Is there a market for digital ART products in traditional agri-business?

To obtain the volume of potential digital transactions, multiply the number shown with the population of the country.





Ranveer Chandra
Chief Scientist, Azure Global at Microsoft



Tom Keane
Corporate Vice President of Azure Global - Microsoft Azure

Microsoft FarmBeats program uses Azure to connect agricultural devices and generate data intended to help farms transform business.

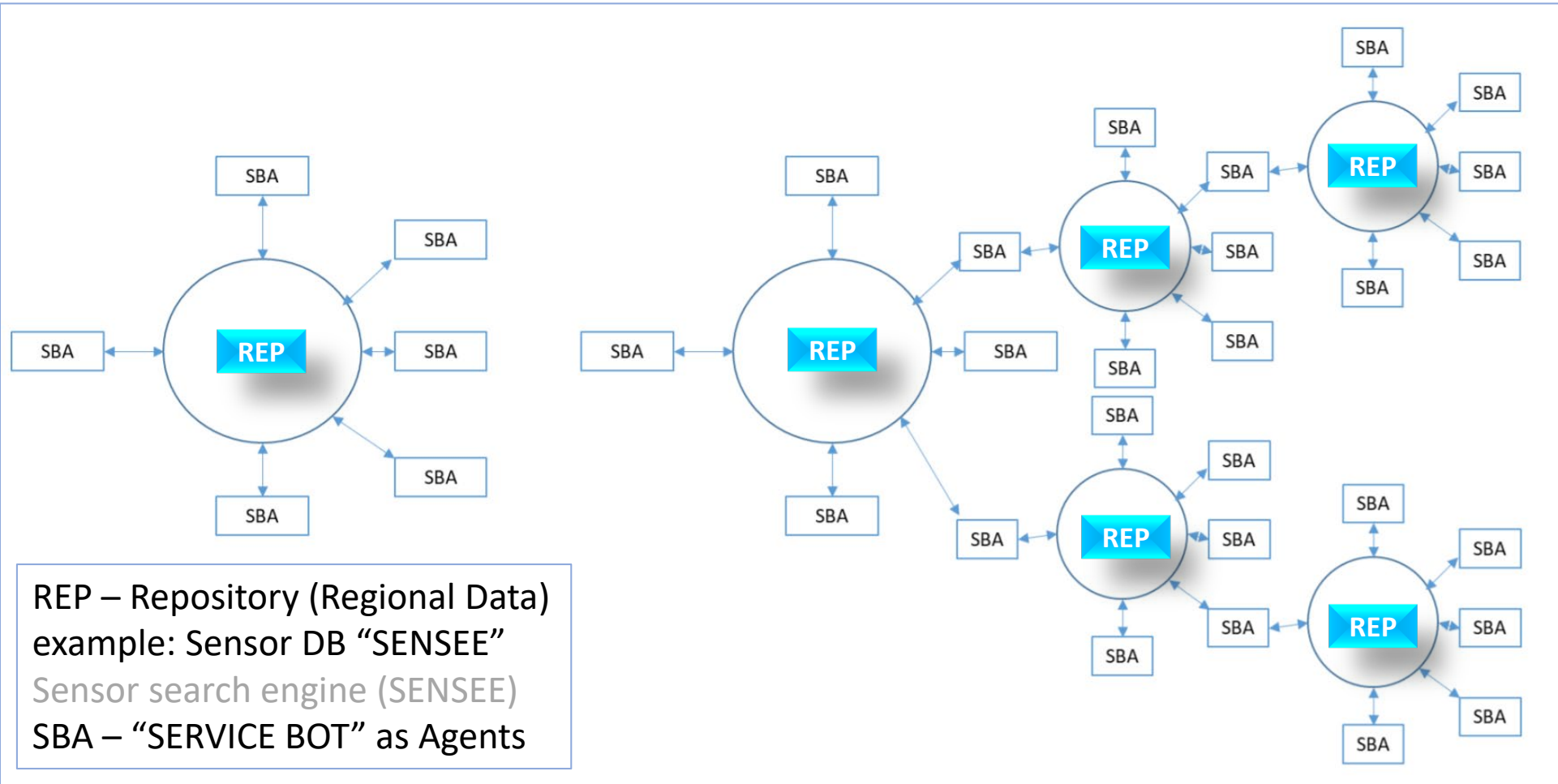




Low hanging fruits in digital-agro

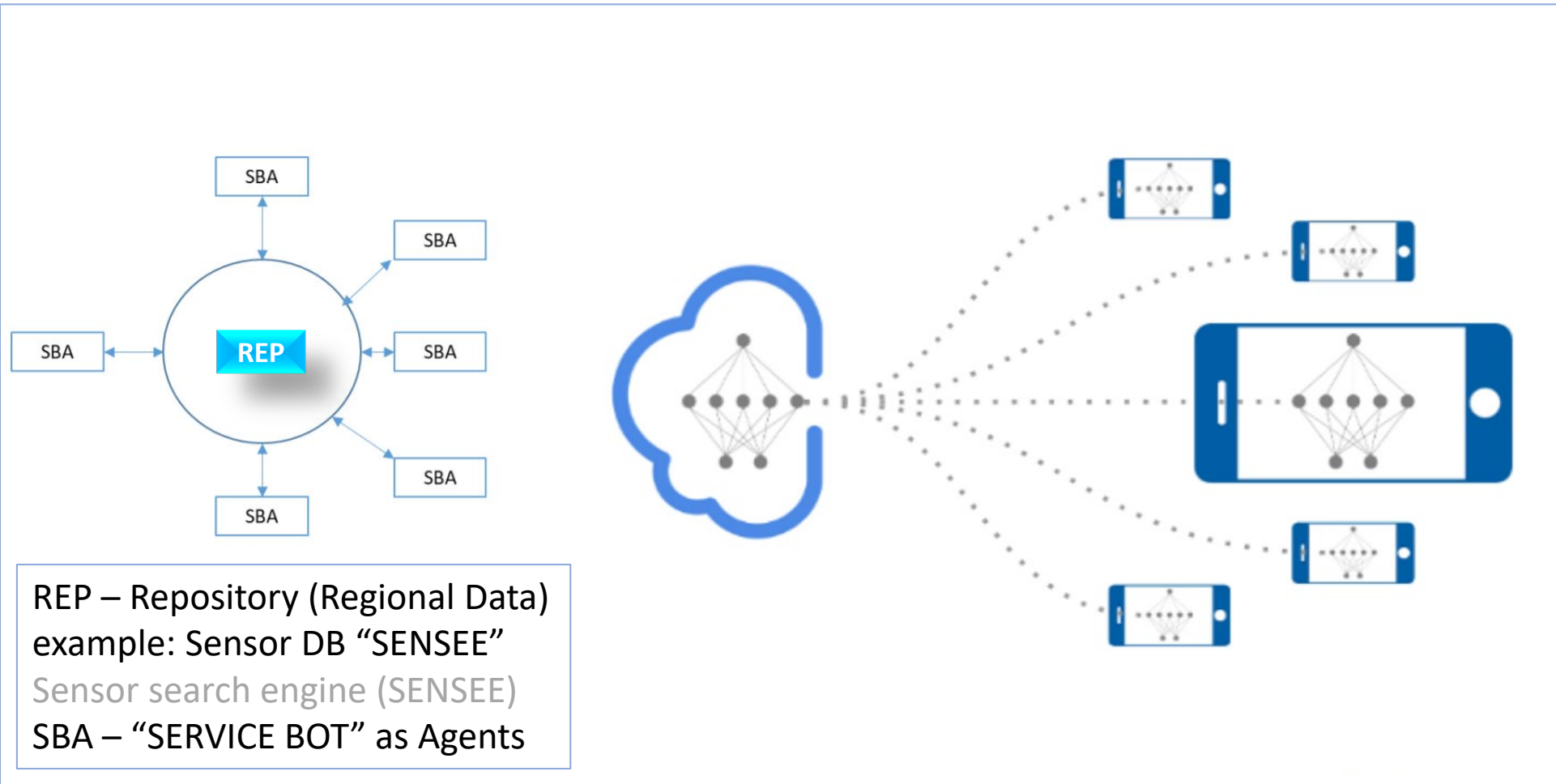
Prevention of food waste, global public health, water and food safety

Intelligent Information Arbitrage



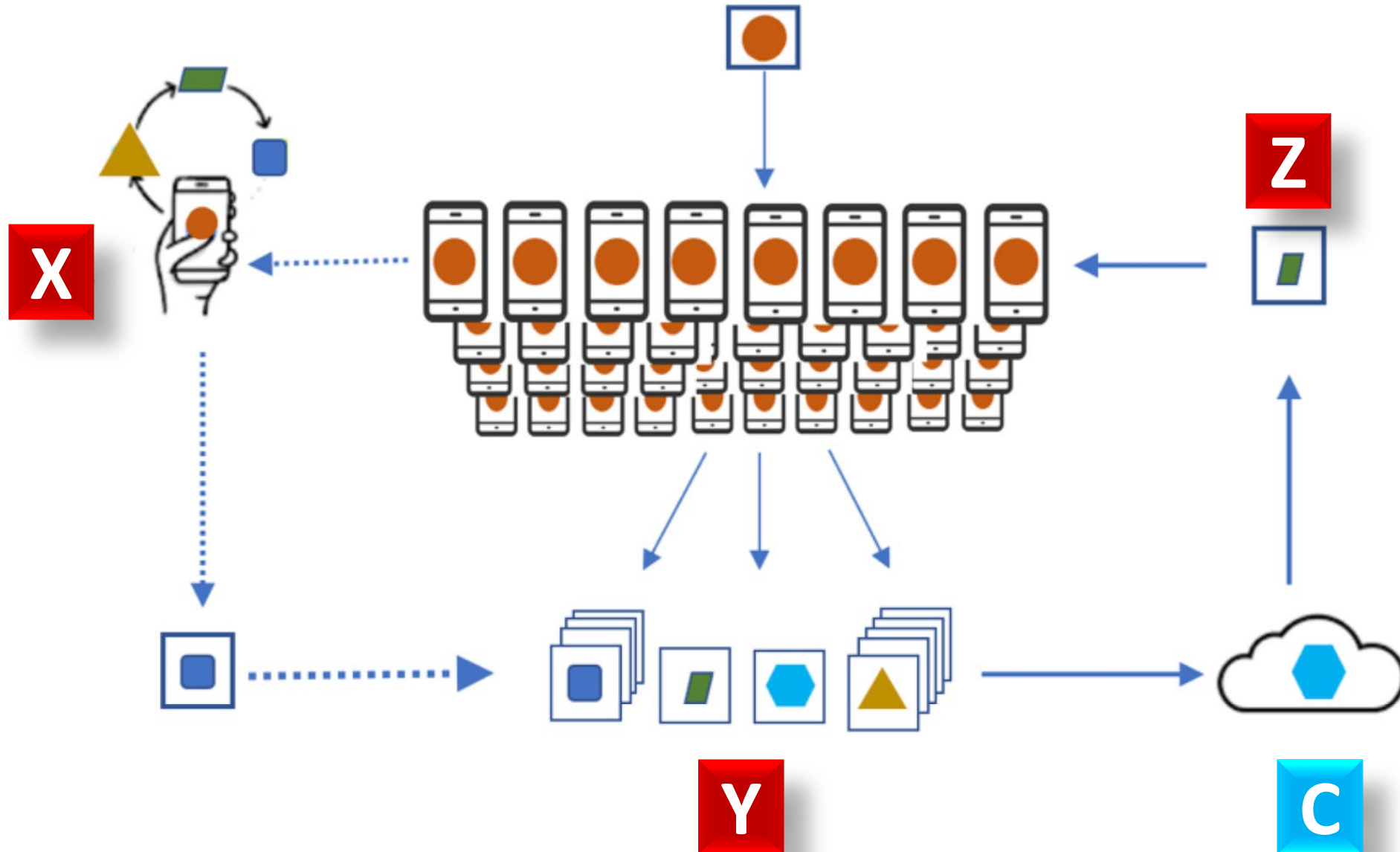
Locally distributed repositories [REP] containing data and questions (relevant to users and growers by crop or environment) can be globally connected using an Agent-based system

Intelligent Information Arbitrage



Locally distributed repositories [REP] containing data and questions (relevant to users and growers by crop or environment) can be globally connected and consumed by any system

Intelligent Information Arbitrage



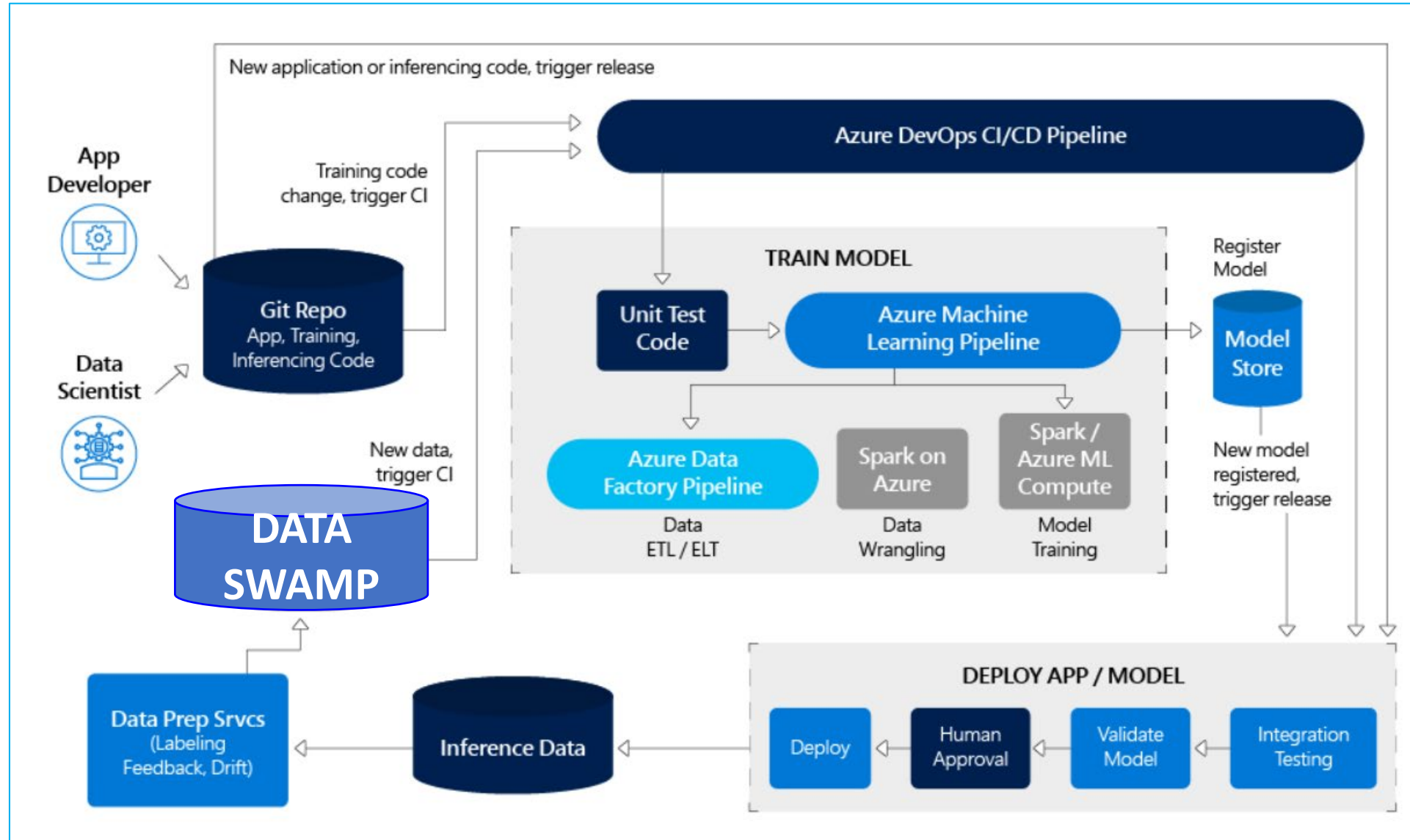
Intelligent Information Arbitrage



The value of the REP concept (SENSEE) may be enhanced by coupling publish-subscribe modes with crowd-sourced data adoption/dissemination. User “X” may update data, recommend tools or techniques or share outcomes/outputs (for example, growers can share photographs of infected produce or sinfully delicious tomatoes). Thus, local user personalization (point X, in the crowd) is sent/stored to the analytical platform (engine Y). An emerging consensus from contributed data (for example, improved technique or data with incorrect units or better use of a tool) is sent to cloud C for expert evaluation and critical analysis. Verified change Z is communicated to all subscribers, globally. This process repeats, to enhance open models and enrich common goals for public goods, using distributed data from crowdsourcing (users, farmers, growers, scientists, engineers, academics, politicians) but deploying a neutral/trusted analytical evaluator (cloud C) to deconstruct/reconstruct, aggregate/disaggregate data and models, to serve the best interest of the system. It may prevent data pollution, act to neutralize cyberthreats and stop, if possible, attacks perpetrated by GAN (general adversarial network) as infectious agents. This suggestion draws from “federated learning models” commonly used by financial institutions and banks to train fraud detection models without sharing their sensitive customer data. Popular frameworks now include TensorFlow Federated, an open source framework by Google for experimenting on decentralized data. PySyft is a open source library that is built on top of PyTorch for encrypted, privacy preserving deep learning. Federated AI Technology Enabler (FATE) is an open-source project initiated by Webank’s AI group to provide a secure computing framework to support the Federated AI ecosystem. Despite the hype whipped up by the glib snake oil salesmen of AI, there is value in this approach, if and when rationally analyzed, for specific purposes, using bonafide tools, which may be customized for specific applications and are based on rigorous mathematics and statistics. It may be useful for SITS and its ecosystem to explore these advanced tools of the future and enterprise solutions around federated learning and other secure computation techniques across different verticals. At present, the primary deployment challenge may be the computational constraint of edge devices (smartphone, tablet) to perform local training, cloud consultations and inferencing. However, smartphones and IoT devices are increasingly equipped with GPUs or sufficient computing hardware to run CNN/RNN and other AI models at the edge to augment near-real time “intelligent” decision support systems, at the point of use. REP/SENSEE may be the SmartPath/SITS approach to harvest these ideas and convert them into actionable transactions that can help the ag industry in the pursuit of food.



Intelligent Information Arbitrage



Intelligent Information Arbitrage

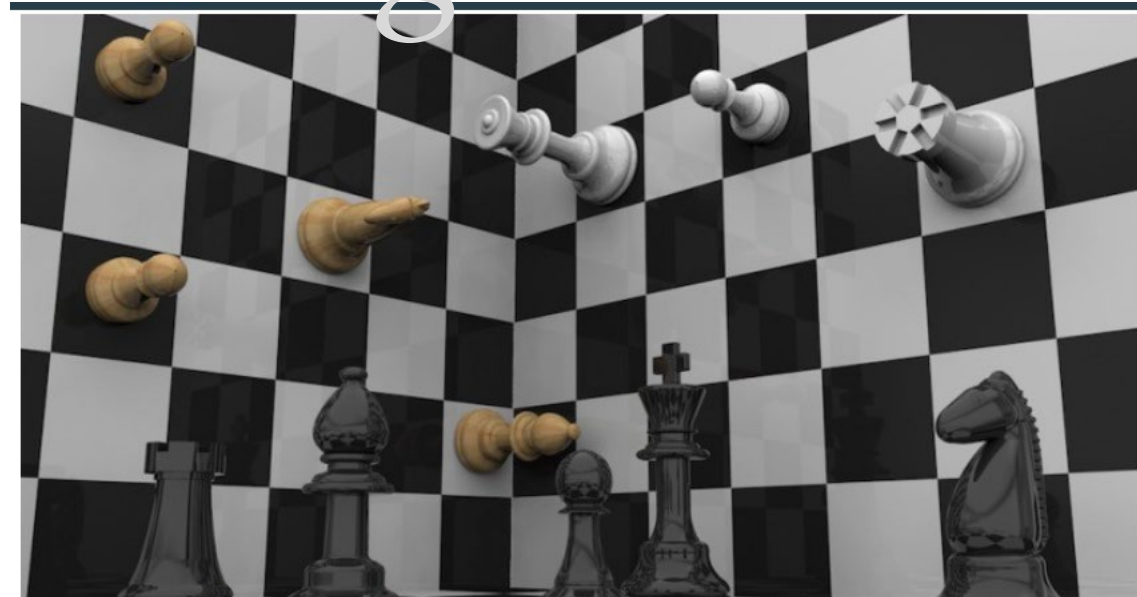


HARVEST and INVEST in UNSTRUCTURED DATA and (MERGE DATA IN CONTEXT FOR INTELLIGENT) DATA ANALYTICS

Intelligent Information Arbitrage

WATER v PEOPLE

Change the rules





中文

Français

Русский

Español

1 in 3 people globally do not have access to safe drinking water – UNICEF, WHO

New report on inequalities in access to water, sanitation and hygiene also reveals more than half of the world does not have access to safe sanitation services.

18 June 2019 | News release | New York, Geneva

Billions of people around the world are continuing to suffer from poor access to water, sanitation and hygiene, according to a new report by UNICEF and the World Health Organization. Some 2.2 billion people around the world do not have safely managed* drinking water services, 4.2 billion people do not have safely managed sanitation services, and 3 billion lack basic** handwashing facilities.



Nada Osseiran

Communications Officer
WHO

Mobile: +41 79 445
1624

Proportion of population with safely managed water (left) and sanitation (right) services, 2017 (%)



(L) Fig 51 (water) and (R) Fig 69 (sanitation) from www.who.int/water_sanitation_health/publications/jmp-2019-full-report.pdf?ua=1







HHS Public Access

Author manuscript

J Public Health Manag Pract. Author manuscript; available in PMC 2019 January 01.

Published in final edited form as:

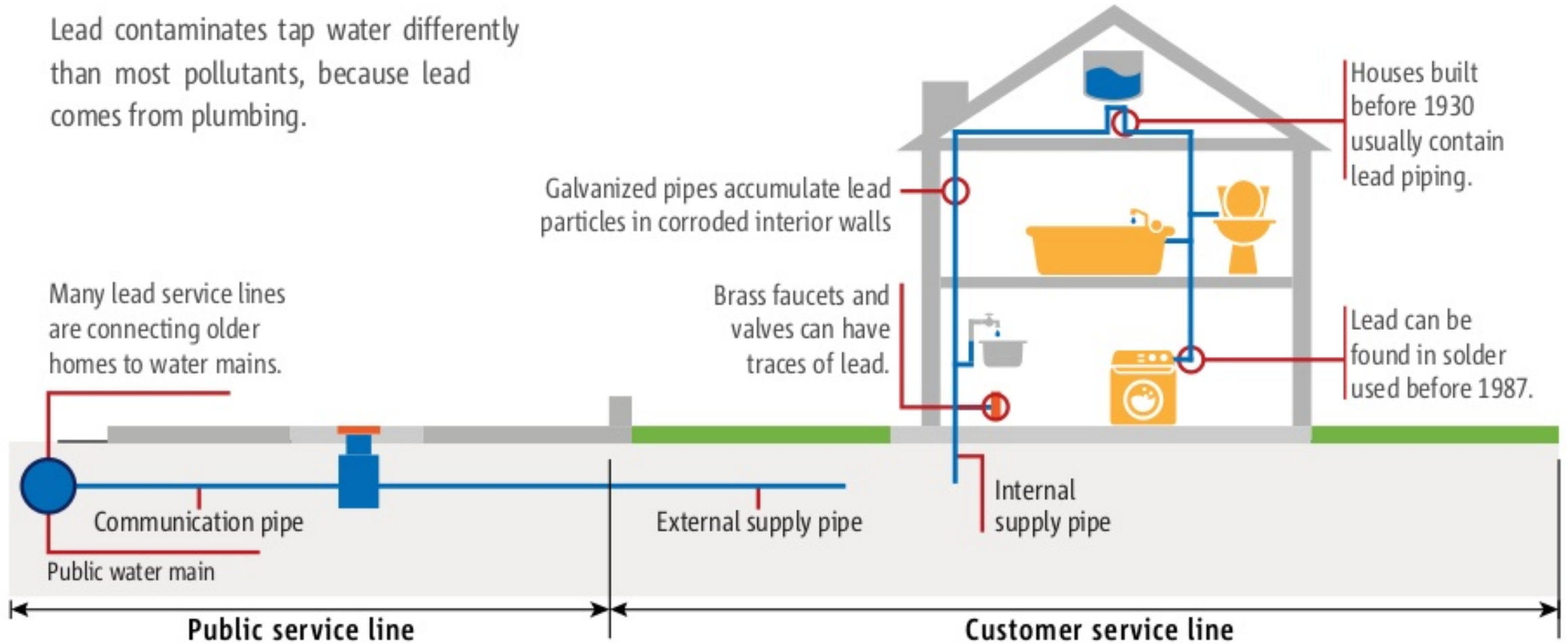
J Public Health Manag Pract. 2019 ; 25(Suppl 1 LEAD POISONING PREVENTION): S84–S90. doi:
10.1097/PHH.0000000000000871.

The Flint Water Crisis: A Coordinated Public Health Emergency Response and Recovery Initiative



THE PIPES

Lead contaminates tap water differently than most pollutants, because lead comes from plumbing.

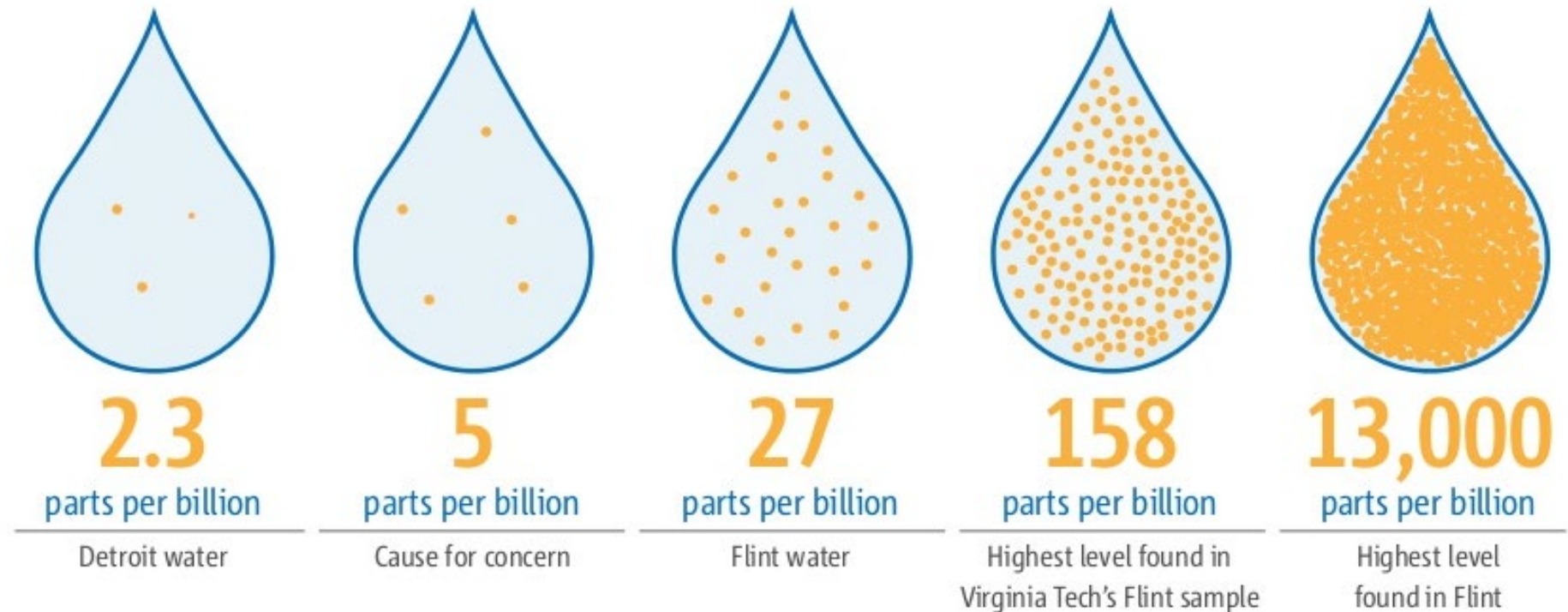


Summing up: water from Flint River moved through lead pipes, picking up the toxin as it went, and spread it throughout the population.

<https://www.slideshare.net/lbuckfire/the-flint-michigan-water-crisis-causes-effects>

THE KEY PROBLEM

Water from the Flint River is highly corrosive (its water has about 8 times more chloride (Cl⁻) in it than Detroit water) to iron and lead. Unfortunately, these pipe materials are widely used throughout Flint.

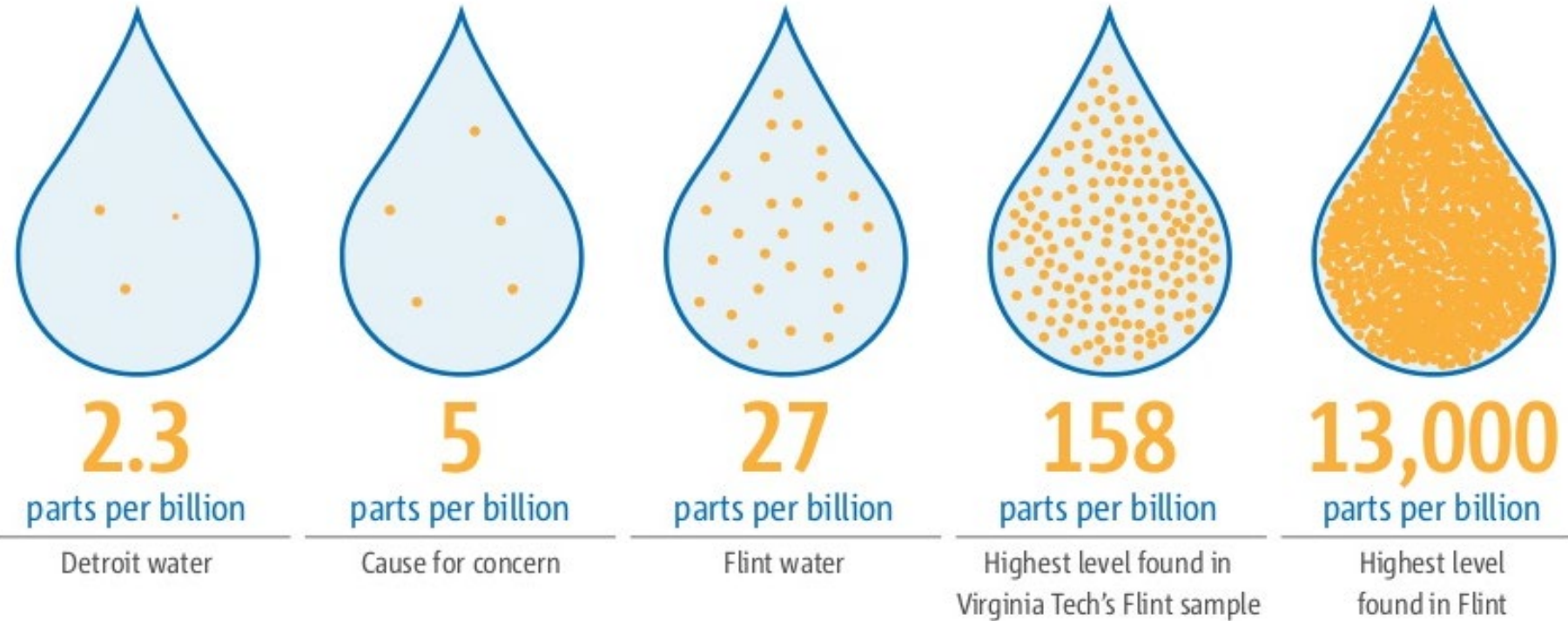


And, if these pipes are exposed to corrosive water, or if water sits too long inside them, the lead could be released and may end up coming out of the tap.

FLINT, MICHIGAN WATER CRISIS - LEAD POISONING FACTS AND FIGURES

THE KEY PROBLEM

Water from the Flint River is highly corrosive (its water has about 8 times more chloride (Cl^-) in it than Detroit water) to iron and lead. Unfortunately, these pipe materials are widely used throughout Flint.



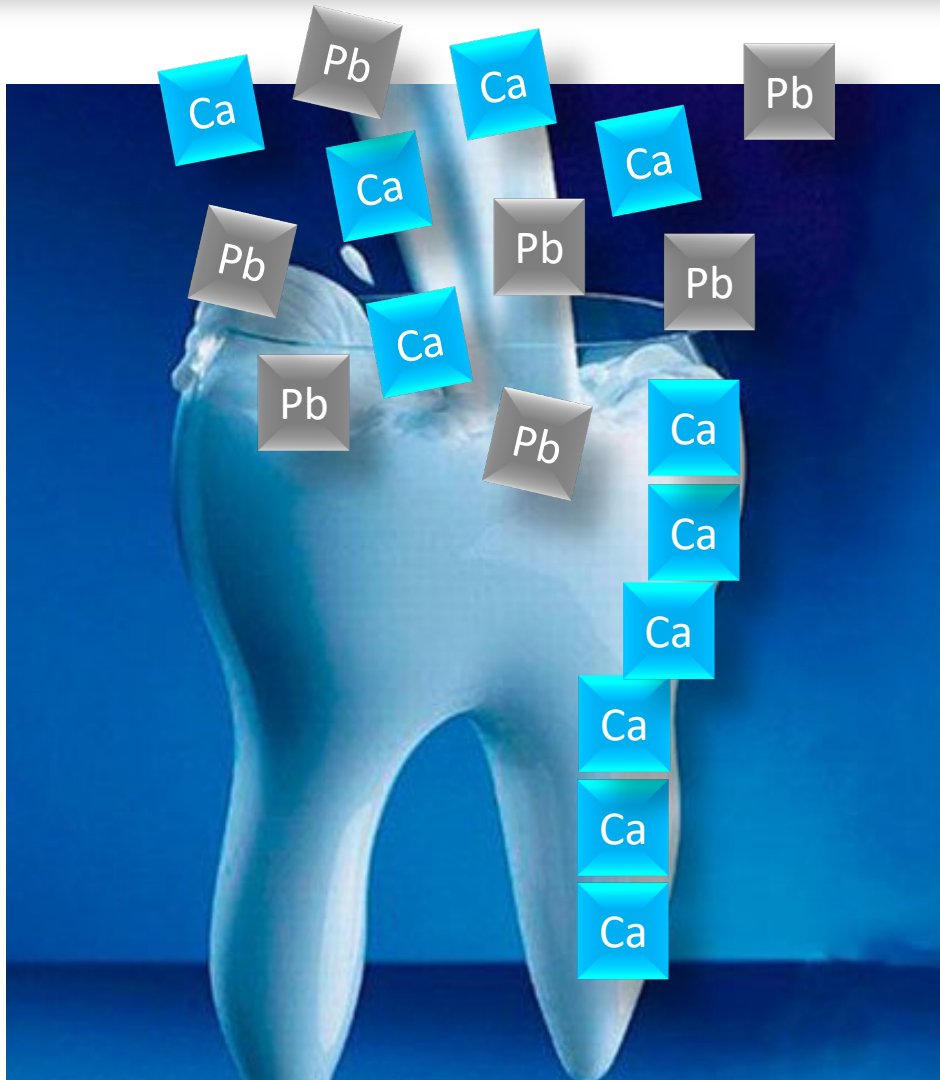
And, if these pipes are exposed to corrosive water, or if water sits too long inside them, the lead could be released and may end up coming out of the tap.

<https://www.slideshare.net/lbuckfire/the-flint-michigan-water-crisis-causes-effects>

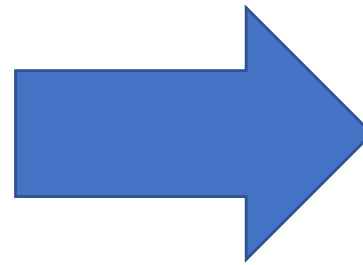
THE
FLINT'S WATER AND THE
POISONED
AMERICAN URBAN TRAGEDY
CITY
ANNA CLARK

Copyrighted Material

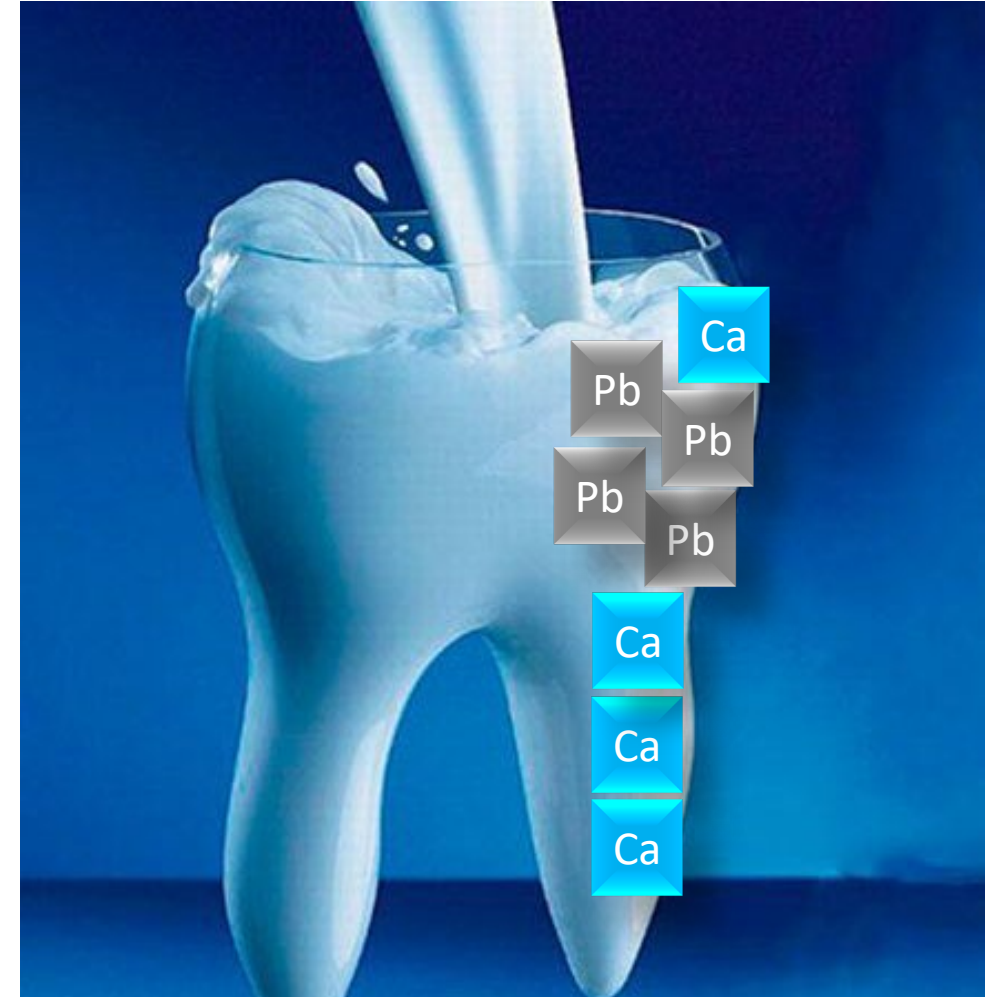
Lead (Pb) accumulates in teeth and bones



More lead exposure



More lead is stored

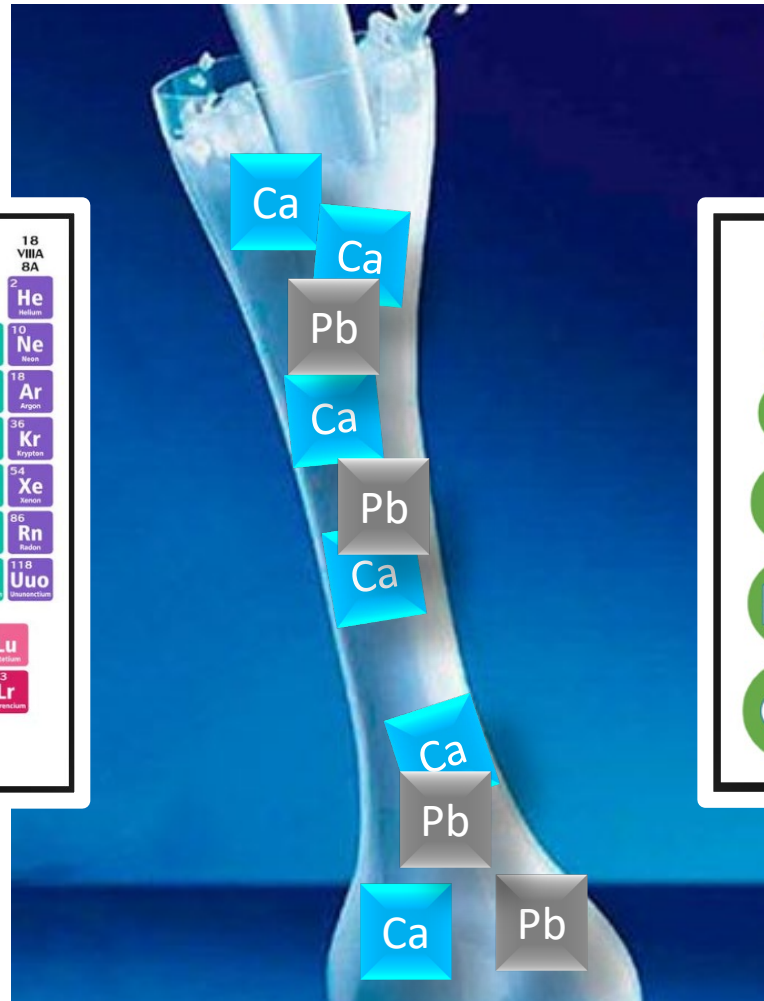


Lead (Pb) accumulates in teeth and bones

Periodic Table of The Elements

The periodic table shows elements arranged by atomic number. A legend indicates the following categories:

- Alkali Metal
- Alkaline Earth
- Transition Metal
- Basic Metal
- Semimetal
- Nonmetal
- Halogen
- Noble Gas
- Lanthanide
- Actinide



A simplified periodic table using colored circles to represent elements. The elements are arranged in a grid, with the following elements shown:

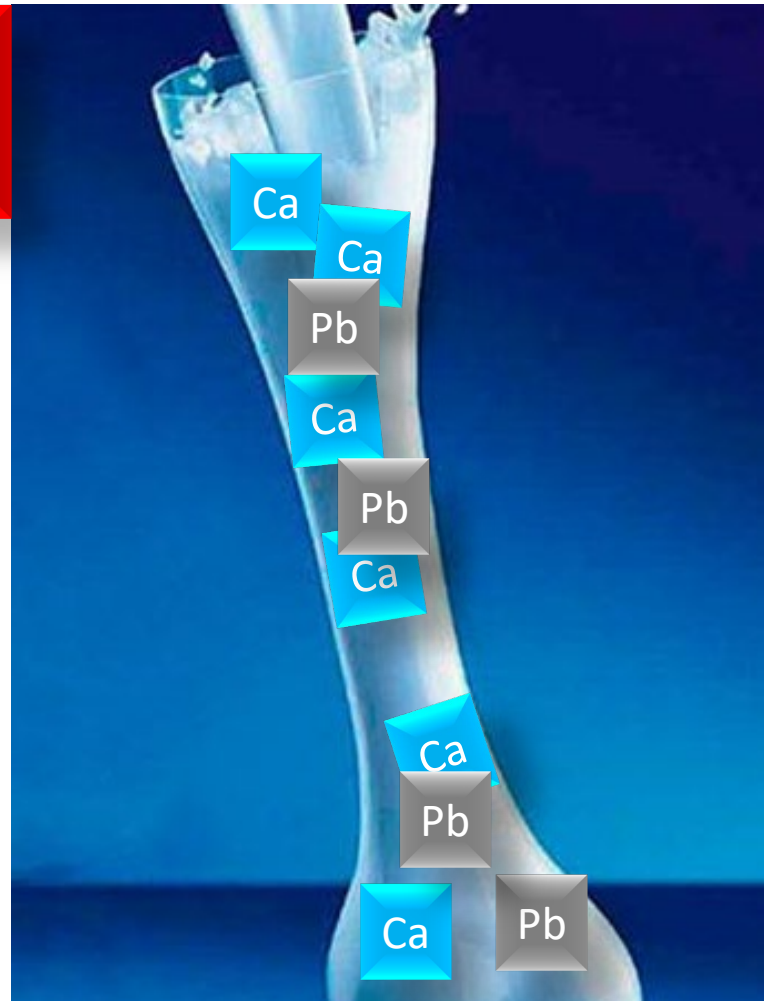
- Row 1: H, He
- Row 2: Li, Be, B, C, N, O, F, Ne
- Row 3: Na, Mg, Al, Si, P, S, Cl, Ar
- Row 4: K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Kr
- Row 5: Rb, Sr, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, In, Sn, Sb, Te, I, Xe
- Row 6: Cs, Ba, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu
- Row 7: Fr, Ra, Ac, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr

A vertical label "Transition Metals" is placed between the d-block and the p-block, with a zigzag line pointing to the d-block elements.

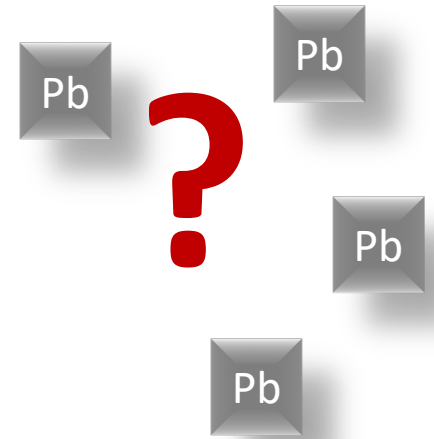
<https://chemistryonline.guru/ionic-radius/>

Lead (Pb) accumulates in teeth and bones

Osteoporosis

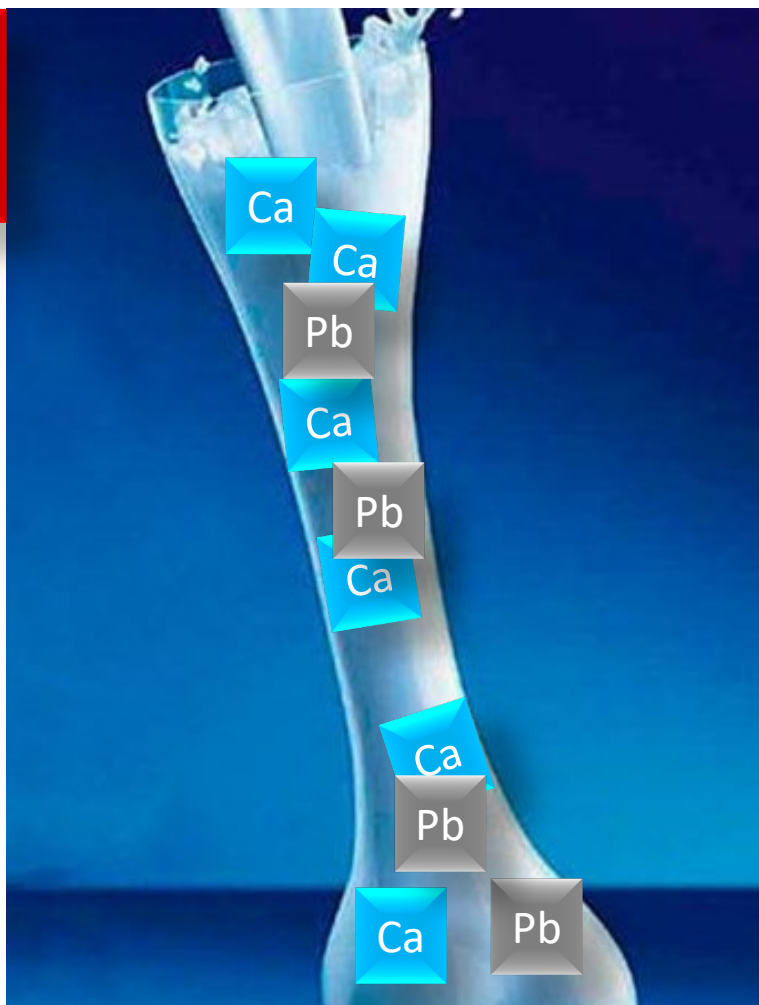


What happens to the **Pb** in the bones?

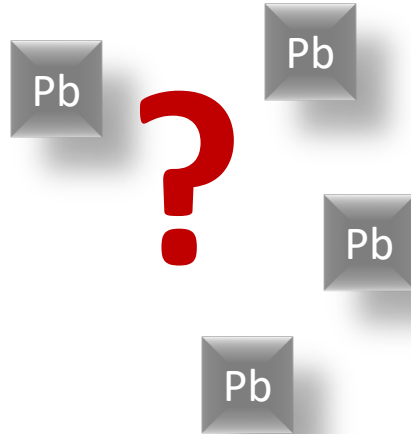


Lead (Pb) concentration increases in the blood

Osteoporosis



What happens to the **Pb** in the bones?



Childhood Lead Poisoning
causes dementia in adults





The Association between Blood Lead Levels and Osteoporosis Adults—Results from the Third National Health and Nutrition Examination Survey (NHANES III)

James R. Campbell and Peggy Auinger

Published: 1 July 2007 | <https://doi.org/10.1289/ehp.9716> | Cited by: 35

78% of the U.S. population (1970s) had blood lead levels $\geq 10 \mu\text{g}/\text{dL}$. Bone is a repository for 90–95% of the total body burden of lead and harbors it for years after initial exposure. Thus, a high proportion of adult Americans may currently have elevated bone lead levels. With this many who were exposed to lead when younger, and the morbidity associated with osteoporosis, it is important to investigate whether an association exists between lead exposure and osteoporosis in humans. Our objective was to conduct a secondary analysis to explore an association between lead exposure and osteoporosis in U.S. adults.

Pb from water accumulates in teeth and bones. When Pb leaches out of bones, it may contribute to osteoporosis in adult life. Increased amount of Pb in blood may also contribute to dementia, Alzheimer's and neurotoxicity.

www.ncbi.nlm.nih.gov/pmc/articles/PMC3567843/pdf/nihms367232.pdf

Published in final edited form as:
Curr Alzheimer Res. 2012 June ; 9(5): 563–573.

Alzheimer's Disease and Environmental Exposure to Lead: The Epidemiologic Evidence and Potential Role of Epigenetics

Kelly M. Bakulski¹, Laura S. Rozek^{1,2}, Dana C. Dolinoy¹, Henry L. Paulson³, and Howard Hu^{1,4,5,*}

¹University of Michigan, School of Public Health, Department of Environmental Health Sciences

²University of Michigan, Medical School, Department of Otolaryngology

³University of Michigan, Department of Neurology

⁴University of Michigan, Department of Epidemiology

⁵University of Michigan, Medical School, Department of Internal Medicine

Abstract

Several lines of evidence indicate that the etiology of late-onset Alzheimer's disease (LOAD) is complex, with significant contributions from both genes and environmental factors. Recent research suggests the importance of epigenetic mechanisms in defining the relationship between environmental exposures and LOAD. In epidemiologic studies of adults, cumulative lifetime lead (Pb) exposure has been associated with accelerated declines in cognition. In addition, research in animal models suggests a causal association between Pb exposure during early life, epigenetics, and LOAD. There are multiple challenges to human epidemiologic research evaluating the relationship between epigenetics, LOAD, and Pb exposure. Epidemiologic studies are not well-suited to accommodate the long latency period between exposures during early life and onset of Alzheimer's disease. There is also a lack of validated circulating epigenetics biomarkers and retrospective biomarkers of Pb exposure. Members of our research group have shown bone Pb is an accurate measurement of historical Pb exposure in adults, offering an avenue for future epidemiologic studies. However, this would not address the risk of LOAD attributable to early-life Pb exposures. Future studies that use a cohort design to measure both Pb exposure and validated epigenetic biomarkers of LOAD will be useful to clarify this important relationship.

Do you know what is in your drinking water?

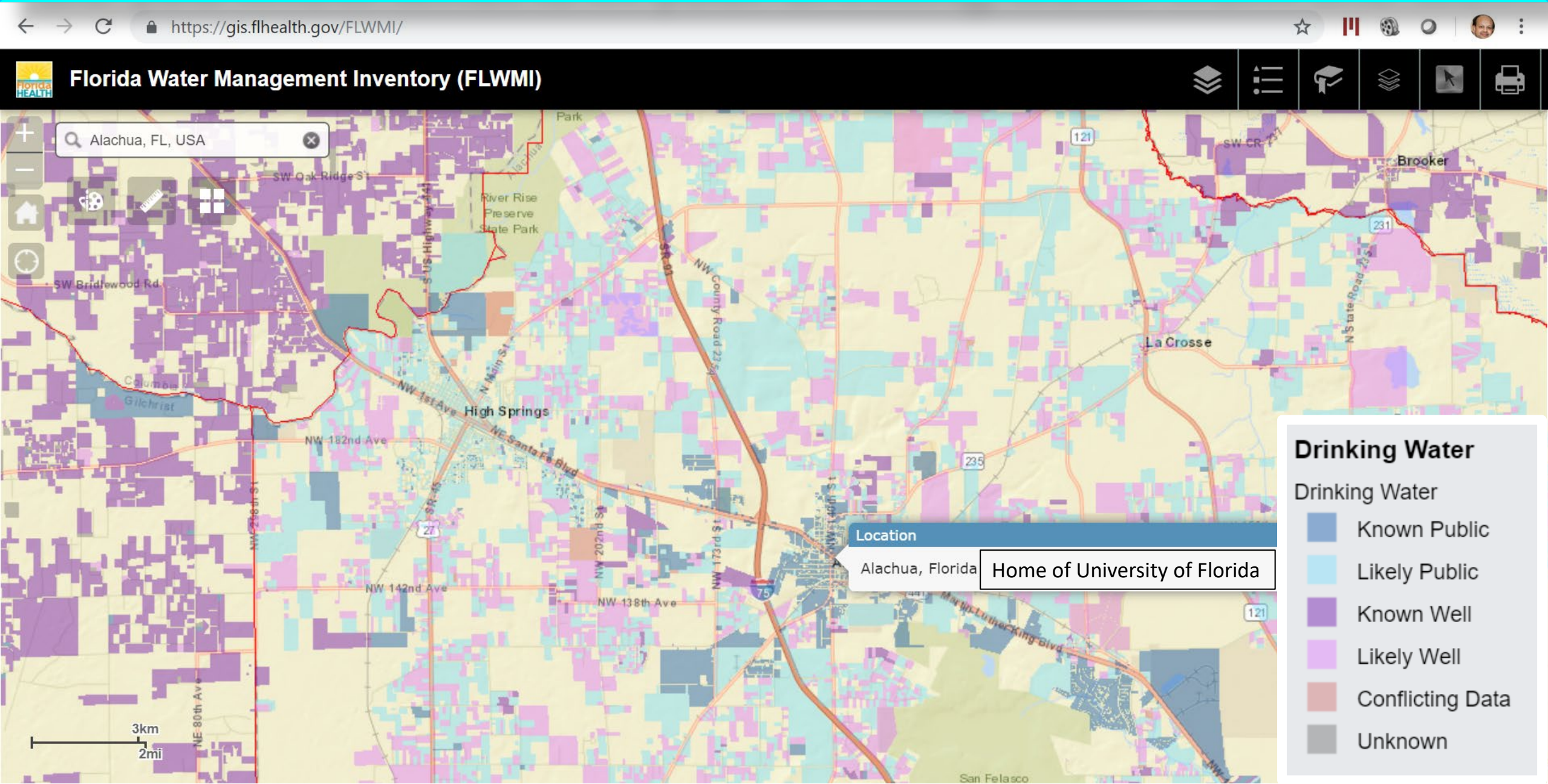
The Impact

535,000

U. S. children ages 1 to 5 years
have blood lead levels high
enough to damage their health.



Do you know what is in your drinking water from the well?



Drinking water from wells – schools near University of Florida

← → ↻ https://gis.flhealth.gov/FLWMI/

Florida Water Management Inventory (FLWMI)

Alachua, FL, USA

Parcel: 03127-010-004 (1 of 2)

Layer Name: Wastewater
Domestic Wastewater Disposal: LikelySeptic
Drinking Water Delivery: LikelyWell
Built Status: BLT
Land Use Category: RES
Physical Address: Null
Physical City: Null
Physical ZipCode: Null
County Parcel Number: 03127-010-004
County Alternate Key: 11982
GIS Acres: 6.246079
DOR County: 11
Wastewater Year Updated: 2014
Wastewater Data Source Type: DOH-HQ
Wastewater Source Name: Centrax 01-SA-06169
Tax Assessment Year: 2016

[Zoom to](#)

Legend

Drinking Water

- Known Public
- Likely Public
- Known Well
- Likely Well
- Conflicting Data
- Unknown

School Bd of Alachua Cty

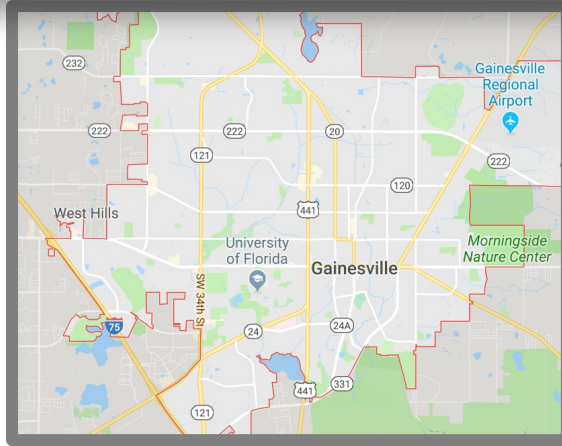
Mebane Middle School

NW 140th St

Drinking water from water treatment plant in Gainesville, FL

Gainesville Regional Utilities (GRU) - Murphree WTP

EWG's drinking water quality report shows results of tests conducted by the water utility and provided to the Environmental Working Group by the Florida Department of Environmental Protection, as well as information from the U.S. EPA Enforcement and Compliance History database (ECHO). For the latest quarter assessed by the EPA (July 2018 - September 2018), tap water provided by this water utility was in compliance with federal health-based drinking water standards.



WHAT ABOUT LEAD?

WANT TO FILTER THESE CONTAMINANTS OUT?

3

contaminants detected above health guidelines

5

other detected contaminants

Includes chemicals detected in 2015 for which annual utility averages exceeded an EWG-selected health guideline established by a federal or state public health authority; chemicals detected under the EPA's Unregulated Contaminant Monitoring Rule (UCMR 3) program in 2013 to 2015, for which annual utility averages exceeded a health guideline established by a federal or state public health authority; radiological contaminants detected between 2010 and 2015.

Chromium (hexavalent) <i>cancer</i>	+
Radiological contaminants <i>cancer</i>	+
Total trihalomethanes (TTHMs) <i>cancer</i>	+

WANT TO FILTER THESE CONTAMINANTS OUT?

Pollution sources

Click on each pollution source to see from which source contaminants come.



Agriculture



Industry



Treatment byproducts



Runoff & sprawl



Naturally occurring

Gainesville Regional Utilities (GRU) - Murphree WTP

EWG's drinking water quality report shows results of tests conducted by the water utility and provided to the Environmental Working Group by the Florida Department of Environmental Protection, as well as information from the U.S. EPA Enforcement and Compliance History database (ECHO). For the latest quarter assessed by the EPA (July 2018 - September 2018), tap water provided by this water utility was in compliance with federal health-based drinking water standards.

WHAT ABOUT LEAD?

WANT TO FILTER THESE CONTAMINANTS OUT?

3

contaminants detected above health guidelines

5

other detected contaminants

Includes chemicals detected in 2015 for which annual utility averages were lower than an EWG-selected health guideline established by a federal or state public health authority; chemicals detected under the EPA's Unregulated Contaminant Monitoring Rule (UCMR 3) program in 2013 to 2015, for which annual utility averages were lower than an EWG-selected health guideline established by a federal or state public health authority.

Chlorate	+
Chromium (total)	+
Haloacetic acids (HAA5)	+
Strontium	+
Vanadium	+

WANT TO FILTER THESE CONTAMINANTS OUT?

www.ewg.org/tapwater/system.php?pws=FL2010946

February 12, 2019

In an [agreement filed by the parties](#) of the 2017 settlement, the city of Flint committed to using a data-driven approach to locate the remaining lead pipes delivering drinking water to residents' homes. The city will use a statistical model—already proven effective in earlier efforts—to guide its selection of homes for service line excavations in 2019. This approach will increase efficiency and help ensure all remaining lead pipes are identified and removed.



OUR WORK OUR EXPERTS OUR STORIES GET INVOLVED ABOUT US

OUR STORIES › GUIDE

Flint Water Crisis: Everything You Need to Know

After officials repeatedly dismissed claims that Flint's water was making people sick, residents took action. Here's how the lead contamination crisis unfolded—and what we can learn from it.

November 08, 2018 | Melissa Denchak

Thursday, June 1, 2017

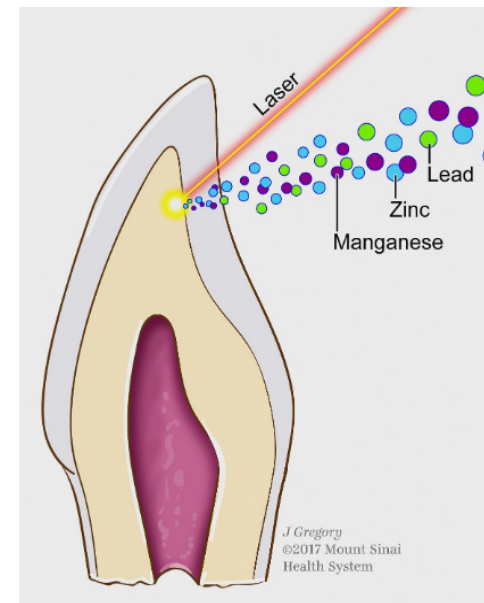
Baby teeth link autism and heavy metals, NIH study suggests



Baby teeth from children with autism contain more toxic lead and less of the essential nutrients zinc and manganese, compared to teeth from children without autism, according to an innovative study funded by the National Institute of Environmental Health Sciences (NIEHS), part of the National Institutes of Health. The researchers studied twins to control genetic influences and focus on possible environmental contributors to the disease. The findings, published June 1 in the journal *Nature Communications*, suggest that differences in early-life exposure to metals, or more importantly how a child's body processes them, may affect the risk of autism.

The differences in metal uptake between children with and without autism were especially notable during the months just before and after the children were born. The scientists determined this by using lasers to map the growth rings in baby teeth generated during different developmental periods.

The researchers observed higher levels of lead in children with autism throughout development, with the greatest disparity observed during the period following birth. They also observed lower uptake of manganese in children with autism, both before and after birth. The pattern was more complex for zinc. Children with autism had lower zinc levels earlier in the womb, but these levels then increased after birth, compared to children without autism.



Cross-section of tooth showing laser removal of the dentine layer, in tan, for analysis of metal content. Mount Sinai Health System

The Association between Blood Lead Levels and Osteoporosis Adults—Results from the Third National Health and Nutrition Examination Survey (NHANES III)

James R. Campbell and Peggy Auinger

Published: 1 July 2007 | <https://doi.org/10.1289/ehp.9716> | Cited by: 35

78% of the U.S. population (1970s) had blood lead levels $\geq 10 \mu\text{g}/\text{dL}$. Bone is a repository for 90–95% of the total body burden of lead and harbors it for years after initial exposure. Thus, a high proportion of adult Americans may currently have elevated bone lead levels. With this many who were exposed to lead when younger, and the morbidity associated with osteoporosis, it is important to investigate whether an association exists between lead exposure and osteoporosis in humans. Our objective was to conduct a secondary analysis to explore an association between lead exposure and osteoporosis in U.S. adults.

Pb from water accumulates in teeth and bones. When Pb leaches out of bones, it may contribute to osteoporosis in adult life. Increased amount of Pb in blood may also contribute to dementia, Alzheimer's and neurotoxicity.



Published in final edited form as:

Curr Alzheimer Res. 2012 June ; 9(5): 563–573.

Alzheimer's Disease and Environmental Exposure to Lead: The Epidemiologic Evidence and Potential Role of Epigenetics

Kelly M. Bakulski¹, Laura S. Rozek^{1,2}, Dana C. Dolinoy¹, Henry L. Paulson³, and Howard Hu^{1,4,5,*}

¹University of Michigan, School of Public Health, Department of Environmental Health Sciences

²University of Michigan, Medical School, Department of Otolaryngology

³University of Michigan, Department of Neurology

⁴University of Michigan, Department of Epidemiology

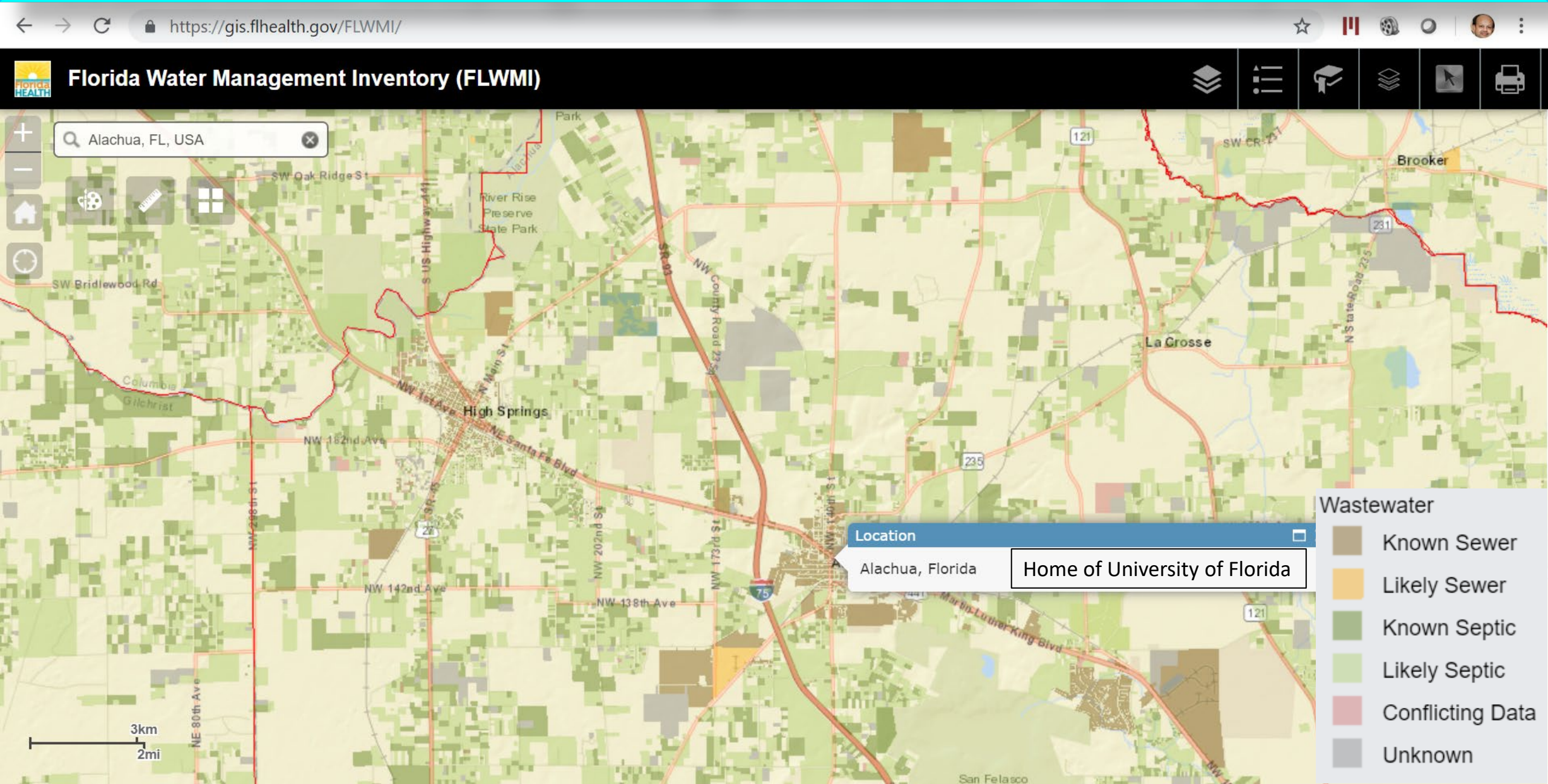
⁵University of Michigan, Medical School, Department of Internal Medicine

Abstract

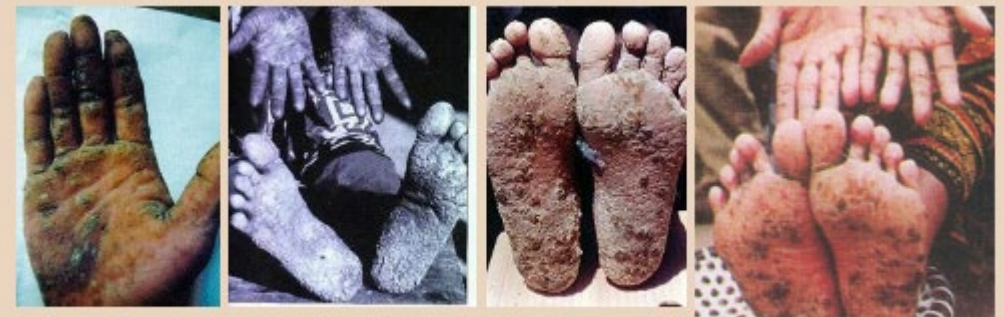
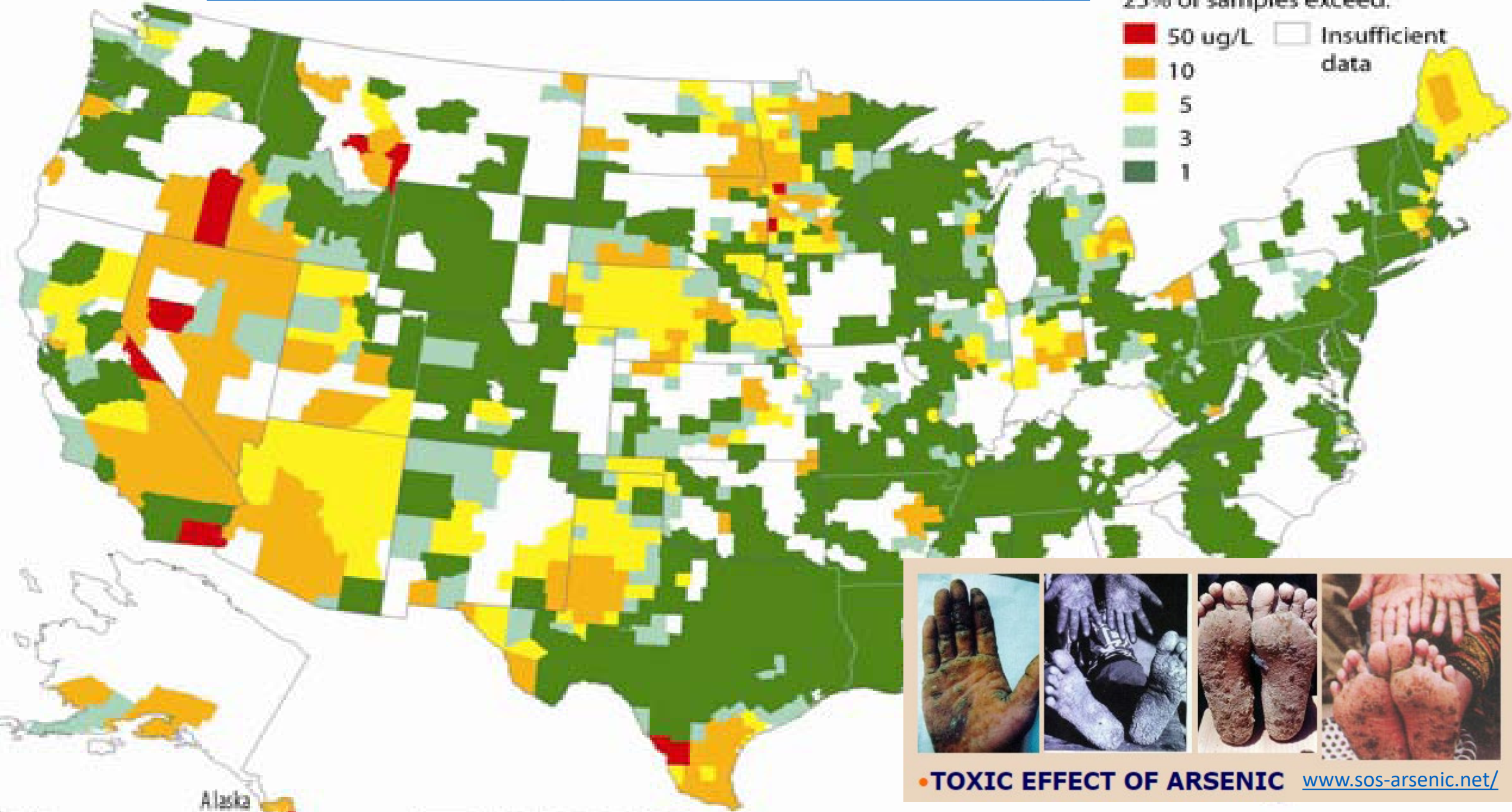
Several lines of evidence indicate that the etiology of late-onset Alzheimer's disease (LOAD) is complex, with significant contributions from both genes and environmental factors. Recent research suggests the importance of epigenetic mechanisms in defining the relationship between environmental exposures and LOAD. In epidemiologic studies of adults, cumulative lifetime lead (Pb) exposure has been associated with accelerated declines in cognition. In addition, research in animal models suggests a causal association between Pb exposure during early life, epigenetics, and LOAD. There are multiple challenges to human epidemiologic research evaluating the relationship between epigenetics, LOAD, and Pb exposure. Epidemiologic studies are not well-suited to accommodate the long latency period between exposures during early life and onset of Alzheimer's disease. There is also a lack of validated circulating epigenetics biomarkers and retrospective biomarkers of Pb exposure. Members of our research group have shown bone Pb is an accurate measurement of historical Pb exposure in adults, offering an avenue for future epidemiologic studies. However, this would not address the risk of LOAD attributable to early-life Pb exposures. Future studies that use a cohort design to measure both Pb exposure and validated epigenetic biomarkers of LOAD will be useful to clarify this important relationship.

www.ncbi.nlm.nih.gov/pmc/articles/PMC3567843/pdf/nihms367232.pdf

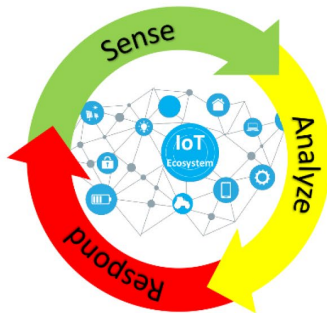
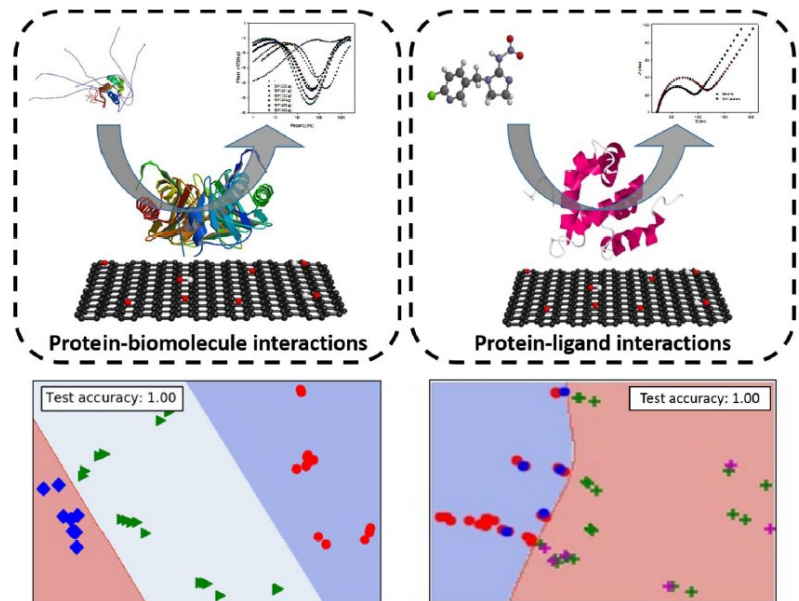
Wastewater seeping into groundwater from septic tanks?



Arsenic concentrations in at least 25% of samples exceed:



Water ART – IoT Data Analytics of Value to End-User



VALUE



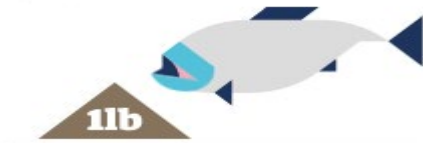
FOOD v PEOPLE

Prevent Food Waste

Estimated 11 billion people to feed at the dawn of the 22nd Century

Pounds of dry feed needed to grow a body mass

Salmon



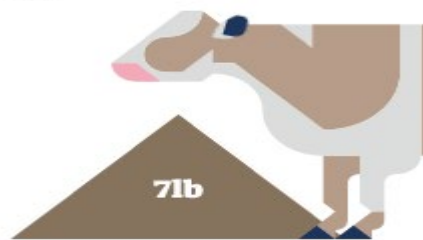
Chicken



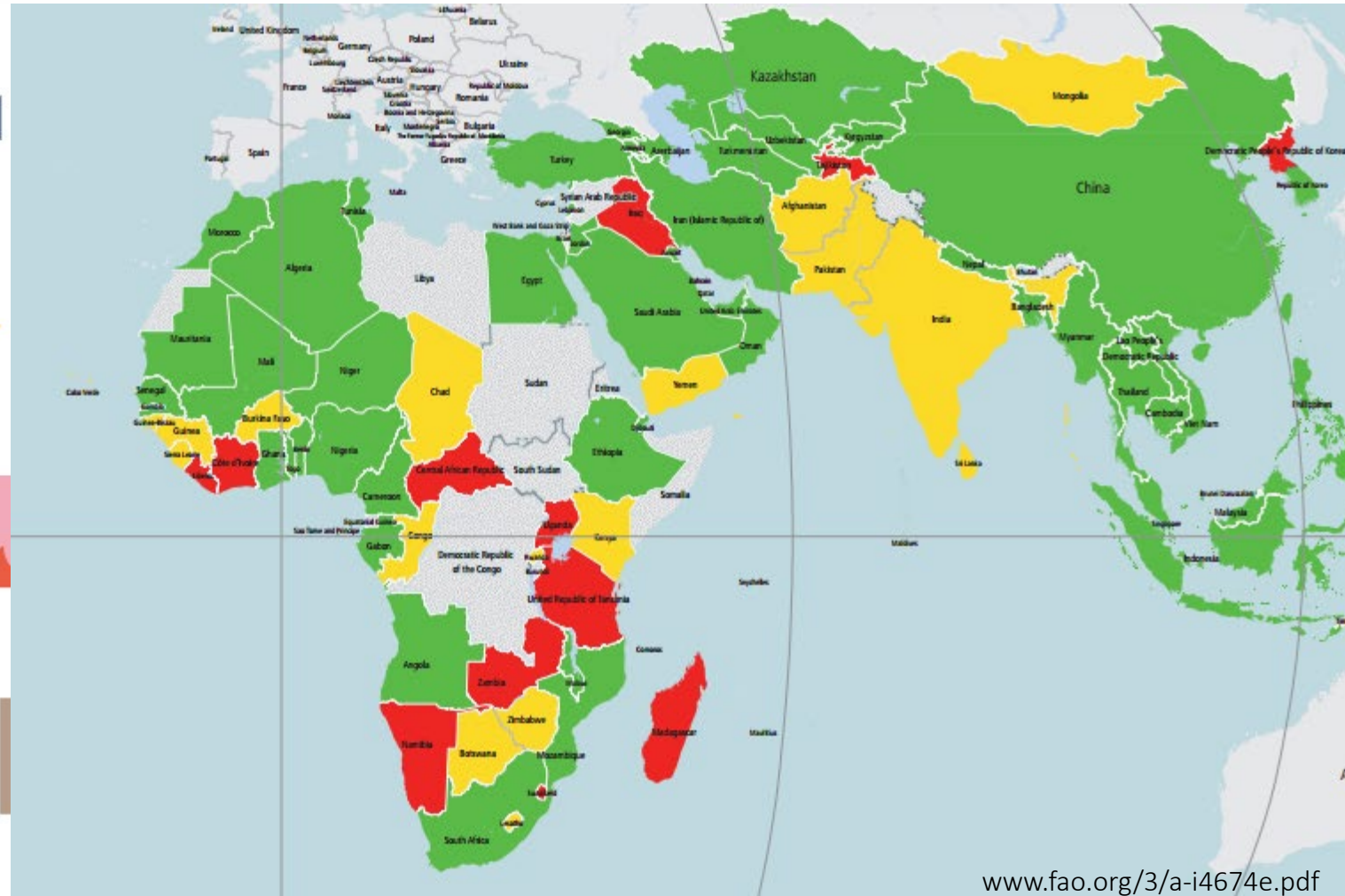
Pork



Beef



The End of Plenty
by Joel K Bourne



www.fao.org/3/a-i4674e.pdf

www.un.org/sustainabledevelopment/blog/2015/07/what-progress-has-been-made-in-ending-global-poverty/
[http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How to Feed the World in 2050.pdf](http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf)

Do we really waste about 68% of the food in the US ?

More than two-thirds of total food
wasted – which is ~ 63 million tons

Value wasted ~ \$150 Billion (total
food wasted value US\$218 Billion)

43

million tons

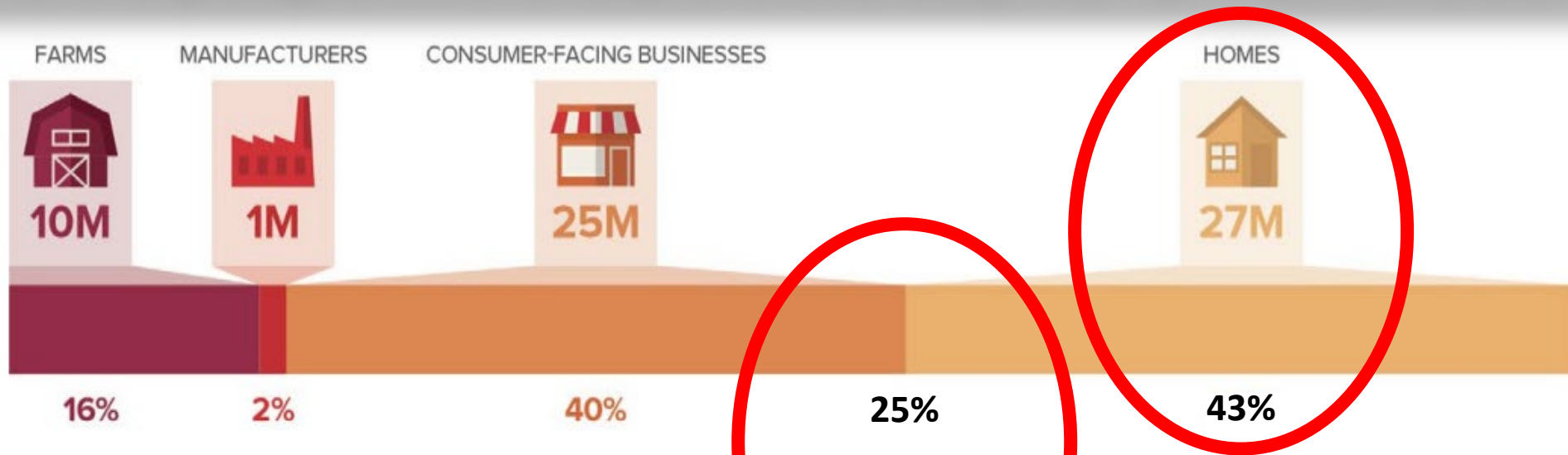
\$150

Billion

US Report • http://www.refed.com/downloads/ReFED_Report_2016.pdf

EU Report • <http://data.consilium.europa.eu/doc/document/ST-10730-2016-INIT/en/pdf> from www.eu-fusions.org/

Yes. We, the people in the US, are the culprits → ~68% FOOD WASTED

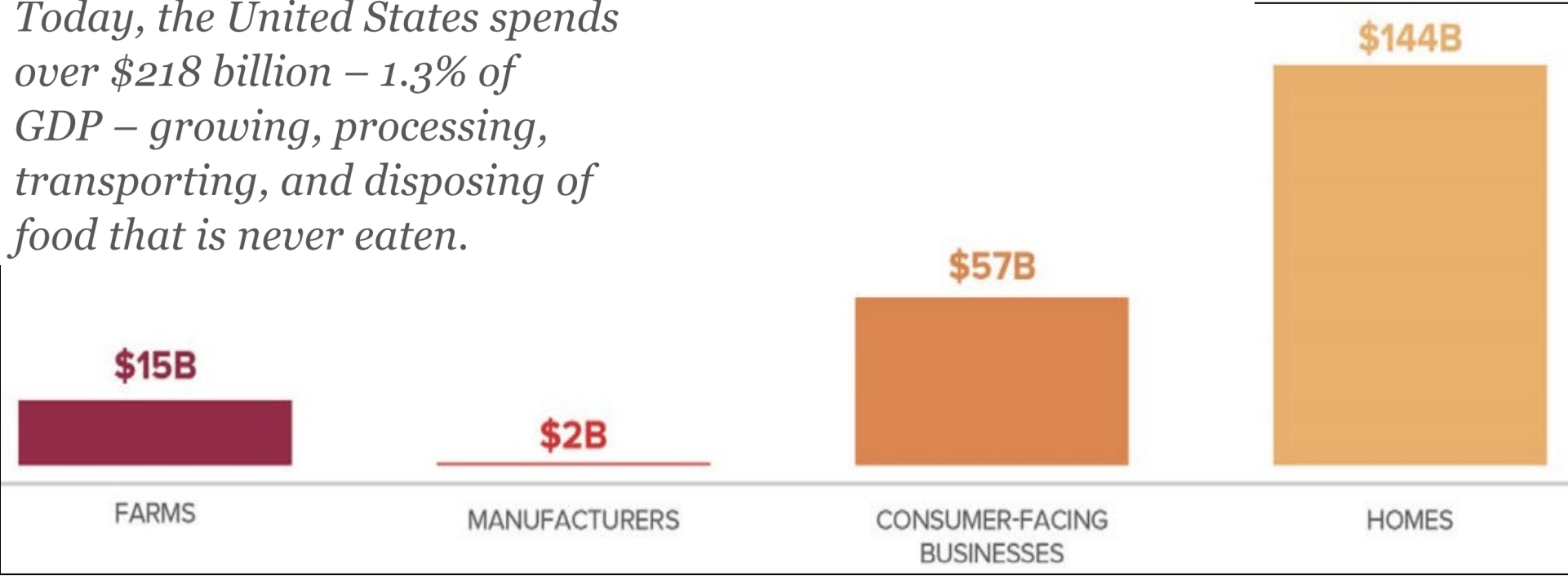


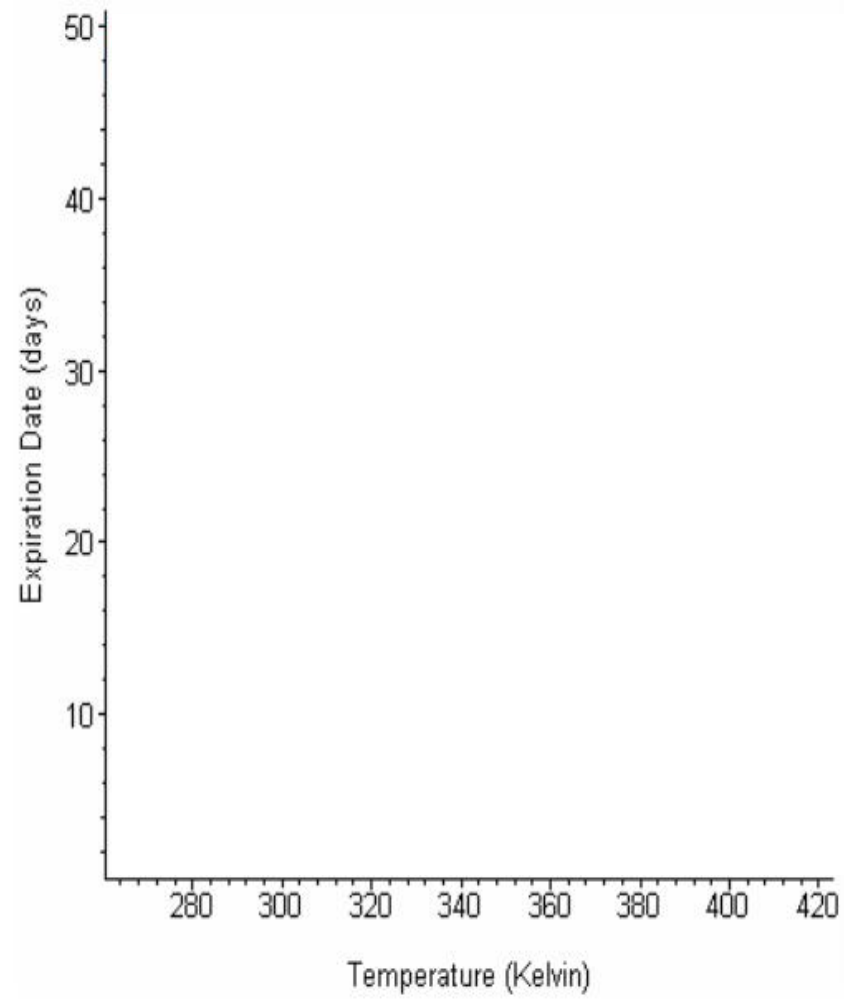
CONSUMER-FACING BUSINESSES INCLUDE



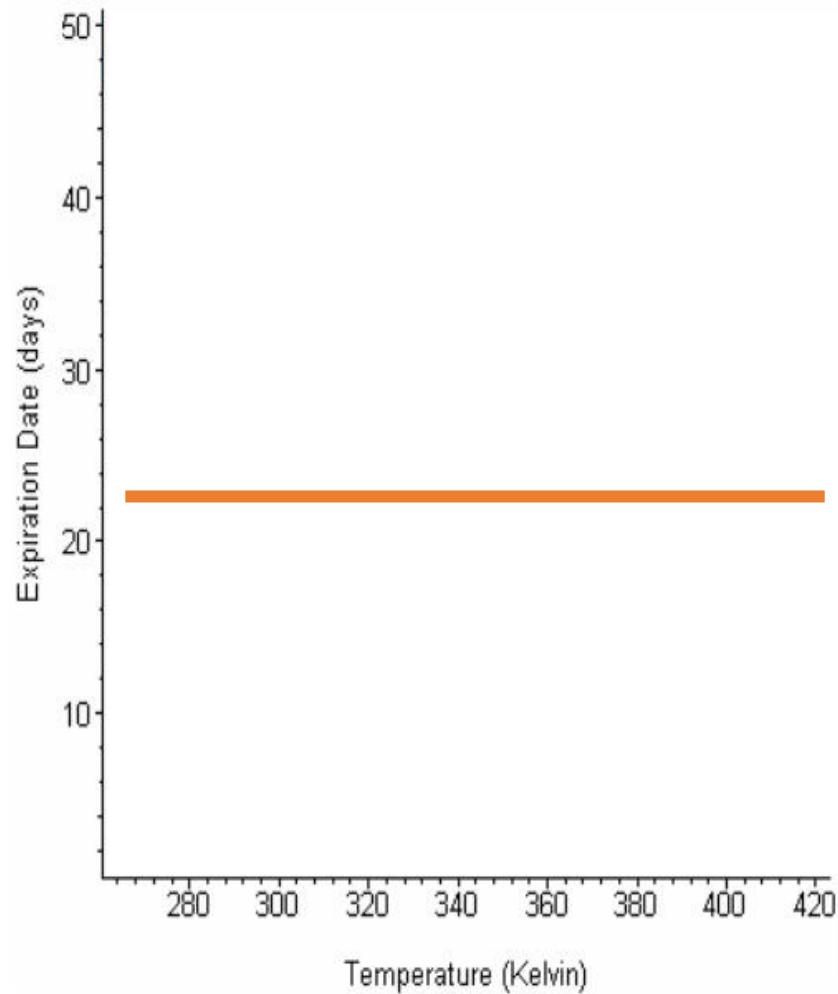
FOOD WASTE in the US: approx. 63 million tons, \$218 billion, 1.3% GDP

Today, the United States spends over \$218 billion – 1.3% of GDP – growing, processing, transporting, and disposing of food that is never eaten.





Storage

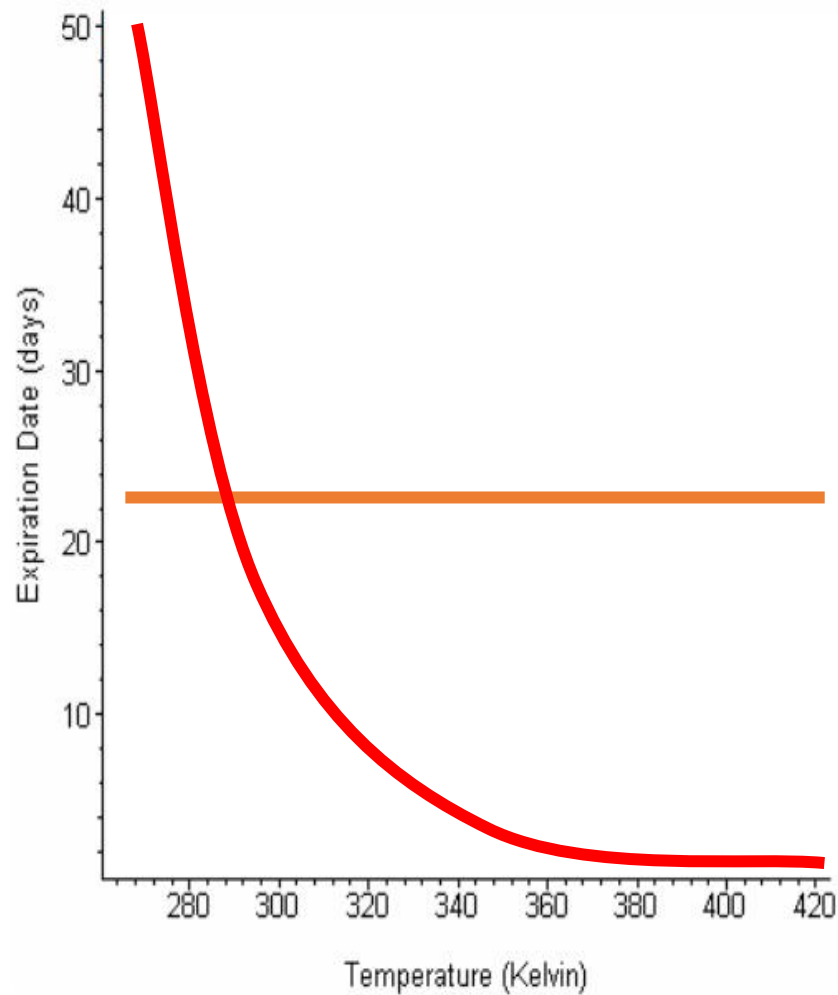


$$\frac{\partial Q}{\partial t} = -k_1 e^{\left[-\frac{E_a}{R_g T(t)} \right]} Q^n$$

Variables

- E_a Activation energy
- k_1 Arrhenius constant
- n Order of the reaction
- T Temperature
- Q Quality
- t Time

Storage


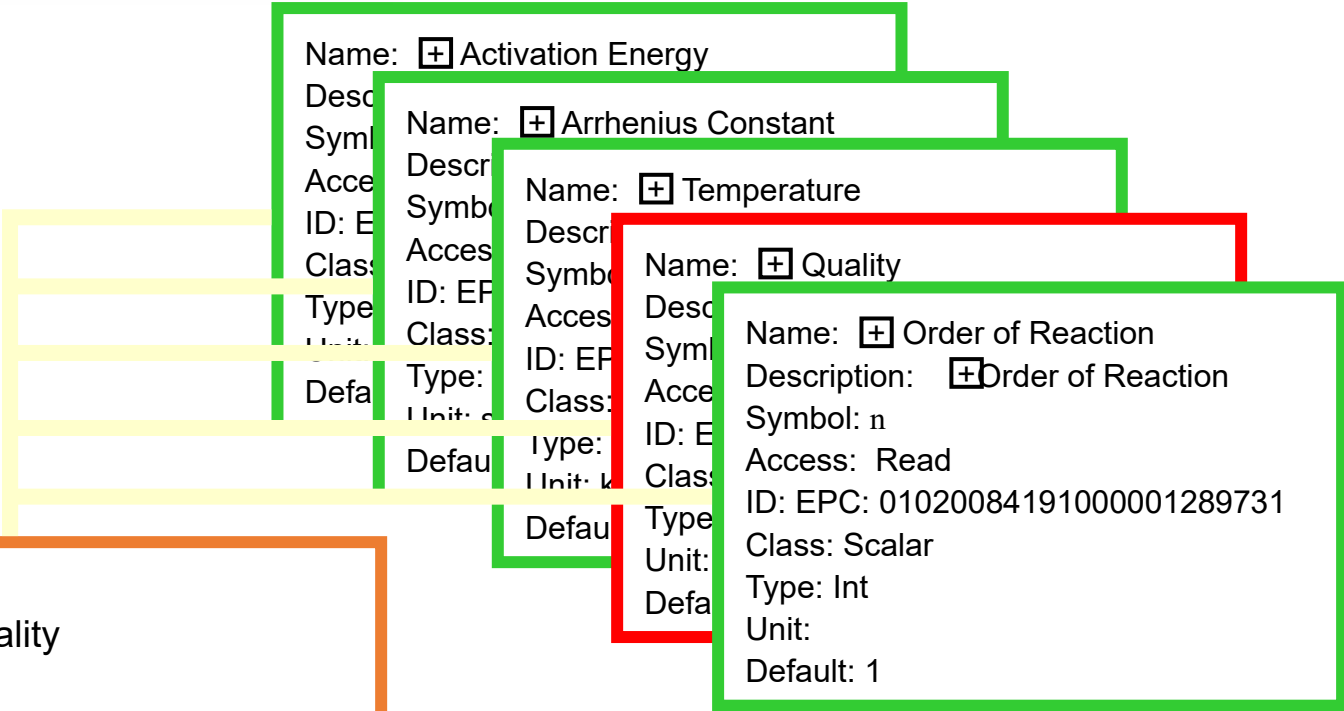


$$\frac{\partial Q}{\partial t} = -k_1 e^{\left[-\frac{E_a}{R_g T(t)} \right]} Q^n$$

Variables

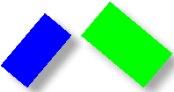
- E_a Activation energy
- k_1 Arrhenius constant
- n Order of the reaction
- T Temperature
- Q Quality
- t Time

Shelf Life

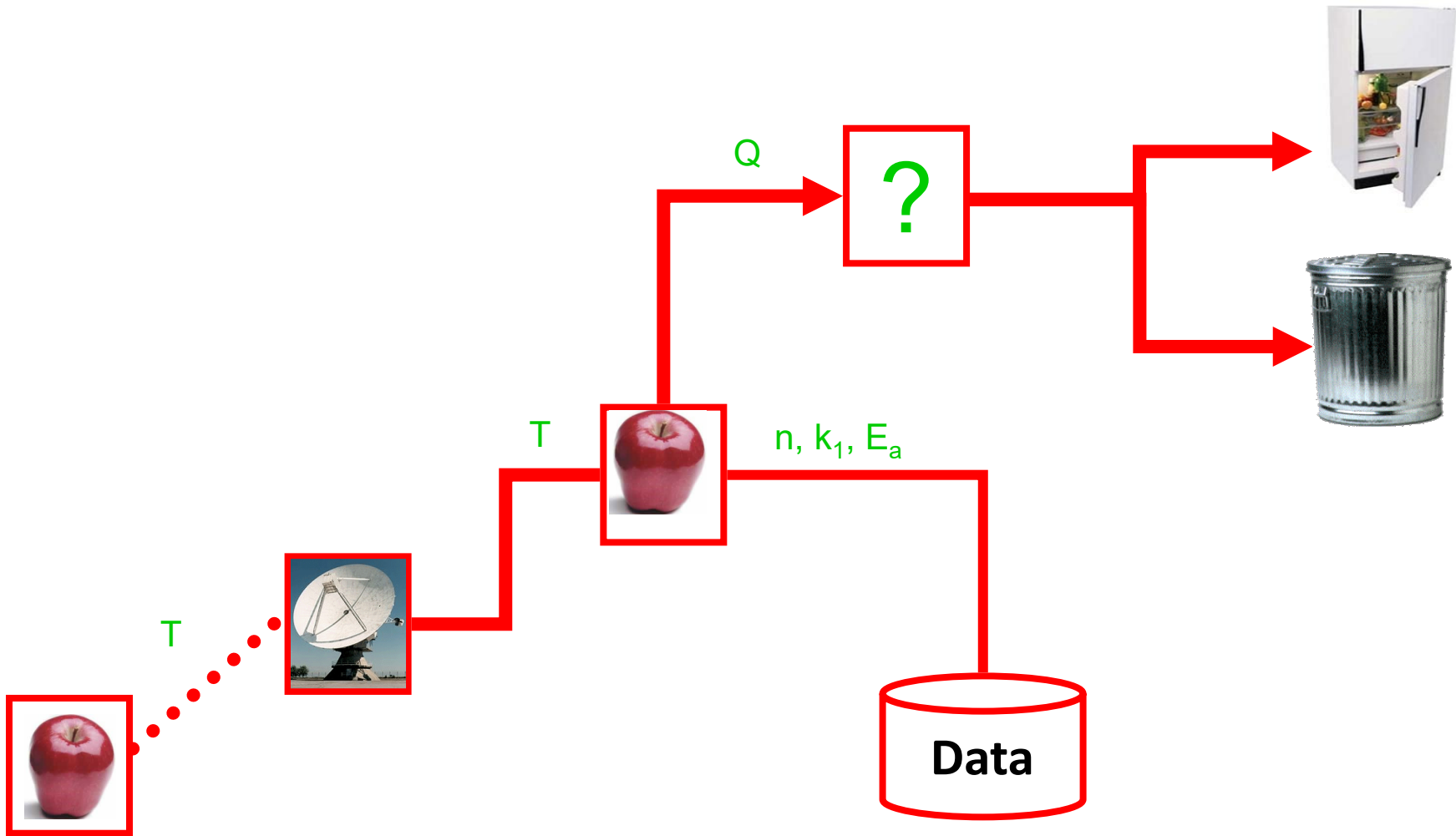


Food Quality

Name: Food Quality
Description: Food Quality based Arrhenius
Developer: Natick Army Laboratories
ID: EPC: 010300908808BF60000000AA
Comp: \$0.25 per month
Type: Analytic
Rate: 1 to 10,000 sec
Algorithm:

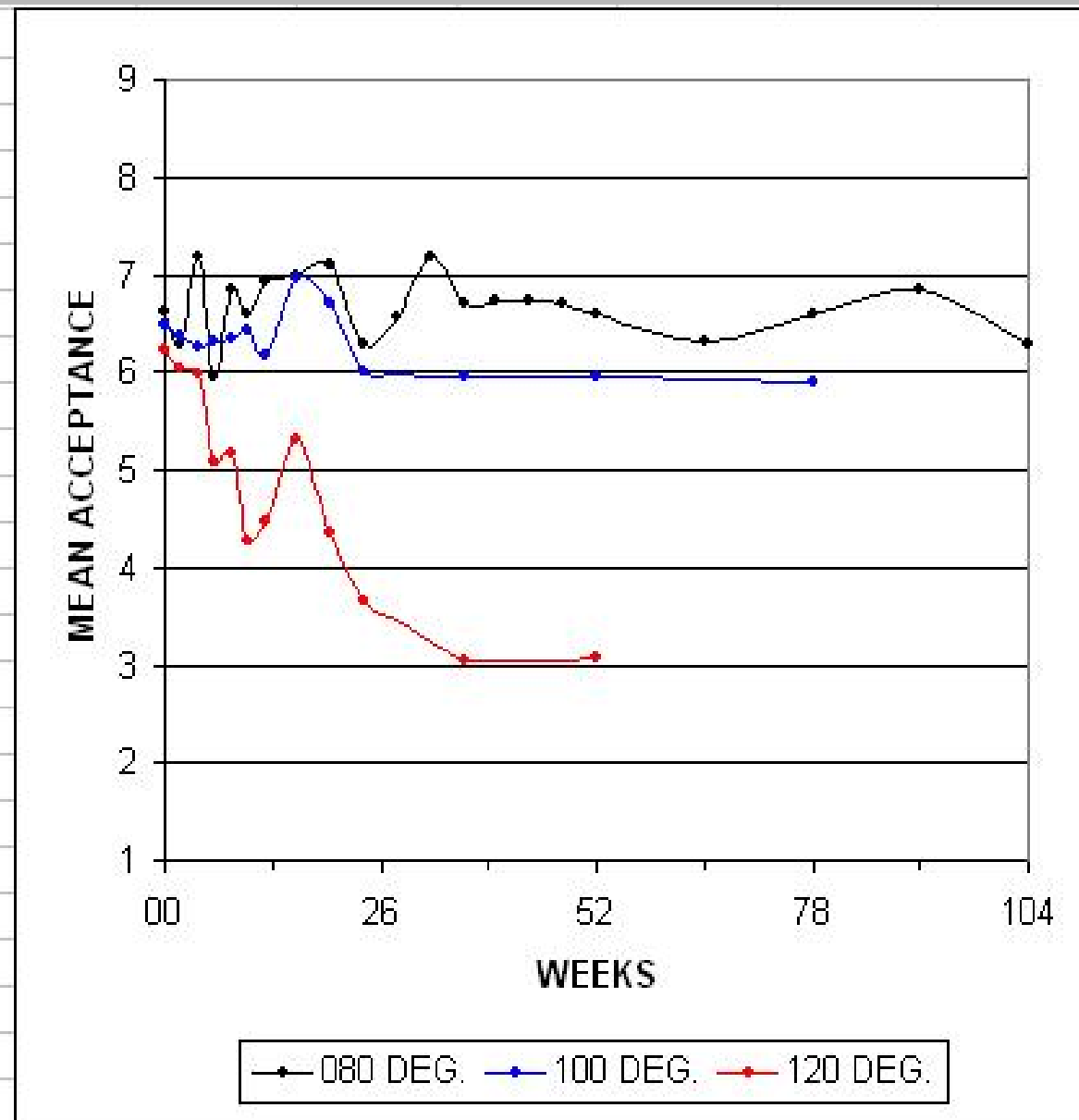


Shelf Life \rightleftharpoons Answers (not numbers)



Monitoring Perishables (MRE Simulation)

WKS	080 DEG.	100 DEG.	120 DEG.
00	6.622	6.486	6.243
02	6.282	6.359	6.026
04	7.194	6.250	5.972
06	5.949	6.308	5.077
08	6.850	6.350	5.175
10	6.600	6.429	4.286
12	6.944	6.167	4.472
16	7.000	6.947	5.316
20	7.111	6.694	4.361
24	6.300	6.000	3.667
28	6.579		
32	7.189		
36	6.694	5.944	3.028
40	6.730		
44	6.730		
48	6.703		
52	6.583	5.944	3.056
65	6.316		
78	6.583	5.889	
91	6.842		
104	6.300		
130			
156			



Please Select an MRE:

01.0000489.00016F.000169DC1

Start Temperature Sensor

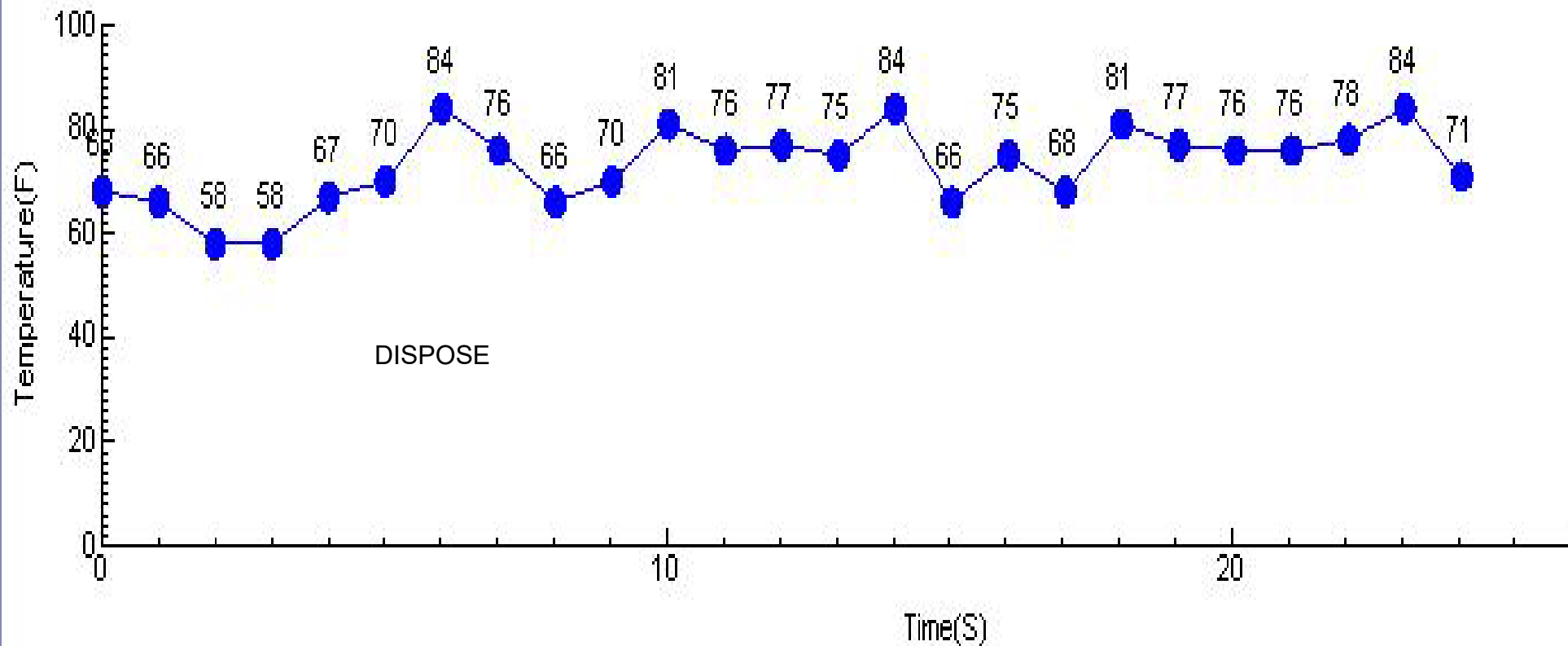
Stop Temperature Sensor

Day: Friday, May 23, 2003

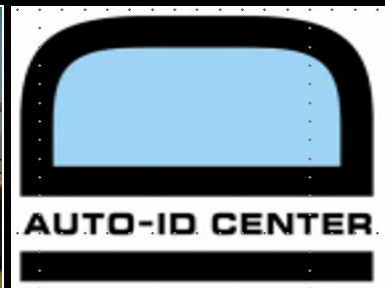
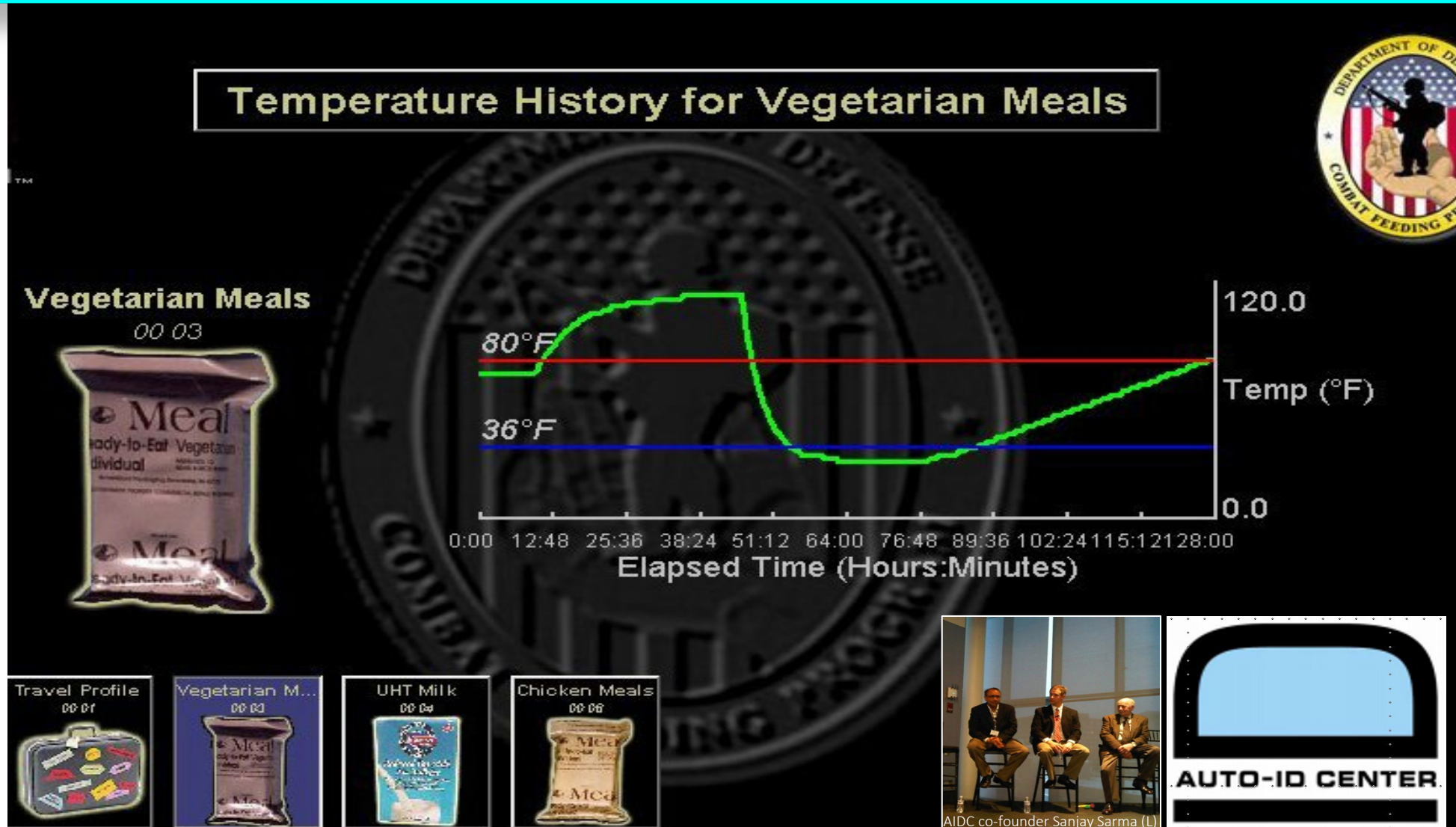
Time: 11:23:07 AM

Temperature: 71

Time Temperature Chart

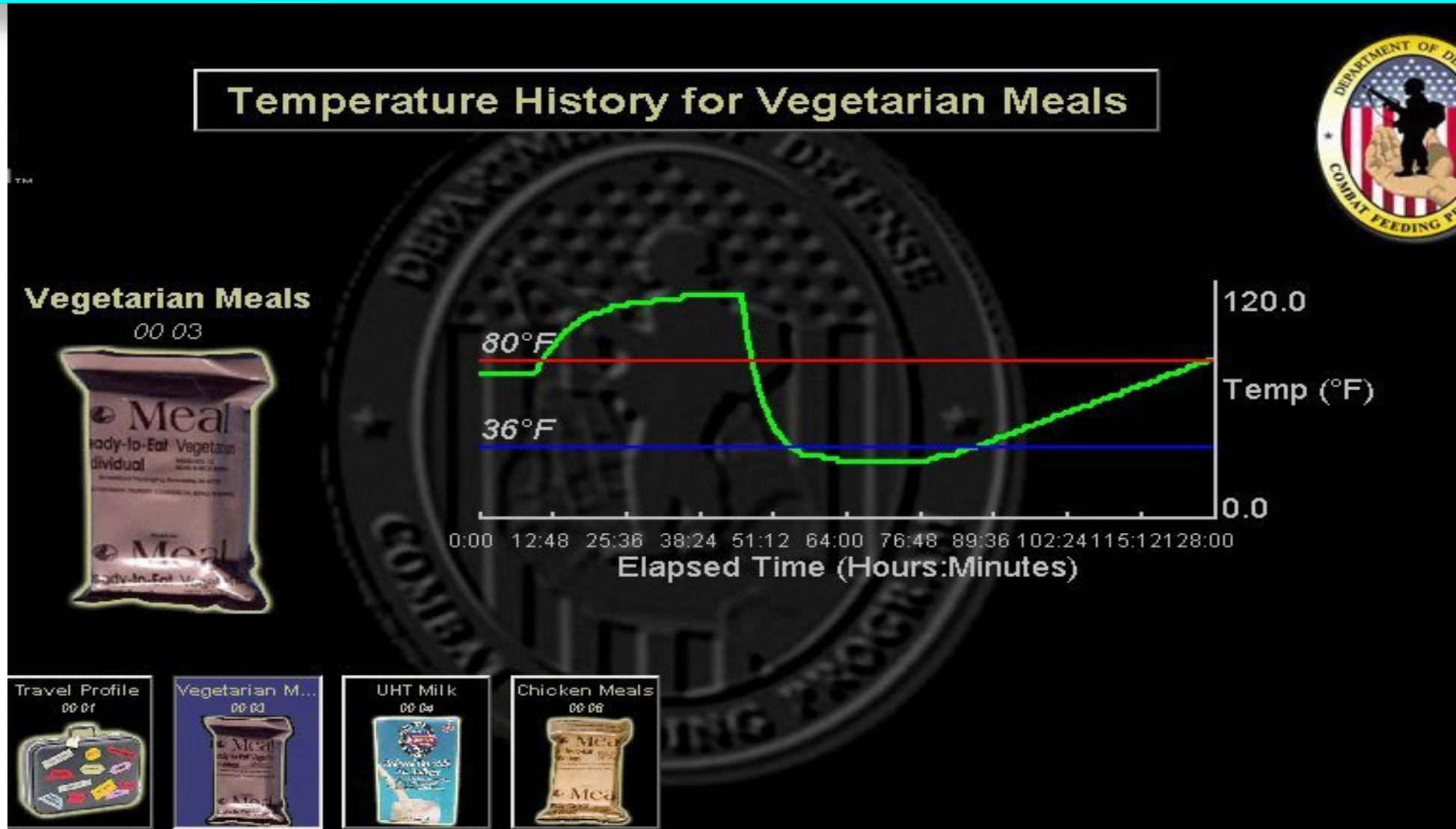


SENSEE can hold RFID + Temperature Sensor Data • Convergence of Systems

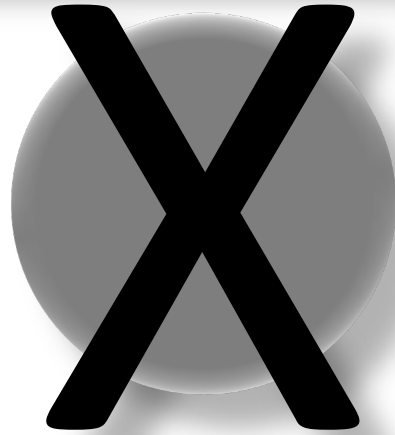


AIDC co-founder Sanjay Sarma (L)

Is this data analytics of value to the end-user on the front lines of a war zone?



NOT GOOD



Knowledge Tools

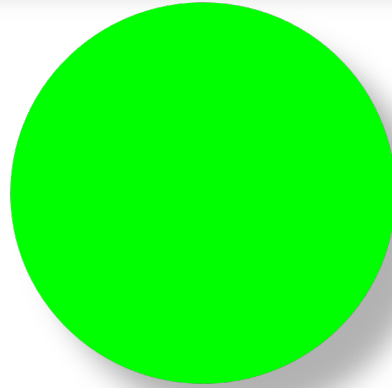
- Agent-based model
- Data-informed models
- Data visualization
- Network models
- Data & database modeling
- Document Modeling
- Metamodeling
- Ontological Modeling
- Business Process Modeling
- Natural language processing
- Machine Learning, ANN, DL

Statistical Tools

- Stochastic
- Bayesian & Adaptive
- Dynamic models
- Hierarchical models
- Factor analysis
- Monte Carlo models
- Population Modeling
- Dynamical system
- Stochastic system eqn
- Social network analysis
- Topic modeling

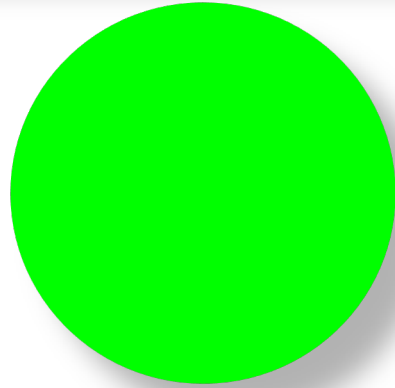
SIMPLICITY – THE TRAFFIC LIGHT OUTCOME – ANSWERS, not numbers

GOOD

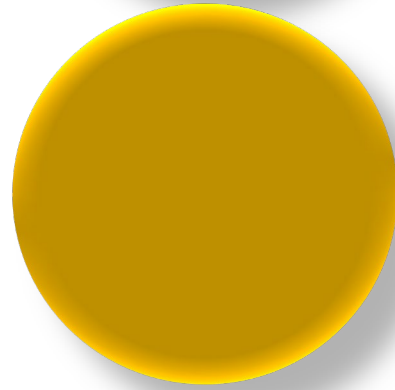


SIMPLICITY – THE TRAFFIC LIGHT OUTCOME – ANSWERS, not numbers

GOOD

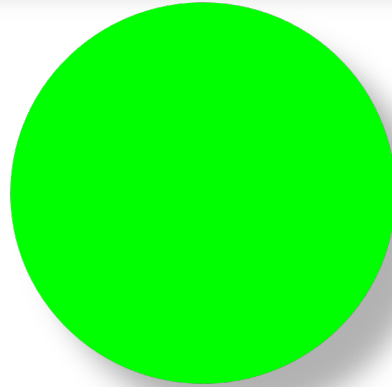


INSPECT

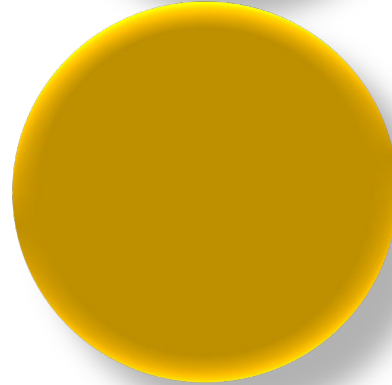


SIMPLICITY – THE TRAFFIC LIGHT OUTCOME – ANSWERS, not numbers

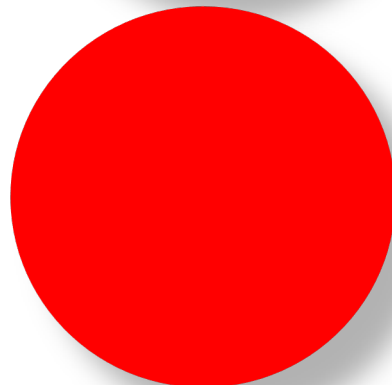
GOOD



INSPECT



REJECT





MRE Quality Application

Please Select an MRE:

01.0000A89.00016F.000169DC1

Quality: 50 -100 Issue, 20 - 49 Inspect, 0 - 19 Discard

ISSUE

INSPECT

DISPOSE

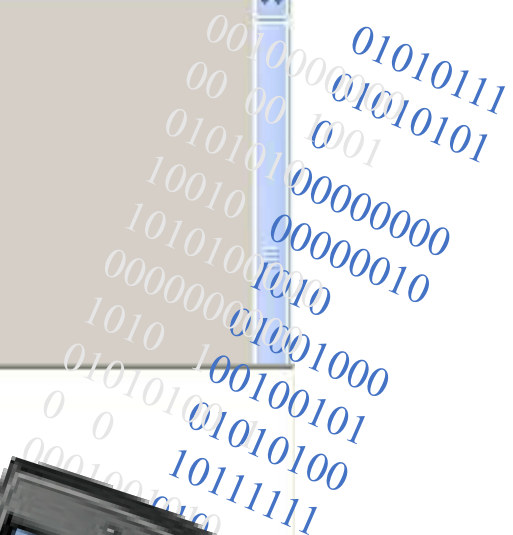
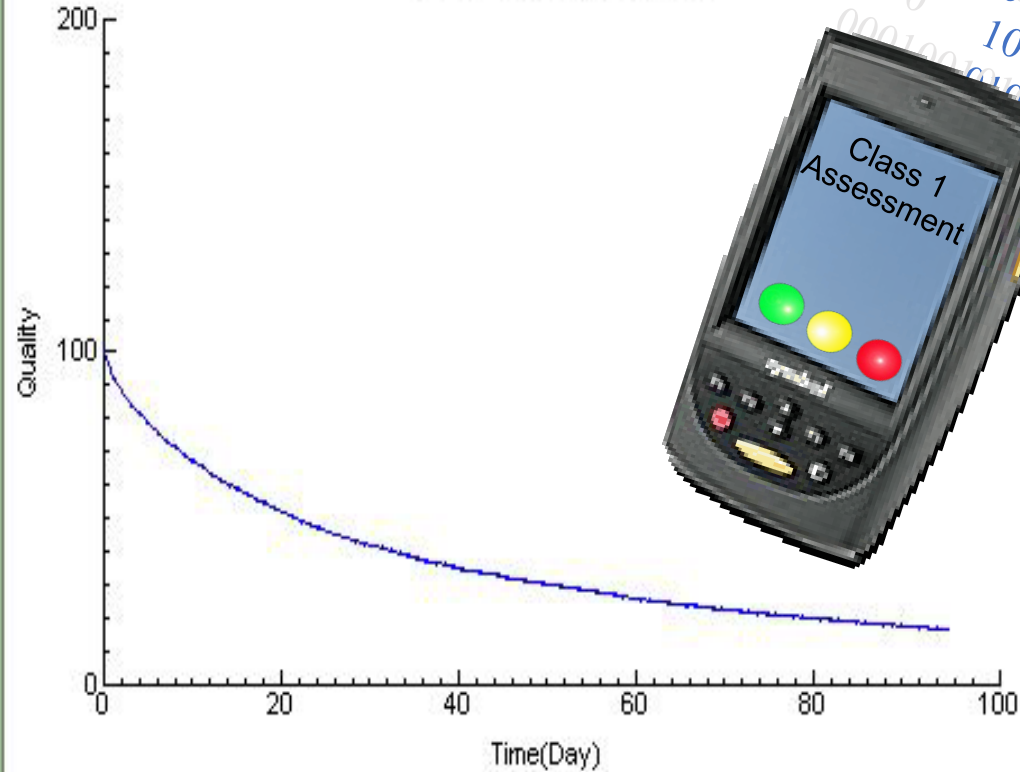
DISPOSE

Discard

Time and Temperature Data:

--1Monday, April 28, 200312:17:32 PM81
 Monday, April 28, 20039:44:10 PM64
 Friday, May 23, 200311:18:54 AM59
 Friday, May 23, 200311:18:55 AM49
 Friday, May 23, 200311:18:56 AM53
 Friday, May 23, 200311:18:57 AM54
 Friday, May 23, 200311:18:58 AM56
 Friday, May 23, 200311:18:59 AM42
 Friday, May 23, 200311:19:00 AM54
 Friday, May 23, 200311:19:01 AM54
 Friday, May 23, 200311:19:02 AM42

Time Quality Chart



Grocery Store Perishability

Is the spinach fresh? Is the fish smelling fishy? Is the chicken safe to eat?



YOU WANT TO KNOW IF THE CHICKEN IS STILL GOOD TO EAT. YOU DON'T TRUST THE "SELL BY" DATE ON THE LABEL

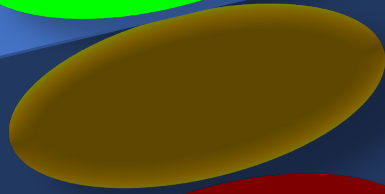
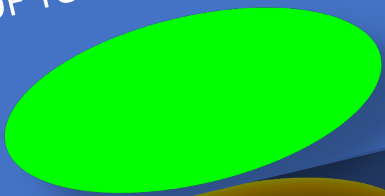
ALWAYS BUY QUALITY



WHAT IF THE PACK OF “CHICKEN” CAN TALK TO YOU AND OFFER YOU A REAL-TIME UPDATE ABOUT ITS QUALITY AND FOOD SAFETY?



THIS IS A NON-TOXIC BIOGENIC AMINE SENSOR TO MONITOR THE SAFETY OF YOUR FRESH FOOD



HARVESTLAND
PERDUE
fresh:
Chicken Thigh Filets
All Natural! • No Hormones or Steroids Added!
PROCESS VERIFIED **USDA** VERIFIED
✓ No Antibiotics Ever
✓ Fed All Vegetarian Diet
✓ No Animal By-Products
✓ Raised Cage Free



Boneless and Skinless • Lean
Minimally processed. No artificial ingredients.
Federal regulations prohibit the use of hormones or steroids in poultry.
Keep Refrigerated • Less than 2% retained water.

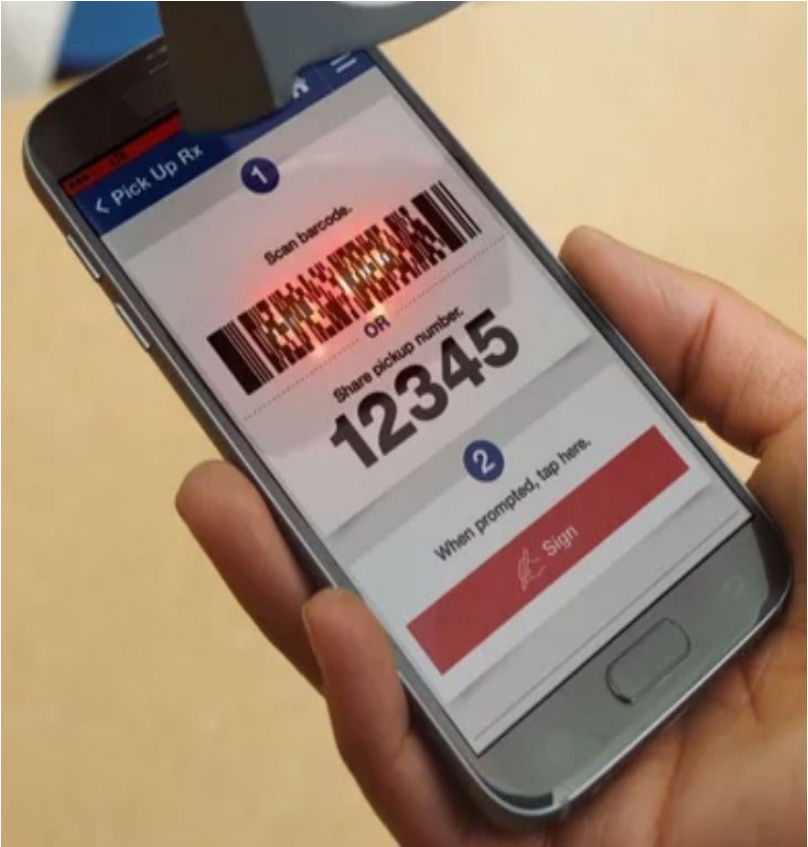


Yes We Can!

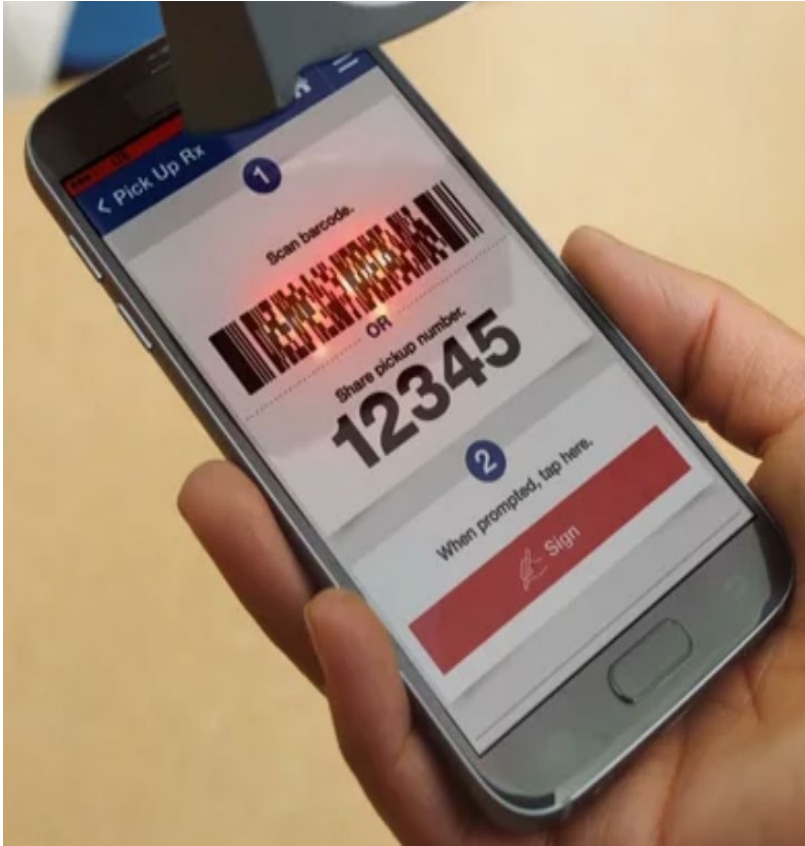




THE SKU (PRODUCT NUMBER) SHOWS ON THE MOBILE APP

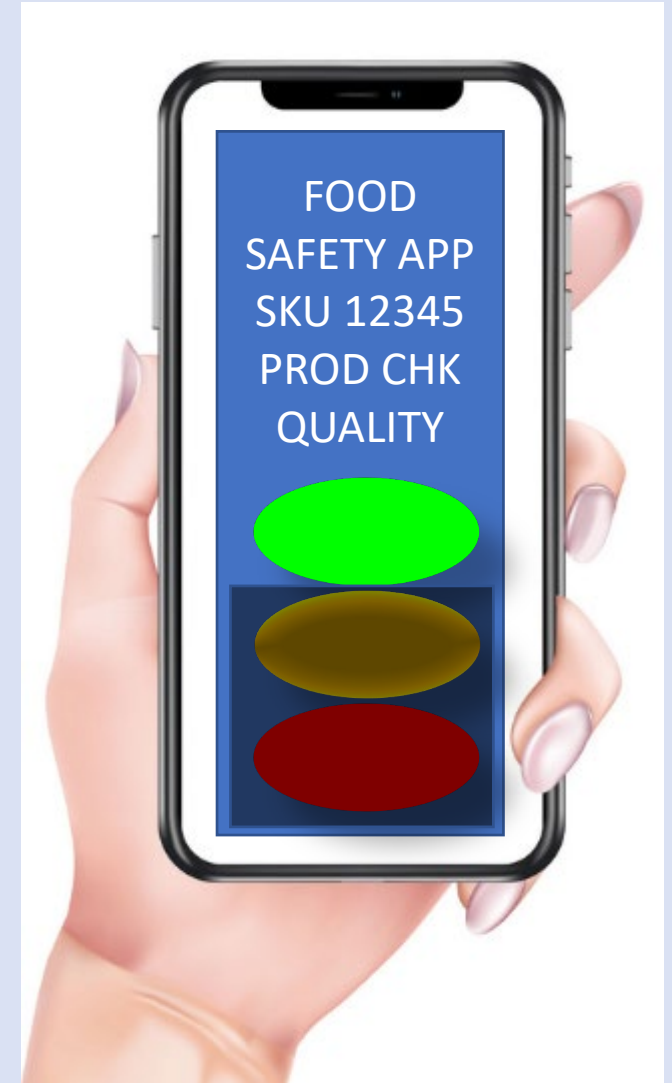


THE SKU (PRODUCT NUMBER) SHOWS ON THE MOBILE APP

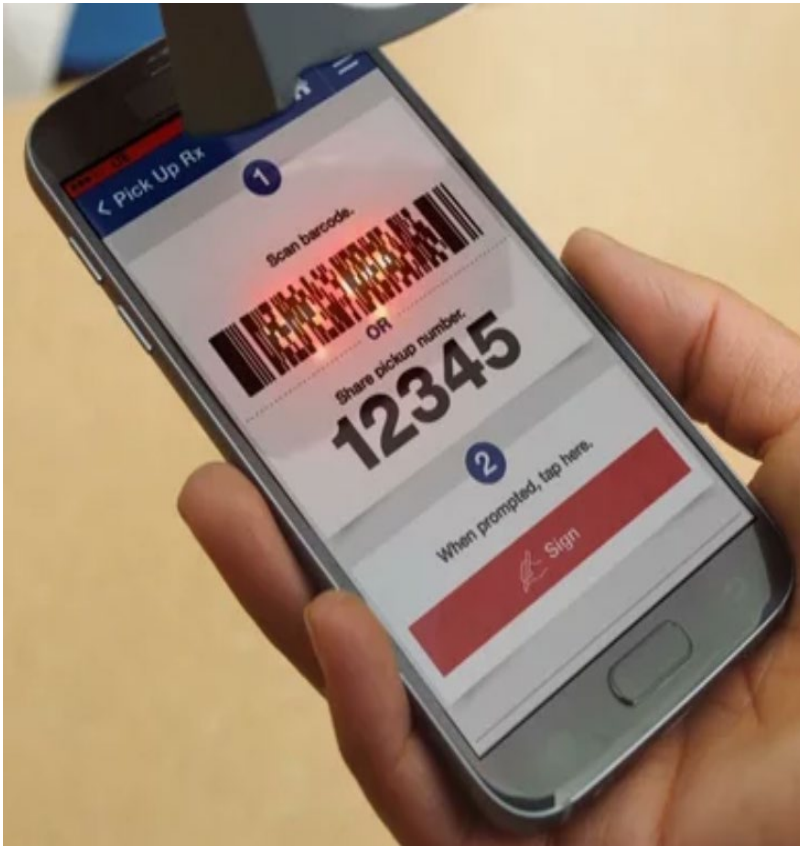


**WOULD YOU PAY 1 CENT TO USE THIS
FOOD APP HEALTH SAFETY SERVICE ?**

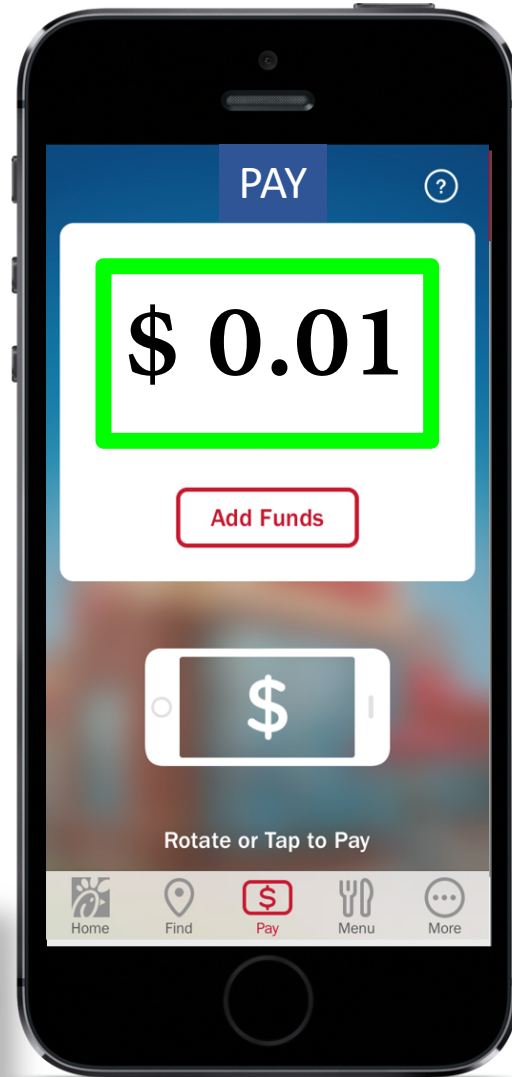
IT IS YOUR HEALTH



THE SKU (PRODUCT NUMBER) SHOWS ON THE MOBILE APP

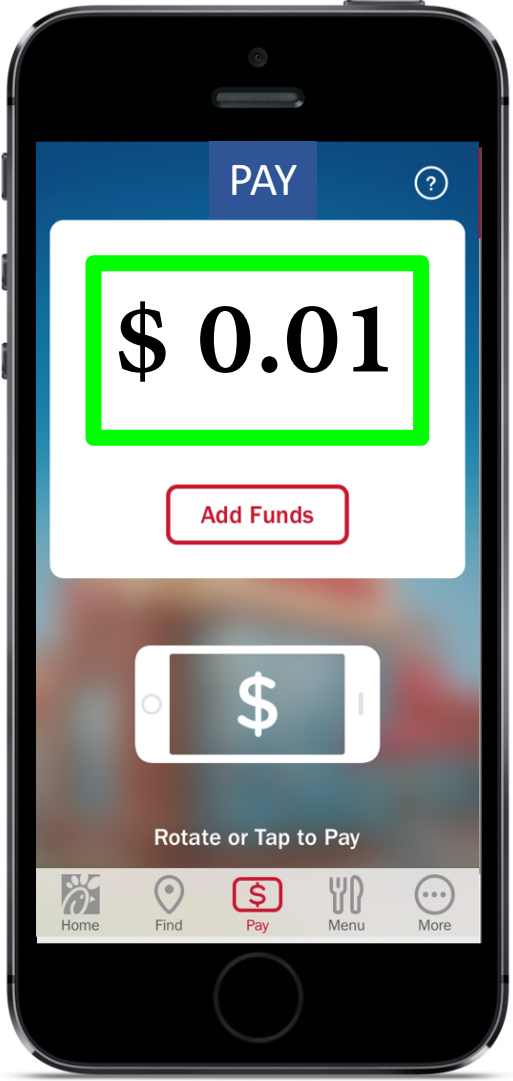


WOULD YOU PAY 1 CENT TO USE THIS FOOD APP HEALTH SAFETY SERVICE ?

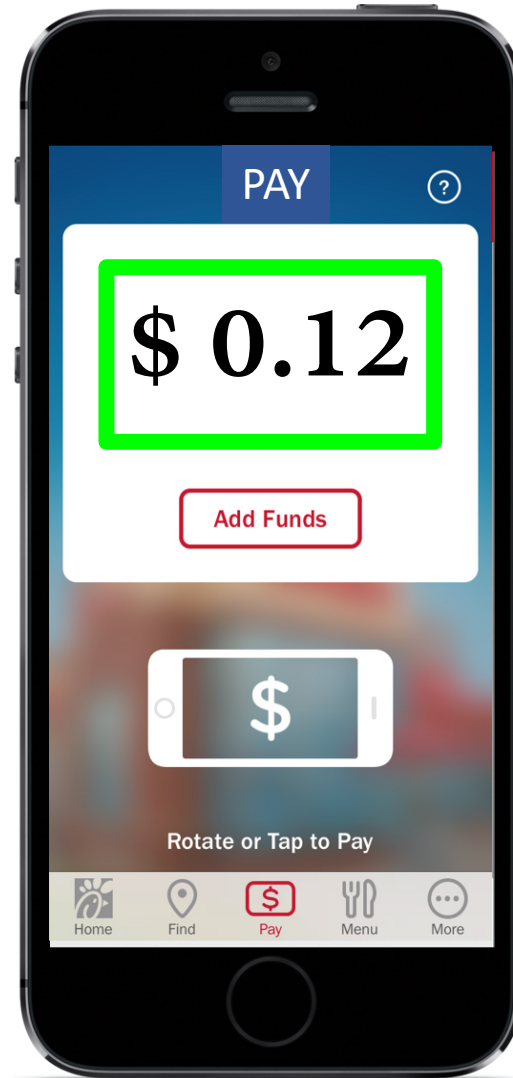


IT IS YOUR HEALTH

PEAS OF YOUR MIND



REMEMBER IoT ? HOW NANO-FEES MAY GENERATE MEGA-MILLIONS



0.12
cents

REMEMBER IoT ? HOW NANO-FEES MAY GENERATE MEGA-MILLIONS

The user will also need access to the cattle tracking and monitoring web application. For example, the cost of an annual subscription to the Cattle Tags Technologies app will be \$5 per animal.



**0.12
cents**

Software subscription cost \$0.0137 per cow per day



LoRaWAN ear tag from Cattle Tags Technologies starts from \$39. Tags have embedded GPS receiver, accelerometer, temperature sensor and replaceable battery. Operator reads RFID-tag with Bluetooth reader (ID sent to ERP system). Installation of activated LoRaWAN ear tag follows. alex.trubitcin@gmail.com

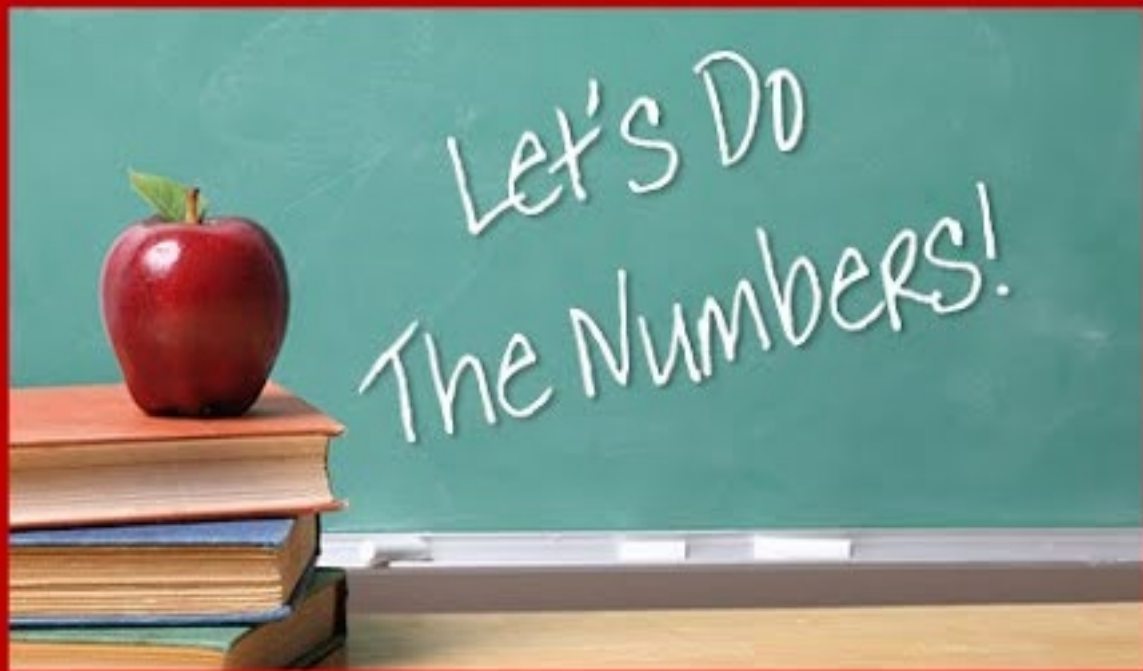
Digital Transformation (Connectivity+App+Tag) Cost \$0.12 per cow per day

Proposal generates following remark from a VC
(Mr Vinod Vaticinator, Venture Capitalist)

A joke? 1 cent ?

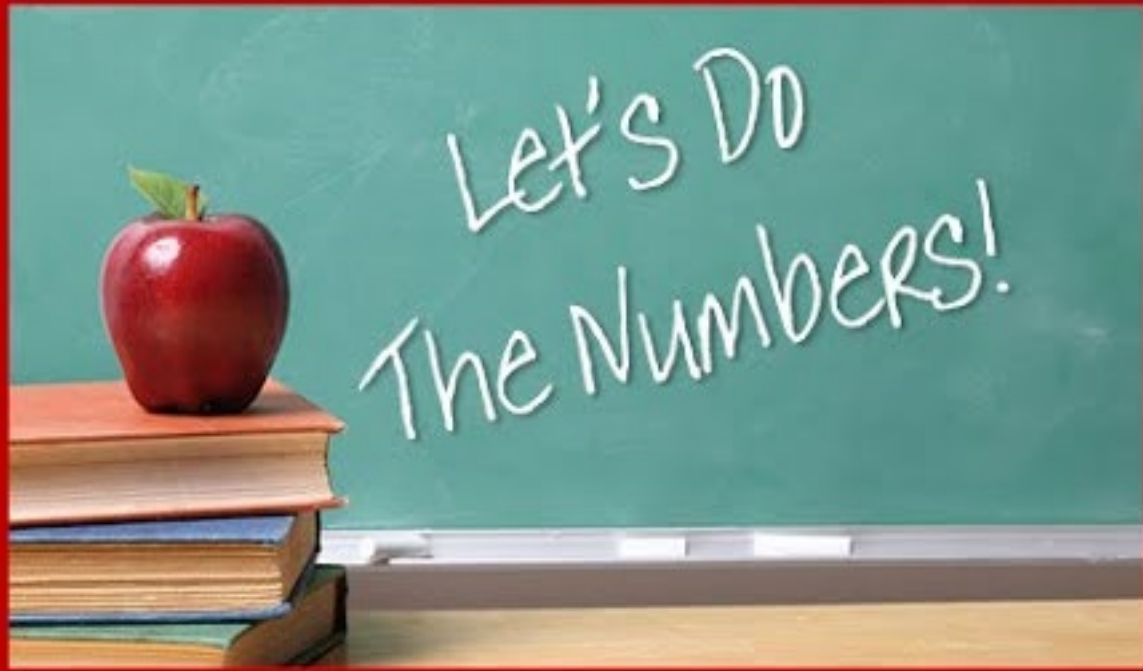
Bad business !!

You are fired !

A man with short, graying hair, wearing a dark suit, light blue shirt, and patterned tie, is speaking into a microphone. He is pointing his right index finger towards the camera. The background is a dark green wall with a faint, larger image of the same man.

KAI RYSSDAL
MARKETPLACE | NOV. 9, 2018

<https://www.marketplace.org/shows/marketplace/07092018/>



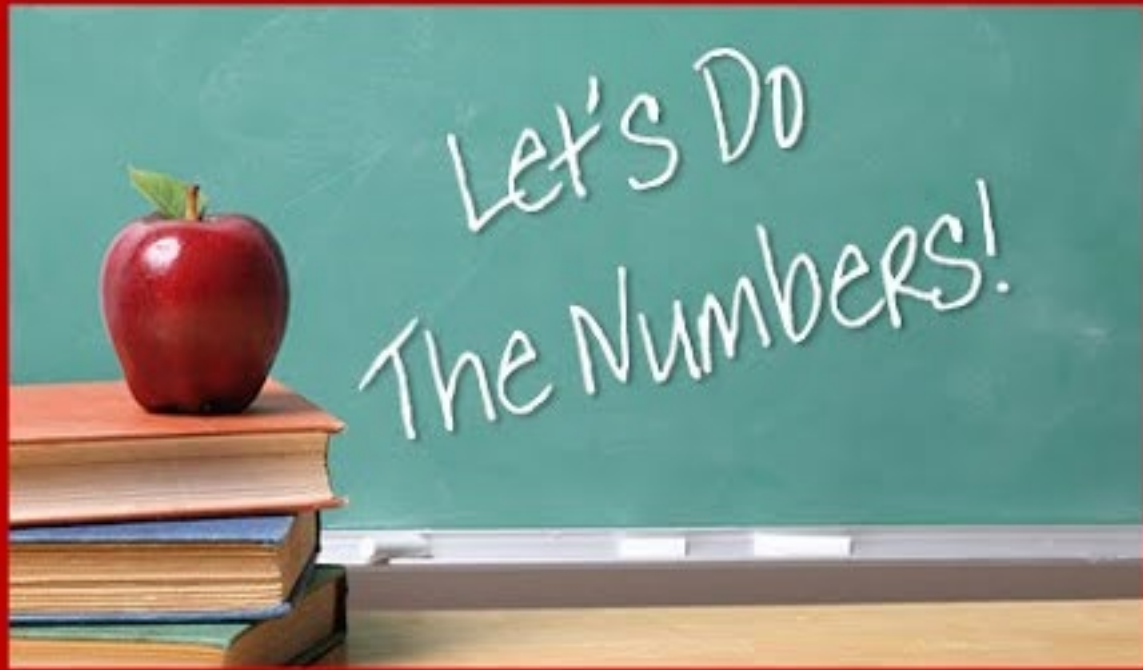
Number of Supermarkets - 2018

*2 million or more in annual sales

Source: [Progressive Grocer Magazine](#)

38,307

Transaction count is the metric you seek. Also known as customer count. It is the number of transactions per period. The most accessible of these is transactions per day. Even a smaller successful grocery store will approach 2000 transactions per a day. You can assume the actual foot traffic is higher as people shop together, but this number is not usually kept track of.



28 BILLION

ANNUAL GROCERY TRANSACTIONS IN US

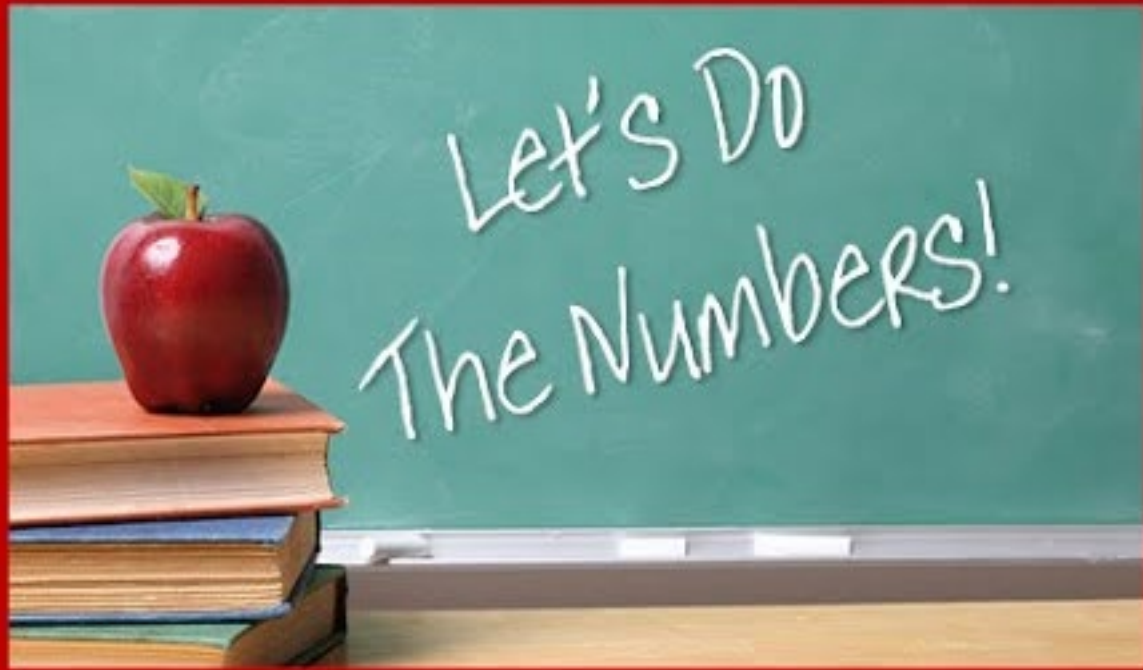
Number of Supermarkets - 2018

*2 million or more in annual sales

Source: [Progressive Grocer Magazine](#)

38,307

Transaction count is the metric you seek. Also known as customer count. It is the number of transactions per period. The most accessible of these is transactions per day. Even a smaller successful grocery store will approach 2000 transactions per a day. You can assume the actual foot traffic is higher as people shop together, but this number is not usually kept track of.



0.28 BILLION

ONLY 1% TRANSACTIONS BOUGHT CHKN
AND CUSTOMER WILLING TO PAY 1 CENT

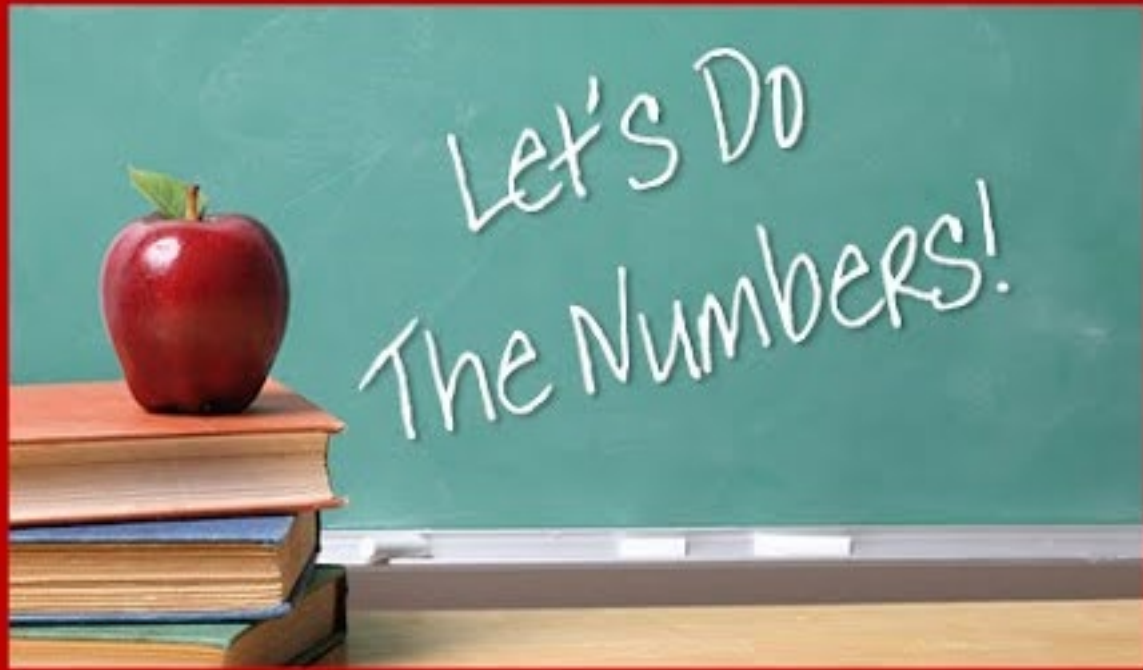
Number of Supermarkets - 2018

*2 million or more in annual sales

Source: [Progressive Grocer Magazine](#)

38,307

Transaction count is the metric you seek. Also known as customer count. It is the number of transactions per period. The most accessible of these is transactions per day. Even a smaller successful grocery store will approach 2000 transactions per a day. You can assume the actual foot traffic is higher as people shop together, but this number is not usually kept track of.



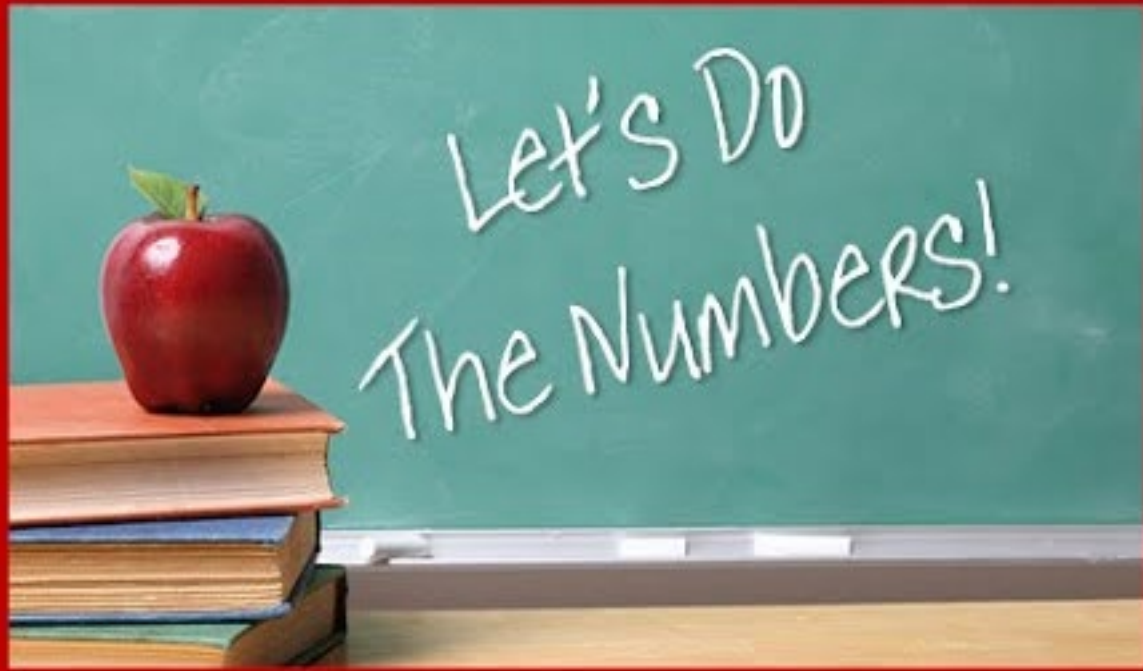
0.28 BILLION

ONLY 1% TRANSACTIONS BOUGHT CHKN
AND CUSTOMER WILLING TO PAY 1 CENT

FROM 1 USE - PAY A PENNY PER USE (PAPPU) - FOR ONLY 1 ITEM

\$2.8 million

ANNUAL REVENUE ONLY IN USA



Average number items carried in
a supermarket in 2017

Source: Food Marketing Institute

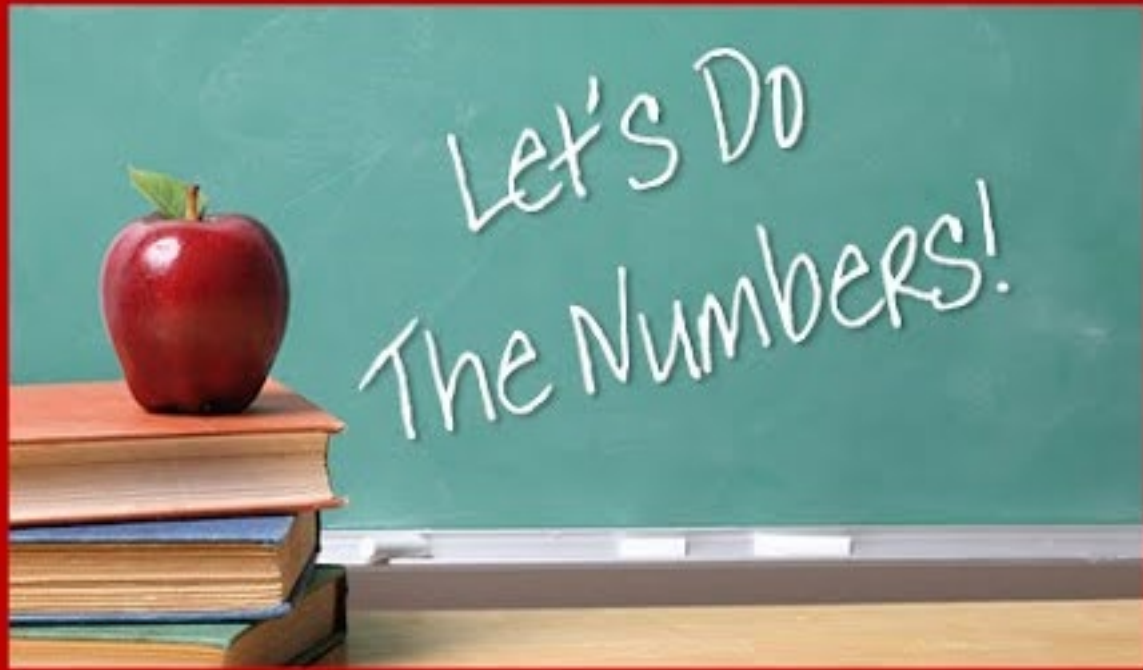
30,098

1% OF ITEMS USE FOOD SAFETY SENSOR
CUSTOMERS PAY 10 CENT/TRANSACTION

FOOD SAFETY - PAY A PENNY PER USE (PAPPU) - 10% TRANSACTIONS

\$280 million

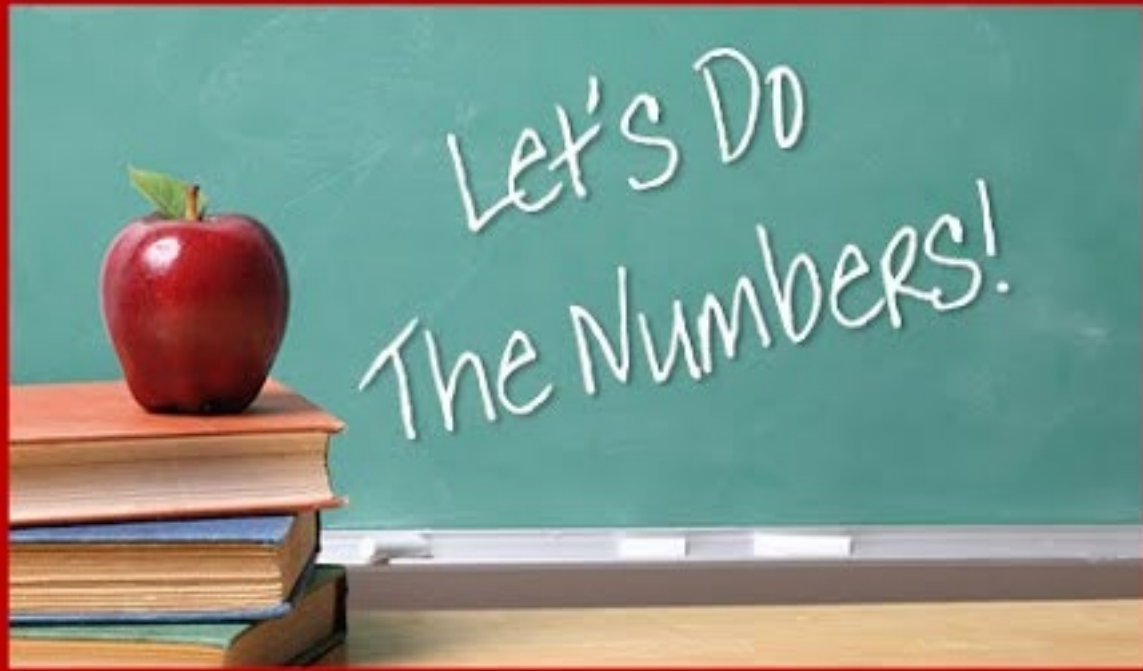
10% of 28 billion transactions pays \$0.10 per transaction = \$280 million revenue p.a.



FOOD SAFETY – PAY A PENNY PER USE (PAPPU) – GLOBAL POTENTIAL

Billion Dollar Industry?

ANNUAL GROSS REVENUE

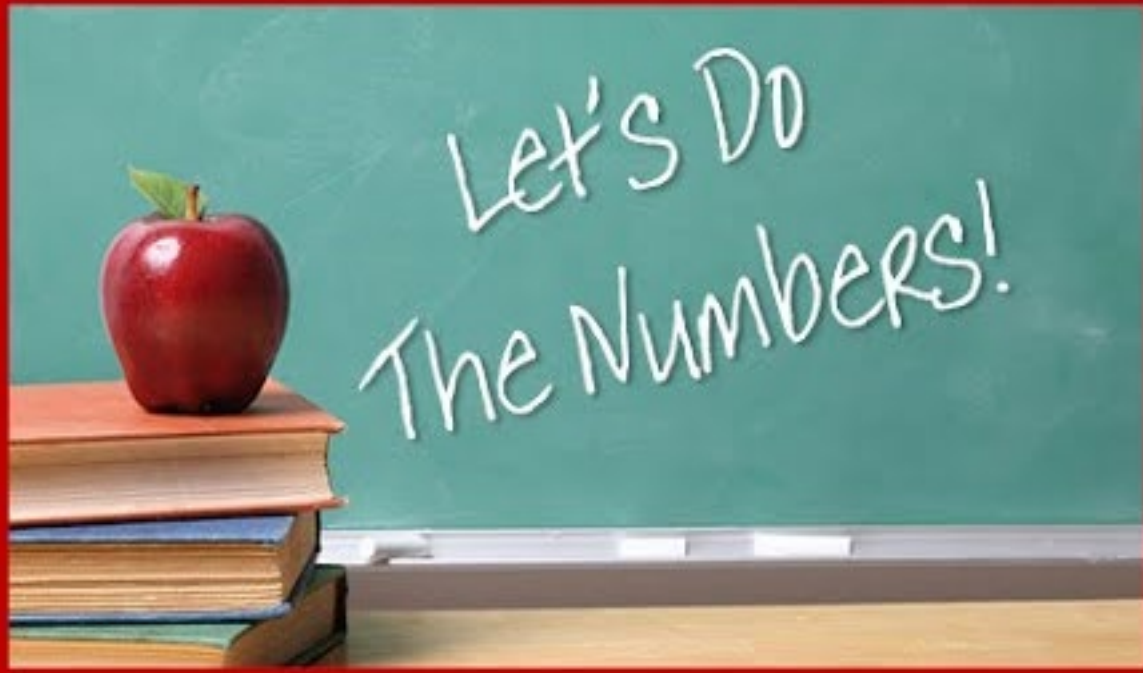


JUST
1 cent
PAPPU

FOOD SAFETY – PAY A PENNY PER USE (PAPPU) – GLOBAL POTENTIAL

Billion Dollar Industry

<http://bit.ly/Economics-of-Technology>
<https://www.law.uchicago.edu/files/file/coase-nature.pdf>
<http://web.pdx.edu/~nwallace/EHP/TCEProgression.pdf>
<https://pdfs.semanticscholar.org/e4e8/a0486808360d056dbe212f7424273558538c.pdf>
http://www.economics-ejournal.org/economics/discussionpapers/2007-3/at_download/file



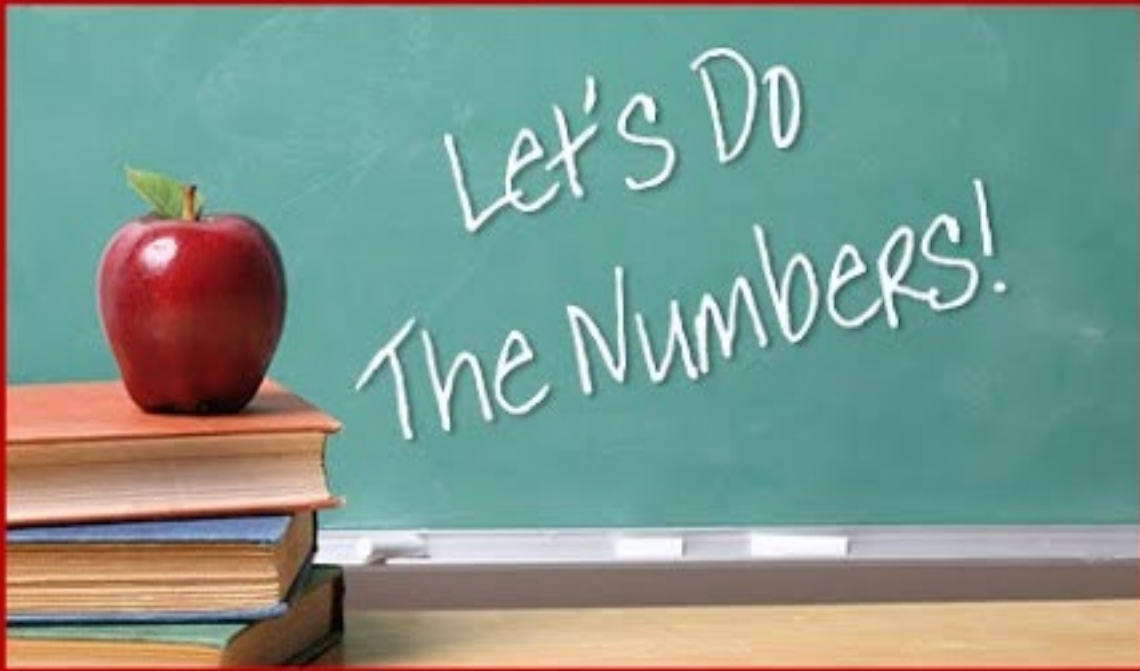
REALITY CHECK

Economies of scale may take several years to reach market penetration to generate mega revenues from nano payments, for example, the PAPPU model.

FOOD SAFETY – PAY A PENNY PER USE (PAPPU) – GLOBAL POTENTIAL

Billion Dollar Industry

THINK FOOD SAFETY AS PAY PER USE PERSONALIZED SERVICE



PAY A PENNY PER USE GLOBAL SERVICES

HPE CEO Pledges to Sell 'Everything as a Service' by 2022

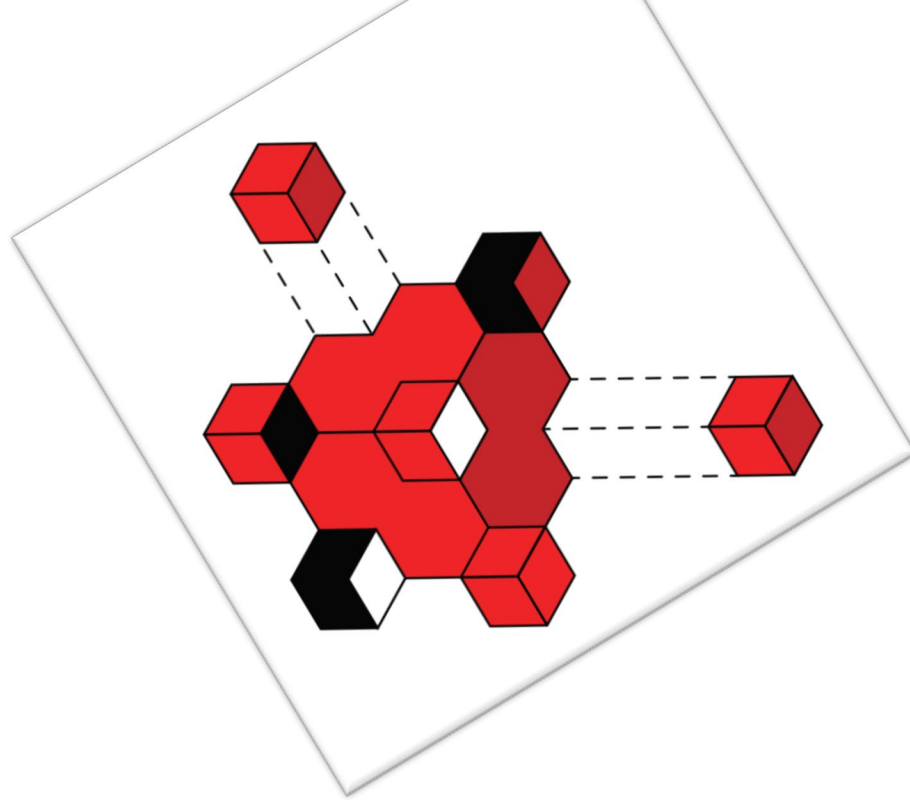
In its boldest move yet to make on-prem IT more like public cloud, the company says GreenLake is its future.

Yevgeniy Sverdlik | Jun 19, 2019

Three years from now, every product Hewlett Packard Enterprise sells will be available as a service. That's the pledge CEO Antonio Neri made from stage Tuesday afternoon during his keynote at the company's Discover conference in Las Vegas. The pledge covers both hardware and software in the enterprise tech giant's sprawling portfolio.

THINK FOOD SAFETY AS PAY PER USE PERSONALIZED SERVICE

<https://www.datacenterknowledge.com/hewlett-packard-enterprise/hpe-ceo-pledges-sell-everything-service-2022>

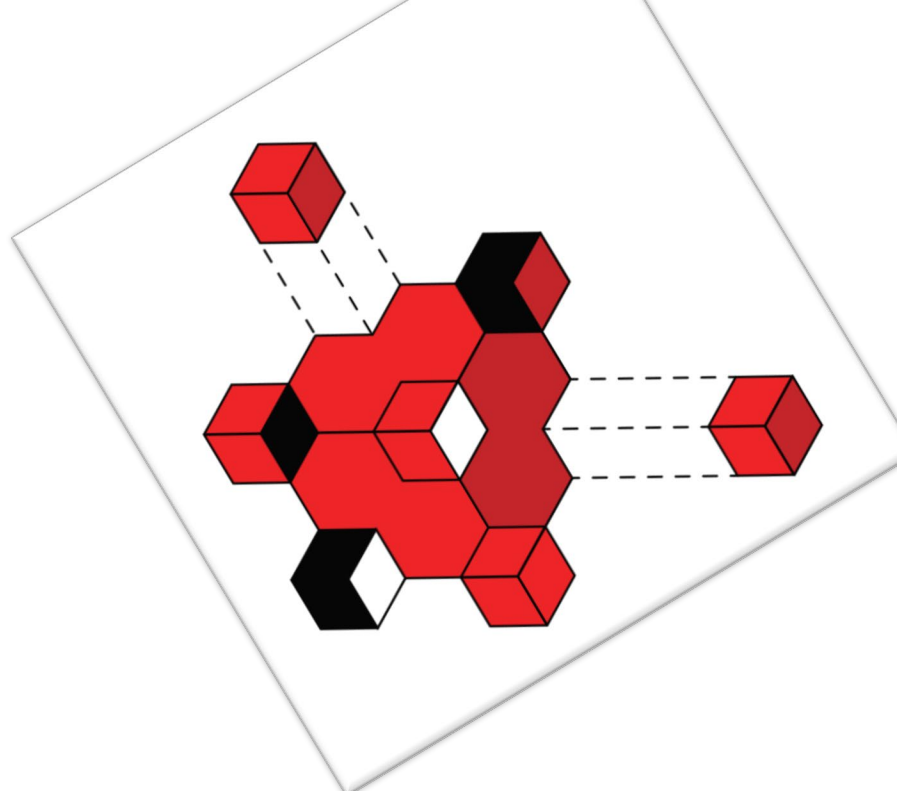


WORLD
ECONOMIC
FORUM

COMMITTED TO
IMPROVING THE STATE
OF THE WORLD

Insight Report

Top 10 Emerging Technologies 2019



WORLD
ECONOMIC
FORUM

COMMITTED TO
IMPROVING THE STATE
OF THE WORLD

Insight Report

Top 10 Emerging Technologies 2019

http://www3.weforum.org/docs/WEF_Top_10_Emerging_Technologies_2019_Report.pdf



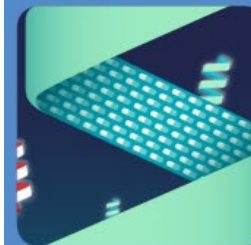
1. Bioplastics for a Circular Economy



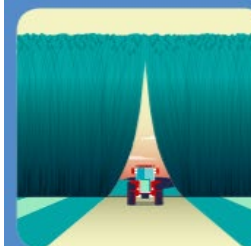
2. Social Robots



3. Tiny Lenses for Miniature Devices



4. Disordered Proteins as Drug Targets



5. Smarter Fertilizers Can Reduce Environmental Contamination



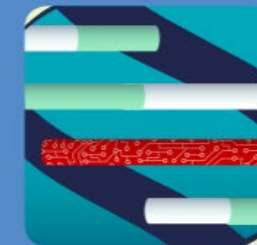
6. Collaborative Telepresence



7. Advanced Food Tracking and Packaging



8. Safer Nuclear Reactors

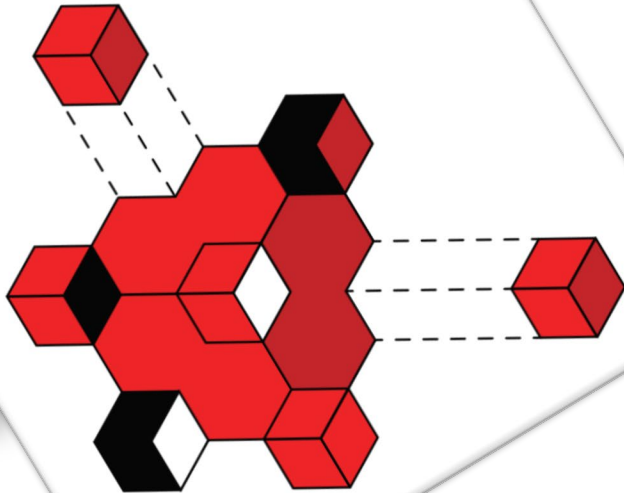


9. DNA Data Storage



10. Utility-Scale Storage of Renewable Energy

THINK FOOD SAFETY
AS A PAY PER USE
PERSONALIZED SERVICE



WORLD
ECONOMIC
FORUM

COMMITTED TO
IMPROVING THE STATE
OF THE WORLD

Insight Report

Top 10 Emerging Technologies 2019

http://www3.weforum.org/docs/WEF_Top_10_Emerging_Technologies_2019_Report.pdf



1. Bioplastics for a Circular Economy



6. Collaborative Telepresence



2. Social Robots



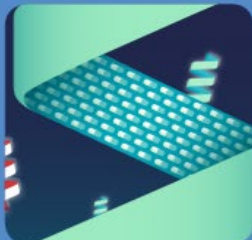
7. Advanced Food Tracking and Packaging



3. Tiny Lenses for Miniature Devices



8. Safer Nuclear Reactors



4. Disordered Proteins as Drug Targets



9. DNA Data Storage



5. Smarter Fertilizers Can Reduce Environmental Contamination



10. Utility-Scale Storage of Renewable Energy

HPE CEO Pledges to Sell 'Everything as a Service' by 2022

In its boldest move yet to make on-prem IT more like public cloud, the company says GreenLake is its future.

Yevgeniy Sverdlik | Jun 19, 2019

Three years from now, every product Hewlett Packard Enterprise sells will be available as a service. That's the pledge CEO Antonio Neri made from stage Tuesday afternoon during his keynote at the company's Discover conference in Las Vegas. The pledge covers both hardware and software in the enterprise tech giant's sprawling portfolio.



Insight Report

Top 10 Emerging Technologies 2019



1. Bioplastics for a Circular Economy



6. Collaborative Telepresence

THINK FOOD SAFETY AS A PAY PER USE PERSONALIZED SERVICE



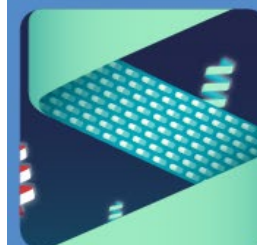
7. Advanced Food Tracking and Packaging



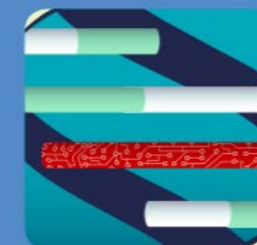
3. Tiny Lenses for Miniature Devices



8. Safer Nuclear Reactors



4. Disordered Proteins as Drug Targets



9. DNA Data Storage



5. Smarter Fertilizers Can Reduce Environmental Contamination

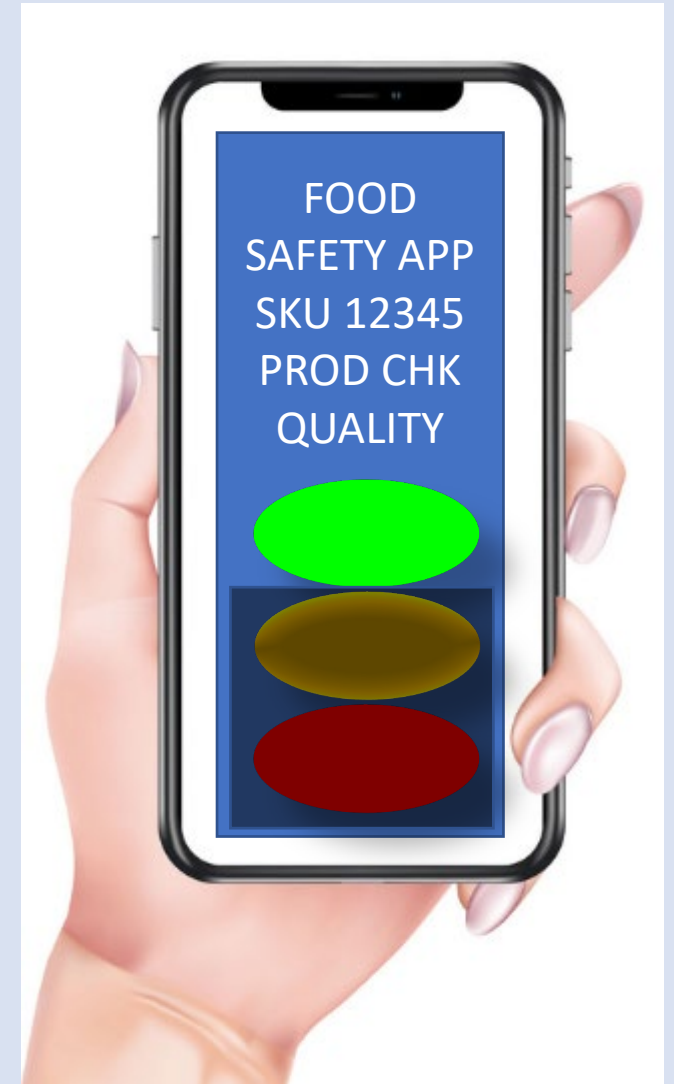


10. Utility-Scale Storage of Renewable Energy

FOOD ART ?

In a Grocery Store Near You

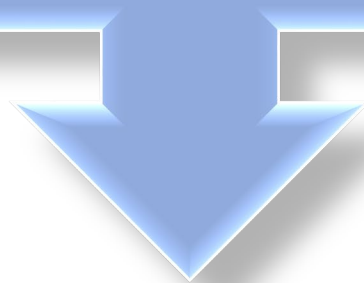
IT IS YOUR HEALTH



PEAS OF YOUR MIND

FRESH SENSE™

CHECK WITH YOUR
FOOD SAFETY APP



FRESH SENSE – A TRADEMARKED SERVICE FROM SHOP-RITE TO GUARANTEE YOUR FRESHNESS IN REAL TIME ON YOUR PHONE

FRESH SENSE™

CHECK WITH YOUR
FOOD SAFETY APP

SENSEE

SMALL PART
BUT USEFUL

FRESH SENSE – A TRADEMARKED SERVICE FROM SHOP-RITE TO GUARANTEE YOUR FRESHNESS IN REAL TIME ON YOUR PHONE

FRESH SENSE™



FRESH SENSE – A TRADEMARKED SERVICE FROM SHOP-RITE TO GUARANTEE YOUR FRESHNESS IN REAL TIME ON YOUR PHONE

FRESH SENSE™



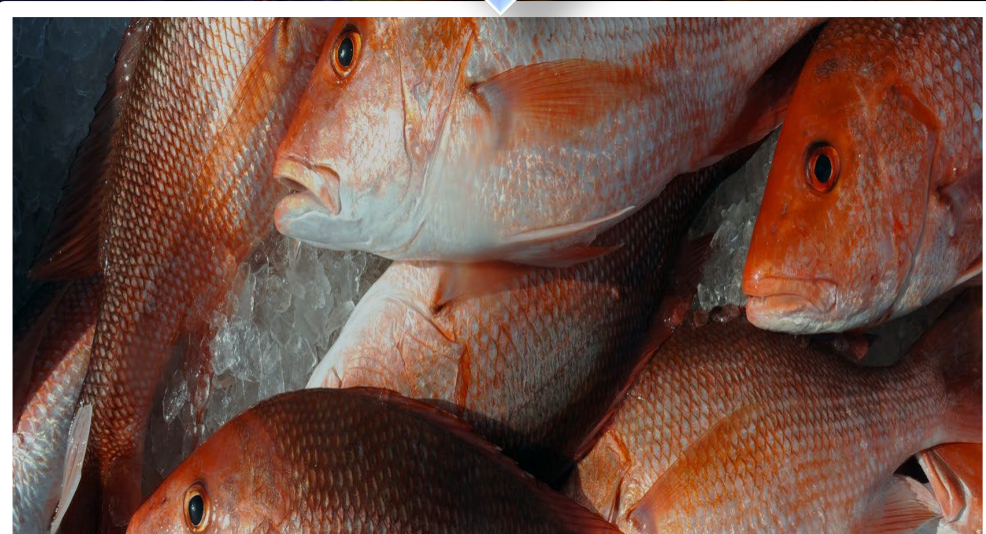
SENSEE
SMALL PART
BUT USEFUL

KIDS

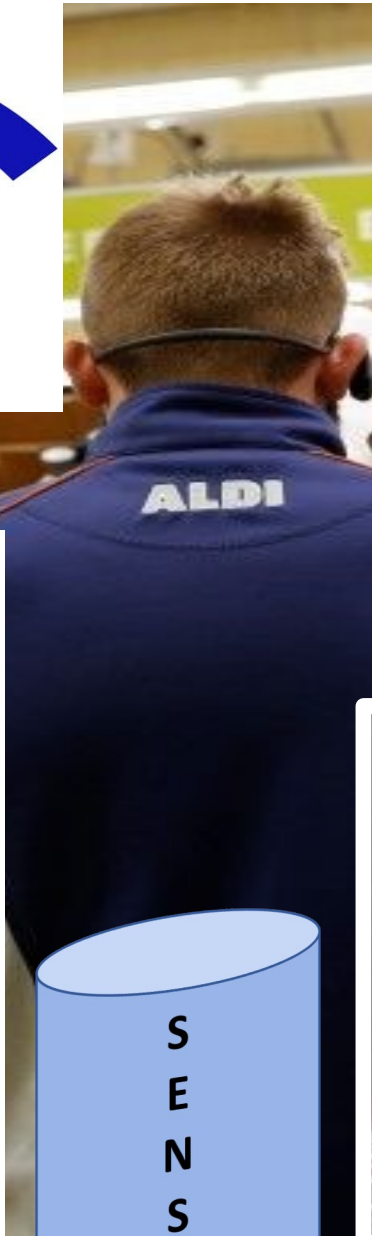
FRESH SENSE – A TRADEMARKED SERVICE FROM SHOP-RITE TO GUARANTEE YOUR FRESHNESS IN REAL TIME ON YOUR PHONE



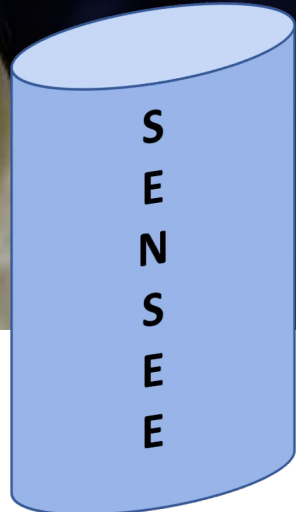
FRESH SENSE™
CHECK WITH YOUR
FOOD SAFETY APP



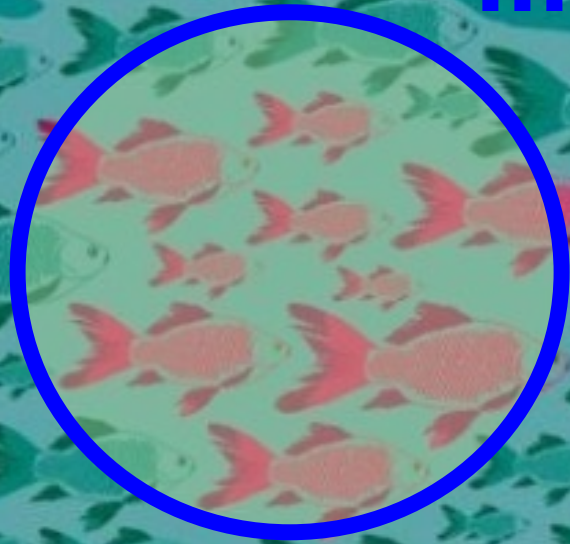
FRESH SENSE – A TRADEMARKED SERVICE FROM SHOP-RITE TO GUARANTEE YOUR FRESHNESS IN REAL TIME ON YOUR PHONE



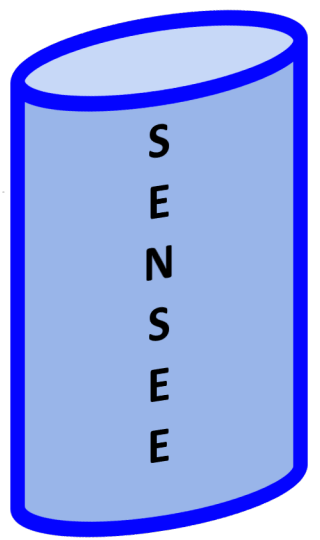
FRESH SENSE™
CHECK WITH YOUR
FOOD SAFETY APP



FOOD ART



THINK FOOD SAFETY
AS A PAY PER USE
PERSONALIZED SERVICE



Summary – A Sense of the Future



SENSEE, SNAPS, ART, DIDA'S, KIDS

Are these ingredients for a Google of Ag and/or fuel for future scientific research ?

PEAS

Platform for the Agro-Ecosystem

A few lofty goals, perhaps best attempted in stages, from data to data-informed, with knowledge-informed as a future performance index (KPI). Granularity of data from sensors feed decisions with information and knowledge. In the short term, offer logic tools (ART) for users, reduce food waste and contribute to food safety.

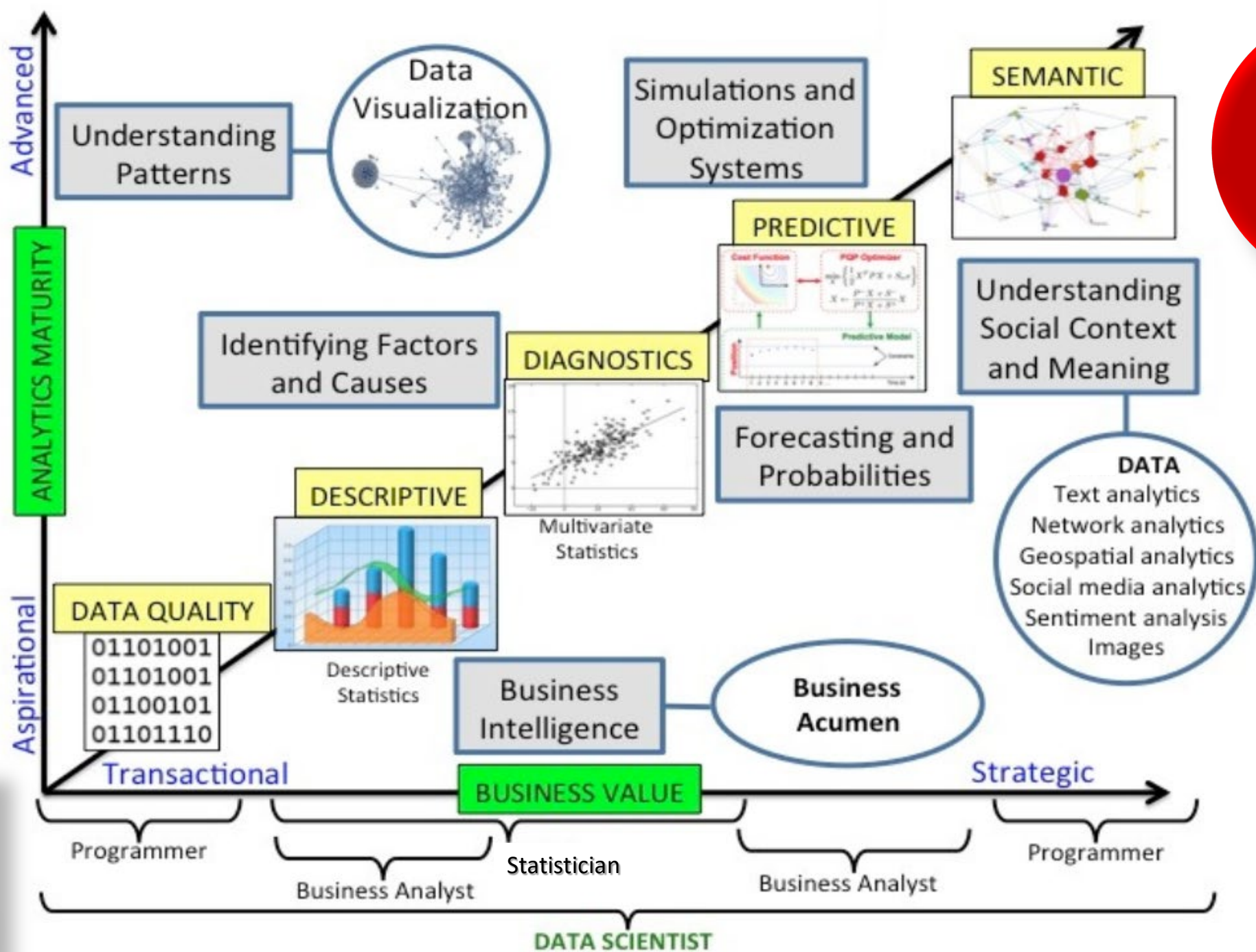
Being KIDS – Is “knowledge-informed” a challenging goal?

Knowledge combination/integration beyond (heterogenous) rules and ontologies are not only difficult, but calls for **new thinking**. The semantics of knowledge bases other than rules (for example, descriptions of temporal processes like workflows which could logically decide when the irrigation system must turn on/off the water pumps, or protocols in spatio-temporal logic) must be integrated. We may need some form of logic framework in which knowledge modules, having different native semantics, can be overlaid with meaningful semantics, preferably agnostic of linguistic bias, ideally as a “plug and play” operation, graph-friendly for non-expert end-users to decompose and/or re-compose the choice of logic and logic tools, based on experience from expert humans in the loop. Chaperoning convergence between distributed domain(s) knowledge, operational rules, data, information, and systems science, is a daunting and challenging goal.

Being KIDS – the path to “knowledge-informed”

KIDS

SENSEE
1.0, 2.0



SENSEE
1.0, 2.0



KIDS

USER

In pursuing the knowledge-informed paradigm using the PEAS platform, users will be confronted with questions that they cannot answer. Unmet needs may fuel research. Hence, KIDS is a catalyst for new ideas, innovation, research in science and engineering.



KIDS

Business
need

In pursuing the knowledge-informed paradigm using the PEAS platform, users will be confronted with questions that they cannot answer. Unmet needs may fuel research. Hence, KIDS is a catalyst for new ideas, innovation, research in science and engineering.

KIDS

Business
need

Idea

In pursuing the knowledge-informed paradigm using the PEAS platform, users will be confronted with questions that they cannot answer. Unmet needs may fuel research. Hence, KIDS is a catalyst for new ideas, innovation, research in science and engineering.



KIDS

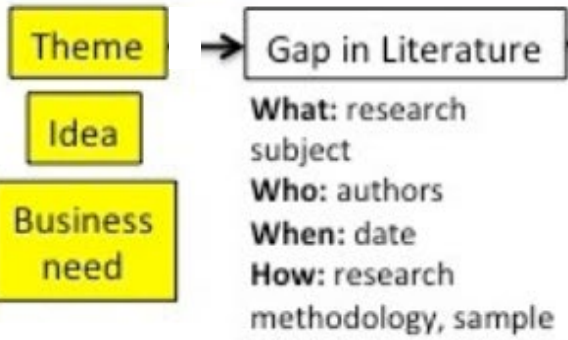
Theme

Idea

Business
need

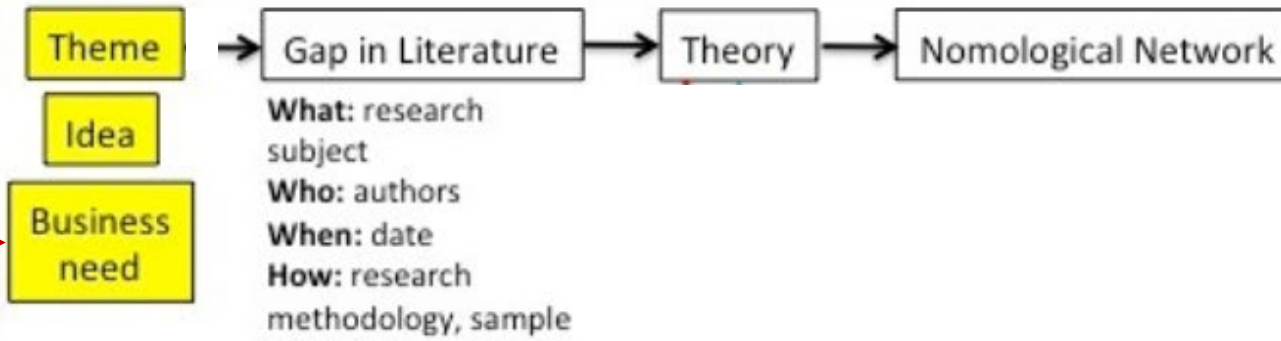
In pursuing the knowledge-informed paradigm using the PEAS platform, users will be confronted with questions that they cannot answer. Unmet needs may fuel research. Hence, KIDS is a catalyst for new ideas, innovation, research in science and engineering.

KIDS



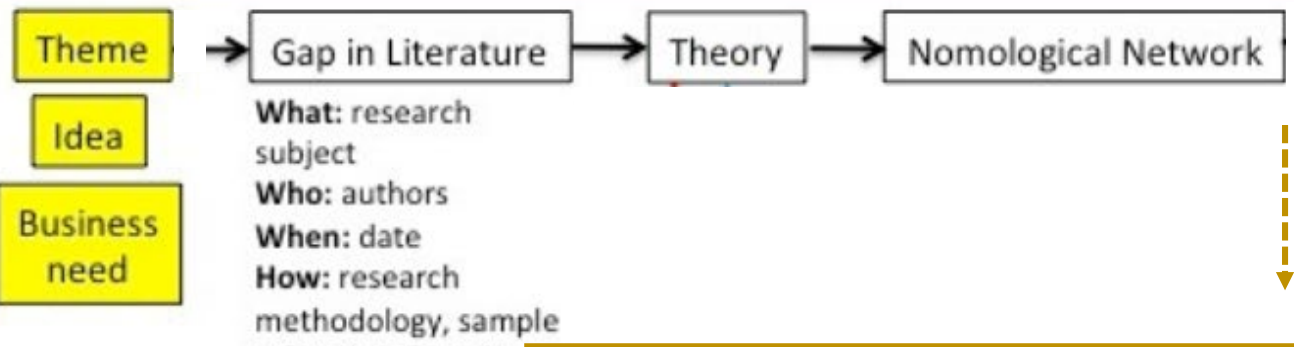
In pursuing the knowledge-informed paradigm using the PEAS platform, users will be confronted with questions that they cannot answer. Unmet needs may fuel research. Hence, KIDS is a catalyst for new ideas, innovation, research in science and engineering.

KIDS

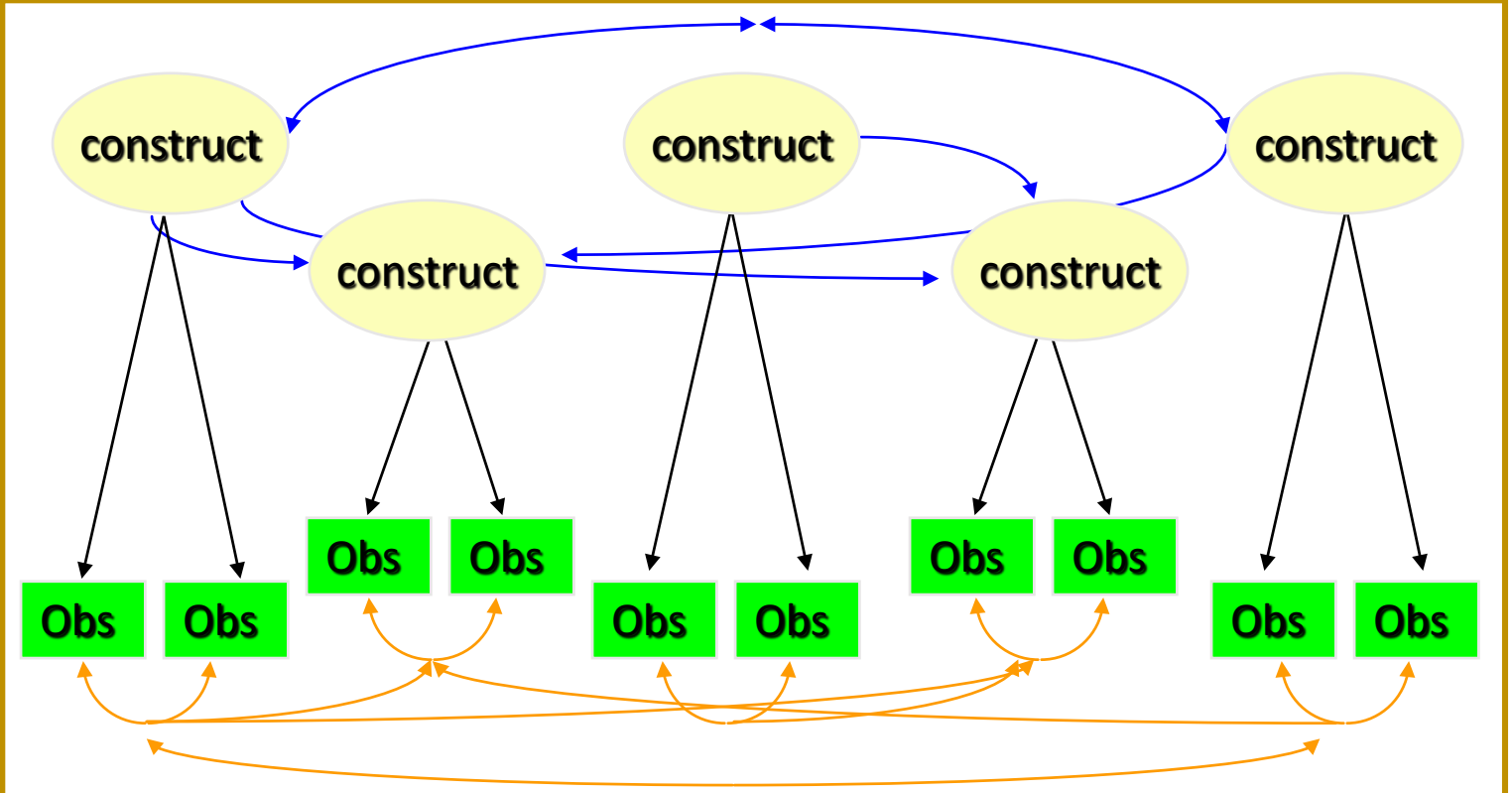


In pursuing the knowledge-informed paradigm using the PEAS platform, users will be confronted with questions that they cannot answer. Unmet needs may fuel research. Hence, KIDS is a catalyst for new ideas, innovation, research in science and engineering.

KIDS

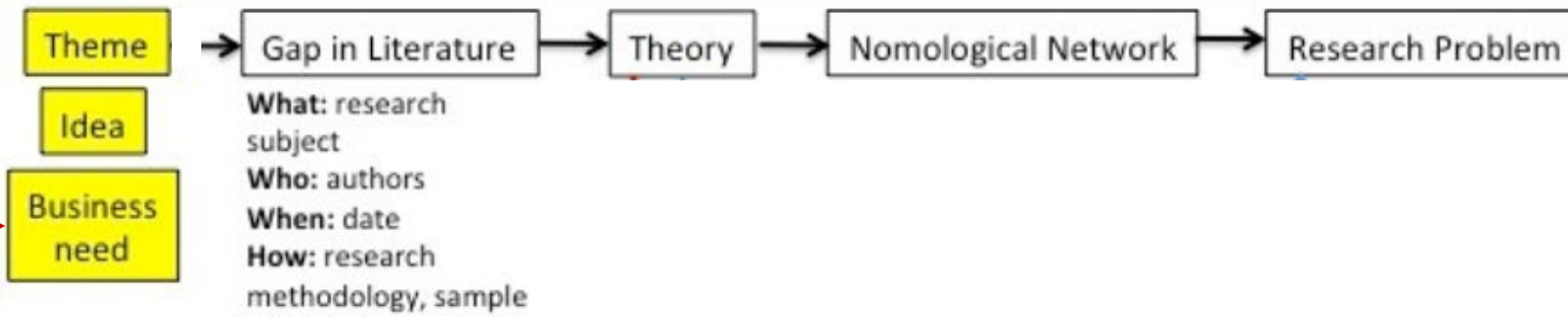


In pursuing the knowledge-informed paradigm using the PEAS platform, users will be confronted with questions that they cannot answer. Unmet needs may fuel research. Hence, KIDS is a catalyst for new ideas, innovation, research in science and engineering.

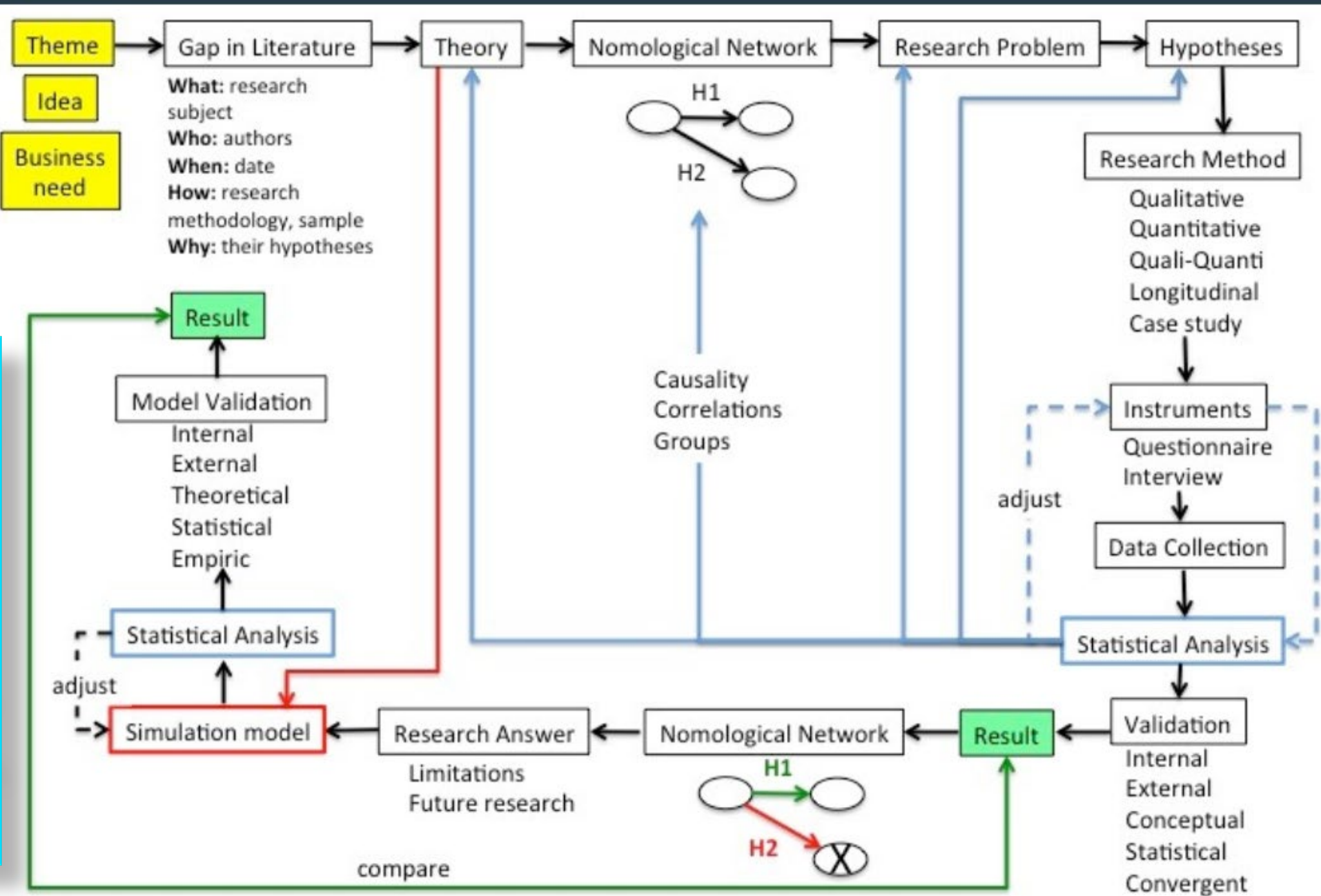
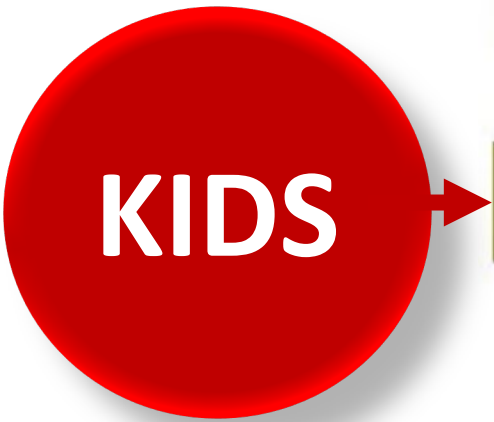


An idea circa 1955, the nomological net represents concepts (constructs) of interest, their observable manifestations and interrelationships. It appears to share common grounds with system dynamics and **knowledge graphs**.

KIDS



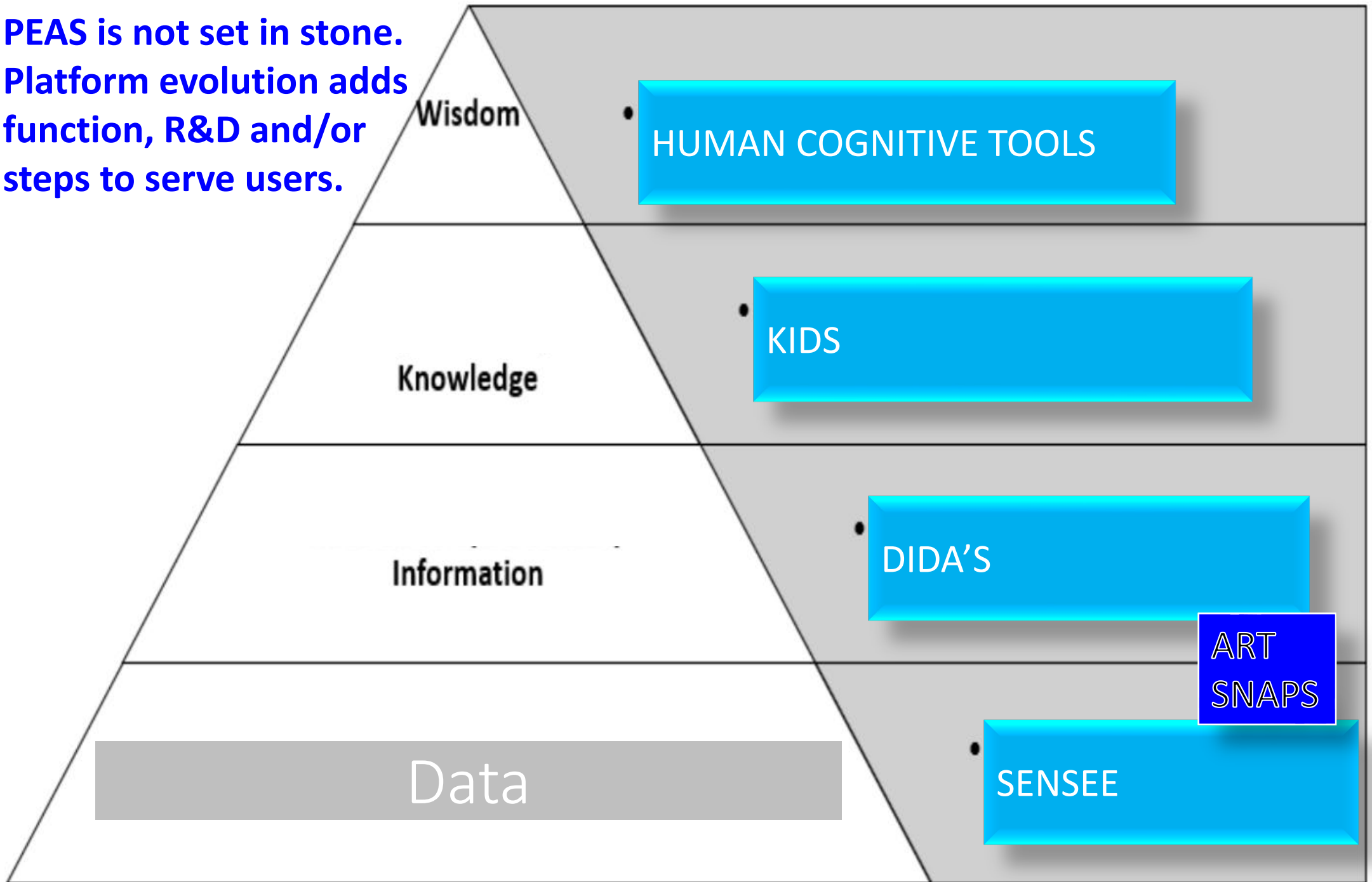
In pursuing the knowledge-informed paradigm using the PEAS platform, users will be confronted with questions that they cannot answer. Unmet needs may fuel research. Hence, KIDS is a catalyst for new ideas, innovation, research in science and engineering.

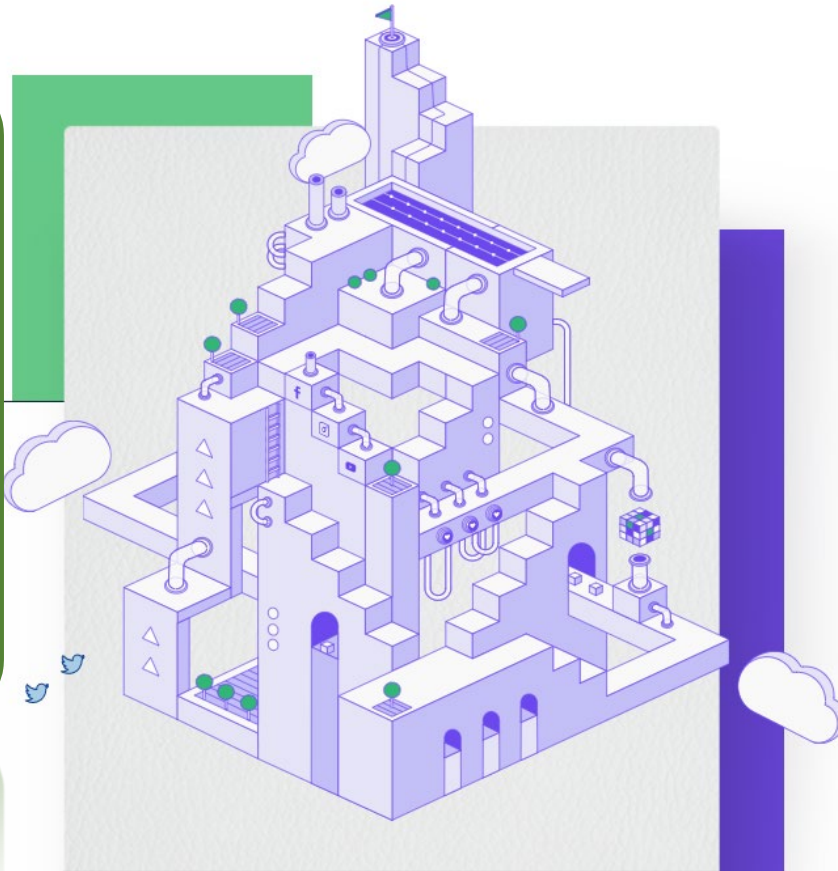
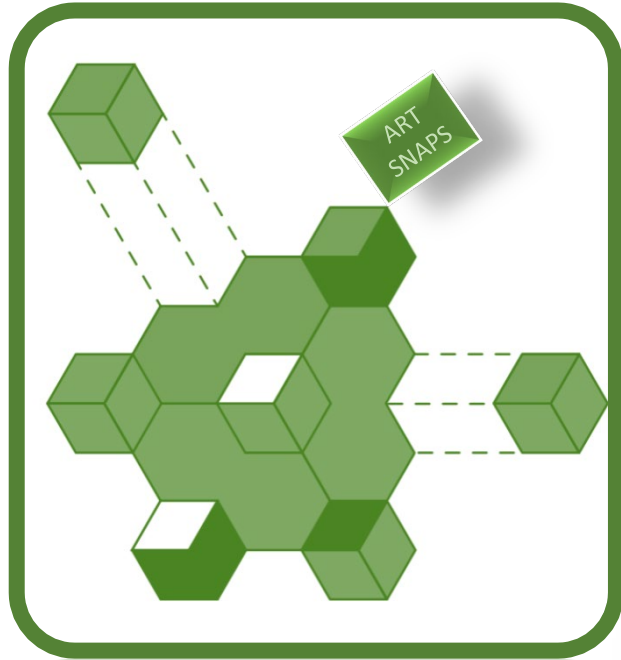


In pursuing the knowledge-informed paradigm using the PEAS platform, users will be confronted with questions that they cannot answer. Unmet needs may fuel research. Hence, KIDS is a catalyst for new ideas, innovation, research in science and engineering.

PEAS PLATFORM

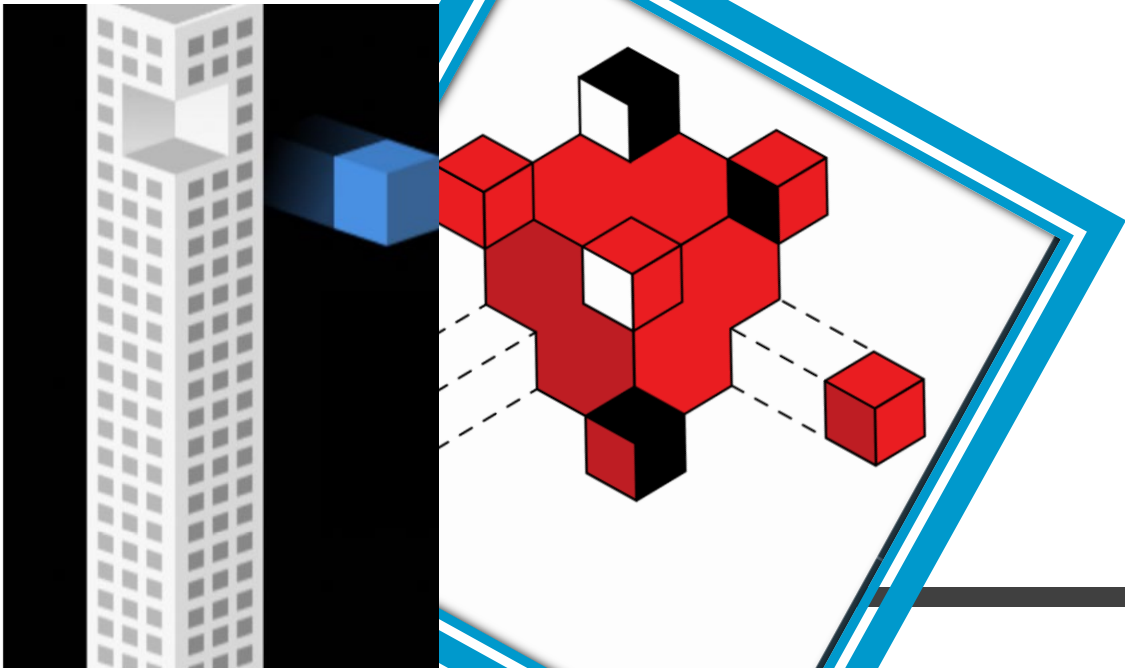
PEAS is not set in stone.
Platform evolution adds
function, R&D and/or
steps to serve users.





KNOWLEDGE SYSTEMS SOLUTIONS
ARE OFTEN MULTI-LAYERED IDEAS





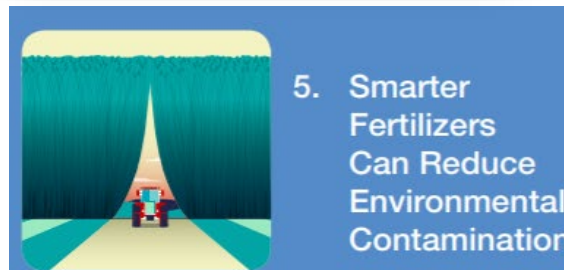
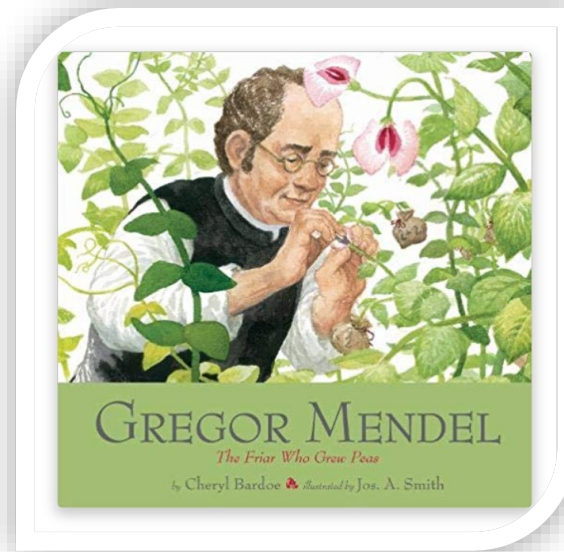
WORLD
ECONOMIC
FORUM

COMMITTED TO
IMPROVING THE STATE
OF THE WORLD

Insight Report

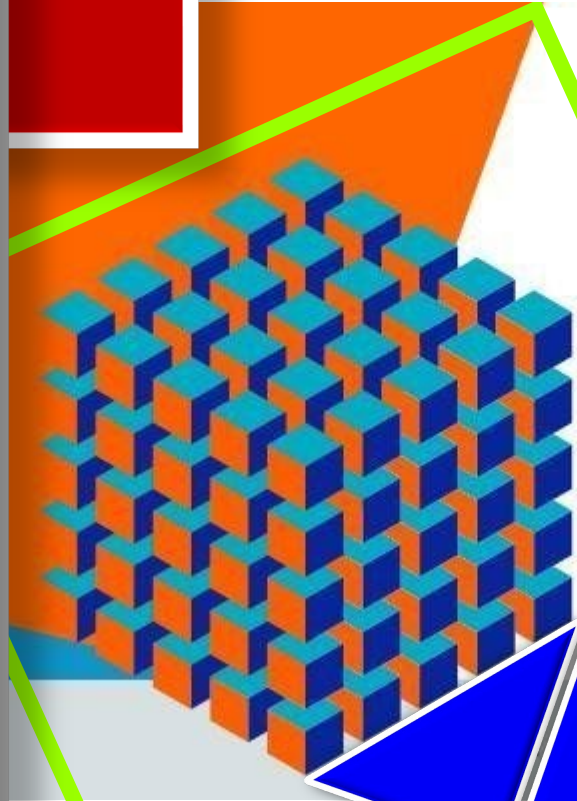
Top 10 Emerging Technologies 2019

http://www3.weforum.org/docs/WEF_Top_10_Emerging_Technologies_2019_Report.pdf



SUMMARY

- 1) Data \neq Information \neq Knowledge
- 2) Develop portfolio of ART (pareto solutions - logic tools - for the next billion users)
- 3) Context determines the perishability phase of data > information > decision > knowledge
- 4) Relationships must be relative to context before connecting relevant contextual data (R2C2)



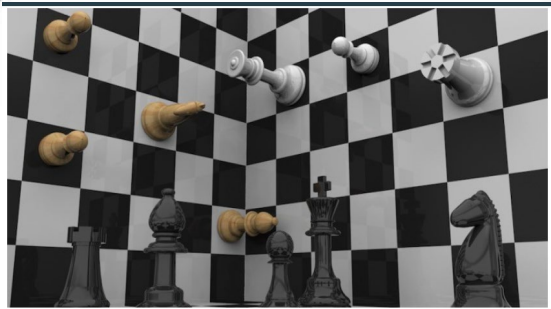
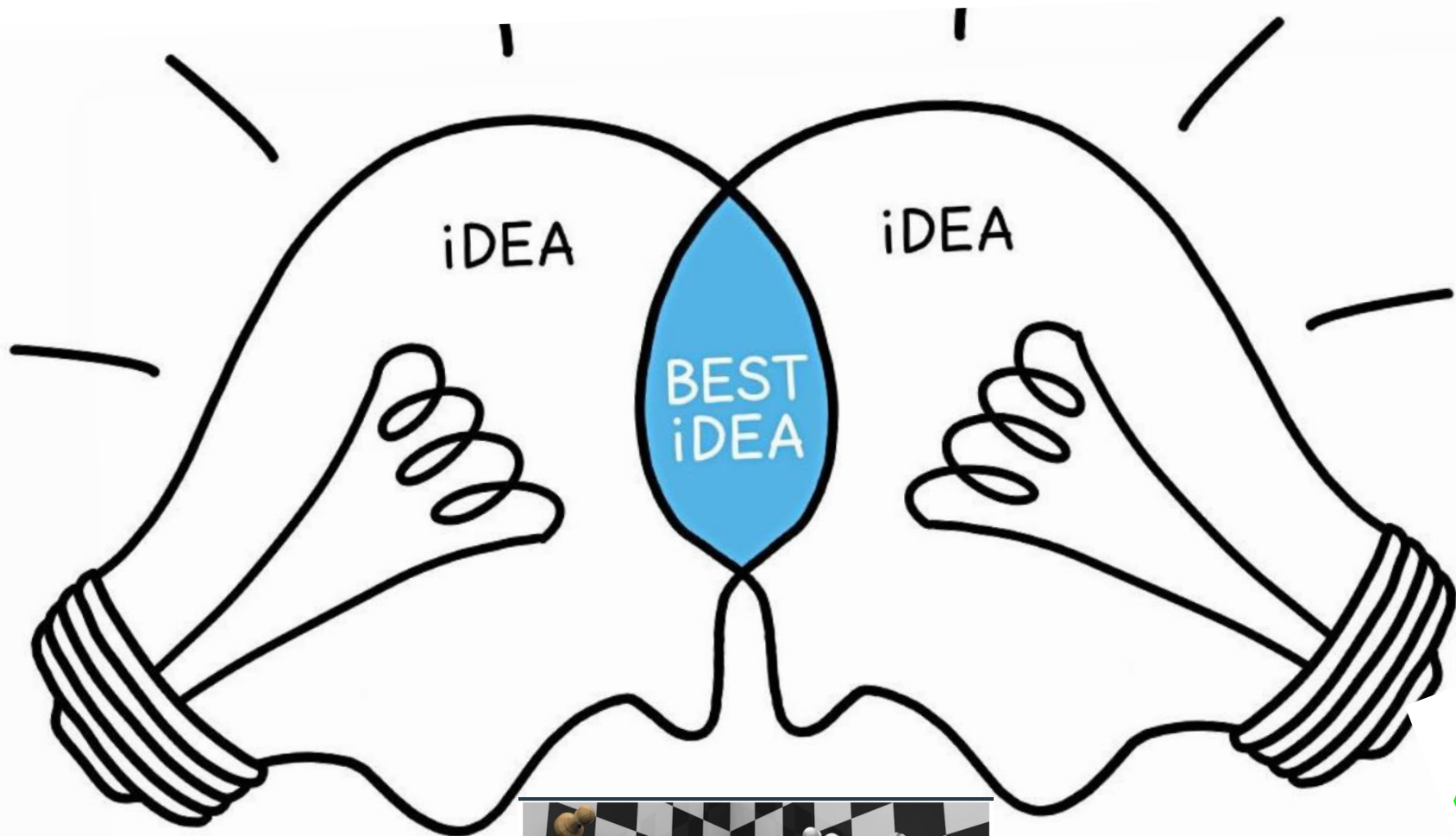
Professor Eric S McLamore
ABE, University of Florida
USDA Center of Excellence



Dr Shoumen Palit Austin Datta
<http://bit.ly/SIGNALS-SIGNALS>

“If your actions inspire others to dream more, learn more, do more and become more, then you are an enabler.” JQA

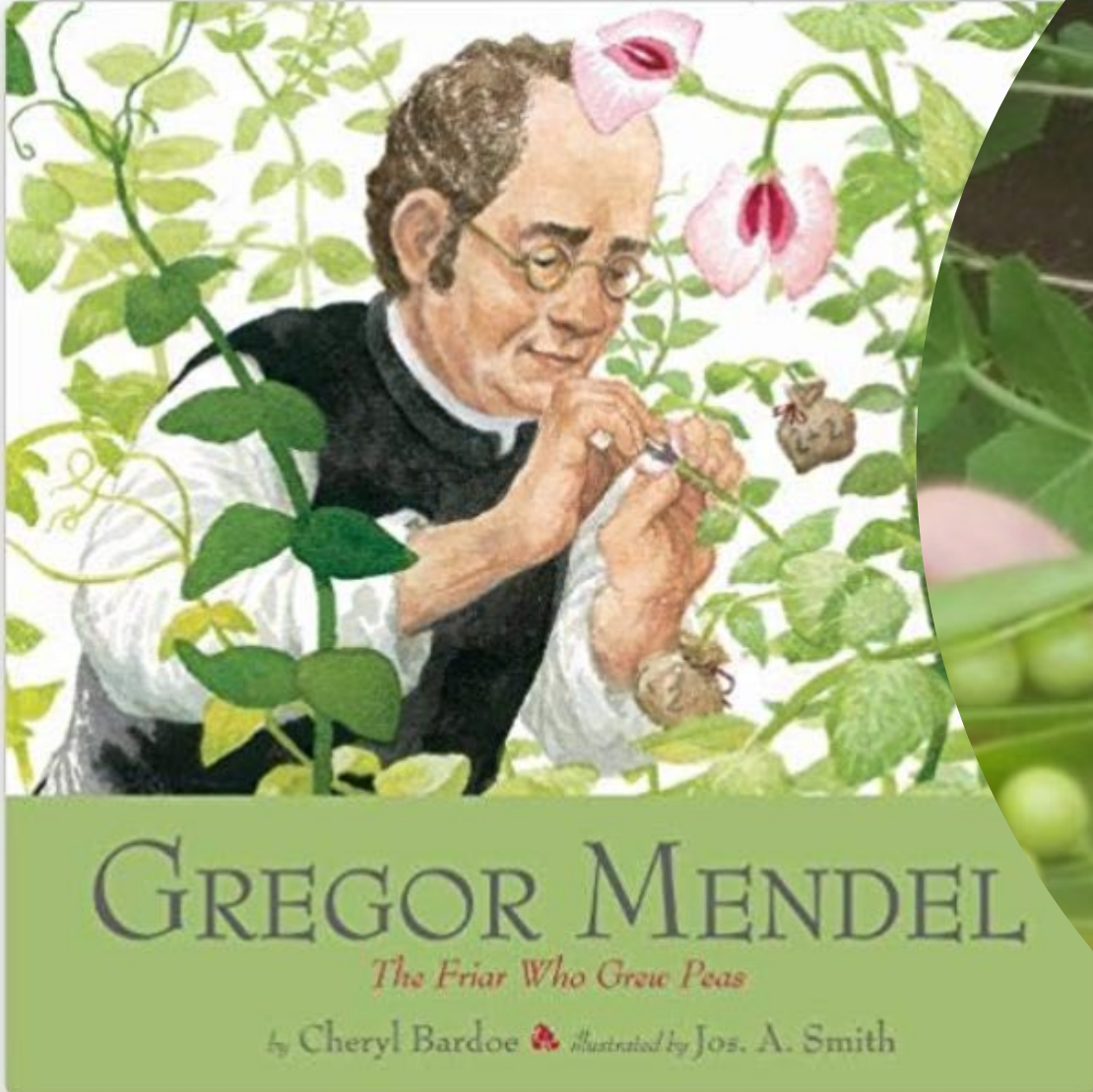
Suggested topics for in-depth exploration:
[0] <https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-441-information-theory-spring-2010/>
[1] <https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-002-introduction-to-computational-thinking-and-data-science-fall-2016/lecture-videos/index.htm>
[2] <https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-034-artificial-intelligence-spring-2005/>
[3] <https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-034-artificial-intelligence-fall-2010/lecture-videos/>
[4] <https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-825-techniques-in-artificial-intelligence-sma-5504-fall-2002/>
[5] <https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-868j-the-society-of-mind-fall-2011/video-lectures/>



Professor Eric S McLamore
ABE, University of Florida
USDA Center of Excellence

Dr Shoumen Palit Austin Datta
<http://bit.ly/SIGNALS-SIGNALS>

PEAS





All Time Usage



Downloads

Page Views

Top countries by item views

Country		👁
Canada	3,050	
France	1,765	
United States	1,401	
Germany	709	
China	97	

Top countries by downloads

Country		⬇
Canada	2,156	
France	1,019	
United States	847	
Germany	480	
China	209	

CAUSATION AND CORRELATION

Logic and reasoning are quintessential ingredients to make sense of data in any attempt to evolve from data-informed tools to knowledge-informed systems.

Causation and correlation are at the core of logic and reasoning processes.

Fundamental Principles

Causation & Correlation: Ground Zero for Data-Informed & Knowledge-Informed Systems

Shoumen Palit Austin Datta, Massachusetts Institute of Technology and Massachusetts General Hospital, Harvard Medical School, Cambridge, Massachusetts 02139

If simulated¹, system dynamics² and³ agent based⁴ models⁵ may allow us to explore⁶ a range of impact⁷ of different variables⁸ on specific⁹ outcomes¹⁰. By altering parameters and metrics which can shape the outcome from these simulations¹¹, we may identify to what degree the variables may influence the outcome, independently and/or collectively. The co-dependencies¹² and inter-relationships¹³ between variables are central, and may become obvious, if models attempt to isolate and test the impact of variables, which cannot be isolated, in reality, due to functional inter-relationships (for example, what if sales and supply¹⁴ were separated). The latter is also applicable to human behavior¹⁵ related scenarios. To transform the output of these tools¹⁶ to deliver meaning, resilience¹⁷ and relevance¹⁸ in the real world, the simulated data (use of agents¹⁹) from pareto-optimal outcomes, may be targets which any tool or development must aspire to attain. For example, to reduce morbidity from diarrhoea by 10% we must increase availability of water by 20% and supply of cooking gas by 5%. On one hand, these numbers (outcome) may guide municipalities or NGOs to catalyze this change through capacity building and/or assess the risk²⁰ of economic²¹ loss if the situation is unattended. On the other hand, data-informed²² outcomes driving decision support²³ tools may guide policy²⁴ and loan managers, in global financial²⁵ institutions, to enable²⁶ financial structures necessary to deliver global²⁷ public goods. Convergence of concepts in physical and digital connectivity²⁸, classical operations research²⁹ with educational use³⁰ of simulation tools may promote systems thinking³¹, which is essential for science³² to better serve³³ society³⁴. Understanding causation³⁵ and true correlation is necessary to avoid hype³⁶. Our ability to use these tools are key for medicine, farming, optimizing milk production and anywhere decision is desired.

¹ <https://ncase.me/loopy/>

² https://www.systemdynamics.org/assets/conferences/2004/SDS_2004/PAPERS/381BORSH.pdf

³ <https://www.tandfonline.com/doi/abs/10.1080/01441647.2012.745632>

⁴ <https://arxiv.org/ftp/arxiv/papers/1108/1108.3235.pdf>

⁵ <http://www.thwink.org/sustain/glossary/SystemDynamics.htm>

⁶ <https://www.techrepublic.com/article/systems-thinking-with-a-chromebook/>

⁷ <https://tangible.media.mit.edu/project/airportsim/>

⁸ <http://vensim.com/vensim-software/>

⁹ <https://doi.org/10.1016/j.phpro.2012.03.263>

¹⁰ https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NERL&dirEntryId=310977

¹¹ <https://www.systemdynamics.org/tools>

¹² https://link.springer.com/content/pdf/10.1007%2F978-0-387-74157-4_45.pdf

¹³ <https://thesystemsthinker.com/from-spreadsheets-to-system-dynamics-models/>

¹⁴ <https://tangible.media.mit.edu/project/tangible-business-process-analyzer/>

¹⁵ <http://dx.doi.org/10.1016/j.jenvman.2017.04.036>

¹⁶ <http://sysdyn.simantics.org/>

¹⁷ http://web.mit.edu/scresponse/repository/Rice_SCRResp_Article_SCMR.pdf

¹⁸ <https://rmas.fad.harvard.edu/pages/change-control>

¹⁹ <https://dspace.mit.edu/handle/1721.1/41914>

²⁰ <https://link.springer.com/content/pdf/10.1007%2Fs13753-017-0154-5.pdf>

²¹ <https://doi.org/10.1007/s13753-018-0190-9>

²² <http://science.sciencemag.org/content/359/6373/325>

²³ <https://www.researchgate.net/publication/267635903>

²⁴ <https://issues.org/esty-2/>

²⁵ <https://www.brettonwoodsproject.org/2005/08/art-320747/>

²⁶ <https://www.ebrd.com/downloads/research/guides/finance.pdf>

²⁷ <https://nautilus.org/gps/applied-gps/global-public-goods/what-are-global-public-goods/>

²⁸ <http://dx.doi.org/10.1109/JIOT.2017.2755620>

²⁹ <http://www.bookmetrix.com/detail/book/7153d069-09a3-4211-a6cf-34588ef367e9#reviews>

³⁰ <http://supplychain.mit.edu/supply-chain-games/beer-game/>

³¹ <http://www.sfu.ca/~vdabbagh/Forrester68.pdf>

³² <https://theconversation.com/marie-curie-and-her-x-ray-vehicles-contribution-to-world-war-i-battlefield-medicine-83941>

³³ <http://science.sciencemag.org/content/295/5557/929>

³⁴ https://preventioncentre.org.au/wp-content/uploads/2018/08/080818_Diabetes_FactSheet.pdf

³⁵ <http://links.jstor.org/sici?sici=0012-9682%28196908%2937%3A3%3C424%3AICRBEM%3E2.0.CO%3B2-L>

³⁶ <https://www.amazon.com/Freakonomics-Economist-Explores-Hidden-Everything/dp/0060731338>

ESSAY BY ISAAC ASIMOV
(1959)

CREATIVITY

*How do people
get new ideas?*



Essay by Isaac Asimov on Creativity (1959)



Isaac Asimov

How do people get new ideas?

Presumably, the process of creativity, whatever it is, is essentially the same in all its branches and varieties, so that the evolution of a new art form, a new gadget, a new scientific principle, all involve common factors. We are most interested in the "creation" of a new scientific principle or a new application of an old one, but we can be general here.

One way of investigating the problem is to consider the great ideas of the past and see just how they were generated. Unfortunately, the method of generation is never clear even to the "generators" themselves.

But what if the same earth-shaking idea occurred to two men, simultaneously and independently? Perhaps, the common factors involved would be illuminating. Consider the theory of evolution by natural selection, independently created by Charles Darwin and Alfred Wallace.

There is a great deal in common there. Both traveled to far places, observing strange species of plants and animals and the manner in which they varied from place to place. Both were keenly interested in finding an explanation for this, and both failed until each happened to read Malthus's "Essay on Population."

Both then saw how the notion of overpopulation and weeding out (which Malthus had applied to human beings) would fit into the doctrine of evolution by natural selection (if applied to species generally).

Obviously, then, what is needed is not only people with a good background in a particular field, but also people capable of making a connection between item 1 and item 2 which might not ordinarily seem connected.

Undoubtedly in the first half of the 19th century, a great many naturalists had studied the manner in which species were differentiated among themselves. A great many people had read Malthus. Perhaps some both studied species and read Malthus. But what you needed was someone who studied species, read Malthus, and had the ability to make a cross-connection.

That is the crucial point that is the rare characteristic that must be found. Once the cross-connection is made, it becomes obvious. Thomas H. Huxley is supposed to have exclaimed after reading *On the Origin of Species*, "How stupid of me not to have thought of this."

But why didn't he think of it? The history of human thought would make it seem that there is difficulty in thinking of an idea even when all the facts are on the table. Making the cross-connection requires a certain daring. It must, for any cross-connection that does not require daring is performed at once by many and develops not as a "new idea," but as a mere "corollary of an old idea."

It is only afterward that a new idea seems reasonable. To begin with, it usually seems unreasonable. It seems the height of unreason to suppose the earth was round instead of flat, or that it moved instead of the sun, or that objects required a force to stop them when in motion, instead of a force to keep them moving, and so on.

A person willing to fly in the face of reason, authority, and common sense must be a person of considerable self-assurance. Since he occurs only rarely, he must seem eccentric (in at least that respect) to the rest of us. A person eccentric in one respect is often eccentric in others.

Consequently, the person who is most likely to get new ideas is a person of good background in the field of interest and one who is unconventional in his habits. (To be a crackpot is not, however, enough in itself.)

Once you have the people you want, the next question is: Do you want to bring them together so that they may discuss the problem mutually, or should you inform each of the problem and allow them to work in isolation?

My feeling is that as far as creativity is concerned, isolation is required. The creative person is, in any case, continually working at it. His mind is shuffling his information at all times, even when he is not conscious of it. (The famous example of Kekule working out the structure of benzene in his sleep is well-known.)

The presence of others can only inhibit this process, since creation is embarrassing. For every new good idea you have, there are a hundred, ten thousand foolish ones, which you naturally do not care to display.

Nevertheless, a meeting of such people may be desirable for reasons other than the act of creation itself. No two people exactly duplicate each other's mental stores of items. One person may know A and not B, another may know B and not A, and either knowing A and B, both may get the idea—though not necessarily at once or even soon.

Furthermore, the information may not only be of individual items A and B, but even of combinations such as A-B, which in themselves are not significant. However, if one person mentions the unusual combination of A-B and another the unusual combination A-C, it may well be that the combination A-B-C, which neither has thought of separately, may yield an answer.

It seems to me then that the purpose of cerebration sessions is not to think up new ideas but to educate the participants in facts and fact-combinations, in theories and vagrant thoughts.

But how to persuade creative people to do so? First and foremost, there must be ease, relaxation, and a general sense of permissiveness. The world in general disapproves of creativity, and to be creative in public is particularly bad. Even to speculate in public is rather worrisome. The individuals must, therefore, have the feeling that the others won't object.

If a single individual present is unsympathetic to the foolishness that would be bound to go on at such a session, the others would freeze. The unsympathetic individual may be a gold mine of information, but the harm he does will more than compensate for that. It seems necessary to me, then, that all people at a session be willing to sound foolish and listen to others sound foolish.

If a single individual present has a much greater reputation than the others, or is more articulate, or has a distinctly more commanding personality, he may well take over the conference and reduce the rest to little more than passive obedience. The individual may himself be extremely useful, but he might as well be put to work solo, for he is neutralizing the rest.

The optimum number of the group would probably not be very high. I should guess that no more than five would be wanted. A larger group might have a larger total supply of information, but there would be the tension of waiting to speak, which can be very frustrating. It would probably be better to have a number of sessions at which the people attending would vary, rather than one session including them all. (This would involve a certain repetition, but even repetition is not in itself undesirable. It is not what people say at these conferences, but what they inspire in each other later on.)

For best purposes, there should be a feeling of informality.

Joviality, the use of first names, joking, relaxed kidding are, I think, of the essence—not in themselves, but because they encourage a willingness to be involved in the folly of creativeness. For this purpose I think a meeting in someone's home or over a dinner table at some restaurant is perhaps more useful than one in a conference room.

Probably more inhibiting than anything else is a feeling of responsibility. The great ideas of the ages have come from people who weren't paid to have great ideas, but were paid to be teachers or patent clerks or petty officials, or were not paid at all. The great ideas came as side issues.

To feel guilty because one has not earned one's salary because one has not had a great idea is the surest way, it seems to me, of making it certain that no great idea will come in the next time either.

Yet your company is conducting this cerebation program on government money. To think of congressmen or the general public hearing about scientists fooling around, boondoggling, telling dirty jokes, perhaps, at government expense, is to break into a cold sweat. In fact, the average scientist has enough public conscience not to want to feel he is doing this even if no one finds out.

I would suggest that members at a cerebation session be given sinecure tasks to do—short reports to write, or summaries of their conclusions, or brief answers to suggested problems—and be paid for that, the payment being the fee that would ordinarily be paid for the cerebation session. The cerebation session would then be officially unpaid-for and that, too, would allow considerable relaxation.

I do not think that cerebation sessions can be left unguided. There must be someone in charge who plays a role equivalent to that of a psychoanalyst. A psychoanalyst, as I understand it, by asking the right questions (and except for that interfering as little as possible), gets the patient himself to discuss his past life in such a way as to elicit new understanding of it in his own eyes.

In the same way, a session-arbiter will have to sit there, stirring up the animals, asking the shrewd question, making the necessary comment, bringing them gently back to the point. Since the arbiter will not know which question is shrewd, which comment necessary, and what the point is, his will not be an easy job.

As for "gadgets" designed to elicit creativity, I think these should arise out of the bull sessions themselves. If thoroughly relaxed, free of responsibility, discussing something of interest, and being by nature unconventional, the participants themselves will create devices to stimulate discussion.

It's okay not to be a "safe" academic.

Sometimes you have to stand up for causes that are bigger than you are, believing that doors that are meant to be opened will be and that nothing can shut them.

Sometimes your character needs to speak louder than your scholarship.

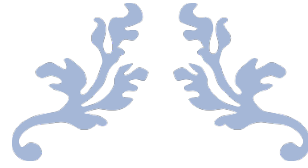
COMMENTARY [F]

Shoumen Datta

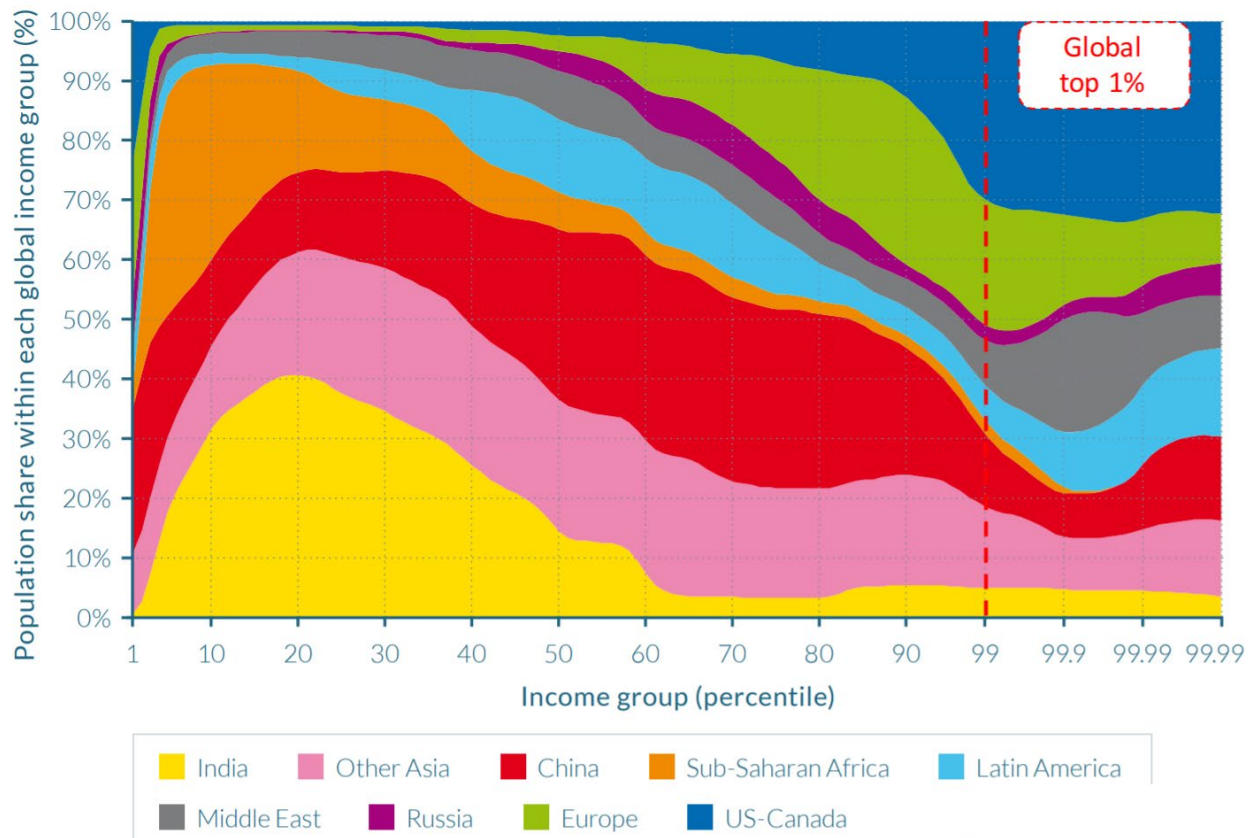
HAPHAZARD REALITY – IOT IS A METAPHOR

THIS PAGE IS LEFT BLANK

COMMENTARY - F



FORUM FOR GLOBAL PUBLIC GOODS APPLICATIONS



FORUM
FOR
GLOBAL
PUBLIC
GOODS
APPLICATIONS

FPGA

FEWSH ideas for 99% of the global population.

FPGA ⇒ CONVERGENCE

CONTEXT ⇒ The principle of convergence is a compass for synergistic integration and key to applications

“Meandering” was the word used, aptly, by a Dutch scientist from Delft (DUT), to describe my attempt to collect and connect the dots (especially outlier events, which may be even more informative). With that badge of honor, in hand, I continue to narrate one example of how things can come together. Wandering through diverse and disparate thoughts, may, occasionally, prove to be beneficial. It reveals the allusion and the allegory of the words “*not all those who wander are lost*” from the poem¹ by Tolkien.

Convergence is a common word with an uncommon semantics. The practice of convergence is an everyday occurrence. Almost all physical activities involve multiple domains and thought. These processes are, quintessentially, a confluence of facts, knowledge and experience. The act of drinking a cup of tea or sipping soda from a glass, using a straw, is made possible by convergence. Over the past decade, several groups have put forward frameworks to emphasize the principles of convergence. The latter are aimed to accelerate multi-disciplinary approaches. However, the organizational matrices are still sterile, devoid of imagination and lacks the solutions approach. When such organizations are constructed, *by design*, to function (Amazon, Apple), they are intensely, and almost exclusively, focused on profit optimization.

Hence, convergence for the less fortunate, is few and far between. But, convergence remains the solution-seekers battle cry and may be driven by necessity. Framing *necessity* in the question is a pivotal step. For example, how do we ensure that drinking water is reasonably safe² from harmful agents? The answer cannot even take shape unless we have a *source* of water³ accessible to the consumer. About every ninety seconds a child dies⁴ due to water-borne illness. Water safety is of paramount importance for billions, in nations where >90% of the global population resides. The key performance indicator is the degree of saturation with respect to the “*last mile*” infrastructure and ease of access to water for the consumer. The fact that lack of installed *infrastructure* is the dominant rate limiting inhibitor is easy to understand when considering the observation that more people have a mobile phone than a toilet (1 in 3 people in the world lack access to a toilet and/or managed sanitation services).

Water safety decision support systems (DSS) require⁵ quantitative data with respect to detection⁵ of biological and chemical contaminants (sensors). The data must be communicated (telecom networks) and analyzed in near real-time to inform distributors (water supply chain, systems and infrastructure) as well as consumers (mobile visualization of data). Quantitative information about harmful agents must be published in a user-friendly format, to inform and instruct, in the *context* of the community, in a manner that inspires users to *act* with confidence, *respond* with prudence, rather than react or sow confusion.

Connectivity between tools, infrastructure and organizational domains, reflects the principle of convergence. When practiced, it benefits society. Thus, convergence of science and engineering serves society, by enabling applications to benefit all societies, under the broad spectrum of global public goods.

¹ https://en.wikipedia.org/wiki/The_Fellowship_of_the_Ring

² https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/PCAST/pcast_drinking_water_final_report_20161221.pdf

³ http://www.who.int/water_sanitation_health/monitoring/fast_facts/en/

⁴ <https://water.org/our-impact/water-crisis/>

⁵ <http://pubs.rsc.org/en/journals/articlecollectionlanding?sercode=lc&themeid=4c264945-7660-4eb1-942d-2561325a2733>

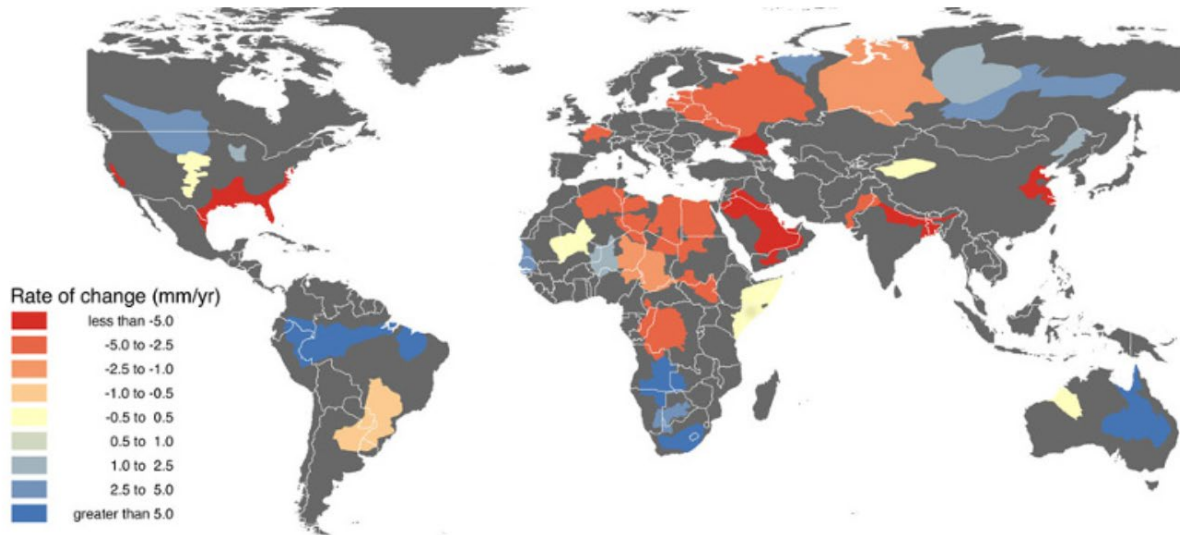


Fig 1: Trends⁶ in groundwater storage 2003-2013 (Source: NASA)

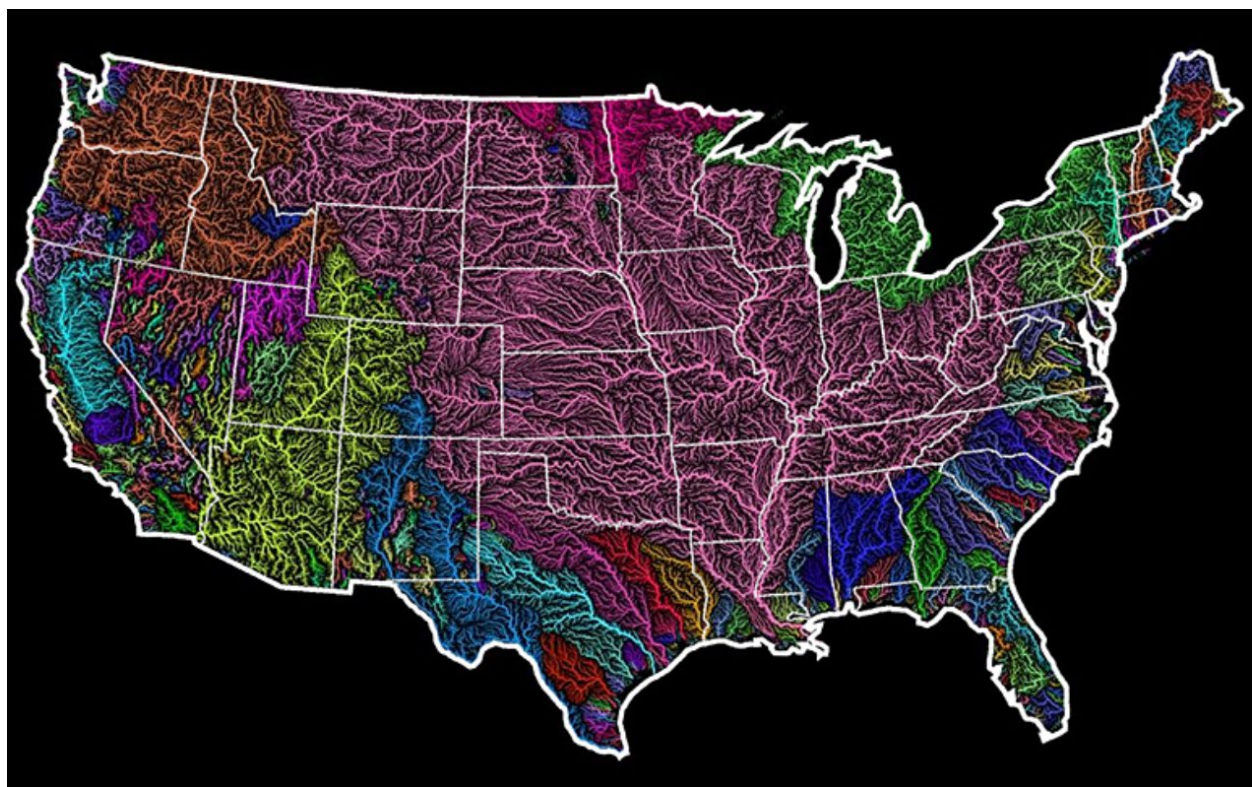


Fig 2: The dominant drainage basin in the US⁷ is the Jefferson-Mississippi-Missouri River system (pink). This massive basin collects water from over 40% of the US and is in contact with 2 Canadian provinces and 31 states, before terminating at the Gulf of Mexico.

⁶ <http://www.visualcapitalist.com/nasa-satellites-show-disturbing-trends-in-water-supply/>

⁷ <http://www.visualcapitalist.com/maps-worlds-watersheds/>

HISTORY ⇨ Stretching to weave an example of convergence spanning ~1000 years ⇨ 1000 to 1995

The debate about pros and cons about convergence⁸ may continue⁹ and evolve¹⁰ in many different disciplines¹¹ (medicine¹², environment¹³), in many countries¹⁴, and in different¹⁵ directions¹⁶ but drivers of convergence, generally, may not appear as obvious or carry a label or found in neat packages.

The standard operating procedure for convergence is quintessentially one of “*haphazard reality*” and likely to be represented by amorphous amalgam of instances, knowledge, developments, from vastly different domains. It may include, directly or indirectly, an array of technologies, based on mathematics, science and engineering, loosely coalesced in the context of the question or purpose. It may offer clues to solutions or pose more questions. It may be driven by unanticipated forces, outlier events, unexpected results, to create what no one had expected, in terms of outcome, or answer, or direction for new roads!

This is one such example, evolving over centuries.

Circa 1593-1594, Carolus Clusius, (Charles de l'Ecluse, 1526-1609) a botanist, begun a botanical garden at the University of Leiden, to cultivate tulips¹⁷ in Netherlands¹⁸. Originally a wildflower, tulips were cultivated in the Ottoman Empire (Turkey, *-stan* states), as early as 1,000 AD and later imported to Holland in the 17th century, where they became a formidable economic force. It was also the first economic bubble to explode¹⁹ circa 1637. Tulips were a key element of the Dutch economy²⁰ in the form of auctions. *Tulipmania* coincided with the formal establishment of the Amsterdam Stock Exchange in 1602. Tulip trade was a catalyst for the Dutch economy, which achieved a high standard of living in Europe by the middle of the 17th century. The newly found affluence spawned a Golden Age, for the Dutch, typified by the great artist Rembrandt van Rijn (1606–1669).

The bursting of the bubble of the tumultuous tulip economy may have been evident from the price of *Semper Augustus*, a variegated tulip with distinct striations on its petals. Around 1636, the price of the bulb of *Semper Augustus* may have been about \$34,584 and as high as \$97,200 (based on other forms of valuation). These colorful patterns are caused by infection due to potyviruses²¹ which are plant viruses with positive-strand RNA genomes, which alters distribution of pigments in the petal due to virus replication. A specific potyvirus, the tulip-breaking virus, causes successive generations of the bulb to shrink until it can no longer flower. Hence, the incredible price²² of the *Semper Augustus* bulb.

⁸ <http://www.aplu.org/projects-and-initiatives/research-science-and-technology/hibar/resources/MITwhitepaper.pdf>

⁹ <https://www.nap.edu/download/18722>

¹⁰ https://www.cmu.edu/nanotechnology-forum/Forum_14/US_Presentation/1_C%20Roco%20NNI_17-0911_NT%20&%20IT%20Convergence_MC%20Roco%20@US-KOREA%20NanoForum_20m.pdf

¹¹ <http://www.convergenceevolution.net/media/>

¹² <http://iopscience.iop.org/article/10.1088/2057-1739/1/2/026001/pdf>

¹³ <http://pubs.acs.org/doi/pdf/10.1021/es503585u>

¹⁴ http://blogs.helsinki.fi/changingdynamics/files/2010/09/Lemola_Convergence_of_ST_policies.pdf

¹⁵ https://www.scienceeurope.org/wp-content/uploads/2015/12/Workshop_Report_Convergence_FINAL.pdf

¹⁶ https://www.nsf.gov/crssprgm/nano/MCR_13-0831_ConvergenceKTS_Roco+Bainbridge_17p.pdf

¹⁷ http://penelope.uchicago.edu/~grout/encyclopaedia_romana/aconite/tulipomania.html

¹⁸ <https://www.press.uchicago.edu/ucp/books/book/chicago/T/bo5414939.html>

¹⁹ <http://www.econ.ku.dk/okocg/Students%20Seminars%C3%98kon-%C3%98velser/%C3%98velse%202007/artikler/Garber-Famous-First-Bubbles-JEP-1990.pdf>

²⁰ <http://www.jstor.org/stable/j.ctt128783w>

²¹ <http://www.virology.ws/2012/03/14/tulips-broken-by-viruses/>

²² <https://tuecontheoryofnetworks.wordpress.com/2013/02/25/the-origin-of-the-dutch-auction>

Tulipmania was brought to its knees by potyviruses (circa 1636-1637) and it contributed to the destruction²³ of the Dutch economy. These viruses still circulate, globally, transmitted by aphids. It is ironic that the decline of the Dutch economy, due to potyviruses, albeit, in part, coincided²⁴ with the bubonic plague, which ravaged Netherlands, a fifth of the population dying in Amsterdam in 1635-1636.



Fig 3: Colorful striations of *Semper Augustus* caused by infection due to the potyvirus, tulip-breaking virus.

Convergence, catalyzed by tulips, dates back to its cultivation circa 1,000 AD. Tulips from Turkey created turbulence within the economies of Europe in the 17th century. The Dutch flower markets did not invent or create auctions, but it certainly made “auction” a household name. It continues at Aalsmeer, NL.

But, the icing on the cake was the auction²⁵ inspired technological amalgam conceived by Pierre Omidyar, who *converged* auctions with the medium of the internet, to establish the first online auction platform, **eBay**, in 1995 (about one year after the establishment of Amazon in 1994).

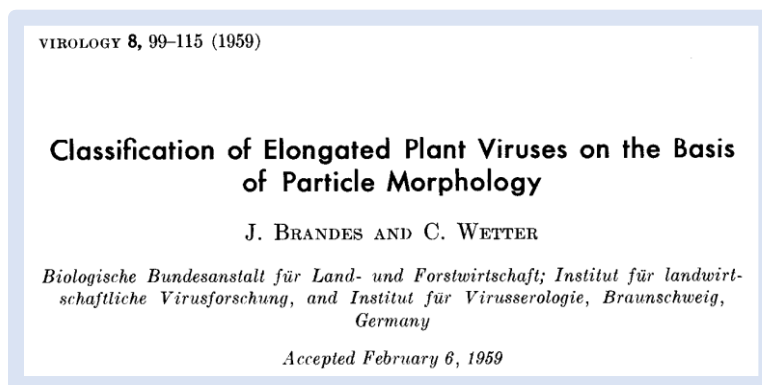


Fig 4: Identification²⁶ of potyvirus (1959) was a biological triumph directly due to tulipmania.

²³ <https://io9.gizmodo.com/5905247/the-virus-that-destroyed-the-dutch-economy>

²⁴ http://penelope.uchicago.edu/~grout/encyclopaedia_romana/aconite/tulipomania.html

²⁵ <https://mikebrandlyauctioneer.wordpress.com/auction-publications/history-of-auctions/>

²⁶ [https://doi.org/10.1016/0042-6822\(59\)90022-4](https://doi.org/10.1016/0042-6822(59)90022-4)

Forum for Global Public Goods Applications → FEWSH ideas for 99% of the global population

Shoumen Palit Austin Datta

PROLOGUE

The “tulip” tales are not structured frameworks, yet convergence is shaped by socio-economic forces and enhanced through science, engineering and technology. Food, energy, water, and the other related pillars of sanitation and healthcare (FEWSH), in combination, are purveyors of civilization. It is a fact, rarely acknowledged, that such grand ideas, to advance civilizations, may often die, a premature death. Under the combined pressure of myopia, analysis and greed, perhaps known as pragmatism, ideas, no matter how profound, crumbles at 495 gigapascals²⁷ or less. This may be one such collection of ideas.

PREFACE

Imagination, invention and innovation, in the affluent 1% world, are born, perhaps, only to race in wealth creation competitions. The incessant drive to create for-profit start-ups, with the tiniest bit of new contribution, is an epidemic that may asphyxiate economic growth for 99% of the population. From life-saving drugs, to basic food and drinking water, existing solutions may partially alleviate global suffering. These are prevented, by deliberate design to desist dissemination, from enriching public goods, by the tentacles of patents, high cost of technology licensing and legal threats from intellectual property rights. The proponents for human rights for economic development, therefore, must seek solutions from scientists and engineers [a] actively contributing their patent-free²⁸ discoveries, [b] enabling no-cost or low-cost technology licensing and [c] creating²⁹ systems feasible for deployment³⁰ in 99% of the world.

INTRODUCTION

Global public goods are goods which may benefit all people, in any nation. Core pillars are food, energy and water (FEW). Water is essential for sanitation, food is inextricably linked with health, and public health connects to food and water. Problems due to lack of sanitation³¹ and access³² to healthcare, makes it imperative to add sanitation and health to the core. Hence, FEW becomes FEWSH, and presents immense problems, in need of solutions. In this proposal we may barely even ‘touch’ the surface. We plan to discuss a few suggestions. Topics may be restricted to things and steps we think may be actionable, if we can find leaders who are willing to assume the risks of leadership. Making food available is the most pressing need³³ in many parts of the world but for this discussion, at present, we will focus on water quality, due to our familiarity with positive outcomes from a few scientists and engineers. The idea is to ***institutionalize change within the infrastructure***, rather than pursuing “flash in the pan” pilot projects.

²⁷ <http://science.sciencemag.org/content/early/2017/01/25/science.aal1579>

²⁸ <https://tatacenter.mit.edu/portfolio/rohit-karnik/>

²⁹ <https://abe.ufl.edu/Faculty/mclamore/index.shtml>

³⁰ <https://pubs.rsc.org/en/content/articlelanding/2018/an/c8an00065d#!divAbstract>

³¹ <https://www.nationalgeographic.com/magazine/2017/08/toilet-defecate-outdoors-stunting-sanitation/>

³² <https://www.newsweek.com/world-bank-who-health-care-poor-global-access-748117>

³³ <https://www.weforum.org/agenda/2017/10/a-plate-of-bean-stew-costs-320-in-this-country/>

Wii

"Water is fluid, soft and yielding. But water will wear away rock, which is rigid and cannot yield. As a rule, whatever is fluid, soft and yielding will overcome whatever is rigid and hard. This is another paradox: what is soft is strong." (Lao Tzu, 500 BC)

BACKGROUND

Forum for Global Public Goods Applications (FPGA) is a platform approach to deliver systems or solutions which may benefit communities. The emphasis is on applications which may improve quality of life. FPGA is not a basic research platform. It expects to coordinate application related applied R&D in research institutions, to harvest the fruits of science, in order to serve society.

Any solution within the broad spectrum of FEWSH may be of interest to FPGA. The outcome, perhaps through multi-disciplinary convergence, must offer solutions, with these attributes: [a] feasible for mass deployment, [b] lends itself to synergistic integration for humans and/or animals, [c] application specificity respects the *context* of the community, [d] possesses potential to be a part of the sustainable infrastructure and [e] may deliver long-term socio-economic growth. The current suggestion focuses on a few issues relevant to water purification and detection of contaminants.

WATER

Society without clean water infrastructure is economically handicapped. It shifts the water burden to women³⁴ and further diminishes economic³⁵ output. Sanitation³⁶ services³⁷ suffer due to water and exacerbate public health issues in communities which lack access to healthcare. Lack of usable water for irrigation influences food production. Natural³⁸ and human³⁹ contamination of water introduces risk for humans, animals and plants. Hence, water purification and detection⁴ tools (sensor systems linked to mobile devices) must evolve as a part of the daily life and routine practices, for affected communities.

Hence, FPGA-FEWSH may wish to prioritize a water initiative, Wii. One "pro" for Wii stems from the results of using plant xylem as a filter. The latter is no longer a lab⁴⁰ experiment but a feasible water purification tool. Can it move beyond the project⁴¹ phase to help install systemic water infrastructure?

³⁴ <http://theconversation.com/women-still-carry-most-of-the-worlds-water-81054>

³⁵ https://www.huffingtonpost.com/shail-khiyara/why-the-global-water-cris_b_12450260.html

³⁶ <http://www.washadvocates.org/2012/07/27/the-silent-barrier-women-water-and-sanitation/>

³⁷ <https://www.nytimes.com/2017/09/03/world/asia/india-toilet-movie.html>

³⁸ <https://www.theguardian.com/global-development-professionals-network/2016/oct/18/arsenic-contamination-poisoning-bangladesh-solutions>

³⁹ https://wp.nyu.edu/gallatin_human_rights_fellows/2017/05/15/gold-gold-mining-and-a-gallatin-human-rights-fellow-in-colombia/

⁴⁰ <https://arxiv.org/ftp/arxiv/papers/1310/1310.4814.pdf>

⁴¹ https://twitter.com/dlab_mit/status/765505700269203457

WATER PURIFICATION – AN INFRASTRUCTURE APPROACH TO INSTITUTIONALIZE CHANGE FOR GOOD

We may eventually explore a variety of low cost tools with reasonable efficiencies, but, at this time, we expect to focus on one⁴² proven approach (Figure 6). In this vein, plant xylem act as a natural system for water purification and produces safe drinking water, albeit in low volumes. One goal of Wii is to build capacity to deploy xylem based water purification process to meet the basic needs of end users (households) in terms of sufficient clean water for daily needs.

The first problem may be sourcing the water (assume it is unclear). Many communities do not even have access to water. FPGA aims to address this issue in communities where FPGA may be involved. If water sourcing is available, the second issue concerns the infrastructure that connects the source to the end user. Many communities do not have basic infrastructure. FPGA aims to address this issue in communities where FPGA may be involved, perhaps indirectly through NGO's working on-site.

If there is limited infrastructure which terminates at nodes (no “last mile” access for end users), the third issue is to explore how xylem-based purification may be applied at these nodes (scale to greater volume). After water purification at the node, clean water will flow through the “last mile” to end-users. This leads to the fourth issue of water purification volumes, rates, flows and efficiencies. The xylem system is efficient for low volume usage in homes and that is the single greatest value of this approach. It solves a problem. However, “multiplying” the system to scale, may be helpful for the ultimate goal of installing clean running water, as a part of the city/town/village *utilities infrastructure*.

The left panel in Figure 5 illustrates the highly effective and strikingly simple solution. The right panel suggests the potential for developing a cartridge which can fit in/out of traditional water pipes. R&D may be necessary to construct and evaluate the performance of this cartridge, which is an aggregate of the narrow tubes with the xylem filter, in a water pipe with a larger diameter. A *modular* cartridge, which may be slipped in/out of pipes with bespoke joints, may enable robotic manufacturing and ease of transportation. The “drag and drop” feature may catalyze “plug-n-play” usage for widespread adoption.

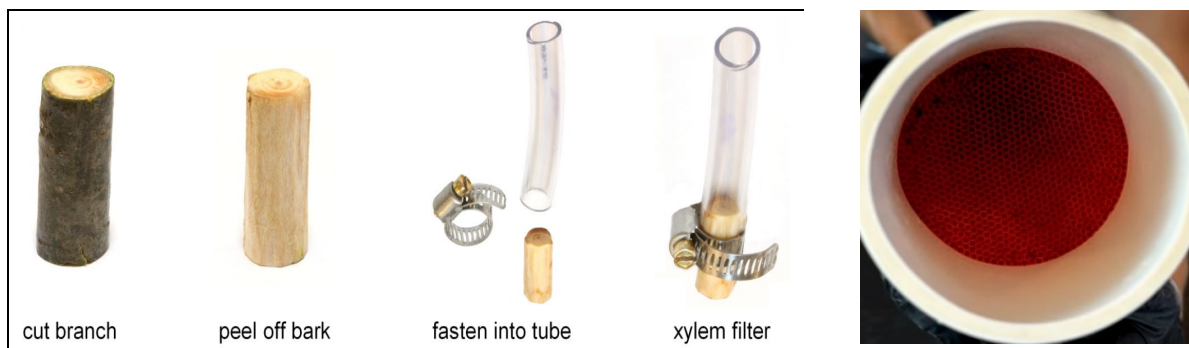


Fig 5: The measured flow rates⁴² of about 0.05 ml per second using only $\sim 1 \text{ cm}^2$ filter area (left panel) correspond to a flow rate of >4 litres per day, sufficient to meet the drinking water requirements of one person. If a branch with a greater circumference was used to increase the filter area, will it affect the flow rate and quality of the filtered water? If xylem filter containing (narrow) tubes (left panel) were packed in a pipe with a larger diameter (right panel, illustration copied from laminar flow diagrams), can it help to scale and increase the volume of filtered water? Will the flow rate decrease? Will it affect water quality?

⁴² <https://dspace.mit.edu/openaccess-disseminate/1721.1/86082>

One task of FPGA is to promote Wii's **R&D mission of developing tools to facilitate clean water infrastructures**. FPGA may aid in the global diffusion of tools, to prevent morbidity and mortality, due to contaminated water. The work of FPGA will be agnostic of geography, from Cali to Calcutta to Cairo.

FPGA Wii expects to interact, create and maintain dialogues with “network of bridges” involving national governments, local governmental agencies, NGOs (non-governmental agencies), global organizations (UN, WHO, World Bank, Asian Development Bank, African Development Bank, European Bank for Reconstruction and Development), global and local foundations, research institutions and academics. In one or more ways, collective and collaborative efforts will bring to the table, proposals, debate solutions and discuss how to fund implementation and installation of clean water infrastructure.

FPGA-FEWSH anticipates that some of the interactions, with appropriate agencies, organizations, and industries, will involve funding requests, to enable and sustain the organization of FPGA-FEWSH. Without a stable FPGA, the knowledge backbone for Wii and other future efforts, may cease to exist.

FPGA expects to [a] assist as “cheerleaders” and proselytizers for local chapters, [b] offer expert R&D guidance for on-site teams, and [c] act as a bridge, case by case basis, for the group or organization or not-for-profit LLC (limited liability corporation), in charge of the local operation. The local body will execute local implementations, and install infrastructure, in the context of the needs of the community. This body will have, or secure, independent fiscal means and human resources to execute the operation.

FPGA is under no illusion that the scale of this endeavor and the bureaucracy surrounding any infrastructure effort, may pose insurmountable barriers. The strength of FPGA is rooted in its credibility and the ethos of the founders. The latter are not racing to patent every iota of invention to pursue start-ups or other enterprises for personal wealth creation. The aim is to lift many boats, not just a few yachts.

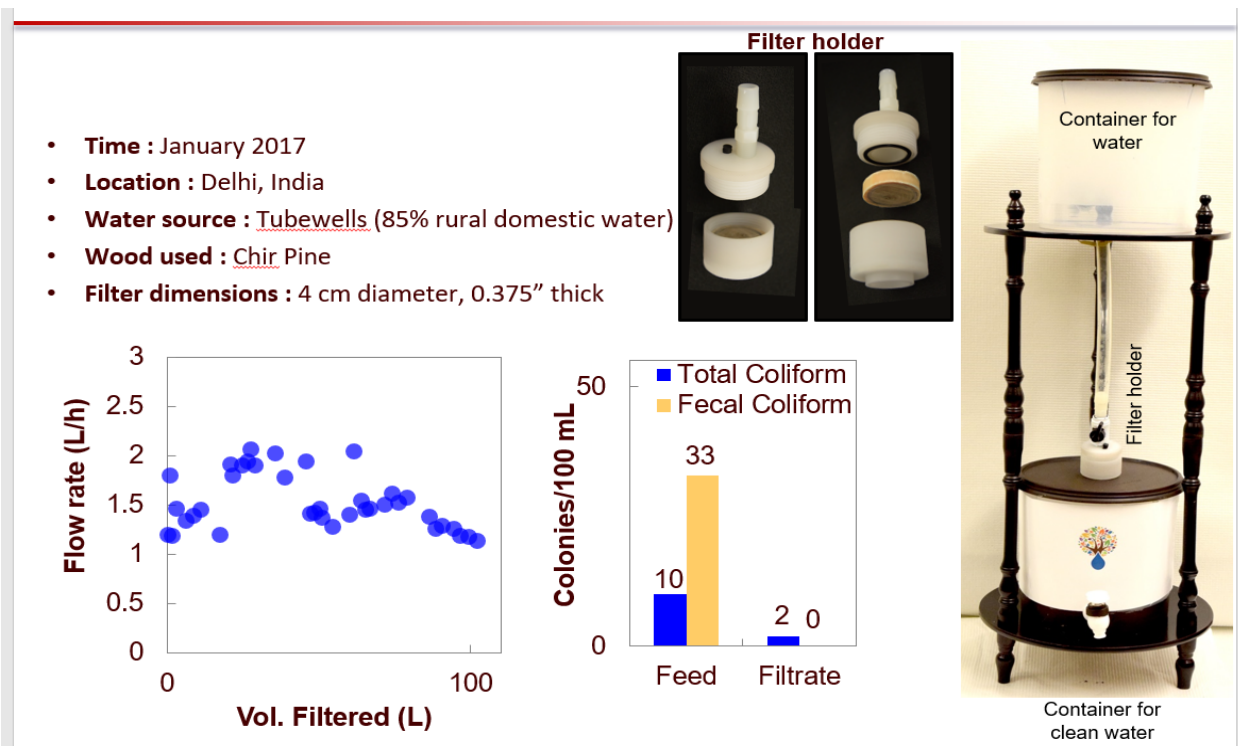


Fig 6: Domestic water purification using wood. **Patent-free** processes developed by Rohit Karnik, MIT.

WATER QUALITY – MEASUREMENTS, MOLECULES AND METRICS FOR A SENSE AND RESPONSE SYSTEM

Mortality and morbidity may exponentially escalate and epidemics can rapidly turn into full blown pandemics, without near real-time data from sense and response⁴³ systems. Drinking water⁴⁴ and food are mediums for spread of disease and public health disasters. The list of benefits from water purification may be considerably shortened without a sensitive, pro-active and agile water quality *detection system*.

Detection is often synonymous with sensors. Mountains of research⁴⁵ to create novel sensors are of limited use unless the sensors are deployed, in action, as a part of detection systems, for purposes that may benefit billions of people. Equally, patenting⁴⁶ every sensor created, solely for the purpose of wealth creation, is unlikely to be useful for the mission of FPGA and initiatives it may wish to champion.

Tools for detection are essential to help mitigate risks exposed by the incredible statistic that 92% of pollution-related deaths⁴⁷ occur in low-income and middle-income countries. Importantly, detection can save the next generation. Extremely low-dose exposures to pollutants *in utero* and in early infancy can result in disease, disability, and death, of children.

Element	Max. acceptable limit (ppm)	Health effects
Arsenic	0.010	Kidney and liver cancer
Cadmium	0.003	Kidney disease and cancer; edema (acutely)
Chromium	0.05	Nasal and lung cancer
Copper	0.05	Liver damage; kidney disease
Lead	0.10	Developmental abnormalities
Mercury	0.001	Nervous system disorders
Nickel	0.02	Cancers
Zinc	5	Digestive disorders

Fig 7: Trace⁴⁴ contaminants in water – a grave and global concern, for adults, children and the unborn.

FPGA wishes to create and deploy low-cost sensor systems⁴⁸ which will contain the sensor, tools for data capture and transmission, near real-time data analytics and rapid display on a mobile device for visualization by system administrators, alert managers, early responders and end-users or consumers at the edge or point-of-service. R&D is necessary to create robust systems, tools for calibration and increase sensitivity. Connectivity of the detection system with the response team will be an important function. It may be viewed as an internet of things (IoT) approach for water and ecosystem of water related nodes.

⁴³ <http://bit.ly/SIP-SAR>

⁴⁴ http://www.who.int/water_sanitation_health/publications/2011/dwq_guidelines/en/

⁴⁵ <http://www-analytik.chemie.uni-regensburg.de/wolfbeis/P2-www.pdf>

⁴⁶ <http://www.c2sense.com/>

⁴⁷ [https://www.thelancet.com/journals/lancet/article/PIIS0140-6736\(17\)32345-0/fulltext](https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(17)32345-0/fulltext)

⁴⁸ <https://pubs.rsc.org/en/content/articlelanding/2018/an/c8an00065d#!divAbstract>

These 3D printed nano-bio sensors cost only a few cents and may be made from locally sourced materials⁴⁹ (need not use any special materials or chemicals). But, the systemic costs may be higher. However, single use sensors, no matter how inexpensive, pose logistical issues if continuous remote monitoring is necessary. Successfully re-calibrating multi-use sensors in the field, after deployment, is a challenge that researchers must address and resolve, successfully.

General multi-use sensors, which can bind with analytes and reverse to the basal state (without the need for expensive microfluidics flushing system) may be more expensive to create but of far greater value. Research is necessary to explore if molecular engineering may create binding sites, for specific and critical analytes (see table in Figure 7), perhaps, using lessons from biomimicry (for example, allosteric⁵⁰ transitions). In an ideal scenario, binding of the analyte may induce conformational changes (in the "active site" on the sensor) which may reduce the affinity (association/dissociation constants) and eject the analyte (due to reduced affinity) just after the signal (impedance⁵¹ or plasmonic⁵² transduction) is communicated (wireless sensor gateway). Elimination of the analyte, may reverse the configuration, increase the affinity, and the cycle repeats (sensor is refreshed). Engineering molecules with steric properties may create sensors for detection of analytes in any medium (air, blood, urine, oil, gas). Further research may improve molecular specificity for identification of analytes, (for example, enantiomeric profiling⁵³ of illicit drugs in sewer water). Nano-wire arrays are emerging for broad spectrum use in environmental health and toxicology. Novel advances⁵⁴ are creating 3D printed electronic sensors using materials that couple, sense, actuate, compute and communicate. The challenge is to go beyond the sensor and create an end to end **system**. It must be feasible for mass use and user-friendly for the client.

Under the auspices of WII, water purification and detection systems may proceed simultaneously. Infrastructure may surface as a rate limiting factor. But, since there are more mobile phones in the world compared to toilets, perhaps communication or transmission of data may not be an arduous task. Sensor detection systems must be able to transmit the data in near real-time. The data must be analyzed before its value perishes. The information extracted from the data must be accessible to the stakeholders within the right time frame. The response, if needed, must have a mechanism to be executed. Multiple and false alarms⁵⁵ due to poor design, system performance and analytical inefficiencies (set range is too narrow for real world fluctuations) often generate detrimental results (as a consequence, alerts are ignored, often).

Synergistic integration of multiple components are necessary to make sense of the data from sense and response systems. Patent-free, low cost systems and open-source platforms, are not usual. The business model for deploying massive scale detection systems must account for service providers who must earn revenue. The **pay-a-penny-per-use** (micro-revenue/micro-payment) model⁵⁶ may stand the test of time. By lowering barriers to entry, IoT concepts can penetrate low-income nations and capture markets of billions. The micro-earnings model depends on economies of scale, i.e., the next billion users.

⁴⁹ <http://www.mdpi.com/2079-6374/8/2/42>

⁵⁰ <https://users.wfu.edu/~shapiro/Biophysics14/mwc.pdf>

⁵¹ <https://www.hindawi.com/journals/js/2017/7638389/>

⁵² <https://www.nature.com/articles/s41598-017-08141-4>

⁵³ <https://doi.org/10.1016/j.watres.2017.11.051>

⁵⁴ <http://science.sciencemag.org/content/347/6228/1261689>

⁵⁵ <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3672485/pdf/cc12525.pdf>

⁵⁶ <https://dspace.mit.edu/handle/1721.1/111021>

TEMPORARY CONCLUSION

FPGA may be fraught with pragmatic growing pains, it is easy to be dismissed due to its immense complexity and perhaps too far removed for most decision makers, to feel sufficiently comfortable to invest in benevolent ideas, and altruistic ideals of FPGA. Although far from unique, its plight to address fundamental issues, which are “wicked problems” rather than grand challenges, channels convergence of camaraderie from honorable institutions. We must undertake the mission of FPGA because the misery from lack of global goods is a thorn in our conscience, because it’s a very hard⁵⁷ task and a fatiguing climb.

The task of FPGA must be a pledge, not a job. Founders must engage their brain, with their heart and soul, in order to face the avalanche of naysayers. Pundits, critics, as well as, well-wishers, may opine that it cannot be done, or we must wait for Google or Amazon to do it. We propose, against all odds, to move forward, with humility, dignity and with the sense, that we can help create the future.

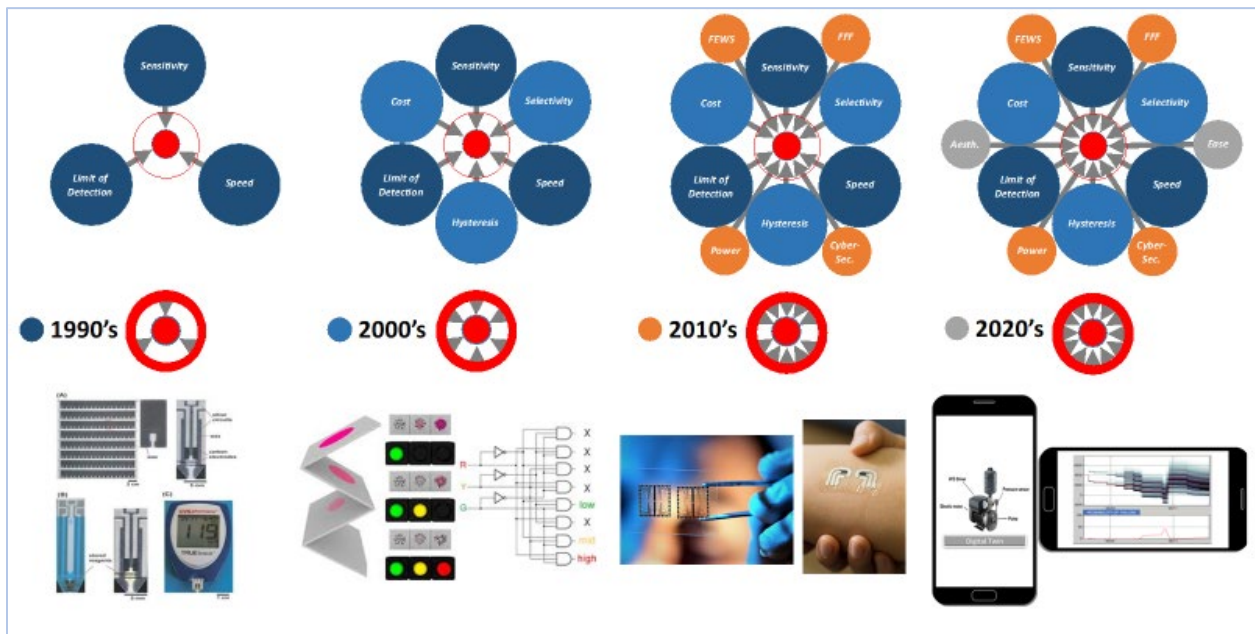


Fig 8: Evolution of sensor engineering to mobile detection **systems**. Eric McLamore, University of Florida.

We choose to go to the moon in this decade and do the other things, not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone.

JFK

⁵⁷ <https://er.jsc.nasa.gov/seh/ricetalk.htm>

FPGA-FEWSH.ORG

This part of the discussion on FPGA is included as **APPENDIX - A**

attached with **COMMENTARY C** (World Sensor Organization)

in the book **“HAPHAZARD REALITY – IoT IS A METAPHOR”**

which may be downloaded from the MIT Library

<https://dspace.mit.edu/handle/1721.1/111021>

TWO SCIENTIFIC PAPERS ARE A PART OF THIS DISCUSSION

Paper 1: Senior Author - Rohit Karnik, MIT

Paper 2: Senior Author - Eric McLamore, University of Florida

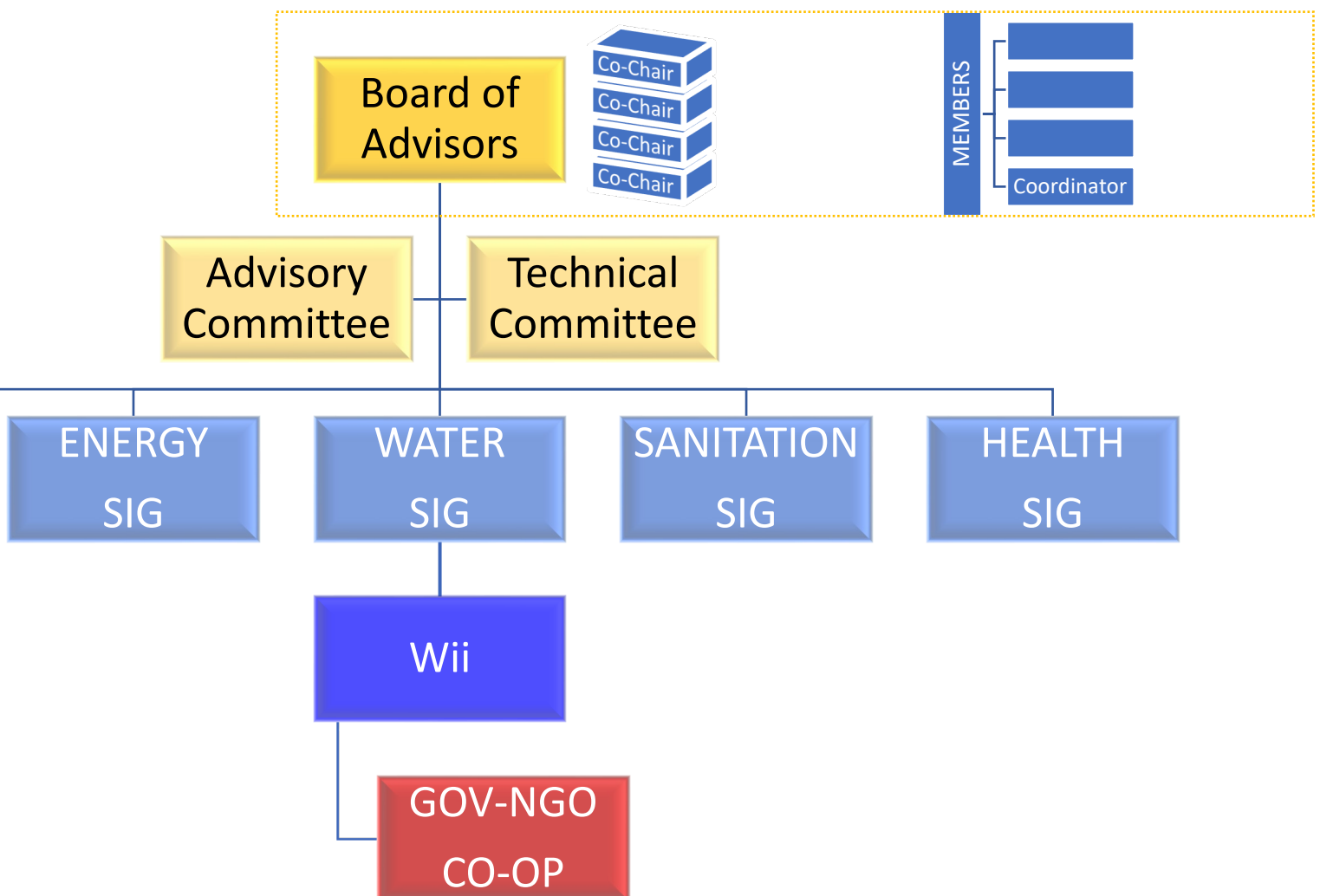
The following section is a working draft of the mission, vision, aims, objectives, modus operandi and suggested organizational structure of the FPGA proposal.

Proposed Mission

FPGA will focus on the path from invention or innovation to implementation of **infrastructure**. R&D with respect to global public goods (food, energy, water, sanitation, health) may be re-structured to serve large communities, villages, towns and cities, in terms of installing systems and infrastructure. We aim to catalyze the fruits of science, engineering and technology, to serve, and improve the quality of life.

Organizational Suggestion (inclusion of names does not imply acceptance or agreement with FPGA)

The need for a dynamic, need-based, adaptable organization, cannot be overemphasized. We expect to commence with a Board of Advisors and seek guidance from distributed complementarity of vision from different perspectives (co-chairs). Members of the Board (10-20) may contribute their expertise and experience, in terms of application-specific technical pragmatism and the real-world issues we must embrace, and are likely to face, when liaising with utilities, installation or infrastructure, on-site. Multiple special interest groups (SIG) may work on the FPGA-FEWSH platform. Water SIG may be the first to kick-off with the Water Initiative for Infrastructure (Wii). Deployment of infrastructure will require independent on-site bodies, collaborations and contractors, to deliver the “last-mile” working solutions.



General Vision

Public goods are pillars which makes civilization possible. Bridges built over these pillars constitute the fabric of life. Dependencies between the pillars and the bridges makes it impossible to divorce any part of this continuum. The vast complexity of the inextricably linked issues and problems, makes it very difficult to expect success from the reductionist approach, prevalent among scientists and engineers. The abundance of stand-alone, isolated, piece-meal solutions are indications that good intentions, great inventions and grand innovations, are epitah on tombstones, which failed to improve the collective human condition, reproducibly.

Public goods viewed as pillars, which makes civilization possible, acts to make life sustainable, through stability of services, which are delivered to the masses, through systemic installed infrastructure. FPGA aims to drive changes, help to build capacity and catalyze improvements in infrastructure, which delivers public goods.

Modus Operandi

After criticizing the reductionist approach, we hasten to take refuge by reducing our current aim from FEWSH to focus only on water, as our first initiative for infrastructure (Wii).

How will we achieve our lofty goal to install infrastructure for clean water, where most needed, which will also address the “last mile” accessibility for clean water? We don’t have all the answers. We don’t know many of the questions. We don’t know if our answers are suitable for their questions. We don’t know things we don’t know. There are key known unknowns (global will, political support, funding) and may be a few or a plethora of unknown unknowns.

The greatest strength of this proposal is the **patent-free** scientific result (Karnik *et al*) that ‘no’ cost plant xylem can be used as a filter, to process water, containing harmful chemical and/or biological agents. Using xylem filter inserted in a simple rubber tube, approximately 4 liters of clean water may be obtained per day, from one domestic set-up. It is suitable for human consumption, especially for drinking. Are there any “competitors” eager to gift their no-cost, patent free, water purification system?

Forum for Global Public Goods Applications (FPGA)



What do we think we need to achieve in order to proceed?

The xylem filter in a rubber tube can make the difference between life and death for a human or animal. At an individual level, its use is a giant leap forward for bio-inspired water purification solution. We must continue to aggressively accelerate the global diffusion of this simple domestic solution, while we strive for systemic solutions to address installation of infrastructure for clean water utilities service. However, this ‘ad-hoc-ism’ must be replaced⁵⁸ with systemic, verifiable, dependable supply of clean water

The first step toward infrastructure involves the transition from 4L of clean drinking water per day to 200L per capita per day of clean water. The diameter of the infrastructure pipes⁵⁹ may range from 6” to 60” for water distribution, whereas the last mile pipes may be 1” in diameter. An average run of domestic pipe 50 feet long with 1” diameter provides a flow of 9 gallons per minute⁶⁰ but increasing the diameter by 25% to 1.25” provides 16 gallons per minute, which is 77% more in volume compared to an 1” pipe. These issues may be germane to standardize (?) the scalability of the xylem filtration system.

Hence, the first group of questions, in the first step toward the real-world application, may ask if we can use one, or a few, or several xylem discs, **aggregated**, to create **modular** filtration “cartridges” to fit various pipes (1” and 6” and 60” pipe diameters)? Can we optimize flow rate without loss of water quality? What is the optimal diameter of the cartridge compared to performance? Can we aggregate the optimized cartridge in a super-set to fit pipes with greater diameter? This task is of **pivotal** importance. An aggregated xylem filtration system, which can scale, may be the next best thing to sliced bread!



Fig 9: Different size lines⁶⁰ provide dramatically different flow rates. Scalability may be transformative, if the xylem filter “cartridge” form factor design is a modular unit (right panel) for “plug-n-play” operation.

⁵⁸ <http://indiaenvironmentportal.org.in/files/Water%20consumption%20patterns.pdf>

⁵⁹ https://www.gbra.org/documents/public/GBRADesignGuidelines_WastewaterLS.pdf

⁶⁰ <http://www.balkanplumbing.com/required-main-water-supply-line-size/>

How to fund proof-of-concept? Demonstrate scalable, infrastructure compatible, plug-n-play cartridges.

This is where the rubber meets the road. The task ahead, for the global science and engineering community, is to create *infrastructure compatible, adaptable and interoperable*, xylem-based filtration **products** and plug-n-play **processes** to facilitate global adoption. The effort must mobilize the paradigm shift from the domestic “*adhocism*” to systemic infrastructure of installed networks distributing running clean water to homes, for example, in Flint, Michigan or Fes, Morocco or Faisalabad, Pakistan.

R&D and 3D concurrent engineering must converge with product design, development and mass manufacturing options. The main function of FPGA is not to install infrastructure but to leave no stone unturned in soliciting funds *to execute this proof of concept*. Grants, contributions, crowd-funding, and all available usual and unusual approaches, professional and personal, are expected to be used. If we fail to garner necessary financial support to create and demonstrate, the proof of concept, then⁶¹ this “*is a tale, told by an idiot (Shoumen Datta), full of sound and fury, signifying nothing.*”

What are the ideal outcomes, anticipated benefits and commercial potential for return on investment?

FPGA is not aiming to operate as a charity to provide public goods as services for the struggling economies. In the optimal scenario, FPGA expects to serve as a R&D conduit to provide public goods related product knowledge to local teams, NGOs and agencies. These on-site organizations will have access to knowledge, and experts, who can guide the operational teams on the ground, to manufacture these products, and install infrastructure, to deliver public goods, in this case, for Wii, it is clean water. Acquisition of funds and human resources to manufacture and install infrastructure are the primary responsibility of the local operation. FPGA will assist the operation by proselytizing the economic benefits of infrastructure for clean water, for example, [1] reduce burden on women to fetch water, [2] empower women to contribute to the economy, [3] improve education in the community [4] which is essential to create the local workforce necessary for manufacturing and installing infrastructure. Taken together, bringing clean water to any community is a catalyst for economic growth by reducing public health burden, enabling managed sanitation services, improving education on-site and online and creating jobs. FPGA will assist operations, globally, by proactively proselytizing these potential economic outcomes, in liaison with local municipal agencies, government departments, local and national banks, global banks (World Bank, ADB, EBRD) and development institutions (UNDP, USAID), to help local (LLC) operations secure sufficient funding to execute the installation of infrastructure for clean water to homes.

FPGA products and processes can be used by for-profit corporations to monetize infrastructure installations in affluent nations and bid for utilities development projects, worldwide. The **choice** of using FPGA guided low-cost programs versus the for-profit corporate offers, is the decision of local authorities. If Flint, MI chooses to contract Veolia or Grundfos or Siemens or ABB, to install plant xylem-based water purification system, for US\$1 billion, then it is the choice of Flint. FPGA is willing to help Flint, MI **and** also those who cannot help themselves, yet, by teaching them *how to fish* and improve their economic health.

⁶¹ <http://shakespeare.mit.edu/macbeth/macbeth.5.5.html>

FPGA products and services, can offer return on investment, even if the mission of FPGA may not commence with any for-profit venture or non-profit start-up. FPGA and its co-founders have faith in the academia-driven public private partnership platform, and the principles of entrepreneurial innovation, without the need to join the start-up bandwagon, at this time. FPGA may change its course, when needed and if suitable, to pursue its mission for global public goods delivery, in this case, for Wii, to help install clean water infrastructure and provide systemic access for clean water at homes for humans and animals. FPGA is cognizant that charity is not a sustainable for viability. FPGA is open to various ideas, options and opportunities, in this regard, but only **after** it has successfully executed its primary mission and helped to uplift lives in a community, village or town. Re-investment of profit will be critical for continuity of FPGA and its mission (FEWSH). One option is to charge for unit delivery of clean water for the end user (point of consumption). An unit may be defined as 100L per capita clean water per day, which is less than unit consumption⁶² in the US. The preferred business model is based on a micro-payment⁶³ structure.

For example, in India, can FPGA expect to receive 0.1 paisa per litre of water⁶⁴ consumed? For a household of four, annual use of 146,000 litres may cost INR146 or about US\$2pa. Household income of three-quarters of the Indian population (1.2 billion) is below INR100/day⁵⁸ or US\$500pa. Can this society afford to pay FPGA's share of US\$2 for water per annum per household? With 250 million households in India, it amounts to US\$500 million in revenue for FPGA per year. If we assume 99% of the revenue to pay for the cost of goods sold (COGS, operational cost), then 1% net profit earns FPGA US\$5 million/year. For the next frontier, the continent of Africa, with a population similar to India (1.2 billion), the potential to deliver 1% net profit may not be unreasonable, that is, another US\$5 million per year for FPGA. Optimistic scenarios where 1% of the global population (7.4 billion) may pay US\$20 per year (5.5 cents per day per person) may not be unrealistic. Cumulative micro-revenue from "affluent" sectors may approach US\$1.5 billion per year. Still assuming 1% net profit, it may contribute US\$15 million per year for FPGA.

There are no short-cuts on the long road to mega-profit from micro-revenue. But most efforts lack the patience to invest in the journey, yet to be. The 1% profit from pay-pennies-per-use model may be the bedrock of ethical sustainability for global public goods applications. These funds may be used to sustain FPGA family of organizations, reduce dependence on charity or grant funding, and accelerate the mission. FPGA is not about the business of global public goods. It's about access to public goods, globally.

The pay-per-use micro-revenue model may also apply to sense and response **detection systems** using nano-bio sensors (McLamore *et al*) and mobile phones for data visualization, analytics and alerts. FPGA Wii ushers in digital transformation⁶³ via the principles and practice of connectivity. Network of things (NoT)⁶⁵ connected in relationship with water, may leads us to the internet of water, an extension of the internet of things⁶³ (IoT) metaphor, including data of things (DoT) and cloud of things⁶⁶ (CoT)⁶⁷.

⁶² <https://water.usgs.gov/edu/qa-home-percapita.html>

⁶³ <https://dspace.mit.edu/handle/1721.1/111021>

⁶⁴ <http://www.worldbank.org/en/news/feature/2011/09/29/india-water>

⁶⁵ <https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-183.pdf>

⁶⁶ <http://news.mit.edu/2012/auto-id-cloud-of-things-big-data>

⁶⁷ <https://hal.inria.fr/hal-01116370/document>

What are the potential problem areas?

Adoption may be compromised by multiple factors, among them, fouling of the filters is a natural expectation. The latter necessitates that cartridges (if it is the unit design) must be easily replaced with minimum disruption of flow and without affecting the outcome (quality of the purified water).

Biological systems⁶⁸ may be refractory to scale-up, colligative properties of molecules changes with volume (hence, kinetics may be sub-optimal). Feedback inhibition⁶⁹ is common. Whether microscale properties of xylem filters can function in larger cross-sections, or when they are aggregated, and under pressure, remains to be explored for application level use, generating consistently reproducible results.

Optimization of cross-section, pressure, flow rate and ease of replacement, are the pre-dominant factors which may determine the effective functional diameter of the pipes capable of using the xylem filter cartridges. This information will be critical to ascertain how much of a “multiplier” may be necessary to fit the system for utility level infrastructure (distribution from nodes or purification stations to homes).

If the filter size and tube dimensions are not scalable, beyond what has been **achieved** at the domestic scale, then, we may have to crowd source engineers, whose ingenuity may enable the existing form factor to adapt, by aggregation, to serve the systemic need (utility level infrastructure deployment). The source of the xylem filter (fir/pine) may be unavailable in certain geographies. Different types of plant xylem may differ in flow rates and purification properties, hence, the need for calibration and standards.

Where are the solution spaces?

An issue of this magnitude can be paralyzed from action due to the deadweight of analysis. The number of unknowns and uncertainties far exceeds what we know, and have at hand, in terms of a water purification solution. Expecting a “business plan” approach is prudent in many cases, but this is not one of them. Without funding for the proof of concept, FPGA will die a cripple. Without visibility and help from a group of diverse, distributed leaders (Board of Advisors), the effort to fund Wii proof of concept cannot commence. There are far more complex⁷⁰ problems. If we are afraid to start Wii, because we may fail, then, we are, albeit inadvertently, burning down the bridges, once sparked by the pursuit of ideas⁷¹.

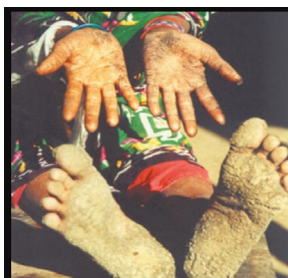


Fig 10: Arsenic Toxicity⁷²

⁶⁸ <https://www.jstor.org/stable/58682>

⁶⁹ <https://pubs.acs.org/doi/10.1021/ef502349v>

⁷⁰ <http://apps.who.int/iris/bitstream/handle/10665/274939/9789241514705-eng.pdf?ua=1>

⁷¹ <https://www.worthpoint.com/worthopedia/photo-essay-book-pursuit-ideas-year-1880630022>

⁷² <https://thisdayinwaterhistory.wordpress.com/2012/11/10/november-10/1110-bangladesh-arsenic/>

FPGA – THE NEXT CHAPTER – 3D PRINTED WATER FILTERS USING BIOCHAR OR DIATOMITE

Scalability of natural xylem filters⁷³ for water⁷⁴ supply infrastructure, for utilities, may stumble, if very frequent replacements are necessary due to fouling, depending on the source of the input water. The raw material for “fresh” xylem may impact the ecosystem of a class of trees, the source of xylem.

Sustainability issues may favor an academic-industry partnership, to explore inexpensive⁷⁵ “old” materials⁷⁶ in combination with advances⁷⁷ in additive manufacturing⁷⁸ (3D printing) to manufacture water filters. This suggestion is based on historical⁷⁹ use of diatomaceous⁸⁰ earth⁸¹ and emerging⁸² use of biochar⁸³ for water⁸⁴ filtration⁸⁵ and purification⁸⁶. There is evidence of commercial⁸⁷ use of diatomite⁸⁸ / diatomaceous earth and biochar⁸⁹ as materials⁹⁰ for 3D printing⁹¹. By exploring techniques⁹² to selectively engineer⁹³ and manage⁹⁴ pore size⁹⁵, these materials, may lead to large area⁹⁶ printed water filters.

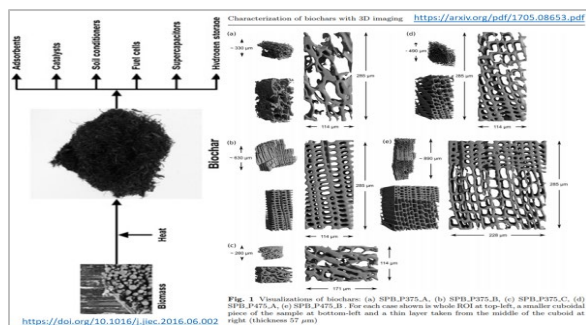


Figure 11: The many uses of biochar and structural characterization

⁷³ <https://arxiv.org/ftp/arxiv/papers/1310/1310.4814.pdf>

⁷⁴ <https://tatacenter.mit.edu/karnik-develops-plant-based-water-filter-for-rural-indian-communities/>

⁷⁵ <http://dx.doi.org/10.1016/j.jhazmat.2017.05.013>

⁷⁶ <https://doi.org/10.1080/10643389.2015.1096880>

⁷⁷ <https://onlinelibrary.wiley.com/doi/abs/10.1002/adma.201800159>

⁷⁸ <http://www.ddmsys.com/technologies/>

⁷⁹ <https://pubs.acs.org/doi/pdf/10.1021/ed007p2829>

⁸⁰ <https://iaspub.epa.gov/tdb/pages/treatment/treatmentOverview.do?processId=1942020127>

⁸¹ http://www.nesc.wvu.edu/pdf/dw/publications/ontap/2009_tbdiatomaceous_DWFSOM39.pdf

⁸² https://www.theseus.fi/bitstream/handle/10024/141397/Nick_Tapani.pdf?sequence=1

⁸³ https://mro.massey.ac.nz/bitstream/handle/10179/4288/02_whole.pdf?sequence=1&isAllowed=y

⁸⁴ <https://www.ncbi.nlm.nih.gov/pubmed/28454068>

⁸⁵ http://pprc.org/wp-content/uploads/2014/08/Emerging-Stormwater-BMPs_Biochar-as-Filtration-Media_2014.pdf

⁸⁶ <https://permies.com/t/86120/charred-biomass-clean-filter-purify>

⁸⁷ <https://patentimages.storage.googleapis.com/b3/05/ef/573e77ab605948/US20180280906A1.pdf>

⁸⁸ <https://pubs-acrs-org.libproxy.mit.edu/doi/pdf/10.1021/acsami.8b05878>

⁸⁹ <https://www.agrifutures.com.au/wp-content/uploads/publications/17-057.pdf#page=49>

⁹⁰ <https://pubs-acrs-org.libproxy.mit.edu/doi/pdf/10.1021/acssuschemeng.8b02283>

⁹¹ <https://core.ac.uk/download/pdf/56362921.pdf>

⁹² <https://ecs.confex.com/ecs/aimes2018/webprogram/Paper115813.html>

⁹³ <https://www.tandfonline.com/doi/abs/10.1080/10643389.2017.1418580>

⁹⁴ <https://doi.org/10.1007/s11368-015-1308-y>

⁹⁵ <http://www.fedoa.unina.it/11779/1/PhD%20thesis%20Ilaria%20CAPASSO.pdf>

⁹⁶ <https://www.3dprintingmedia.network/additive-manufacturing/am-technologies/what-is-lamp-technology/>

FIGURE 12 – BUSINESS MODEL – 3D PRINTED WATER FILTERS USING BIOCHAR OR DIATOMITE

The real value, from 3D printed filters made of biochar or diatomite, may be realized with rapid diffusion and adoption of the system, by the masses. Manufacturing and service cost for delivery of water is an issue with respect to earning capacity (GDP/capita) of the poorest places⁹⁷ on the earth (~\$2/day). Hence, the unit cost of delivered water must be affordable by the Central African Republic⁹⁸ and the unit volume of clean water is 0.1 cubic meters or 100 liters / person / day (36.5 cubic meters / capita / year).

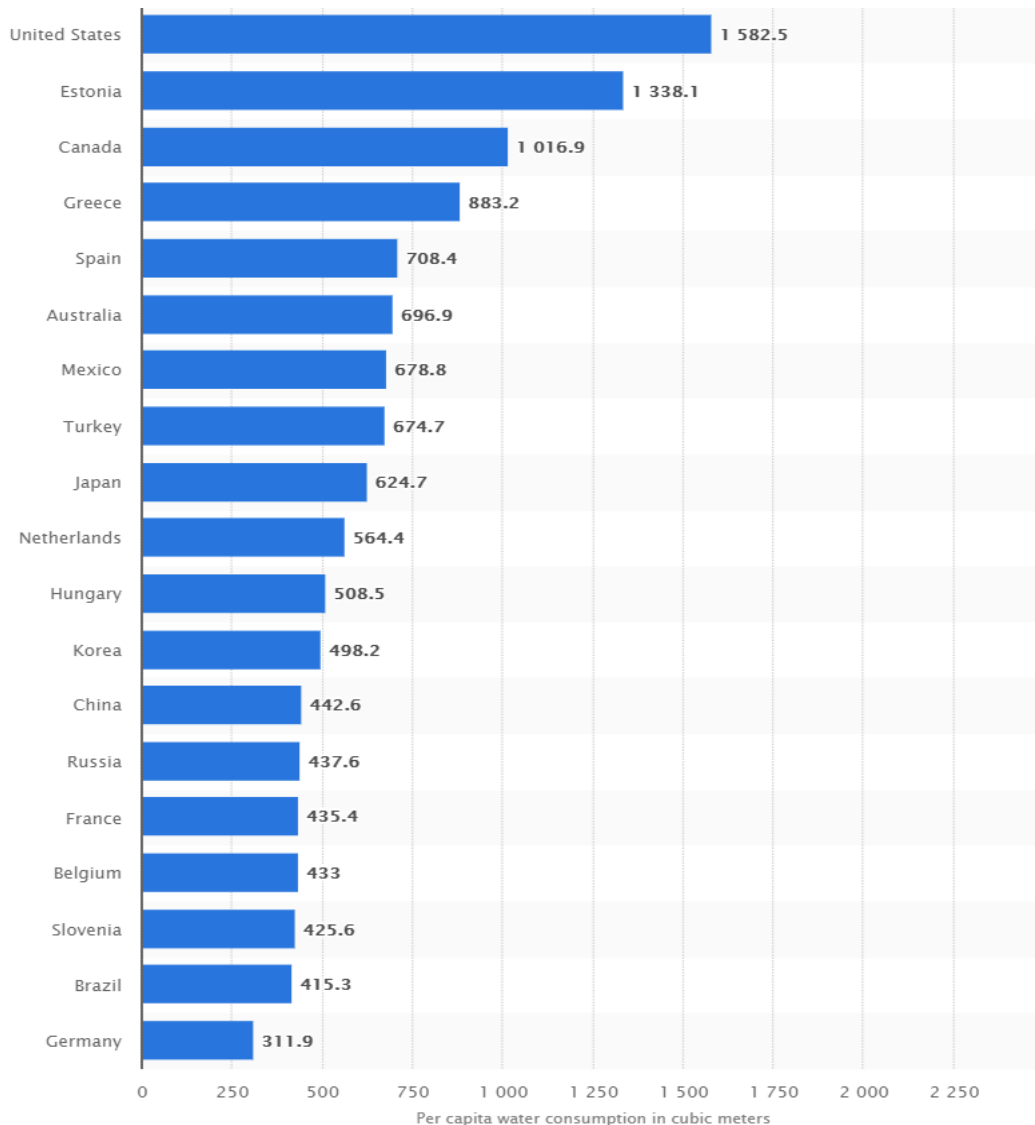


Figure 12: Annual water consumption⁹⁹ per capita (2016). Compare 36.5 m³ with US use of 15823 m³

⁹⁷ <https://borgenproject.org/poorest-countries-in-the-world/>

⁹⁸ <https://www.cia.gov/library/publications/the-world-factbook/geos/ct.html>

⁹⁹ <https://www.statista.com/statistics/263156/water-consumption-in-selected-countries/>

The suggested “unit” volume of clean water (0.1 cubic meters or 100 liters / person / day) was based on water consumption rates¹⁰⁰ in Figure 13. The suggested cost for 0.1 cubic meters of clean water is recommended to be a minimum of 0.1 cents (US\$0.001) and a maximum of 1.0 cents (US\$0.01). For a household of five, the maximum annual cost for clean water may not exceed US\$36.50, if the household consumes 1 cubic meter of water per day (equivalent US consumption more than 20 cubic meters / day). If a billion households, globally, used this system, gross annual earnings may be US\$36.5 billion. If only 0.1% of this revenue turns out to be profit, the net profit is US\$36.5 million per year.

Cities	Per Household		Per Capita	
	Mean	Std Deviation	Mean	Std Deviation
Delhi	377.7	256.8	78.0	49.9
Mumbai	406.8	158.6	90.4	32.6
Kolkata	443.2	233.6	115.6	64.9
Hyderabad	391.8	172.0	96.2	43.8
Kanpur	383.7	286.2	77.1	58.2
Ahmedabad	410.9	224.1	95.0	54.6
Madurai	363.1	182.1	88.2	44.4
Total	398.3	220.20	91.56	51.51

Figure 13: Domestic Water Consumption (L/day). Multiply liters (cm³) by 0.001 to convert to m³ (ref 100).

CONCLUSION – SOCIAL ENTREPRENEURSHIP MAY HELP INCULCATE ETHICAL PROFITABILITY

Social entrepreneurs may recognize that nano-earnings or micro-payments, are not divorced from creating financially *self-sustaining* structures, albeit over time, which can promote access to global public goods. Social business is not profit-less. It is the business of ethical profitability. Harvesting 0.1% to 1.0% profit could potentially lead to an embarrassment of riches, given the vast economies of scale.

Monitoring and monetizing pay-per-use schemes are linked to internet of things (IoT) metaphor. Systems connectivity for water delivery and water quality monitoring (an array of sensors) offers granular track and trace tools. If events are logged, usage-based charges may be recovered from consumers.

Manufacturing filters using AM (3D printing) may spawn a class of dedicated 3D printers. This 3D printer and material (biochar, diatomite, other) must be made available to every nook and cranny in the world, to local authorities, municipalities and communities. Convergence¹⁰¹ of cyber-manufacturing¹⁰² will make it possible to print the filters on demand, on site and stimulate economic growth and job creation. The implementation of infrastructure, by integrating these filters in utilities and water supply, are local public works undertaking (with global supervision). Involvement of industry is essential to manufacture these (specific) 3D printers and materials (powders). The operation must be structured as a MNC/global business, rather than an arm of a NGO or an academic goodwill gesture or a haphazard philanthropy.

844 million people lack even a basic drinking-water service. Globally, at least 2 billion people¹⁰³ use a drinking water source contaminated with faeces. About 4 billion people lack access to even basic sanitation¹⁰⁴ services, such as toilets, in part, due to lack of access to water.

¹⁰⁰ <http://indiaenvironmentportal.org.in/files/Water%20consumption%20patterns.pdf>

¹⁰¹ <http://dx.doi.org/10.1016/j.cirp.2016.06.005>

¹⁰² <https://www.sciencedirect.com/science/article/pii/S2213846316300049>

¹⁰³ <http://www.who.int/news-room/fact-sheets/detail/drinking-water>

¹⁰⁴ <https://www.un.org/sustainabledevelopment/water-and-sanitation/>

Causation – Correlation

Shoumen Palit Austin Datta, Massachusetts Institute of Technology and Massachusetts General Hospital, Harvard Medical School, Cambridge, Massachusetts 02139

If simulated¹, system dynamics² and³ agent based⁴ models⁵ may allow us to explore⁶ a range of impact⁷ of different variables⁸ on specific⁹ outcomes¹⁰. By altering parameters and metrics which can shape the outcome from these simulations¹¹, we may identify to what degree the variables may influence the outcome, independently and/or collectively. The co-dependencies¹² and inter-relationships¹³ between variables are central, and may become obvious, if models attempt to isolate and test the impact of variables, which cannot be isolated, in reality, due to functional inter-relationships (for example, what if sales and supply¹⁴ were separated). The latter is also applicable to human behavior¹⁵ related scenarios. To transform the output of these tools¹⁶ to deliver meaning, resilience¹⁷ and relevance¹⁸ in the real world, the simulated data (use of agents¹⁹) from pareto-optimal outcomes, may be targets which development economics must aspire to attain. For example, to reduce morbidity from diarrhoea by 10% we must increase availability of water by 20% and supply of cooking gas by 5%. On one hand, these numbers (outcome) may guide local municipalities or NGOs or development teams, to catalyze this change through capacity building and/or assess the risk²⁰ of economic²¹ loss if the situation is unattended. On the other hand, data-driven²² outcomes driving decision support²³ tools may guide policy²⁴ and loan managers, in global financial²⁵ institutions, to enable²⁶ financial structures necessary to deliver global²⁷ public goods. Convergence of concepts in physical and digital connectivity²⁸, classical operations research²⁹ with educational use³⁰ of simulation tools may promote systems thinking³¹, which is essential for science³² to better serve³³ society. Understanding causation³⁴ and true correlation is necessary to avoid hype³⁵.

¹ <https://ncase.me/loopy/>

² https://www.systemdynamics.org/assets/conferences/2004/SDS_2004/PAPERS/381BORSH.pdf

³ <https://www.tandfonline.com/doi/abs/10.1080/01441647.2012.745632>

⁴ <https://arxiv.org/ftp/arxiv/papers/1108/1108.3235.pdf>

⁵ <http://www.thwink.org/sustain/glossary/SystemDynamics.htm>

⁶ <https://www.techrepublic.com/article/systems-thinking-with-a-chromebook/>

⁷ <https://tangible.media.mit.edu/project/airportsim/>

⁸ <http://vensim.com/vensim-software/>

⁹ <https://doi.org/10.1016/j.phpro.2012.03.263>

¹⁰ https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NERL&dirEntryId=310977

¹¹ <https://www.systemdynamics.org/tools>

¹² https://link.springer.com/content/pdf/10.1007%2F978-0-387-74157-4_45.pdf

¹³ <https://thesystemsthinker.com/from-spreadsheets-to-system-dynamics-models/>

¹⁴ <https://tangible.media.mit.edu/project/tangible-business-process-analyzer/>

¹⁵ <http://dx.doi.org/10.1016/j.jenvman.2017.04.036>

¹⁶ <http://sysdyn.simantics.org/>

¹⁷ http://web.mit.edu/screponse/repository/Rice_SCRsp_Article_SCMR.pdf

¹⁸ <https://rmas.fad.harvard.edu/pages/change-control>

¹⁹ <https://dspace.mit.edu/handle/1721.1/41914>

²⁰ <https://link.springer.com/content/pdf/10.1007%2Fs13753-017-0154-5.pdf>

²¹ <https://doi.org/10.1007/s13753-018-0190-9>

²² <http://science.sciencemag.org/content/359/6373/325>

²³ <https://www.researchgate.net/publication/267635903>

²⁴ <https://issues.org/esty-2/>

²⁵ <https://www.brettonwoodsproject.org/2005/08/art-320747/>

²⁶ <https://www.ebrd.com/downloads/research/guides/finance.pdf>

²⁷ <https://nautilus.org/gps/applied-gps/global-public-goods/what-are-global-public-goods/>

²⁸ <http://dx.doi.org/10.1109/JIOT.2017.2755620>

²⁹ <http://www.bookmetrix.com/detail/book/7153d069-09a3-4211-a6cf-34588ef367e9#reviews>

³⁰ <http://supplychain.mit.edu/supply-chain-games/beer-game/>

³¹ <http://www.sfu.ca/~vdabbagh/Forrester68.pdf>

³² <https://theconversation.com/marie-curie-and-her-x-ray-vehicles-contribution-to-world-war-i-battlefield-medicine-83941>

³³ <http://science.sciencemag.org/content/295/5557/929>

³⁴ <http://links.jstor.org/sici?sici=0012-9682%28196908%2937%3A3%3C424%3AICRBEM%3E2.0.CO%3B2-L>

³⁵ <https://www.amazon.com/Freakonomics-Economist-Explores-Hidden-Everything/dp/0060731338>

COMMENTARY [G] D6, SNAPS & MORE

Shoumen Datta

HAPHAZARD REALITY – IOT IS A METAPHOR



SNAPS: A TRILOGY

PARTS – [0] [1] [2]

COMBINED

Shoumen Datta

HAPHAZARD REALITY – IOT IS A METAPHOR



Analyst

Accepted Manuscript

This article can be cited before page numbers have been issued, to do this please use: Y. Rong, A. Padron, K. Hagerty, N. Nelson, S. Chi, N. O. Keyhani, J. Katz, S. P. A. Datta, C. L. Gomes and E. S. McLamore, *Analyst*, 2018, DOI: 10.1039/C8AN00065D.



This is an Accepted Manuscript, which has been through the Royal Society of Chemistry peer review process and has been accepted for publication.

Accepted Manuscripts are published online shortly after acceptance, before technical editing, formatting and proof reading. Using this free service, authors can make their results available to the community, in citable form, before we publish the edited article. We will replace this Accepted Manuscript with the edited and formatted Advance Article as soon as it is available.

You can find more information about Accepted Manuscripts in the [author guidelines](#).

Please note that technical editing may introduce minor changes to the text and/or graphics, which may alter content. The journal's standard [Terms & Conditions](#) and the ethical guidelines, outlined in our [author and reviewer resource centre](#), still apply. In no event shall the Royal Society of Chemistry be held responsible for any errors or omissions in this Accepted Manuscript or any consequences arising from the use of any information it contains.

Post hoc support vector machine learning for biosensors based on weak protein-ligand interactions

Y. Rong^a, A.V. Padron^a, K. J. Hagerty^a, N. Nelson^b, S. Chi^{c,d}, N. O. Keyhani^d, J. Katz^e, S.P.A. Datta^{f,g}, C. Gomes^h, and E.S. McLamore^{*a}

Received 00th January 20xx,
Accepted 00th January 20xx

DOI: 10.1039/x0xx00000x

www.rsc.org/

Impedimetric biosensors for measuring small molecules based on weak/transient interactions between bioreceptor and target analyte are a challenge for detection electronics, particularly in field studies or in analysis of complex matrices. Protein-ligand binding sensors have enormous potential for biosensing, but accuracy in complex solutions is a major challenge. There is a need for simple *post hoc* analytical tools that are not computationally expensive, yet provide near real time feedback on data derived from impedance spectra. Here, we show use of a simple, open source support vector machine learning algorithm for analyzing impedimetric data from multiple protein-based biosensors, and we show that the tool can be used for point of need applications in analysis of small molecules such as acetone using a mobile phone. In all conditions tested, the open source classifier was capable of performing as well, or better, than equivalent circuit analysis for characterizing weak/transient interactions between a model ligand (acetone) and a small chemosensory protein derived from tsetse fly. In addition, the tool has a low computational requirement, facilitating use for mobile acquisition systems such as mobile phone. The protocol is deployed through Jupyter notebook (an open source computing environment available for mobile phone, tablet, or computer use) and the code was written in Python. For each of the applications we provide step-by-step instructions in English, Spanish, Mandarin, and Portuguese to facilitate widespread use. All codes were based on *scikit-learn*, an open source software machine learning library in the Python language, and were processed in Jupyter notebook, an open-source web application for Python. The tool can easily be integrated with mobile biosensor equipment for rapid detection, facilitating use by a broad range of impedimetric biosensor users. This *post hoc* analysis tool can serve as a launchpad for convergence of nanobiosensors in planetary health monitoring applications based on mobile phone hardware.

Introduction

Biosensors offer rapid analysis of targets ranging from small molecules, to biomolecules or cells, and can be applied across a wide variety of planetary health applications in medical, agricultural, and environmental analysis^{1,2}. With the advent of mobile phone electrochemical and plasmonic acquisition systems³⁻⁵, the portfolio of biosensors used in applied field studies is rapidly expanding. Biosensor accuracy, speed, range, and limit of detection are a function of the nature of molecular interactions between target analyte and bioreceptor structure, the transduction mechanism, inclusion of nanomaterials which enhance transduction, type of detection hardware, and acquisition approach (including *post hoc* analysis).

Among the various transduction approaches, electrochemical biosensors are one of the most popular device types, and most current devices combine electroactive nanomaterials (e.g., graphene, nanometal, electropolymers) with biorecognition

structures such as enzymes, antibodies, or aptamers, among others⁶⁻¹⁰. Use of transducer nanomaterials enhances signal acquisition, while the biological material is used to impart selective targeting and in some cases, catalyze a reaction¹¹⁻¹³. Impedimetric biosensors are most commonly developed based on Faradaic impedance (with redox couple in solution), but label-free biosensors using non-Faradaic impedance (absence of redox couple) are increasing in popularity^{14,15}. In either case, the output impedance depends on changes in the interfacial electron transfer resistance and/or electrostatic repulsion that result from steric hindrance caused by interactions of the target and bioreceptor¹⁶⁻¹⁸.

Interpretation of impedimetric biosensor data is often not trivial, particular for fast electron transfer processes in nanomaterial-modified electrodes, non-Faradaic impedance, or weak/transient interactions between bioreceptor and target. Impedance data are usually fit to an equivalent circuit model using χ^2 testing, and parameters derived from the model to describe the underlying electrochemistry. Changes in equivalent circuit parameters are commonly reported as sensor output, although impedance at a single frequency is occasionally used as sensor output¹⁴. Equivalent circuit analysis is based on combinations of the Principle of Superposition, Ohm's Law, and Kirchoff's Laws, and is very accurate for simple electrode geometries with homogenous surfaces. However, as circuit models are assumed *a priori*, there is not necessarily a correspondence between circuit elements and underlying physico-chemical processes¹⁹. Furthermore, inclusion of transducer nanomaterials on the sensor surface complicates the equivalent circuit model, requiring additional "fitting" elements. Thus, interpreting impedance data in complex solutions or with complex electrode geometries is challenging,

^a Agricultural & Biological Engineering, Institute of Food and Agricultural Sciences, University of Florida.

^b Biological & Agricultural Engineering, North Carolina State University.

^c Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences; Key Laboratory of Microbial Resources, Ministry of Agriculture, Beijing, China.

^d Department of Microbiology and Cell Sciences, Institute of Food and Agricultural Sciences, University of Florida.

^e Department of Oral and Maxillofacial Diagnostic Sciences, University of Florida

^f MIT Auto-ID Labs, Department of Mechanical Engineering, Massachusetts Institute of Technology,

^g Biomedical Engineering Program, Department of Anaesthesiology, Massachusetts General Hospital, Harvard Medical School.

^h Department of Mechanical Engineering, Iowa State University

* Footnotes relating to the title and/or authors should appear here.

Electronic Supplementary Information (ESI) available: [details of any supplementary information available should be included here]. See DOI: 10.1039/x0xx00000x

and is sometimes more art than science²⁰. The main challenge for planetary health biosensors is to balance enhancing conductivity with transducer nanomaterials (improving limit of detection) while limiting computational cost (maintaining speed), and at the same time developing simple label-free devices that can be used in diverse applications (ensuring robustness).

To improve limit of detection, many labs coat electrodes with nanomaterials such as graphene and/or nanometal, which is known to significantly enhance conductivity and electroactive surface area²¹⁻²³ while significantly decreasing charge transfer resistance (R_{ct}). This results in fast electron transfer processes, where Faradaic current is represented by a near-linear Nyquist plot. In a classic Randles-Ershler equivalent circuit, *post hoc* sensor analysis is usually constrained to R_{ct} , as other circuit parameters are a function of the solution resistance or inductance, which are not strong indicators of molecular interactions between bioreceptor and target analyte. This situation is particularly challenging for weak/transient interactions, where more complex circuit models with fitting parameters are required, increasing the computational cost while producing output parameters that have no physico-chemical meaning in the electrochemical circuit. There is a need for simple *post hoc* analytical techniques that can be used for point of need biosensors, particularly for field applications.

Machine learning has emerged as a powerful tool for analysis of sensor data in a wide range of applications, including: flow cytometry²⁴, electronic tongue/nose²⁵⁻²⁷, wearable sensors^{28, 29}, whole organism biosensing^{30, 31}, protein detection³², sensor material optimization³³, food safety risk analysis³⁴, environmental pollutant monitoring³⁵ and multiplexing sensors arrays³⁶⁻³⁸. These techniques provide a platform for development of systems-level planetary health solutions that focus on convergence of nanobiosensors, mobile phone sensor acquisition, and data analytics.

Here, we present an open source machine learning algorithm applied for label-free biosensors based on weak/reversible interactions that can be used with common mobile hardware (mobile phone or tablet). We demonstrate the utility of this approach for analysis of a biosensor based on reversible interactions between a small molecule (acetone) and insect-derived chemosensory proteins. *In vivo*, CSP solubilize volatile odorants and facilitate transport to downstream odorant receptors (ORs) through reversible association/disassociation^{39, 40}. This represents a model impedimetric biosensor based on interactions between low molecular weight binding proteins and small molecules. Biosensors based on CSP are becoming popular, but the transient ligand interactions and relationship to underlying electrochemistry are not well documented. As a comparison, we also analyzed weak/transient protein-biomolecule interactions (both protein-DNA and protein-protein) using well-known binding proteins with equivalent circuit analysis and machine learning. The protocol is based on Jupyter notebook (open source computing environment available for mobile phone, tablet, or computer use) and the code was written in Python. For each of the applications we provide step-by-step instructions in English, Spanish,

Mandarin, and Portuguese to facilitate widespread use for a variety of applications. The open source tool can easily be integrated with mobile biosensor equipment for rapid detection, facilitating use by a broad range of biosensor users.

Methodology

Strains and reagents

Escherichia coli strain Rosetta DE3 (Promega, Madison WI, USA) was routinely grown in Luria-Bertani broth (LB) and/or on LB-agar (1.5%) plates containing 50 $\mu\text{g}/\text{mL}$ kanamycin. All reagents and chemicals were purchased from Sigma-Aldrich (St. Louis, MO, USA) or Thermo Fischer Scientific (Waltham, MA, USA) except as noted. Potassium ferrocyanide ($\text{K}_4\text{Fe}(\text{CN})_6$), potassium ferricyanide ($\text{K}_3[\text{Fe}(\text{CN})_6]$), and potassium chloride (KCl) were purchased from EMD chemicals (Billerica, MA, USA). Ni- and Co-NTA agarose was purchased from Gold Biotech (St. Louis, MO, USA). Thrombin was purchased from Amersham-Pharmacia Biotech (Little Chalford, UK). Polycrystalline diamond suspensions (3 and 1 mm) alumina slurry (0.05mm) were purchased from Buehler (Lake Bluff, IL, USA).

Electrochemical analysis

For all electrochemical analysis, a three-electrode system was used together with an electrochemical impedance analyzer (ERZ100, eDAQ, Colorado, USA). All electrochemical impedance spectroscopy (EIS) studies used Pt/Ir working electrodes (MF-2013, 1.6 mm diameter, BASi, West Lafayette, USA), Ag/AgCl reference electrodes (BASi, West Lafayette, USA) and platinum auxiliary electrodes (BASi, West Lafayette, USA) with nanoplatinum deposited as previously described^{41, 42}. Before all experiments, the Pt/Ir working electrodes were polished with two sizes of polycrystalline diamond suspensions (3 and 1 μm), rinsed with methanol, polished with alumina slurry (0.05 μm) and then rinsed with deionized water. Probes were cleaned in a sonication bath in DI water for 15 min, then with 0.1 M H_2SO_4 using cyclic voltammetry (CV) at a potential range of -1.0V to +1.0V until the peak current changed by less than 1%, and then finally cleaned in a sonication bath in DI water for 15 min. To ensure consistency during adsorption studies, electrodes were fitted with a plastic cap that was 3D printed on a Makerbot Replicator 2 Desktop 3D printer (see supplemental Figure S1 for specifications).

EIS analyses were conducted at 0.25V (DC), with a 100mV (AC) amplitude in the range of 100 kHz to 1 Hz in a solution with 2.5 mM potassium ferrocyanide ($\text{K}_4[\text{Fe}(\text{CN})_6]$), 2.5 mM potassium ferricyanide ($\text{K}_3[\text{Fe}(\text{CN})_6]$), and 100 mM potassium chloride (KCl). For equivalent circuit analysis, all EIS data was transformed to Nyquist Plots and analyzed using ZMAN (WonATech, South Korea) 2.2 software or support vector classification analysis as noted.

Protein expression and purification

Recombinant insect chemosensory proteins (CSP) derived from *Glossina morsitans* (Gmm, tsetse fly) were heterologously expressed and purified from *E. coli* hosts using the methods described in detail by Song et al⁴³. Briefly, GmmCSP3 sequences were identified from genomic databases, codon optimized for *E. coli* expression, and synthesized/cloned into a

pUC vector (Genewiz, Plainfield, NJ). Expression constructs were synthesized with a 10X-histidine (10X C terminal His) tag and transformed into *E. coli* host cells. Single colony isolated via selection for ampicillin resistance on LB/ampicillin plates (100 µg/ml). Cells were harvested by centrifugation, washed with Co²⁺ equilibrium buffer, and suspended in the buffer. Protein purification was achieved using Co²⁺ affinity chromatography and elution of the bound protein with increasing concentrations of imidazole. Purity of the protein was assessed by SDS- polyacrylamide gel electrophoresis (SDS-PAGE) and pure fractions were pooled and dialyzed (3000kDa) against buffer (20 mM HEPES, pH 7.5). Protein concentration was quantified with SDS-PAGE, and samples were frozen at -80 °C until used.

Expression and purification of TATA binding protein (TBP) and multiprotein bridging factor 1 (MBF1) from *Beauveria bassiana* have been described in detail previously⁴³. Briefly, the coding sequences for both genes were codon optimized for expression in *E. coli* and synthesized (Genewiz) as above for the CSP proteins. Expression plasmids were transformed into competent *E. coli* Rosetta DE3 cells for expression and purification as above. Purified proteins were dialyzed, aliquoted and stored at -80°C until used. After protein elution using, purity was confirmed by SDS-PAGE. Protein concentration was determined using Pierce™ BCA Protein Assay Kit (Thermo Scientific).

PCR products were digested, and then cloned into respective sites of an expression vector to produce plasmids. Expression plasmids were transformed into competent *E. coli* Rosetta DE3 cells and transformed *E. coli* were cultured in LB broth, harvested, lysed, and then purified using Ni- or Co-NTA agarose columns. Purified 10XHis-tagged proteins were aliquoted and stored at -80°C until used. After protein elution using imidazole buffers, purity was confirmed by SDS-polyacrylamide gel electrophoresis (SDS-PAGE) and protein concentration was determined using Pierce™ BCA Protein Assay Kit (Thermo Scientific).

Protein adsorption onto sensor surface and sensor characterization

For characterizing acetone-CSP interactions, the optimal CSP concentration from previous studies⁴⁴ was used or all testing. Briefly, 2 µL of His-tagged GmmCSP3 (9.23 mg/mL) was drop cast on the surface of an electrodes, dried at 20°C for 5 minutes, and rinsed three times with DI water. A 5mM acetone stock solution was prepared in DI water, which is representative of salivary acetone levels for patients with DKA⁴⁵. Where noted, aliquots (2 µL) of acetone stock solution were drop cast on the surface of the biosensor, stored at 20°C for 2 minutes, and rinsed with DI water three times prior to testing. For biosensors based on protein-biomolecule interactions, the concentration in each experiment was based on Song et al⁴³. A 2 µL aliquot of His-tagged TBP was first drop cast on the surface of the electrode, agitated gently, allowed to dry at 20°C for 5 minutes, and rinsed with DI water prior to impedance analysis. Next, 2 µL aliquots of MBF1 (no His-tag) or TATA¹ (a 40 bp DNA sequence containing two potential TATA motifs) was drop cast onto the TBP-functionalized electrode, dried at 20°C for 5 minutes, and then rinsed with deionized

water three times prior to impedance analysis. Control experiments included using uncoupled (no TBP) surfaces as well as TBP-coupled + bovine serum albumin (BSA) solutions and TBP-coupled + TATA⁰ (a 35 bp DNA sequence lacking the TATA sequence in TATA¹).

Data analysis and statistics

EIS plots were analyzed with ZMAN 2.2 using an equivalent circuit model based on Chi² analysis. Equivalent circuit parameters, namely solution resistance (R_s), charge transfer resistance (R_{ct}), Warburg impedance (Z_w), double layer capacitance (C_{dl}), and constant phase element (Q) were estimated using Chi² fitting in the ZMAN software.

Nyquist and Bode plots were generated with ZMAN 2.2 and several key values were extracted within the software from equivalent circuit analysis. Namely, the Nyquist with equivalent circuit analysis were used to extract R_s, R_{ct}, Z_w, and C_{dl} from a Randels-Ershler equivalent circuit. Bode plots were used to extract the impedance at a given cutoff frequency and associated phase angle. In addition to the Randels-Ershler circuit, various equivalent circuit models (shown in supplemental S5) were tested with the model search function in ZMAN software where noted.

Support vector machine (SVM) classification

For protein-ligand interactions, EIS data were exported and transformed into samples with 152 features that represent both real and imaginary impedance at frequencies from 100kHz to 1Hz. The number of features was selected to satisfy expected confidence levels for principle components analysis. A total of 54 EIS scans were randomly split into two groups, with 80% of the data used as the training set and 20% used as the testing set. Each of the 54 data sets were binary labeled, with baseline impedance data in the absence of acetone labeled as "0", and labeled 1 in the presence of 5mM acetone. EIS data for both baseline (no acetone) and positive (5mM acetone) experiments were standardized and transformed into a two-dimensional dataset, and then mapped in a new data space. To initially screen the data, the four most common types of SVM kernels⁴⁶ were used to screen the data. A shuffled K-fold cross validation was used for all applications of SVM in this study⁴⁷; the training dataset was divided into ten folds and shuffled,, with 20% of the total data used for testing. The test accuracy shown for each kernel is the percentage of the prediction accuracy based on the decision boundaries. Prior to running the SVM algorithm, principal component analysis (PCA) was applied through singular value decomposition (SVD) to reduce the 152 features to two principal components. PCA was used to reduce the dimension of 152 features in the raw EIS data to a two-dimensional principal components matrix. Depending on the number of components to extract, full or randomized truncated SVD was used; this procedure was performed in LAPACK⁴⁸. To ensure generalizability across other varied application-specific biosensors, code screens were prepared for four types of SVM kernels (linear, sigmoidal, radial basis function, and polynomial) to identify which approach best segregates the

training data. This feature of the open source algorithm allows the user to select the most appropriate kernel for a given analysis by comparing the cross-validation results across kernel types. SVM hyperparameters (C and gamma) were optimized using grid search and random search methods^{46, 49}. C is a tradeoff between misclassification and simplicity of the decision surface. Gamma is proportional to the radius of influence for selected support vectors⁵⁰. All SVM codes were produced with “scikit-learn”, an open source machine learning library in Python⁵⁰, and were processed with Jupyter notebook, an open-source web application for Python (see supplemental section for step-by-step instructions in English, Spanish, Mandarin, and Portuguese and Python code).

To validate the functionality of the SVM classifier for a well-known detection system, a TBP-protein and TBP-DNA biosensor were fabricated based on published methods⁴³. The biosensor is based on interactions between TBP and either multiprotein bridging factor 1 (MBF1) (protein-protein binding) or TBP and TATA (protein-DNA). His-tagged TBP was first adsorbed to the electrode surface, and then EIS was used to study the interactions of TBP with either MBF (a 17 kDa protein) or TATA¹ (a TBP-binding 40mer DNA sequence). As a control, EIS data were also recorded after addition of buffer, a non-binding protein (BSA), and a non-binding 35mer sequence (TATA⁰). To challenge the approach for detection of small molecules, a CSP biosensor for detecting acetone was also developed. The experimental conditions were based on levels relevant to diagnosis of diabetic ketoacidosis (DKA), a potentially fatal outcome from complications associated with diabetes.

All experiments were repeated in triplicate, resulting in a total of 54 data sets. Analysis of variance (one-way ANOVA with Games-Howell method and 99% confidence) and student's t-test (two-sample t-test with 99.9% confidence) were performed for analyzing EIS data derived from equivalent circuit modeling as noted. All error bars represent the standard deviation of the arithmetic mean.

Results & Discussion

First, the functionality of the SVM classifier was validated for a well-known detection system using TBP-protein and TBP-DNA based on Song et al⁴³. This well-documented biosensor produces large changes in impedance after target binding, and serves as a simple case study for the machine learning tool. The biosensor is based on interactions between TBP and either MBF (protein-protein binding) or TBP and TATA¹, a 40 mer nucleotide sequence containing the TATA motif that is the recognition sequence bound by TBP, (protein-DNA). His-tagged TBP was first adsorbed to the electrode surface, and then EIS was used to study the interactions of TBP with either MBF (a 17 kDa protein) or TATA¹. As a control, EIS data were also recorded after addition of buffer, a non-binding protein (BSA), and a 35-mer nucleotide sequence lacking the TATA motif (TATA⁰).

Representative Nyquist plots show that adsorption of His-tagged TBP on the sensor surface caused a significant increase in R_{ct} , as expected (Fig 1a). Binding between TBP and MBF also

resulted in a significant change in charge transfer resistance, as did binding between TBP and TATA¹. A Randles-Ershler equivalent circuit ($\chi^2=1087 \pm 212$) was used to extract R_s , R_{ct} , Z_w , C_{dl} for each experiment (see supplemental Table S1 for details). Similar to other manuscripts in the literature⁵¹, R_{ct} was used as the most accurate parameter for characterizing protein-biomolecule interactions (Fig 1b). For comparison, addition of BSA or buffer did not result in any significant change in impedance due to non-specific binding (see supplemental Figure S2). EIS data was further analyzed by SVM classification by dividing the dataset into groups of TBP, TBP+MBF, and TBP+TATA¹. Of the screened kernels, the linear type successfully classified each of the interactions (test accuracy =100%) and was the simplest of the considered kernel types. Such accuracy was not surprising given the large change in R_{ct} for a protein-biomolecule interaction of this type (see Fig 1). Results associated with the other common, but more complex, kernels and their optimization parameters are shown in supplemental Figure S3-S4.

The molecular interactions between TBP and MBF/TATA¹ shown in Fig 1 can be viewed as between transient and permanent interactions⁵². For these moderate to tight biomolecule interactions, a basic Randles-Ershler equivalent circuit or SVM (linear kernel) analysis can be used to analyze the data. In the following section, we show that for analysis of much weaker reversible protein-ligand interactions, equivalent circuit analysis is not sufficient and more complicated SVM classification must be used for accurate analysis.

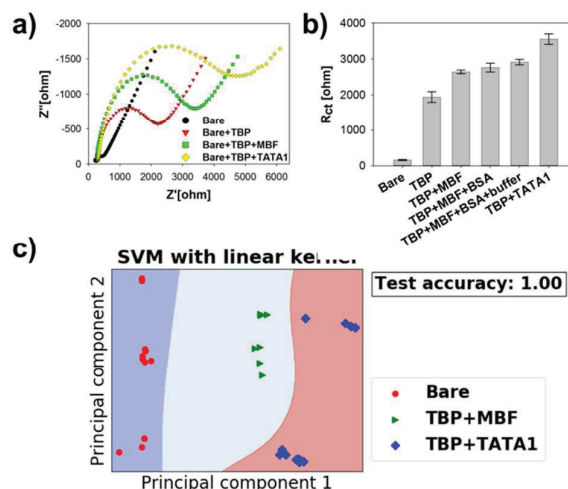


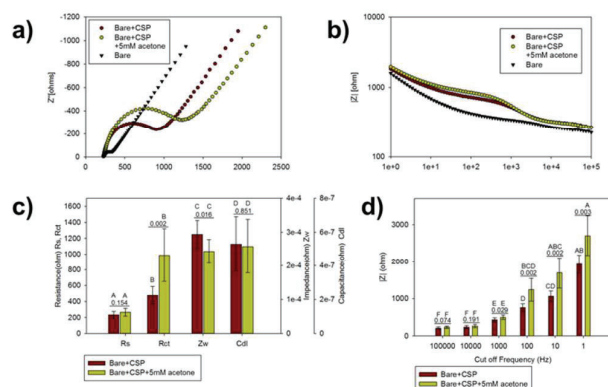
Figure 1. Impedimetric biosensor for the detection of protein-protein or protein-DNA interactions. **a)** Representative Nyquist plots for TBP-MBF interactions or TBP-TATA interactions clearly show an increase in charge transfer resistance after addition of target. **b)** Average R_{ct} derived from Randles-Ershler equivalent circuit model show significant results for TBP-biomolecule interactions but no significant change after addition of buffer or BSA (p values shown for each test group). **c)** Support vector machine (SVM) classification results with linear kernel. Additional Nyquist plots, average charge transfer resistance, and other SVM kernels are shown in the supplemental section.

Reversible protein-ligand interactions

To further challenge the machine learning tool, a CSP biosensor for detecting acetone at levels relevant for DKA triage diagnosis was developed and tested. DKA is a potentially fatal outcome from

1 complications associated with diabetes, and accurate measurement
 2 of acetone is challenging. CSP are an excellent candidate for binding
 3 volatiles such as acetone, but to date the technology has not been
 4 proven. Representative Nyquist plots (**Fig 2a**) and Bode plots (**Fig**
 5 **2b**) show that the adsorption of CSP onto the electrode caused a
 6 significant change in EIS spectra, but the change after addition of
 7 clinically relevant acetone (5 mM) was less pronounced.

8 For a more detailed *post hoc* analysis, a Randles-Ershler equivalent
 9 circuit was used to derive R_s , R_{ct} , Z_w , and C_{dl} as previously described
 10 (**Fig 2c**). In addition, net impedance at various cut-off frequencies
 11 was extracted from Bode plots (**Fig 2d**). Using a 99.9% confidence
 12 level, there was no significant difference between baseline
 13 measurements and average R_s ($p=0.015$), R_{ct} ($p=0.002$) Z_w ($p=0.016$),
 14 or impedance at any cut-off frequency ($p<0.002$) after addition of
 15 5mM acetone.



16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
Figure 2. EIS analysis of CSP-acetone interactions in the presence and absence of 5mM acetone. Representative a) Nyquist plots and b) Bode plots. c) Average parameters from Randles-Ershler equivalent circuit analysis (R_s , R_{ct} , Z_w and C_{dl}) from Randle's equivalent circuit, baseline data and EIS in the presence of 5mM acetone. d) Net impedance at representative cut off frequencies. In panels ac and d, numbers denote the p-value and uppercase letters denote statistically significant groups.

To further analyze the spectra, more complex equivalent circuit models were analyzed using ZMAN software with χ^2 fitting. All equivalent circuits with improved χ^2 fit (relative to Randles-Ershler) had more than four elements in various parallel/series connections, including at least one resistive element(R), capacitive element(C), constant phase element (Q) and inductive element (I) (see supplemental Fig S5). However, statistical analysis of the output parameters for these circuits also showed no significant difference in baseline and in the presence of acetone for replicate biosensors. Furthermore, there is no direct physical analogous biological structure to the constant phase elements (Q) produced by the model, further complicating the interpretation of the results and inducing bias on the interpretation.

The case study in **Fig 2** represents a common issue in non-Faradaic impedimetric biosensing where the device is based on interaction of proteins and small molecules. In such a case, the individual biosensor responds to target analyte, but variability of replicate sensors is high and interpretation of results at relevant levels is challenging. This is particularly true for weak/reversible interactions between small molecules and proteins where there is not an inherent reaction (as is the case for CSP-ligand binding). The CSP biosensor system is a promising biomimetic sensor system, but

more accurate *post hoc* tools are needed for accurate detection of target biomarkers. As described by Liu et al⁵³, the underlying cause for this challenge is likely a result of the nature of CSP-ligand binding in sensors. Liu et al showed that protein conformation change (backbone displacement) plays a major role in the electrical (Faradaic) properties of the sensor; this work was based on the honeybee protein Ac-ASP3. Since conformation changes can occur with non-specific interactions such as hydrogen bonding, CSP biosensors are subject to erroneous outputs due to non-specific interactions. To alleviate the false negative issue shown in **Fig 2**, EIS data was further analyzed by SVM classification.

SVM classification for acetone-CSP interactions

The decision boundaries for each kernel are shown in **Fig 3**, where testing data that fall into blue areas is predicted as negative (no acetone) and those that fall in red areas as positive (≥ 5 mM acetone). As discussed by Liu et al⁵⁴, other *post hoc* algorithms not analyzed here, such as random forest, may be more accurate in some cases. However, these approaches often increase accuracy by overfitting the data⁵⁵, which ultimately decreases the robustness of the classifier. Moreover, many of these are computationally expensive and cannot be analyzed using mobile hardware such as a mobile phone or tablet. The Gaussian radial base function (RBF) kernel (accuracy = 98%) had the highest test accuracy for classifying the training dataset. However, using the default kernel settings the dataset was not linearly separable and the RBF kernel had an overfitting issue, requiring further analysis and tuning of the parameters.

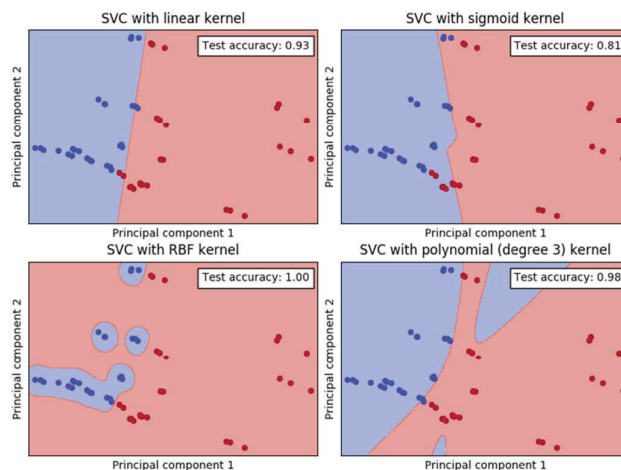


Figure 3. SVM classification for CSP-acetone biosensors using four common kernels. a) linear kernel (test accuracy =96%), b) sigmoidal kernel (test accuracy =83%), c) radial base function kernel (test accuracy =98%), and d) polynomial kernel (test accuracy =96%). Blue dots represented baseline EIS signals (no acetone in samples) and red dots represented positive EIS signals (5mM acetone in samples). The decision surface of these four SVM classifiers are plotted by red and blue regions.

To tune the RBF kernel parameters, a grid search and cross validation were performed. In cross validation, the original dataset was shuffled and divided into ten different training and testing sets, with 20% of the total data used for testing. Next, each training set was used to fit the SVM classifier and average test accuracy calculated for each split training set. In the RBF kernel, the two governing hyper-parameters are the

penalty parameter (C) and non-linear kernel coefficient (γ). The penalty hyper-parameter trades off misclassification against simplicity of decision surface, where lower C values tolerate more mistakes. The non-linear parameter defines the influence of a single training example on the output, and can be seen as the inverse of the radius of the influence of support vectors⁵⁰. Each of these parameters were optimized using a grid parameter search function using the RBF kernel (Fig 4). In the top left panel of Fig 4, where C is low, the penalty for misclassification is small and the decision surface is simple relative to values in the first column with higher C values. As the nonlinear hyper-parameter increases (from left to right in Fig 4), the influence radius decreases, causing over-fitting. The protocol described herein resolves this issue by creating a visualization tool to select the optimum hyper-parameters.

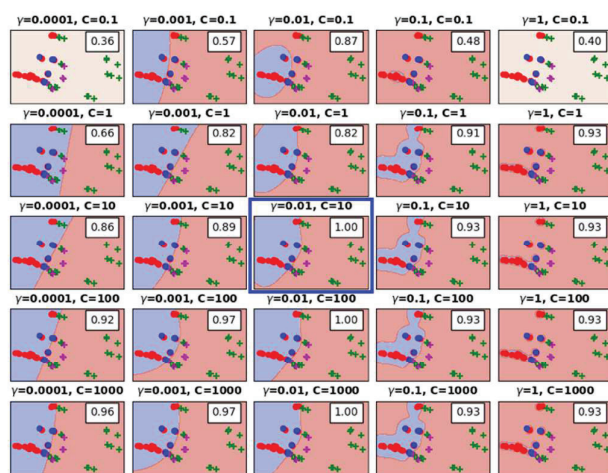


Figure 4. Tuning of RBF hyper-parameters (C and γ) for CSP acetone interactions. Representative SVM classification results for one training and testing set show the effects of parameters C and γ in the output of the RBF kernels. Red and blue circles represent the baseline samples in training and testing sets; green and purple plus symbols represent the positive signals in training and testing sets. The background blue and red region indicated the classifier decision surface, where all data fall into the red region are predicted as positive. Cross-validation scores are shown in the top right corner of each subplot. The optimal classifier zone is highlighted with a blue rectangle in the center of the image.

The Python code has a built-in function to optimize the hyper-parameters from data such as that shown in Fig 4. Based on this heat map (Fig 5), the optimum value of γ was 0.01, and the optimum value of C was 10. Using these parameters, the Python code is then modified (see details in step-by-step user guide) and the data is analyzed. Using the optimized kernel selection and hyper-parameters, the SVM demonstrated an accuracy of $95 \pm 4\%$ in cross validation and prediction of test samples.

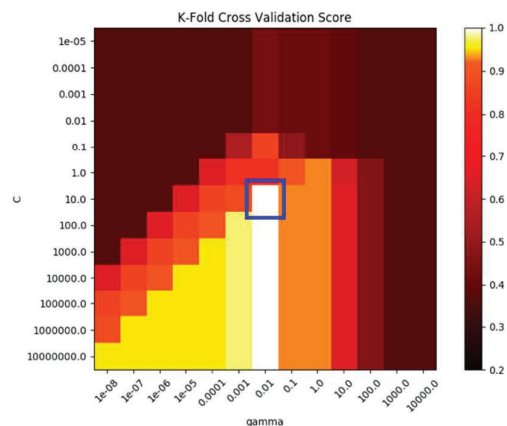


Figure 5. Heatmap of validation accuracy as a function of RBF parameters C and γ . The color indicates the cross-validation accuracy, where lighter colors represent a higher cross-validation score. Optimal parameters are highlight with a blue rectangle in the center

Decomposition of high dimensional EIS data to two-dimensional data with PCA is known to improve sensor/detector accuracy due to identification of uncorrelated variables from a large set of data⁵⁶. PCA explains the maximum amount of data variance with the fewest number of principal components. For a semi-quantitative biosensor application such as the data in Fig 1-5, the use of only two principal components can lead to loss of useful information during data decomposition. However, for the RFP kernel with optimal tuning parameters the results were statistically significant at the 95% confidence interval. To further analyze the dataset, classifiers with 3 and 10 principal components were built and the cross-validation accuracy was improved ($97 \pm 3\%$), which is expected as less information was lost during decomposition (a 3D data representation for data analyzed with three principal components is shown in supplemental Fig S6). This result was expected, as use of reductionist clustering (i.e., using two-dimensional PCA) increases the risk of eliminating important outliers within the data. For example, over-clustering could result in important deviations from the "normal", for example in the case of silent ischemia⁵⁷. In this case the data curation can be improved by analyzing polar coordinates in lieu of, or in addition to, Cartesian coordinates from impedimetric sensor data. However, analysis of classifiers with a dimension larger than two is computationally expensive, and can make use of mobile phone based analytical systems challenging. Care should be taken to discern as to whether the computational need outweighs the ability to analyze data on site using mobile equipment such as a tablet or mobile phone. To maintain focus on mobile-enabled diagnostic systems in this study, we used a two-dimensional PCA analysis, which is valid for semi-quantitative biosensor data where a regulatory or diagnostic metric is known (such as the case of DKA salivary biomarkers shown here).

Although not used here, computational speed and memory requirement can be improved by using more advanced computational tools such as the tensor compiler by Kjolstad et al⁵⁸. This approach is particularly useful for multidimensional data analysis, and provides a generic mechanism that can

generate code for compound tensor operations with sparse tensors, eliminating the need for writing optimized code for a specific problem. This tensor algebra compiler library represents an excellent next step forward to improve the work herein.

The SVM tool shown here is highly useful for point of need small molecule analysis using mobile detection and analysis systems (see supplemental Figure S7). Rapid triage analysis of breath biomarkers (including acetone and β -hydroxybutyrate) is vital for triage analysis of patients with DKA symptoms, and mobile phone solutions can bring this diagnosis to rural areas where health care is limited. The overall mortality rate for DKA ranges from 1 to 10% of all patient admissions, and an even higher mortality rate is found among non-hospitalized patients and children under the age of 10⁵⁹. Convergent technologies for triage diagnostics require systems-level solutions that are based on readily accessible hardware such as mobile phones or tablets⁶⁰.

Conclusions

Biosensors based on weak/transient interactions between small molecules and bioreceptors are a challenge for detection electronics, particularly in field studies or in analysis of complex matrices (e.g., body fluids, food, river water, etc.) using non-Faradaic impedimetric sensors. Support vector machine learning tools are facile *post hoc* analysis tools that do not require significant computational power and can be used for *in situ* analysis with mobile hardware such as a mobile phone or tablet. Here, we show use of a simple, open source machine learning algorithm for analysing such impedimetric data, and we show that the tool can be used for point of need applications.

Conflicts of interest

There are no conflicts to declare.

Acknowledgements

The authors would like to thank the Agricultural & Biological Engineering PhD Fellowship (YR), the UF Opportunity Fund grant (ESM, NOK), the National Science Foundation Nanobiosensors program (ESM; Grant No. CBET-1511953, Nanobiosensing) and China Scholarship Council Fellowship (CS; No. 201303250074). The authors also thank Dr. Daniel Jenkins (University of Hawaii-Manitoba) for collaborating on use of the mobile phone acquisition system using an Android phone (ABE STAT).

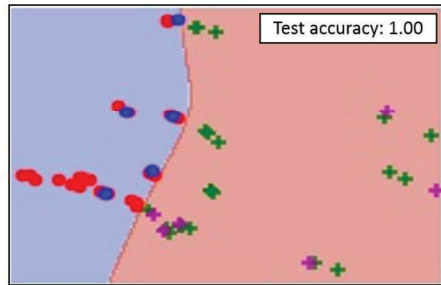
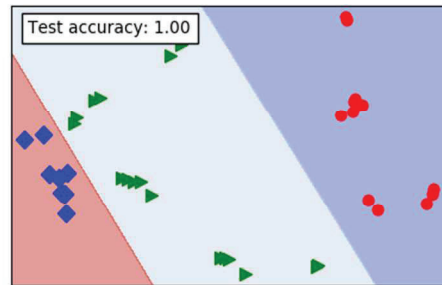
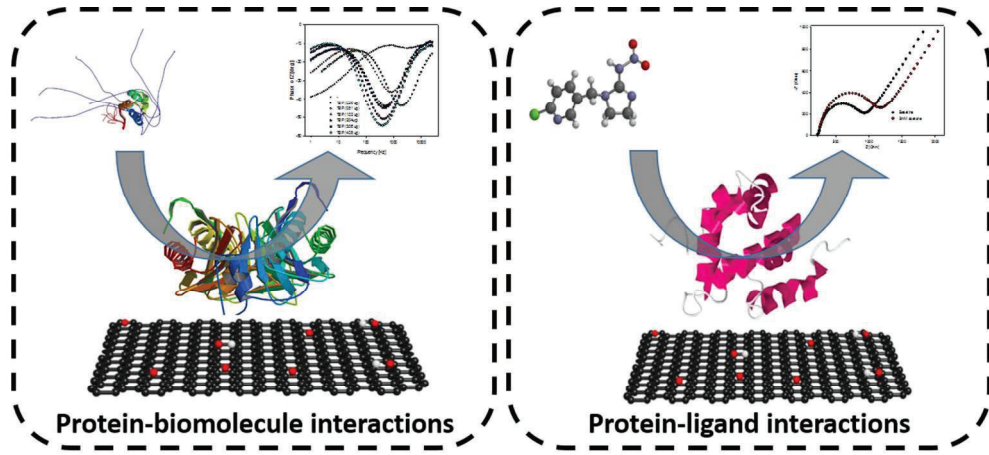
References

1. A. P. F. Turner, *Chemical Society reviews*, 2013, **42**, 3184-3196.
2. A. R. Demaio and J. Rockstroem, *Lancet*, 2015, **386**, E36-E37.
3. D. Z. Ji, L. Liu, S. Li, C. Chen, Y. L. Lu, J. J. Wu and Q. J. Liu, *Biosens Bioelectron*, 2017, **98**, 449-456.

4. L. Liu, D. M. Zhang, Q. Zhang, X. Chen, G. Xu, Y. L. Lu and Q. J. Liu, *Biosens Bioelectron*, 2017, **93**, 94-101.
5. D. M. Zhang, J. Jiang, J. Y. Chen, Q. Zhang, Y. L. Lu, Y. Yao, S. Li, G. L. Liu and Q. J. Liu, *Biosens Bioelectron*, 2015, **70**, 81-88.
6. A. Hayat and J. L. Marty, *Front Chem*, 2014, **2**.
7. D. Vanegas, C. Gomes and E. McLamore, *Biosens J*, 2016, **5**, 2.
8. A. Walcarius, S. D. Minter, J. Wang, Y. Lin and A. Merkoçi, *J Mater Chem B*, 2013, **1**, 4878-4908.
9. A. Bonanni, A. H. Loo and M. Pumera, *TrAC Trends in Analytical Chemistry*, 2012, **37**, 12-21.
10. T. Yin and W. Qin, *TrAC Trends in Analytical Chemistry*, 2013, **51**, 79-86.
11. M. A. Daniele, M. Pedrero, S. Burrs, P. Chaturvedi, W. W. A. Wan Salim, F. Kuralay, S. Campuzano, E. McLamore, A. A. Cargill, S. Ding and J. C. Claussen, in *Nanobiosensors and Nanobioanalyses*, eds. M. d. C. Vestergaard, K. Kerman, I. M. Hsing and E. Tamiya, Springer Japan, Tokyo, 2015, DOI: 10.1007/978-4-431-55190-4_8, pp. 137-166.
12. C. Z. Zhu, G. H. Yang, H. Li, D. Du and Y. H. Lin, *Anal Chem*, 2015, **87**, 230-249.
13. E. S. McLamore, M. Convertino, I. Ocsoy, D. C. Vanegas, M. Taguchi, Y. Rong, C. Gomes, P. Chaturvedi and J. C. Claussen, in *Semiconductor-Based Sensors*, WORLD SCIENTIFIC, 2016, DOI: 10.1142/9789813146730_0002, pp. 35-67.
14. J. S. Daniels and N. Pourmand, *Electroanal*, 2007, **19**, 1239-1257.
15. E. B. Bahadir and M. K. Sezgenturk, *Artif Cells Nanomed Biotechnol*, 2016, **44**, 248-262.
16. M. I. Prodromidis, *Electrochim Acta*, 2010, **55**, 4227-4233.
17. J.-G. Guan, Y.-Q. Miao and J.-R. Chen, *Biosensors and Bioelectronics*, 2004, **19**, 789-794.
18. R. Elshafey, A. C. Tavares, M. Siaj and M. Zourob, *Biosens Bioelectron*, 2013, **50**, 143-149.
19. D. D. Macdonald, *Electrochim Acta*, 2006, **51**, 1376-1388.
20. M. E. Orazem, P. Agarwal and L. H. Garciarubio, *J Electroanal Chem*, 1994, **378**, 51-62.
21. S. R. Das, Q. Nian, A. A. Cargill, J. A. Hondred, S. W. Ding, M. Saei, G. J. Cheng and J. C. Claussen, *Nanoscale*, 2016, **8**, 15870-15879.
22. W. J. Yuan, Y. Zhou, Y. R. Li, C. Li, H. L. Peng, J. Zhang, Z. F. Liu, L. M. Dai and G. Q. Shi, *Sci Rep-Uk*, 2013, **3**.
23. I. I. Suni, *TrAC Trends in Analytical Chemistry*, 2008, **27**, 604-611.
24. H. Song, Y. Wang, J. M. Rosano, B. Prabhakarpandian, C. Garson, K. Pant and E. Lai, *Lab Chip*, 2013, **13**, 2300-2310.
25. R. Kumar, A. P. Bhondekar, R. Kaur, S. Vig, A. Sharma and P. Kapur, *Sensor Actuat B-Chem*, 2012, **171**, 1046-1053.
26. Q. Dong, L. Du, L. Zhuang, R. Li, Q. Liu and P. Wang, *Biosens Bioelectron*, 2013, **49**, 263-269.
27. L. Lu, S. P. Deng, Z. W. Zhu and S. Y. Tian, *Food Analytical Methods*, 2015, **8**, 1893-1902.
28. Y. X. Dai, X. Wang, P. B. Zhang and W. H. Zhang, *Measurement*, 2017, **109**, 408-424.
29. X. Ding, Z. Lv, C. Zhang, X. Gao and B. Zhou, *IEEE Access*, 2017.
30. Z. Qin, B. Zhang, K. Gao, L. Zhuang, N. Hu and P. Wang, *Sensors and Actuators B: Chemical*, 2017, **239**, 746-753.
31. O.-P. Smolander, A. S. Ribeiro, O. Yli-Harja and M. Karp, *Sensors and Actuators B: Chemical*, 2009, **141**, 604-609.
32. E. Akbari, Z. Buntat, E. Shahraki, R. Parvaz and M. J. Kiani, *Journal of biomaterials applications*, 2016, **30**, 677-685.

- 1 33. F. F. Gonzalez-Navarro, M. Stilianova-Stoytcheva, L. Renteria-Gutierrez, L. A. Belanche-Muñoz, B. L. Flores-Rios and J. E. Ibarra-Esquer, *Sensors-Basel*, 2016, **16**, 1483.
- 2
- 3 34. Z. Q. Geng, S. S. Zhao, G. C. Tao and Y. M. Han, *Food Control*, 2017, **78**, 33-42.
- 4
- 5 35. S. De Vito, E. Esposito, M. Salvato, O. Popoola, F. Formisano, R. Jones and G. Di Francia, *Sensors and Actuators B: Chemical*, 2017, DOI: <https://doi.org/10.1016/j.snb.2017.07.155>.
- 6
- 7
- 8 36. O. Sadik, W. H. Land, A. K. Wanekaya, M. Uematsu, M. J. Embrechts, L. Wong, D. Leibensperger and A. Volykin, *Journal of chemical information and computer sciences*, 2004, **44**, 499-507.
- 9
- 10
- 11 37. T. Alizadeh and S. Zeynali, *Sensors and Actuators B: Chemical*, 2008, **129**, 412-423.
- 12
- 13 38. Y. Zuo, S. Chakrabartty, Z. Muhammad-Tahir, S. Pal and E. C. Alocilja, *Ieee Sens J*, 2006, **6**, 1644-1651.
- 14
- 15 39. R. G. Vogt, in *Comprehensive Molecular Insect Science*, Elsevier, Amsterdam, 2005, DOI: <https://doi.org/10.1016/B0-44-451924-6/00047-8>, pp. 753-803.
- 16
- 17
- 18 40. A. Sanchez-Gracia, F. G. Vieira and J. Rozas, *Heredity*, 2009, **103**, 208-216.
- 19
- 20 41. D. C. Vanegas, M. Taguchi, P. Chaturvedi, S. Burrs, M. Tan, H. Yamaguchi and E. S. McLamore, *Analyst*, 2014, **139**, 660-667.
- 21
- 22 42. S. L. Burrs, D. C. Vanegas, Y. Rong, M. Bhargava, N. Mechulan, P. Hendershot, H. Yamaguchi, C. Gomes and E. S. McLamore, *Analyst*, 2015, **140**, 1466-1476.
- 23
- 24 43. C. Song, A. Ortiz-Urquiza, S. H. Ying, J. X. Zhang and N. O. Keyhani, *Plos One*, 2015, **10**.
- 25
- 26 44. Y. Rong, J. Kieran-Lewis, N. O. Keyhani and E. S. McLamore, 2016.
- 27
- 28 45. S. Fujii, T. Maeda, I. Noge, Y. Kitagawa, K. Todoroki, K. Inoue, J. Z. Min and T. Toyo'oka, *Clin Chim Acta*, 2014, **430**, 140-144.
- 29
- 30 46. C.-W. Hsu, C.-C. Chang and C.-J. Lin, 2003.
- 31
- 32 47. T. Hastie, R. Tibshirani and J. Friedman, in *The Elements of Statistical Learning: Data Mining, Inference, and Prediction*, Springer New York, New York, NY, 2009, DOI: 10.1007/978-0-387-84858-7_7, pp. 219-259.
- 33
- 34 48. N. Halko, P. G. Martinsson and J. A. Tropp, *Siam Rev*, 2011, **53**, 217-288.
- 35
- 36 49. J. Bergstra and Y. Bengio, *J Mach Learn Res*, 2012, **13**, 281-305.
- 37
- 38 50. F. Pedregosa, G. Varoquaux, A. Gramfort, V. Michel, B. Thirion, O. Grisel, M. Blondel, P. Prettenhofer, R. Weiss, V. Dubourg, J. Vanderplas, A. Passos, D. Cournapeau, M. Brucher, M. Perrot and E. Duchesnay, *J Mach Learn Res*, 2011, **12**, 2825-2830.
- 39
- 40 51. S. W. Ding, C. Mosher, X. Y. Lee, S. R. Das, A. A. Cargill, X. H. Tang, B. L. Chen, E. S. McLamore, C. Gomes, J. M. Hostetter and J. C. Claussen, *Acs Sensors*, 2017, **2**, 210-217.
- 41
- 42 52. I. M. Nooren and J. M. Thornton, *Journal of molecular biology*, 2003, **325**, 991-1018.
- 43
- 44 53. Q. J. Liu, H. Wang, H. L. Li, J. Zhang, S. L. Zhuang, F. N. Zhang, K. J. Hsia and P. Wang, *Biosens Bioelectron*, 2013, **40**, 174-179.
- 45
- 46 54. M. Liu, M. Wang, J. Wang and D. Li, *Sensors and Actuators B: Chemical*, 2013, **177**, 970-980.
- 47
- 48 55. T. Hastie, R. Tibshirani and J. Friedman, in *The Elements of Statistical Learning: Data Mining, Inference, and Prediction*, Springer New York, New York, NY, 2009, DOI: 10.1007/978-0-387-84858-7_2, pp. 9-41.
- 49
- 50 56. H. Abdi and L. J. Williams, *Wiley interdisciplinary reviews: computational statistics*, 2010, **2**, 433-459.
- 51
- 52 57. P. F. Cohn, K. M. Fox and C. Daly, *Circulation*, 2003, **108**, 1263-1277.
- 53
- 54 58. F. Kjolstad, S. Kamil, S. Chou, D. Lugato and S. Amarasinghe, 2017.
- 55
- 56 59. R. Ganesh, N. Suresh and J. Ramesh, *The National medical journal of India*, 2006, **19**, 155-158.
- 57
- 58 60. R. Chiu, C. Ho, S. Tong, K. Ng and C. Lam, *Hong Kong medical journal= Xianggang yi xue za zhi/Hong Kong Academy of Medicine*, 2002, **8**, 172-176.
- 59
- 60

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60



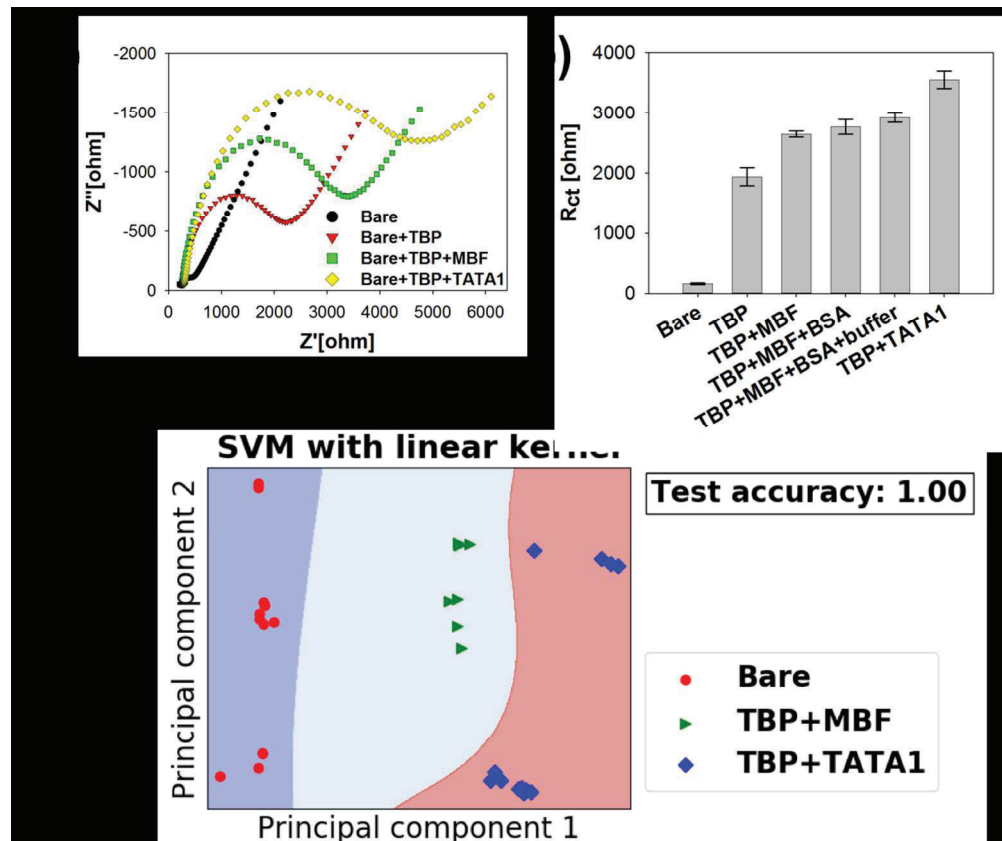


Figure 1. Impedimetric biosensor for the detection of protein-protein or protein-DNA interactions. a) Representative Nyquist plots for TBP-MBF interactions or TBP-TATA interactions clearly show an increase in charge transfer resistance after addition of target. b) Average R_{ct} derived from Randles-Ershler equivalent circuit model show significant results for TBP-biomolecule interactions but no significant change after addition of buffer or BSA (p values shown for each test group). c) Support vector machine (SVM) classification results with linear kernel. Additional Nyquist plots, average charge transfer resistance, and other SVM kernels are shown in the supplemental section

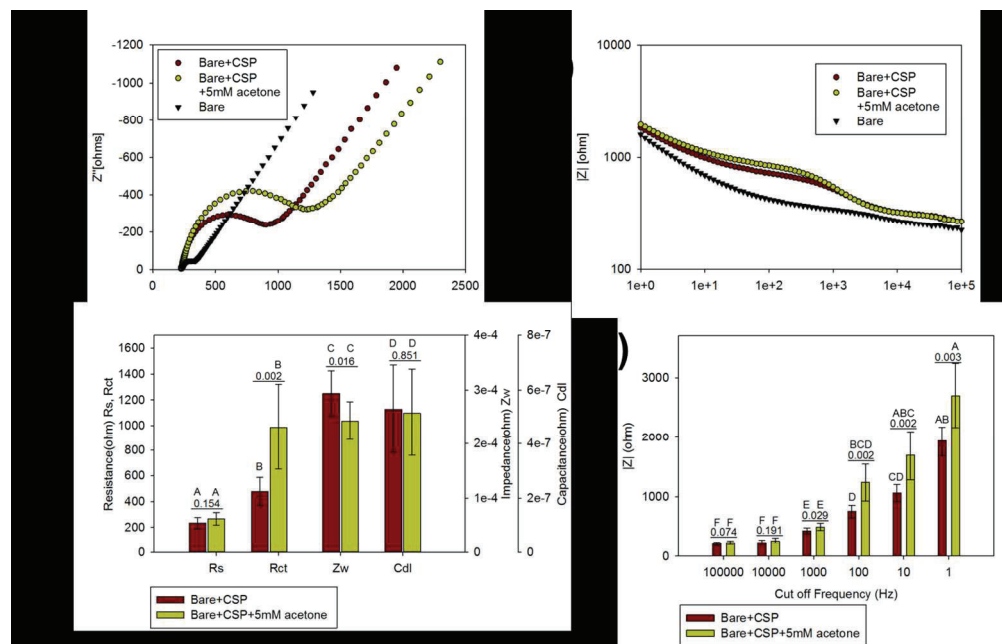


Figure 2. EIS analysis of CSP-acetone interactions in the presence and absence of 5mM acetone. Representative a) Nyquist plots and b) Bode plots. c) Average parameters from Randles-Ershler equivalent circuit analysis (R_s , R_{ct} , Z_w and C_{dl}) from Randel's equivalent circuit, baseline data and EIS in the presence of 5mM acetone. d) Net impedance at representative cut off frequencies. In panels ac and d, numbers denote the p-value and uppercase letters denote statistically significant groups.

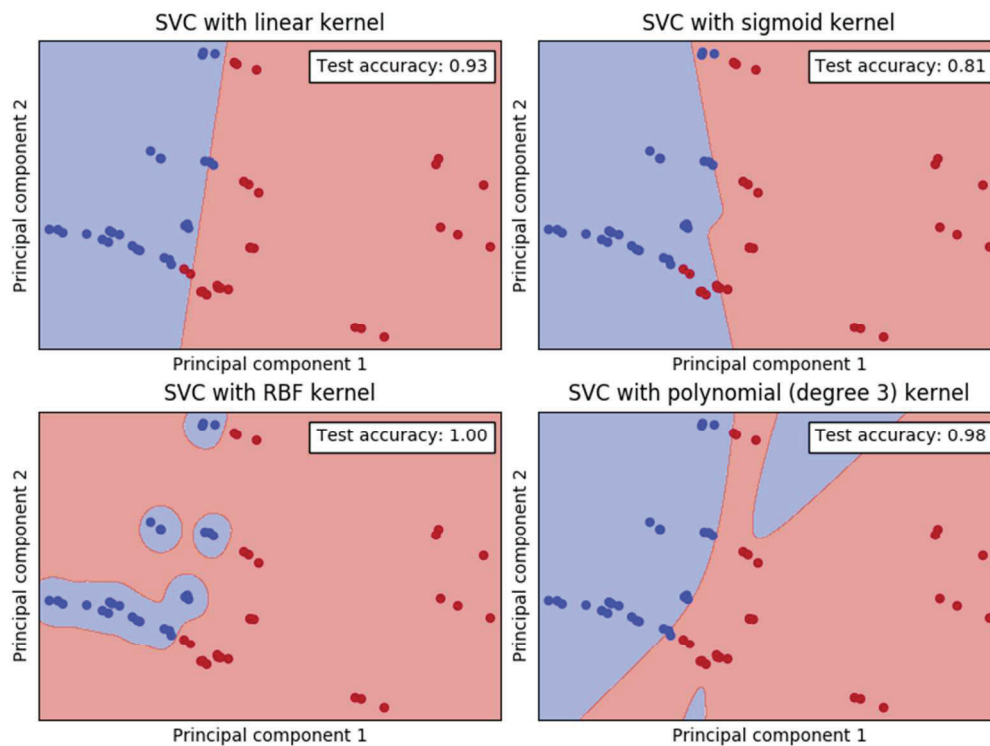


Figure 3. SVM classification for CSP-acetone biosensors using four common kernels. a) linear kernel (test accuracy =96%), b) sigmoidal kernel (test accuracy =83%), c) radial base function kernel (test accuracy =98%), and d) polynomial kernel (test accuracy =96%). Blue dots represented baseline EIS signals (no acetone in samples) and red dots represented positive EIS signals (5mM acetone in samples). The decision surface of these four SVM classifiers are plotted by red and blue regions.

203x151mm (100 x 100 DPI)

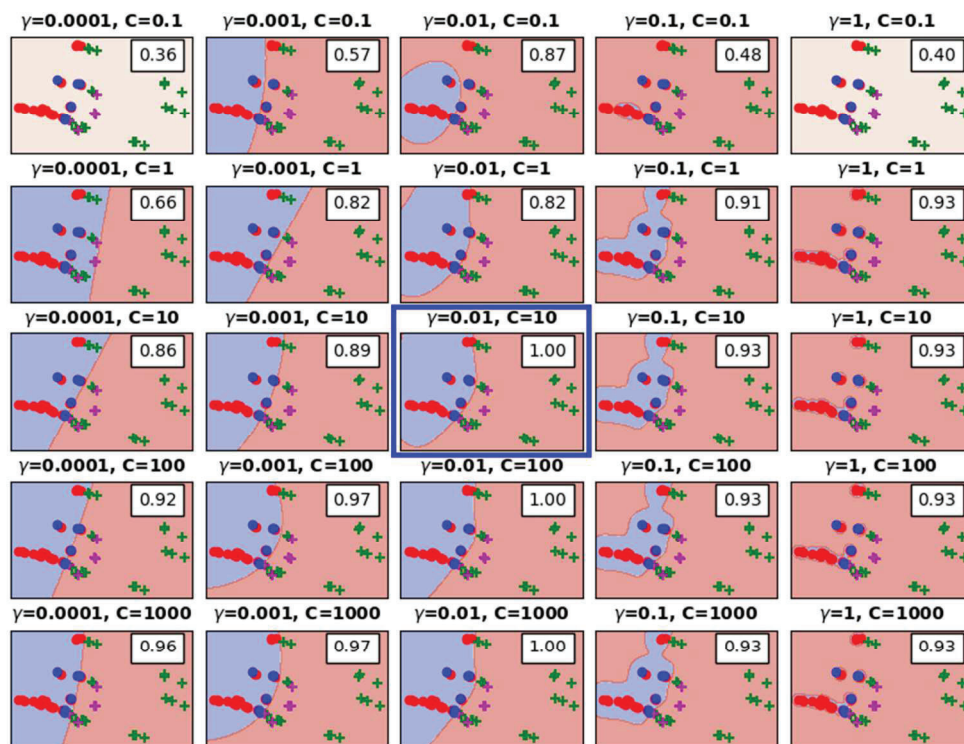
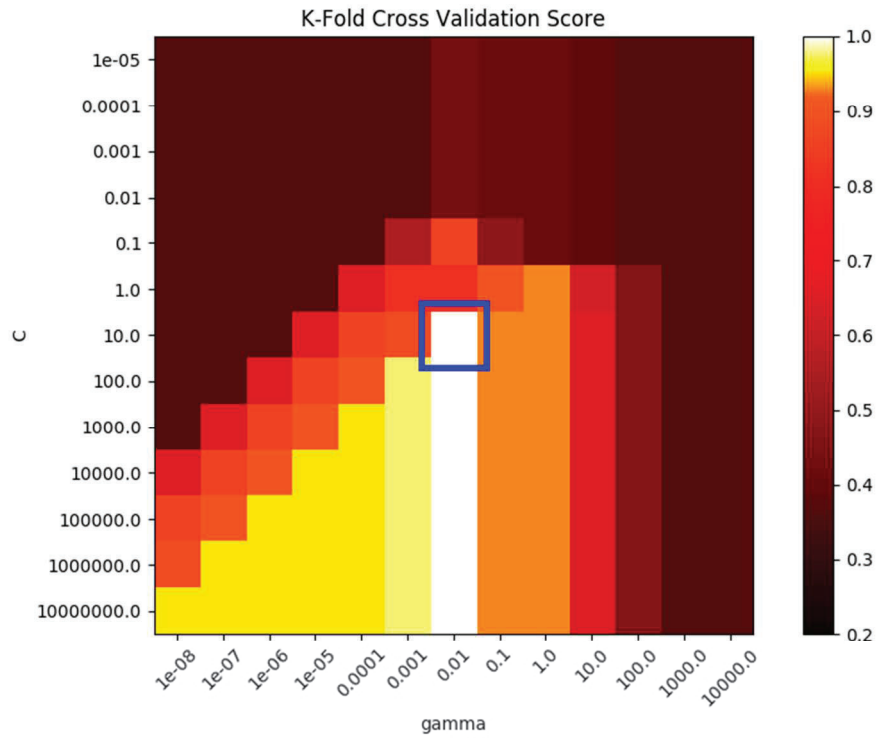


Figure 4. Tuning of RBF hyper-parameters (C and γ) for CSP acetone interactions. Representative SVM classification results for one training and testing set show the effects of parameters C and γ in the output of the RBF kernels. Red and blue circles represent the baseline samples in training and testing sets; green and purple plus symbols represent the positive signals in training and testing sets. The background blue and red region indicated the classifier decision surface, where all data fall into the red region are predicted as positive. Cross-validation scores are shown in the top right corner of each subplot. The optimal classifier zone is highlighted with a blue rectangle in the center of the image.

203x151mm (100 x 100 DPI)



31 Figure 5. Heatmap of validation accuracy as a function of RBF parameters C and γ . The color indicates the
32 cross-validation accuracy, where lighter colors represent a higher cross-validation score. Optimal parameters
33 are highlight with a blue rectangle in the center

34 203x151mm (100 x 100 DPI)

35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

SUPPLEMENTAL

Table S1. Randles-Ershler equivalent circuit analysis results for TBP-MBF binding and TBP-TATA¹ binding.

Binding	Circuit element	Value (ohm)	Standard deviation
TBP	R_s	265.73	0.38
	R_{ct}	2021.65	45.63
	Z_w	1.80E-04	6.38E-07
	C_{dl}	5.10E-07	4.58E-10
TBP-MBF	R_s	266.50	1.78
	R_{ct}	2640.88	52.30
	Z_w	1.80E-04	1.85E-06
	C_{dl}	4.91E-07	8.03E-09
TBP-TATA1	R_s	328.45	2.78
	R_{ct}	3395.19	302.53
	Z_w	1.41E-04	1.46E-05
	C_{dl}	5.85E-07	2.75E-08

Figure S1. Picture of a 3D printed plastic cap fitted onto standard Basi Pt/Ir electrode, and engineering drawing design of the cap.

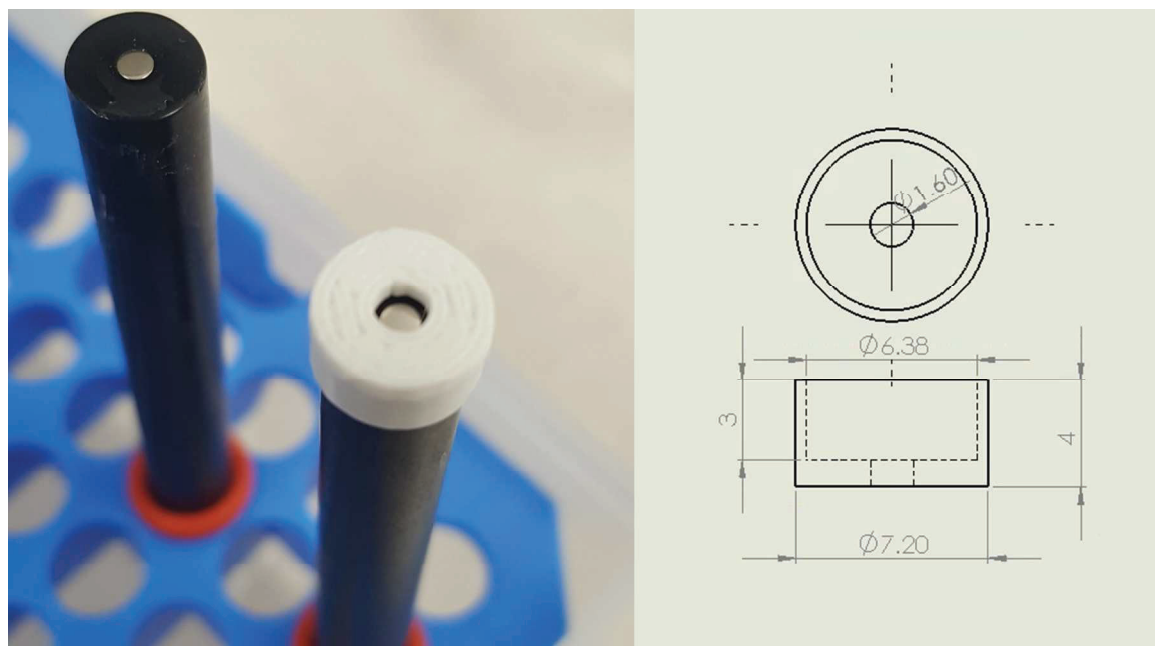


Figure S2. Charger transfer resistance (R_{ct}) from a Randel's model for addition of BSA or buffer to TBP coupled electrodes and TBP-MBF coupled electrodes.

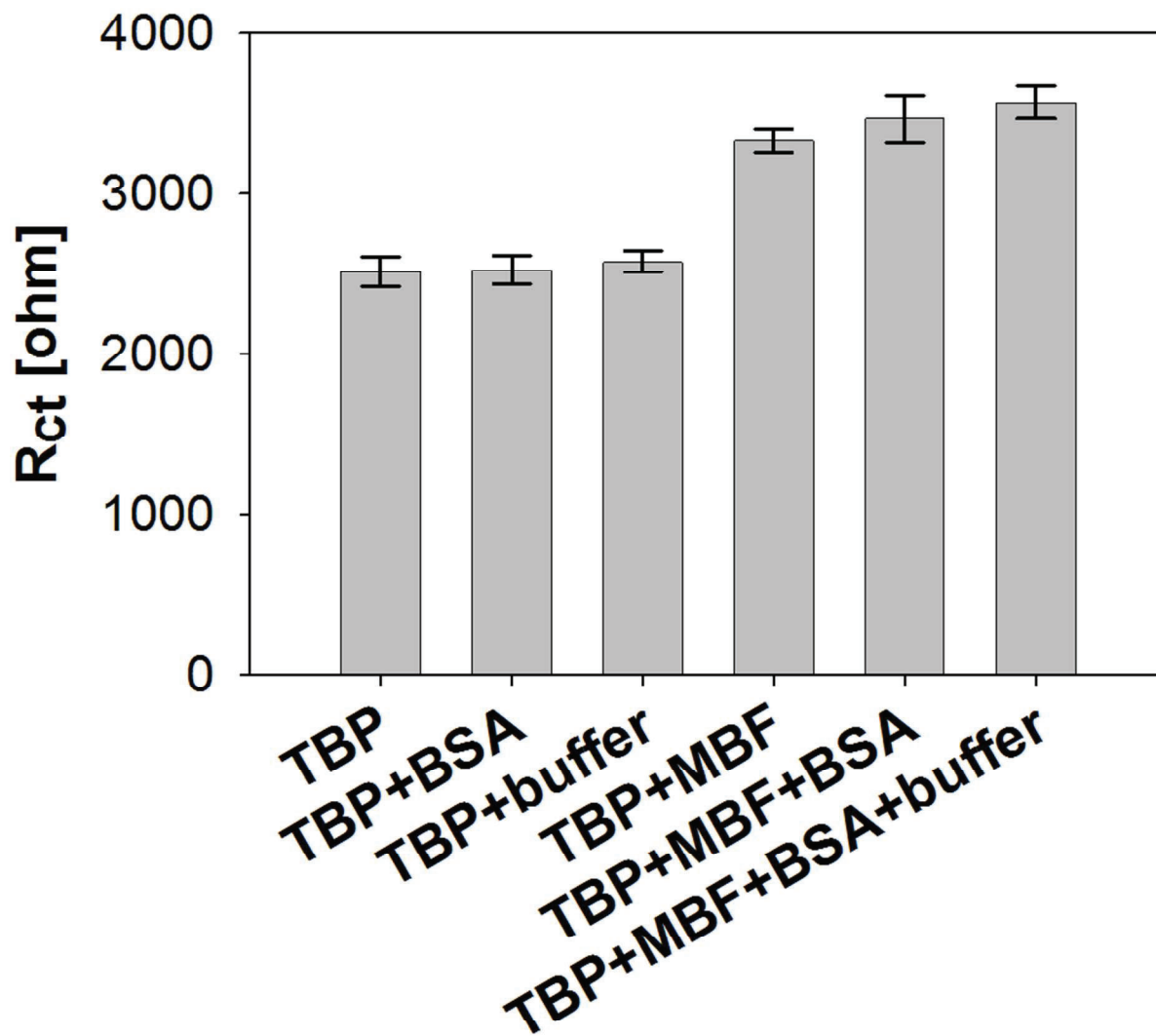
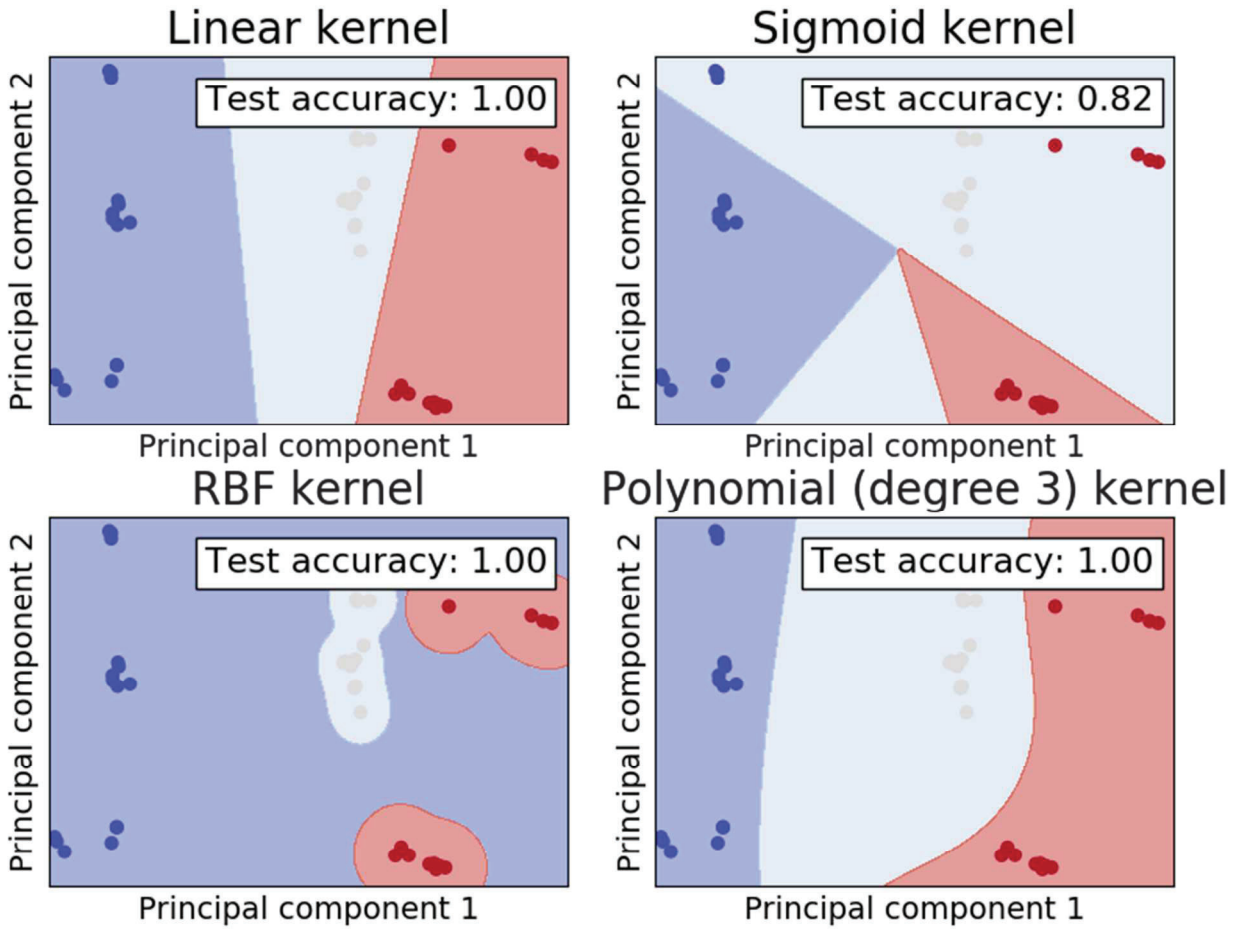


Figure S3. SVM results for TBP, TBP+MBF and TBP+TATA¹ calasification with common kernels.



1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Figure S5. Representative equivalent circuit models tested with model search function in ZMAN software.

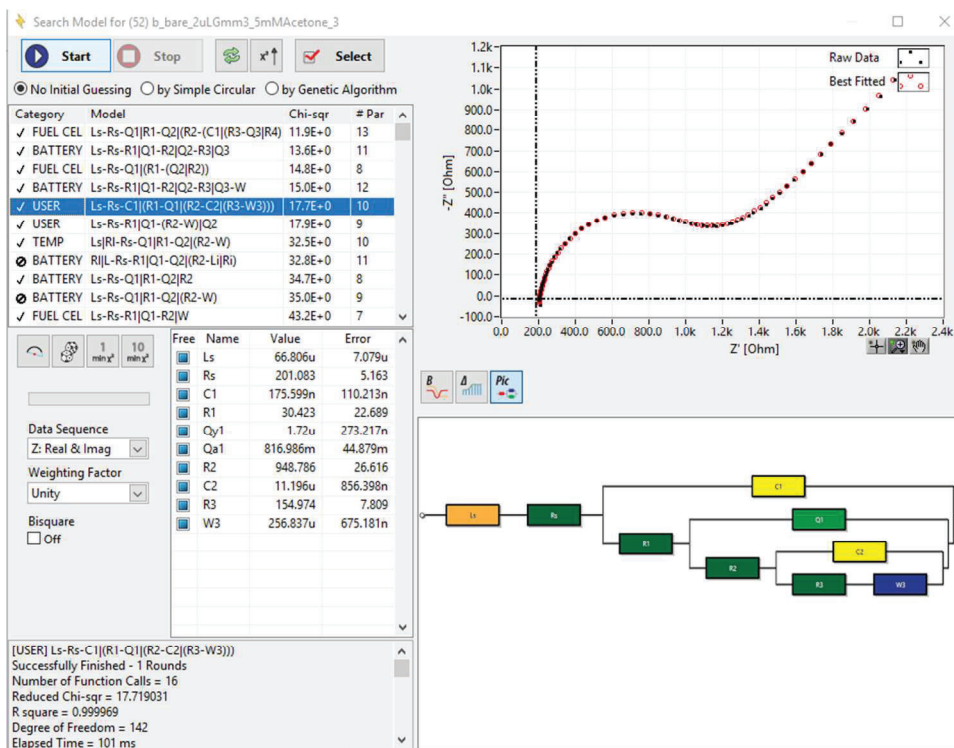
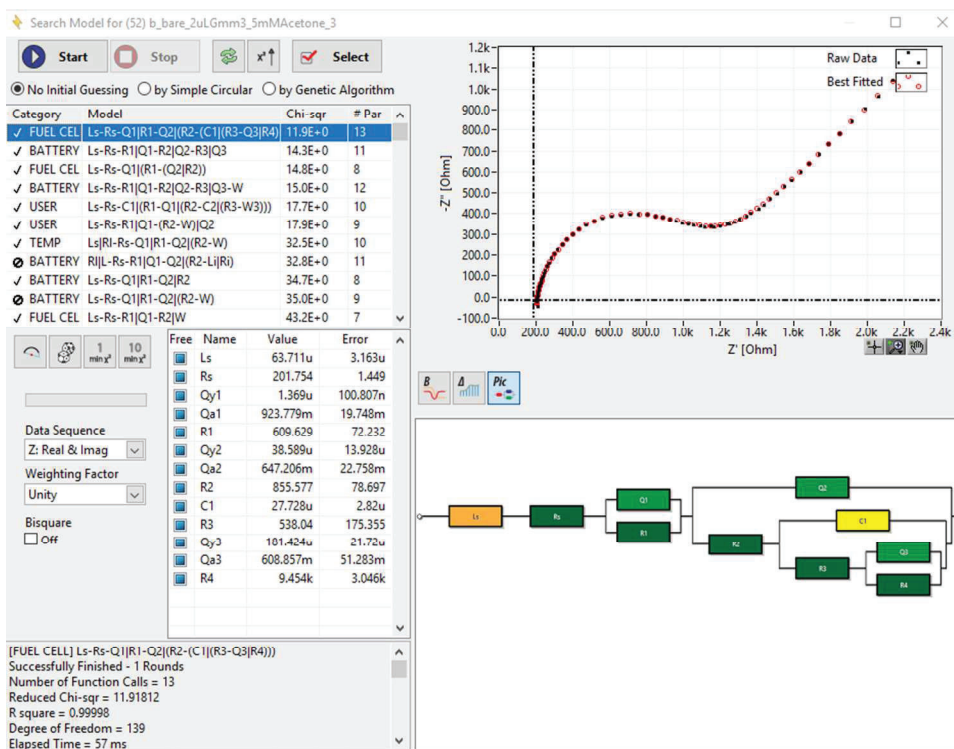


Figure S6. 3D data representation for data analyzed with three principal components. Red dots represented baseline signals of Gmm CSP biosensor, green plus represented 5mM acetone detection signals.

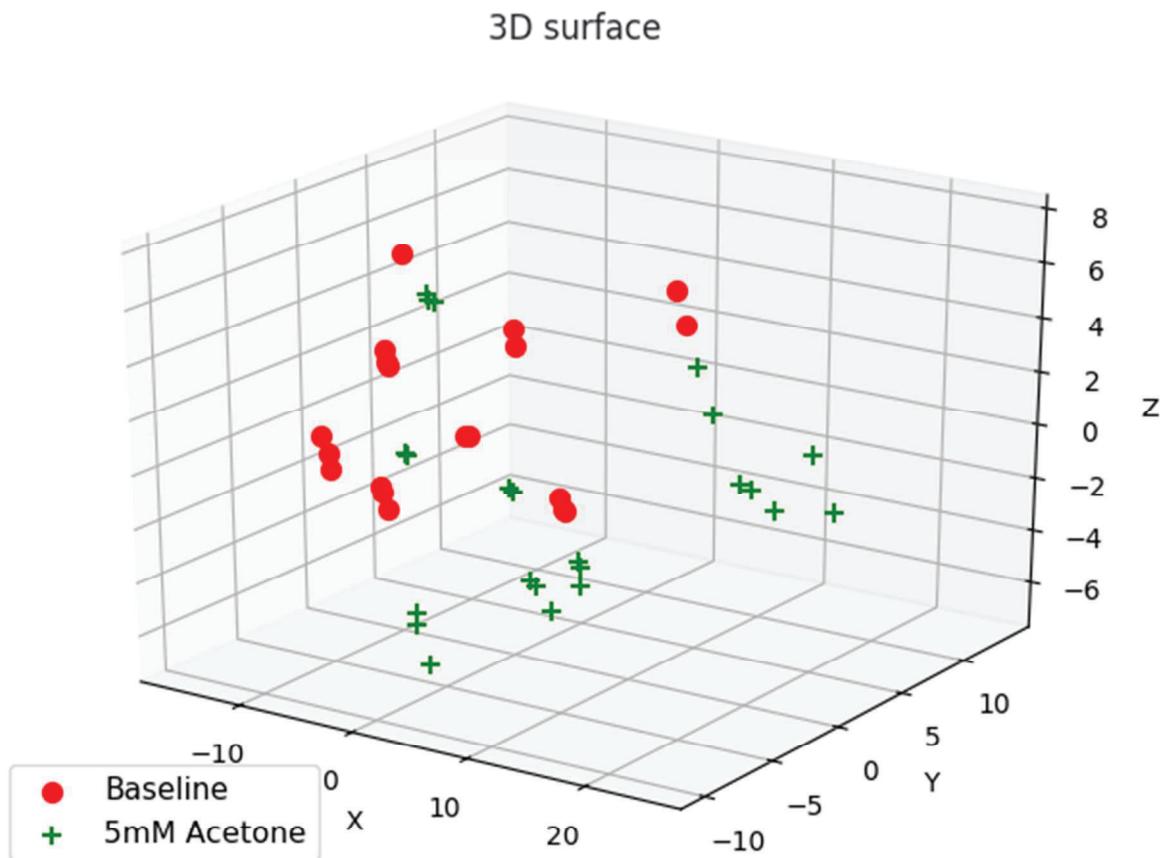
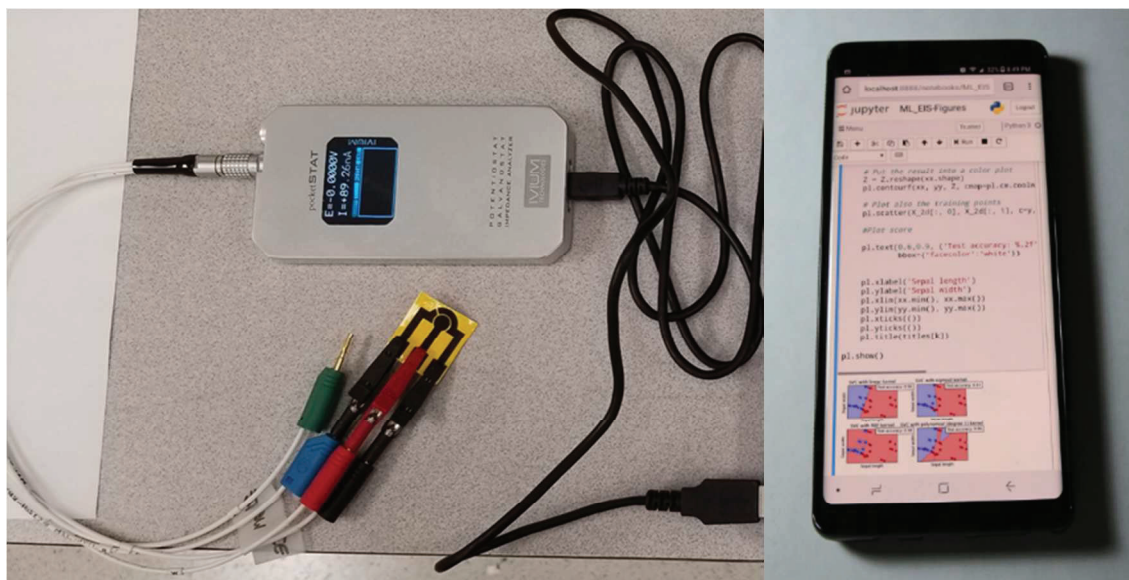


Figure S7. Support vector machine learning software installed on Android phone with small molecule using mobile detection and analysis systems. Screenshot showed Jupyter notebook running a SVM kernel selection code.



SVM Machine Learning for EIS data analysis step-by-step user guide

Yue Rong, Agricultural and Biological Engineering, University of Florida

1. Software preparation

1.1. Download Anaconda installer

“Anaconda is a freemium open source distribution of the Python and R programming languages for large-scale data processing, predictive analytics, and scientific computing, that aims to simplify package management and deployment.” --[https://en.wikipedia.org/wiki/Anaconda_\(Python_distribution\)](https://en.wikipedia.org/wiki/Anaconda_(Python_distribution))

It includes all the packages and tools we need and is completely free.

It can be downloaded at:

<https://www.continuum.io/downloads>

There are different versions of Anaconda for Windows, macOS and Linux; Python 3.6 and 2.7. It will be about 2 Gb after installation and downloading all packages. We suggest Python 3.6.

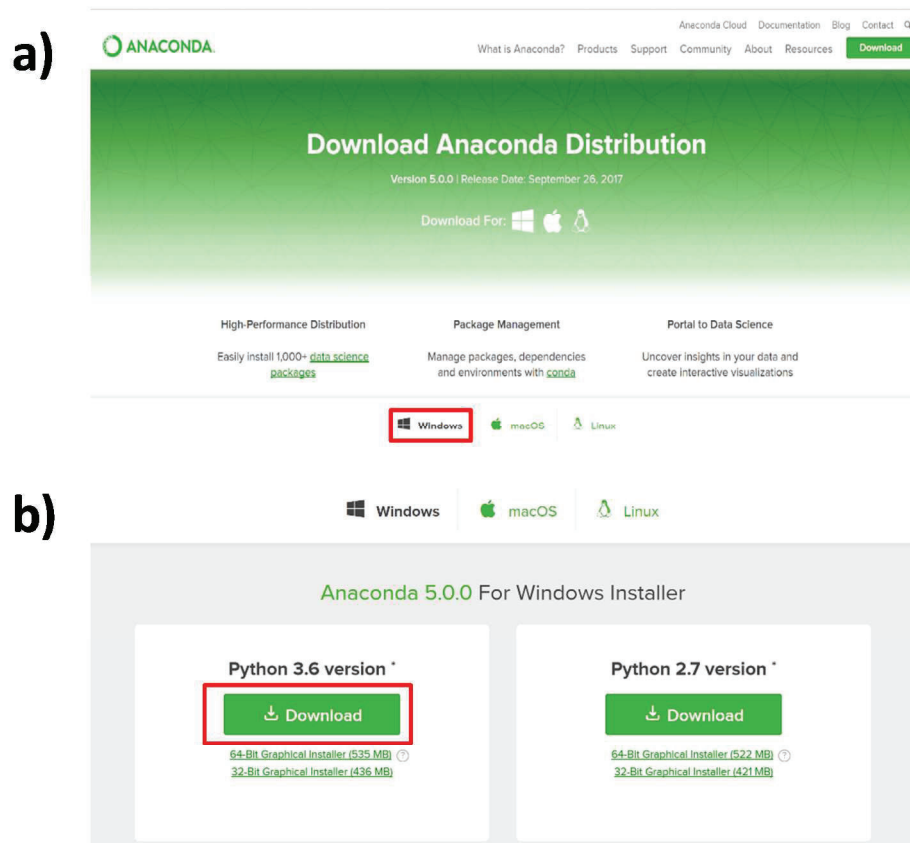


Figure U1. Download Anaconda

1.2. Install Anaconda

Double click the installer to launch

NOTE: If you encounter any issues during installation, temporarily disable your anti-virus software during install, then re-enable it after the installation concludes. If you have installed for all users, uninstall Anaconda and re-install it for your user only and try again.

Click Next.

Read the licensing terms and click “I Agree”

Select an install for “Just Me” unless you’re installing for all users (which requires Windows Administrator privileges) and click Next.

Select a destination folder to install Anaconda and click the Next button.

NOTE: Install Anaconda to a directory path that does not contain spaces or unicode characters.

NOTE: Do not install as Administrator unless admin privileges are required.

Choose whether to add Anaconda to your PATH environment variable.

We recommend not adding Anaconda to the PATH environment variable, since this can interfere with other software. Instead, use Anaconda software by opening Anaconda Navigator or the Anaconda Prompt from the Start Menu.

Choose whether to register Anaconda as your default Python 3.6.

Unless you plan on installing and running multiple versions of Anaconda, or multiple versions of Python, you should accept the default and leave this box checked.

Click the Install button.

You can click Show Details if you want to see all the packages Anaconda is installing.

Click the Next button

After a successful installation, you will see the “Thanks for installing Anaconda” dialog box:

Click the Finish button

After your install is complete, verify it by opening Anaconda Navigator, a program that is included with Anaconda: from your Windows Start menu, select the shortcut Anaconda Navigator. If Navigator opens, you have successfully installed Anaconda.

Anaconda Navigator

If you had any issue installing the Anaconda, please visit <https://docs.anaconda.com/anaconda/install/> for help.

2. Getting started

2.1. Open Anaconda Navigator

Find Anaconda 3 in “Windows Start Menu” and click “Anaconda Navigator” to open

2.2. Click “Launch” to open “Jupyter Notebook”

It will open in your internet browser (for me it's a Chrome) and the default file location is under your system user folder. (for example C:\Users\Username)

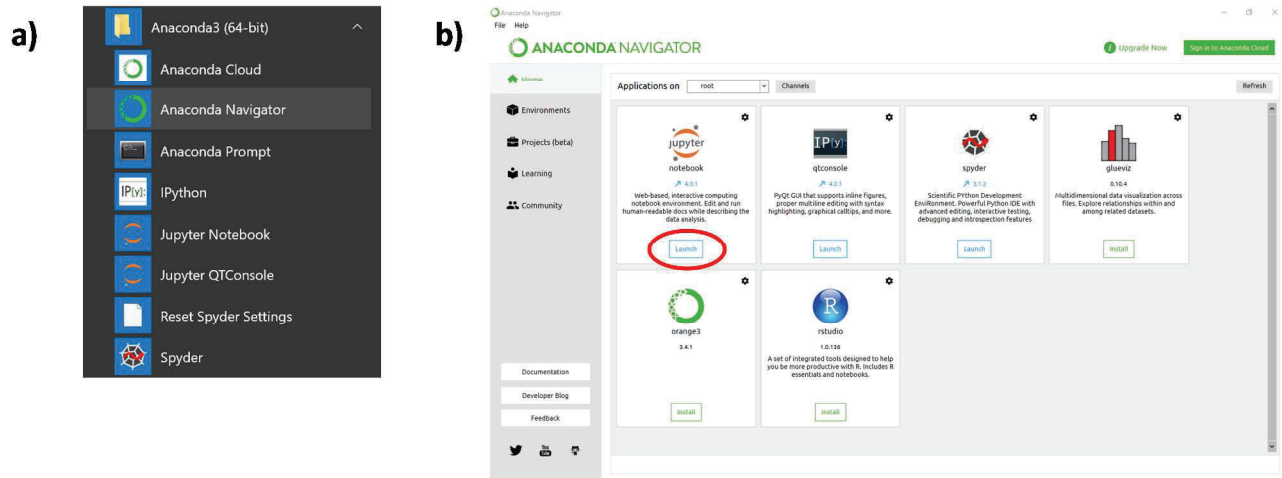


Figure U2. Open Jupyter Notebook

2.3. Run an example code

Download an example code from the link below and save it to “downloads” folder.

http://scikit-learn.org/stable/downloads/plot_svm_nonlinear.ipynb

use the file browser to navigate and open the download source code above. It should look like Figure U3 below.

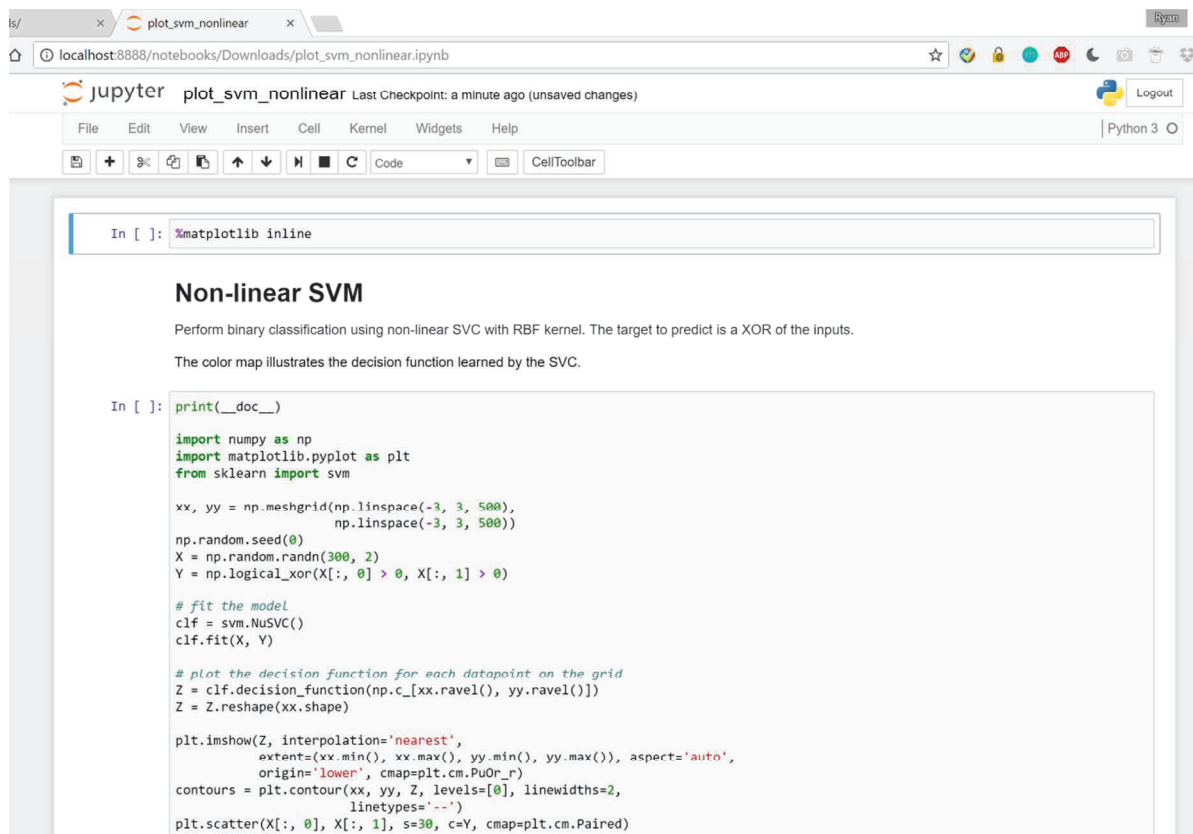



Figure U3. Example code for non-linear SVM

In “Cell” click “Run All” or run cells by clicking the  as shown in Figure U4.

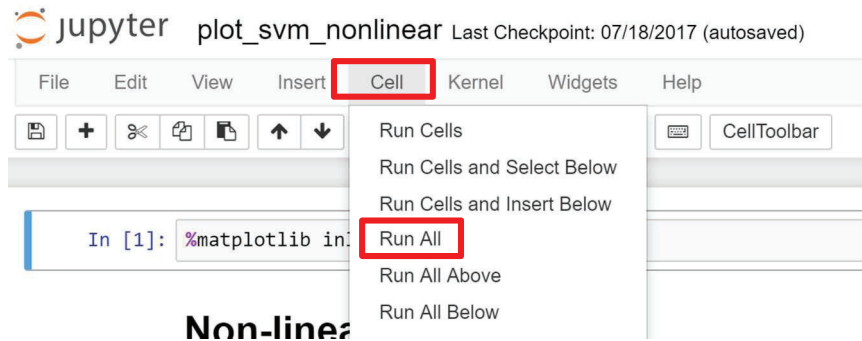


Figure U4. Run All cells to test the example code

The program should generate a plot similar to Figure U5.

```
plt.scatter(X[:, 0], X[:, 1], s=30, c=Y, cmap=plt.cm.Paired)
plt.xticks(())
plt.yticks(())
plt.axis([-3, 3, -3, 3])
plt.show()
```

Automatically created module for IPython interactive environment

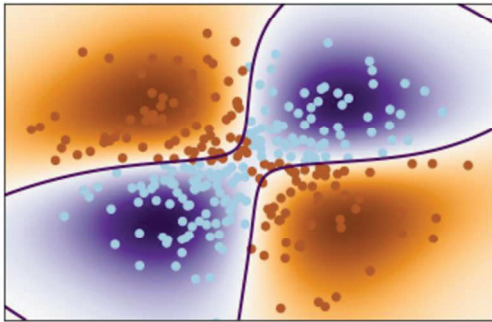


Figure U5. Expected output from example code

3. EIS data analysis with SVM machine learning

3.1. Data preparation

Raw EIS data usually includes frequency with real impedance (Z') and imaginary impedance (Z'') at that frequency as shown in Figure U6.

	A	B	C
	Frequency [Hz]	Z' _raw [Ohm]	Z'' _raw [Ohm]
0	99999.99984	258.054229	-7.637512
1	85769.58917	255.299691	-17.882566
2	73564.22411	278.492955	-18.88002
3	63095.73291	275.258838	-15.963164
4	54116.95083	289.347566	-28.062849
5	46415.88639	287.247927	-26.796648
6	39810.71513	286.058176	-32.585536
7	34145.48673	296.438676	-33.791812
8	29286.44376	301.039143	-34.728174
9	25118.8625	300.781714	-35.632715
10	21544.34515	307.305851	-40.781186
11	18478.4963	308.219676	-39.220288
12	15848.93039	312.550444	-44.296644
13	13593.56249	311.666707	-50.051774
14	11659.14268	315.616756	-54.547519
15	9999.998792	318.54106	-58.196081
16	8576.957885	322.457927	-63.004504
17	7356.421543	326.558636	-69.321829
18	6309.57253	330.949427	-77.043239
19	5411.69444	336.52842	-84.527607
20	4641.588089	343.795531	-92.286639
21	3981.071029	352.501566	-102.064143
22	3414.548269	359.595675	-112.278786
23	2928.644022	372.104547	-122.381571
24	2511.885947	385.386363	-134.632903

Figure U6. A part of representative raw EIS data.

Make sure all you EIS test are using the same frequency range then **create an excel sheet** as shown in Figure U7, where first column are names, second column are labels, each following column is one feature which is either real impedance or imaginary impedance at a frequency.

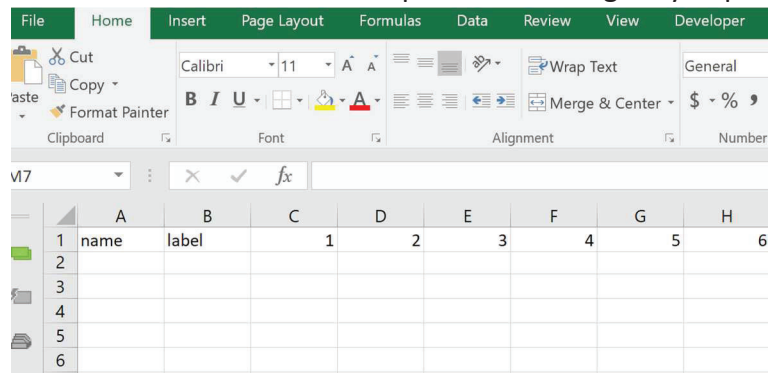


Figure U7. Excel template first step

Then, copy and transpose paste all real impedance (column B in Figure 12) to row 2 in Figure 13 starting at column C. (you may need to transpose paste the data in its original sheet then copy and paste to the template).

Next, using similar method as described above, copy all imaginary impedance (column C in Figure 12) to row 2 in Figure 13 starting at column CA (I have 76 frequencies in one EIS, I named row 1 from C as 1,2,3...76,77, to 152). Use your own naming system to give each EIS scan a unique name and put it in column A. Set a label (0 or 1 for binary classification) and put it in column B as shown in Figure U8.

	A	B	C	BZ	CA	CB	EW	EX
1	name	label	1	76	77	78	151	152
2	4B2G1	0	258.054229	1621.41	-7.63751	-17.8826	-873.914	-939.174

Figure U8. Pasted imaginary impedance into row 2 from column CA to EX (columns D-BY and CC-EV are hidden). Name and label added

Transfer all you EIS data that you are interested in classification (usually with similar experimental setting and a single variable) to the template and save it as *.csv file

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	name	Label	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	4B2G1	0	258.0542	255.2997	278.493	275.2588	289.3476	287.2479	286.0582	296.4387	301.0391	300.7817	307.3059	308.2197	312.5504	311.6667	315.6168	318.5411
3	4B2G2	0	265.8894	268.0702	273.757	285.1902	278.4257	290.3433	291.5499	293.6509	302.0073	302.9377	307.6231	308.7262	312.3669	313.9265	315.5427	319.354
4	4B2G3	0	267.317	266.4577	276.3333	275.4226	286.8759	282.8898	294.9838	298.7177	299.2943	304.1186	306.9148	307.7466	312.0538	312.9816	315.566	318.3924
5	5B2G1	0	212.9031	210.1753	226.3933	227.7355	227.9052	226.8304	234.8648	238.0592	239.7823	242.3075	242.45	245.1441	246.9025	247.1612	249.6174	253.1013
6	5B2G2	0	221.8998	225.2367	231.5692	227.6233	227.1677	228.3944	234.2414	240.8749	242.4335	243.288	244.2544	247.5539	247.3955	248.675	250.9991	253.9048
7	5B2G3	0	220.5023	213.8915	224.6013	228.9741	225.4477	231.434	239.4562	239.4411	240.5017	244.0199	246.1277	246.6161	248.3261	249.4041	251.0594	253.8992
8	6B2G1	0	166.9949	173.7204	184.3192	169.5682	173.2099	176.5317	179.8662	179.617	183.9284	185.823	186.4487	188.3658	190.5809	191.4963	193.6587	196.2139
9	6B2G2	0	179.0694	182.0632	171.9485	169.2709	183.162	179.8637	183.721	182.0691	184.8741	185.6762	187.9043	189.6923	191.1944	191.7999	192.7237	196.459
10	6B2G3	0	168.6349	182.5261	178.646	174.2017	177.7401	179.4154	182.8754	184.2721	187.3621	184.121	186.3112	189.6721	191.2342	191.5679	193.5646	196.0216
11	4B2G5A1	1	259.9313	259.0188	266.8876	284.1592	285.0439	286.6123	294.9715	297.3411	304.1833	302.6753	305.6459	309.1808	311.1617	310.8451	313.0142	317.0626
12	4B2G5A2	1	263.466	266.4305	283.5566	278.298	285.1393	285.0858	289.288	298.2087	300.9645	302.7892	303.546	306.7226	309.8123	310.6402	311.6402	316.1097
13	4B2G5A3	1	265.7502	266.4175	272.3123	276.0552	276.7814	288.0103	291.8241	293.7257	299.5611	301.3291	303.3106	303.8075	308.4623	310.1837	312.8859	316.5454
14	5B2G5A1	1	214.0163	227.5339	223.9881	230.3015	225.7774	232.9494	236.9239	240.9703	242.9936	241.4223	245.6318	249.8173	249.9303	249.7395	251.7926	253.9502
15	5B2G5A2	1	221.6863	218.2461	224.2944	225.4269	234.8084	235.1881	237.1379	239.1588	242.6543	243.4588	245.48	247.0395	249.6863	250.0278	251.7821	254.6247
16	5B2G5A3	1	219.98	212.6655	217.8348	232.9979	229.0809	234.607	239.0655	242.7952	240.4469	246.9357	247.8388	248.3381	250.0531	249.12	250.7349	254.3541
17	6B2G5A1	1	186.333	178.2627	177.4258	185.1232	182.1481	184.8892	182.5009	183.927	188.007	190.4824	191.2653	190.0282	193.1123	193.4678	194.8699	196.8375
18	6B2G5A2	1	179.8914	173.6595	173.5661	180.1657	180.2534	182.6176	184.5293	184.7471	186.4101	187.6895	187.2631	189.8662	190.9922	191.2556	192.9192	194.9413
19	6B2G5A3	1	182.3292	179.924	177.2412	167.8647	180.4624	179.4651	185.4587	183.6399	188.3154	186.6553	189.5718	189.8636	191.809	191.5059	193.1888	195.5724
20	4B1G5A1	1	286.9791	291.5914	297.6871	292.363	306.4467	314.4559	308.4549	322.7986	324.8604	325.3788	325.2187	333.2716	331.9342	333.5523	336.6442	337.86
21	4B1G5A2	1	272.9672	281.8878	288.8579	313.4164	310.8411	312.8765	312.6907	309.6892	323.1059	325.5448	327.3001	327.981	332.406	333.0716	333.1723	337.3366
22	4B1G5A3	1	295.2762	283.1599	300.0213	297.0929	299.5606	307.4459	310.4039	321.0305	319.0035	325.234	326.0285	330.9777	332.898	331.6771	334.3737	338.3772

Figure U9. Example raw EIS dataset ready for SVM machine learning

This example file can be downloaded from:

<https://www.dropbox.com/s/7ftbm75mpyj6mc1/dataProject.csv?dl=0>

Each row is a data from one run of a sample (one EIS/CV scan)

The label column is used for supervised classification/regression. It could be binary or quantitative depends on your applications.

For example:

In this dataset, "0" represent the blank/negative EIS results with no acetone in the samples; "1" represent the positive results with 5mM acetone concentration in the samples.

If you are testing glucose with 0, 1, 10 and 100 mM, you may label them as either "0,1,2,3" or "0,1,10,100" depending on doing classification or regression.

Each column followed is called a "feature" that in EIS is the real or imaginary impedance at a certain frequency.

3.2. SVM code for EIS data

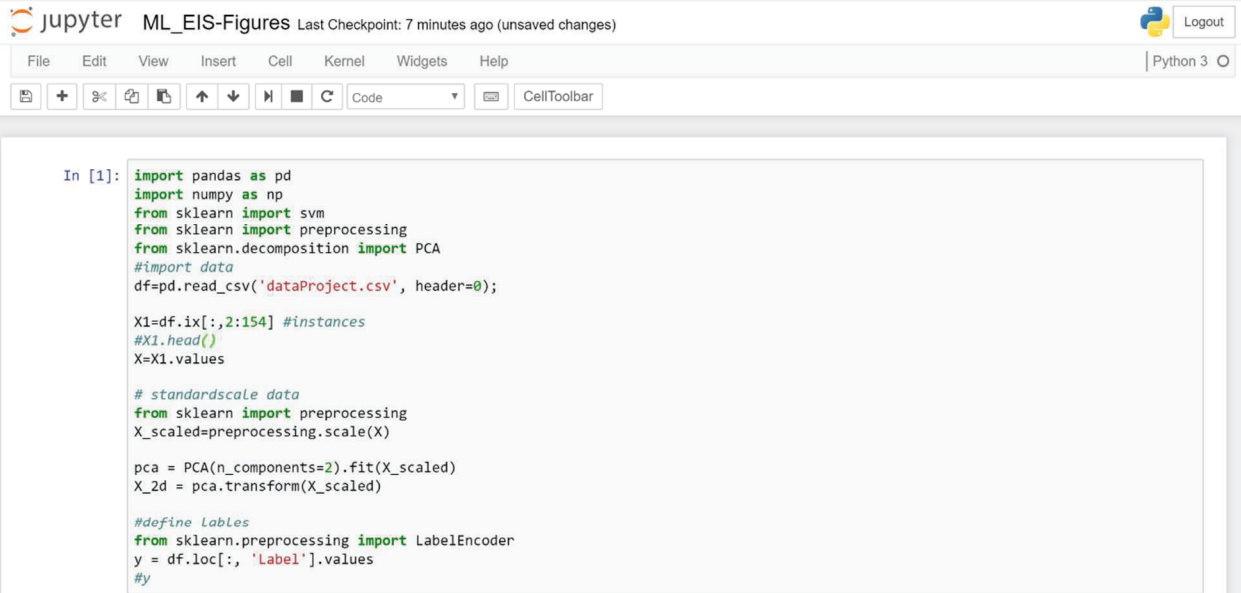
The code can be downloaded from:

<https://www.dropbox.com/s/7ftbm75mpyj6mc1/dataProject.csv?dl=0>

Opened it in "Jupyter notebook" and put the datafile prepared as above in the same folder.

Run the code by cells.

用“Jupyter notebook”



```

In [1]: import pandas as pd
import numpy as np
from sklearn import svm
from sklearn import preprocessing
from sklearn.decomposition import PCA
#import data
df=pd.read_csv('dataProject.csv', header=0);

X1=df.ix[:,2:154] #instances
#X1.head()
X=X1.values

# standardscale data
from sklearn import preprocessing
X_scaled=preprocessing.scale(X)

pca = PCA(n_components=2).fit(X_scaled)
X_2d = pca.transform(X_scaled)

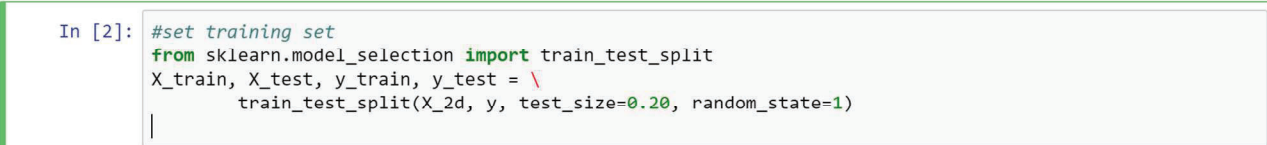
#define Labels
from sklearn.preprocessing import LabelEncoder
y = df.loc[:, 'Label'].values
#y

```

Figure U10. reading EIS dataset and data preprocessing

This cell read the EIS dataset from 'dataProject.csv'

The data was scaled using `preprocessing.scale(X)`. And a principle component analysis (PCA) was performed to decompose the data into two dimensional.



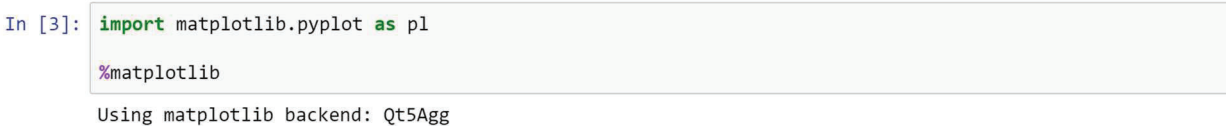
```

In [2]: #set training set
from sklearn.model_selection import train_test_split
X_train, X_test, y_train, y_test = \
    train_test_split(X_2d, y, test_size=0.20, random_state=1)

```

Figure U11. Split data into training and testing sets.

EIS data were split into 80% training and 20% testing.



```

In [3]: import matplotlib.pyplot as plt

%matplotlib

Using matplotlib backend: Qt5Agg

```

Figure U12. Pyplot from matplotlib package was imported and figures are set to appear in a new window.

Figures plotting tools was loaded.

```

In [4]: #=====
#Fig 2
#=====
h = .02 # step size in the mesh
#C = 10 # SVM regularization parameter
svc = svm.SVC(kernel='linear').fit(X_train, y_train)
rbf_svc = svm.SVC(kernel='rbf').fit(X_train, y_train)
poly_svc = svm.SVC(kernel='poly').fit(X_train, y_train)
sigmod_svc = svm.SVC(kernel='sigmoid').fit(X_train, y_train)

# create a mesh to plot in
x_min, x_max = X_train[:, 0].min() - 1, X_train[:, 0].max() + 1
y_min, y_max = X_train[:, 1].min() - 1, X_train[:, 1].max() + 1
xx, yy = np.meshgrid(np.arange(x_min, x_max, h),
                    np.arange(y_min, y_max, h))

# title for the plots
titles = ['SVC with linear kernel',
         'SVC with sigmoid kernel',
         'SVC with RBF kernel',
         'SVC with polynomial (degree 3) kernel']

for k, clf in enumerate((svc, sigmod_svc, rbf_svc, poly_svc)):
    # Plot the decision boundary. For that, we will assign a color to each
    # point in the mesh [x_min, x_max]x[y_min, y_max].
    pl.subplot(2, 2, k + 1)
    pl.subplots_adjust(wspace=0.4, hspace=0.4)

    Z = clf.predict(np.c_[xx.ravel(), yy.ravel()])

    # Put the result into a color plot
    Z = Z.reshape(xx.shape)
    pl.contourf(xx, yy, Z, cmap=pl.cm.coolwarm, alpha=0.5)

    # Plot also the training points
    pl.scatter(X_2d[:, 0], X_2d[:, 1], c=y, cmap=pl.cm.coolwarm, s=20)

    #Plot score
    pl.text(0.6, 0.9, ('Test accuracy: %.2F' % clf.score(X_2d, y)), transform=pl.gca().transAxes,
           bbox={'facecolor': 'white'})

    pl.xlabel('Sepal length')
    pl.ylabel('Sepal width')
    pl.xlim(xx.min(), xx.max())
    pl.ylim(yy.min(), yy.max())
    pl.xticks(())
    pl.yticks(())
    pl.title(titles[k])

pl.show()

```

Figure U13. code cell for kernel selection

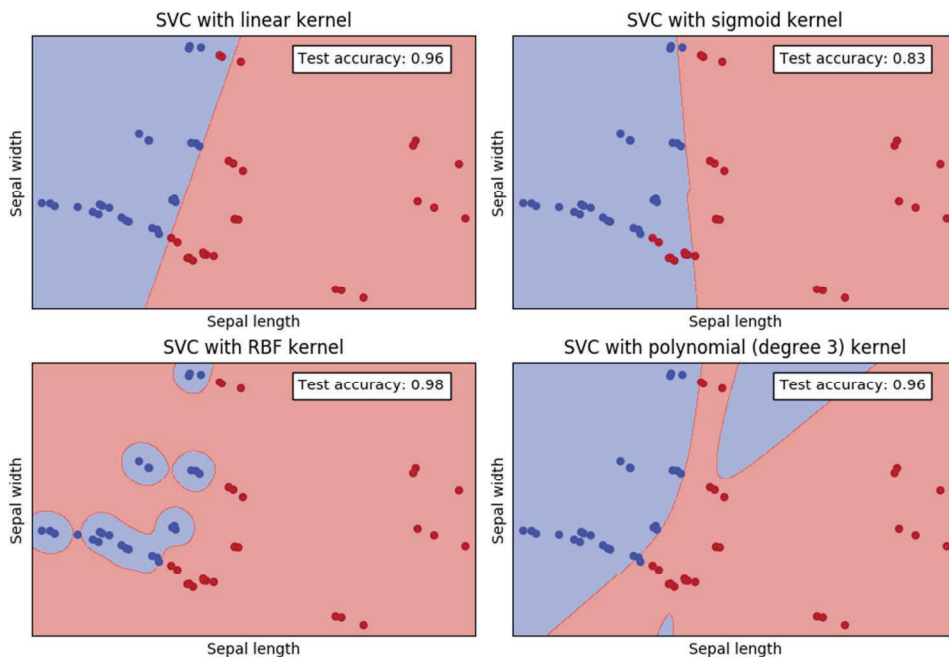


Figure U14. Result figure from the kernel selection code


```

1 In [9]: import matplotlib.pyplot as plt
2         #plt.figure(figsize=(8, 6))
3         #xx, yy = np.meshgrid(np.linspace(-3, 3, 200), np.linspace(-3, 3, 200))
4         h=1
5         x_min, x_max = X_train[:, 0].min() - 1, X_train[:, 0].max() + 1
6         y_min, y_max = X_train[:, 1].min() - 1, X_train[:, 1].max() + 1
7         xx, yy = np.meshgrid(np.arange(x_min, x_max, h),
8                             np.arange(y_min, y_max, h))
9         for (k, (C, gamma, clf)) in enumerate(classifiers):
10            # evaluate decision function in a grid
11            Z = clf.decision_function(np.c_[xx.ravel(), yy.ravel()])
12            Z = Z.reshape(xx.shape)
13
14            # visualize decision function for these parameters
15            plt.subplot(len(C_2d_range), len(gamma_2d_range), k + 1)
16            plt.subplots_adjust(wspace=0.3, hspace=0.3)
17            plt.title("gamma=10^%d, C=10^%d" % (np.log10(gamma), np.log10(C)),
18                    size='medium')
19
20            # visualize parameter's effect on decision function
21            Z = clf.predict(np.c_[xx.ravel(), yy.ravel()])
22            Z = Z.reshape(xx.shape)
23            plt.contourf(xx, yy, Z, cmap=plt.cm.coolwarm, alpha=0.5)
24            #plt.pcolormesh(xx, yy, -Z, cmap=plt.cm.RdBu)
25            #plt.scatter(X_train[:, 0], X_train[:, 1], c=y_train, cmap=plt.cm.coolwarm)
26            #plt.scatter(X_test[:, 0], X_test[:, 1], y_test, cmap=plt.cm.RdBu_r)
27
28            for i in range(0, X_train.shape[0]):
29                if y_train[i] == 0:
30                    c1 = plt.scatter(X_train[i,0],X_train[i,1],c='r',marker='o', s = 20 )
31                elif y_train[i] == 1:
32                    c2 = plt.scatter(X_train[i,0],X_train[i,1],c='g',marker='+', s = 30 )
33            for i in range(0, X_test.shape[0]):
34                if y_test[i] == 0:
35                    c3 = plt.scatter(X_test[i,0],X_test[i,1],c='b',marker='o', s = 20 )
36                elif y_test[i] == 1:
37                    c4 = plt.scatter(X_test[i,0],X_test[i,1],c='m',marker='+', s = 30 )
38
39            plt.xticks(())
40            plt.yticks(())
41            plt.axis('tight')
42
43            scores = grid.cv_results_['mean_test_score'].reshape(len(C_range),
44                                                            len(gamma_range))

```

Figure U17. Code to visualize effect of parameters for RBF kernel.

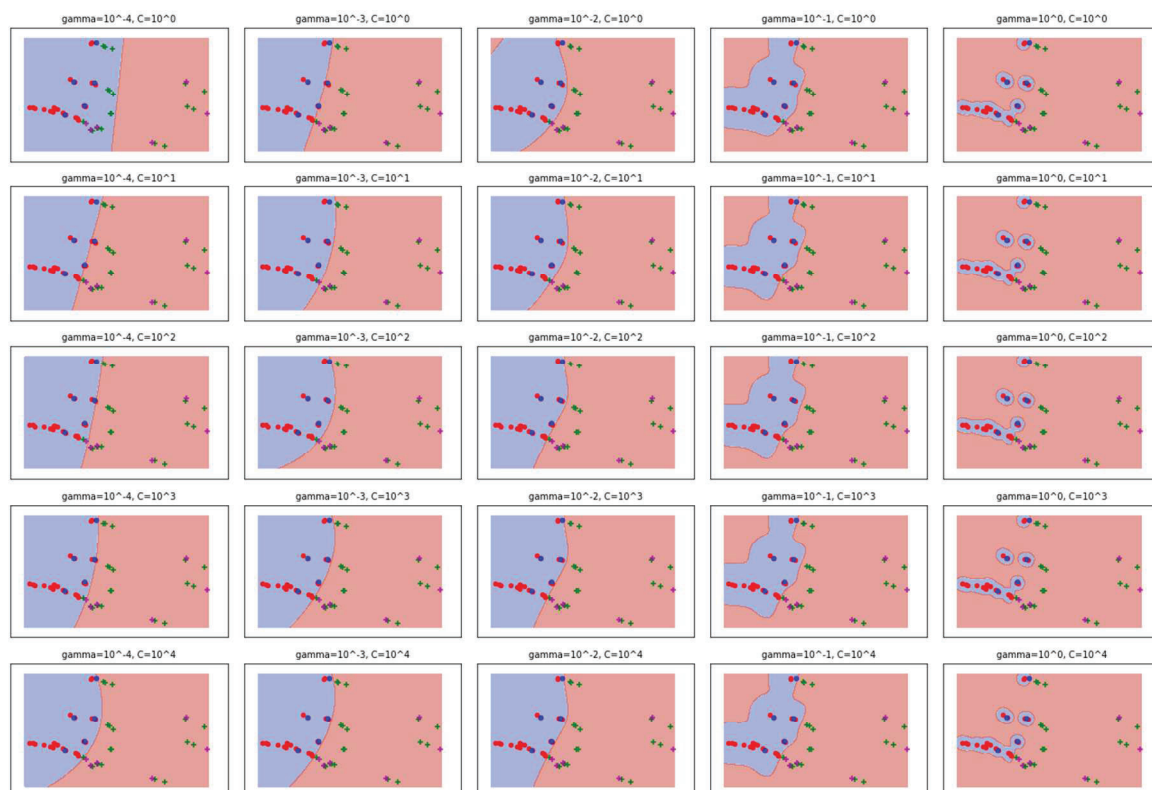


Figure U18. Effect of parameters for RBF kernel.

1 If you have your dataset prepared like this you may easily modify my code or the codes available online
2 and test it out.
3

4 **3.3. Scikit-Learn**

5 <http://scikit-learn.org/stable/index.html>

6 If you have time, checkout this site.
7

8 Most of my code and knowledge is based on the information and example from this open source
9 project.
10

11 Good Luck!
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

10/23/2017

SVM Machine Learning for EIS data analysis step-by-step user guide

支持向量机机器学习用于电化学阻抗谱数据分析的使用指南

Yue Rong

荣越

UF Biosensor Lab

佛罗里达大学生物传感器实验室

1. Software preparation (软件准备)

1.1. Download Anaconda installer (下载 anaconda 安装包)

“Anaconda is a freemium open source distribution of the Python and R programming languages for large-scale data processing, predictive analytics, and scientific computing, that aims to simplify package management and deployment.” --[https://en.wikipedia.org/wiki/Anaconda_\(Python_distribution\)](https://en.wikipedia.org/wiki/Anaconda_(Python_distribution))

“Anaconda 是一个免费开源的 Python 及 R 语言开发环境。它主要用于大规模的数据处理，预测分析和科学计算，致力于简化程序包的管理和使用” —来自维基百科

It includes all the packages and tools we need and is completely free.

该软件包含了我们全部需要的工具

It can be downloaded at:

可以在以下地址下载:

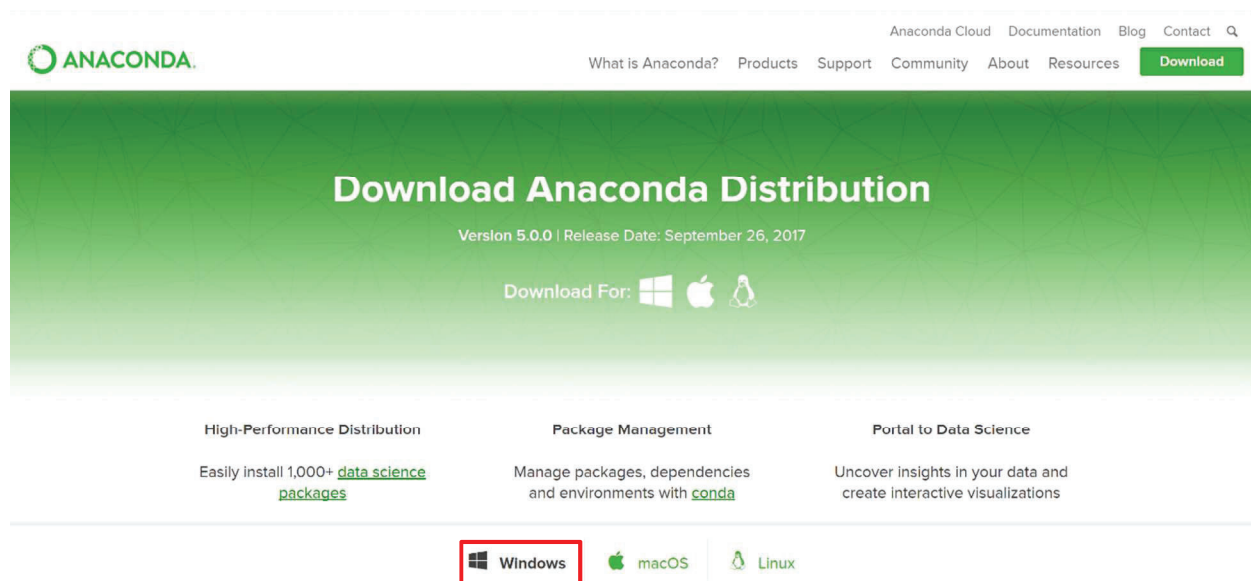


Figure 1 Choose your operating system by clicking “Windows”, “macOS” or “Linux”.

<https://www.continuum.io/downloads>

There are different versions of Anaconda for Windows, macOS and Linux; Python 3.6 and 2.7. It will be about 2 Gb after installation and downloading all packages. We suggest Python 3.6.

该网站提供了 Anaconda 为 Windows, macOS 和 Linux 三种平台的安装包。并且都有 Python 3.6 和 2.7 两个版本。下载安装完成大概需要 2Gb 的硬盘空间。我们建议使用 Python 3.6 版本。

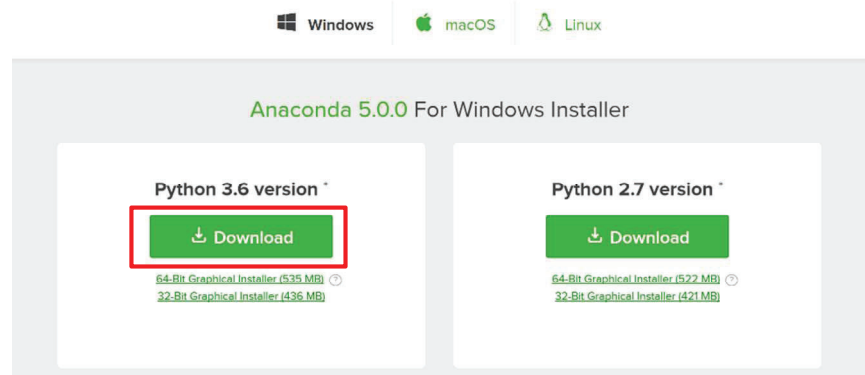


Figure 2 Click to download Python 3.6 version installer (macOS and Linux are similar)

1.2. Install Anaconda (安装 Anaconda)

Double click the installer to launch. (双击安装包开始)

NOTE: If you encounter any issues during installation, temporarily disable your anti-virus software during install, then re-enable it after the installation concludes. If you have installed for all users, uninstall Anaconda and re-install it for your user only and try again.

注意: 如果在安装过程中遇到任何问题, 暂时关闭反病毒软件, 安装完成后重新开启。如果你选择了“为所有用户”安装, 请删除 Anaconda, 重新安装并选择“只为自己”安装。

Click Next. (点击继续)

Read the licensing terms and click “I Agree”. (阅读并点击同意)

Select an install for “Just Me” unless you’re installing for all users (which requires Windows Administrator privileges) and click Next.

选择“只为我”安装, 除非你要为所有用户安装(要求 Windows 管理员权限)点击继续。

Select a destination folder to install Anaconda and click the Next button. (选择安装位置)

NOTE: Install Anaconda to a directory path that does not contain spaces or unicode characters.

注意: 安装目录中不要含有空格或者特殊符号

NOTE: Do not install as Administrator unless admin privileges are required.

注意: 不要以管理员身份安装, 除非管理员权限需要的时候

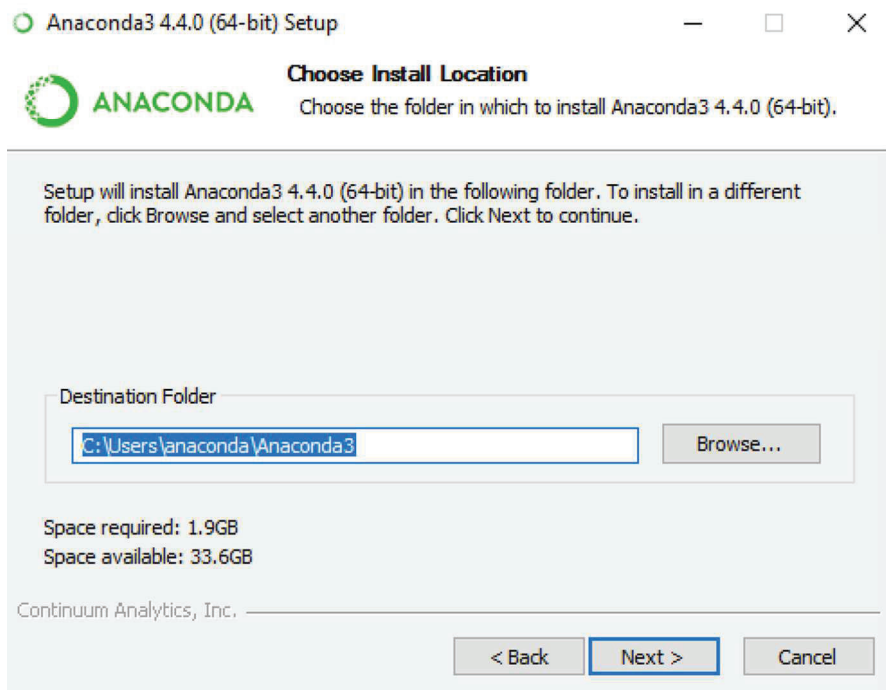


Figure 3 Select a destination folder to install Anaconda and click the Next button

Choose whether to add Anaconda to your PATH environment variable.（选择是否将 Anaconda 加入你的 PATH 环节变量）

We recommend not adding Anaconda to the PATH environment variable, since this can interfere with other software. Instead, use Anaconda software by opening Anaconda Navigator or the Anaconda Prompt from the Start Menu.

我们不推荐把 Anaconda 加入 PATH 环境变量，因为这可能会影响其他软件。所以我们建议从开始菜单打开 Anaconda Navigator 或者 Anaconda Prompt 来使用。

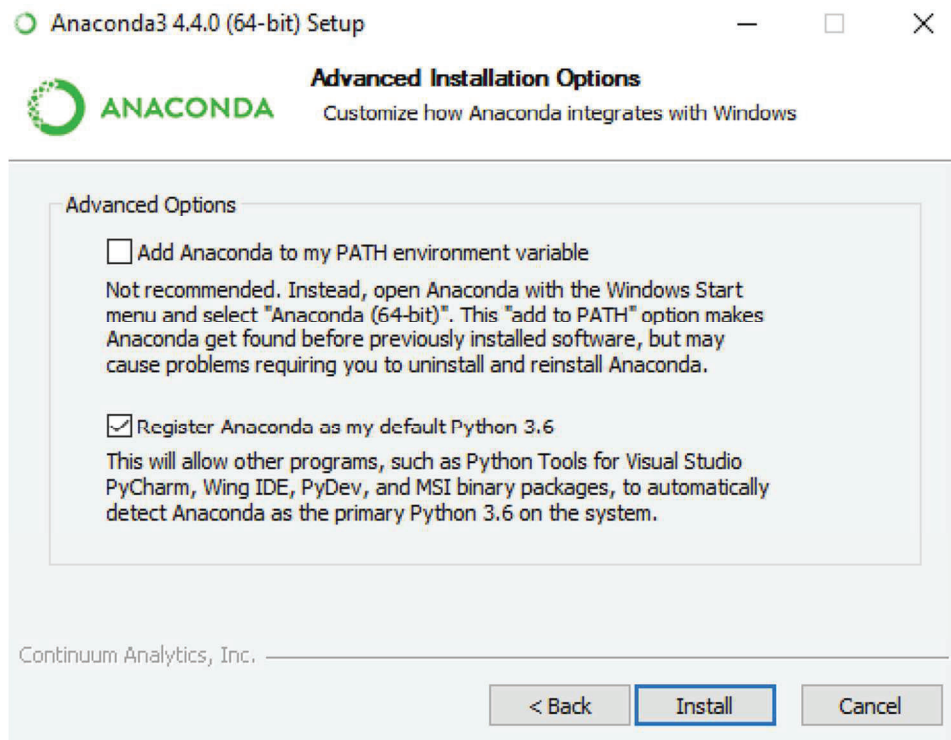


Figure 4 register Anaconda as your default Python 3.6

Choose whether to register Anaconda as your default Python 3.6.（选择是否把 Anaconda 设为默认的 Python 3.6）

Unless you plan on installing and running multiple versions of Anaconda, or multiple versions of Python, you should accept the default and leave this box checked.

除非你有多版本的 Anaconda 或者多版本的 Python，你应该接受这个默认设置。

Click the Install button.（点击安装）

You can click Show Details if you want to see all the packages Anaconda is installing.

你可以点击产看详情，如果你想看到所有 Anaconda 正在安装的程序包

Click the Next button.（点击继续）

After a successful installation, you will see the “Thanks for installing Anaconda” dialog box:

安装完成后，你会看到“感谢安装 Anaconda”的对话框

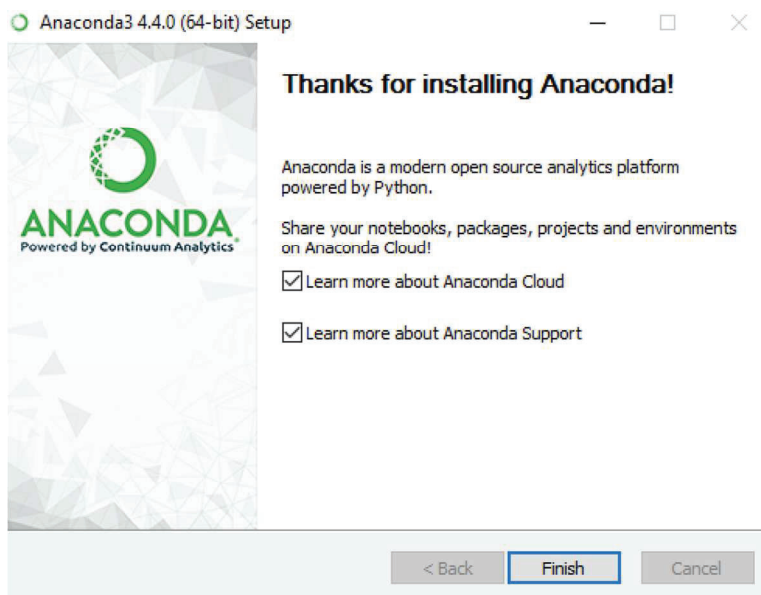


Figure 5 successful installation dialog

Click the **Finish** button. (点击完成)

After your install is complete, verify it by opening Anaconda Navigator, a program that is included with Anaconda: from your Windows Start menu, select the shortcut Anaconda Navigator. If Navigator opens, you have successfully installed Anaconda.

安装完成后，通过打开 **Anaconda Navigator** 来确认。如果你能打开 Anaconda Navigator，说明你已经成功安装了 Anaconda。

If you had any issue installing the Anaconda, please visit <https://docs.anaconda.com/anaconda/install/> for help.

如果你在安装过程中遇到其他问题，请访问：<https://docs.anaconda.com/anaconda/install/>

2. Getting started (准备开始)

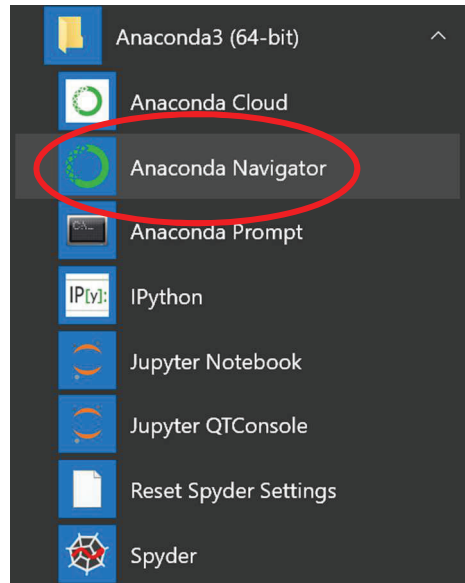
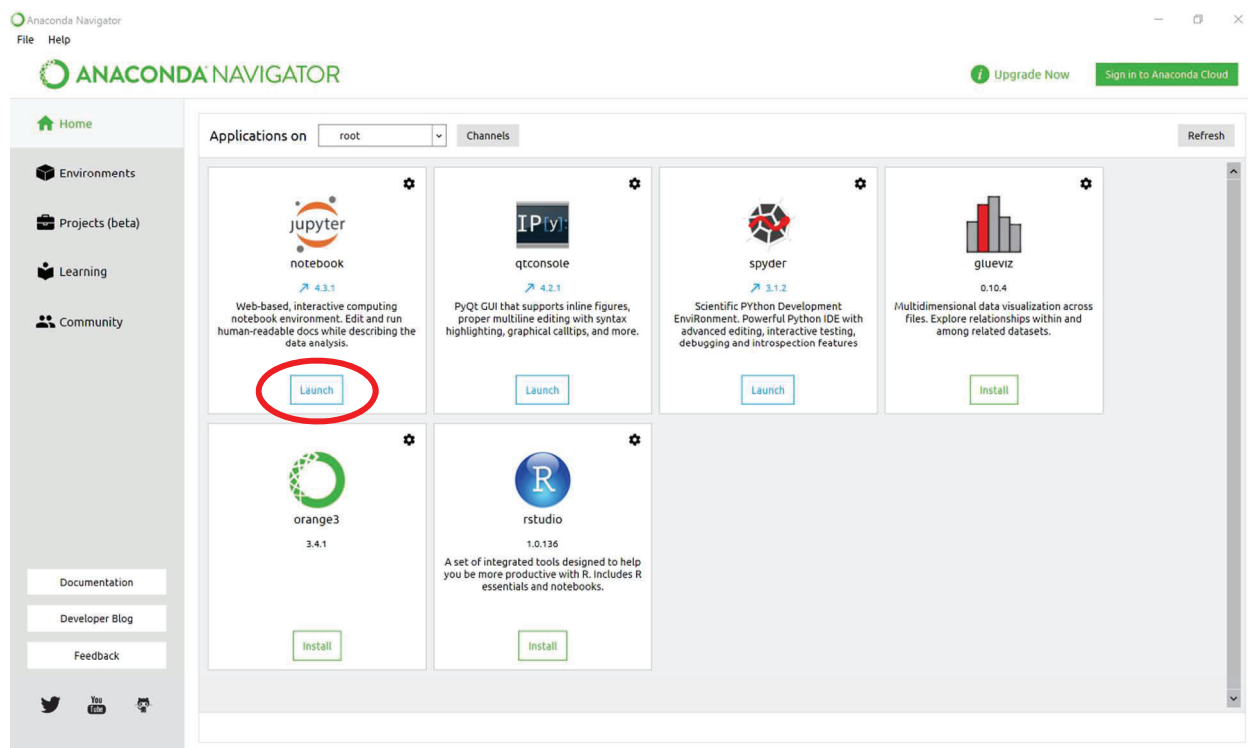


Figure 6 Find Anaconda 3 and open “Anaconda Navigator”

2.1. Open Anaconda Navigator (打开 Anaconda Navigator)

Find Anaconda 3 in “Windows Start Menu” and click “Anaconda Navigator” to open
在开始菜单中找到 Anaconda 3 并双击 “Anaconda Navigator” 打开



2.2. Click “Launch” to open “Jupyter Notebook” (点击 “Jupyter notebook” 下的 “Launch” 按钮)

It will open in your internet browser (for me it's a Chrome) and the default file location is under your system user folder. (for example C:\Users\Username)

Figure 7 Lunch “Jupyter Notebook” in Anaconda Navigator

它会在你默认的网络浏览器（我用的是 Chrome）中打开，默认的文件位置是在你的系统用户文件夹。

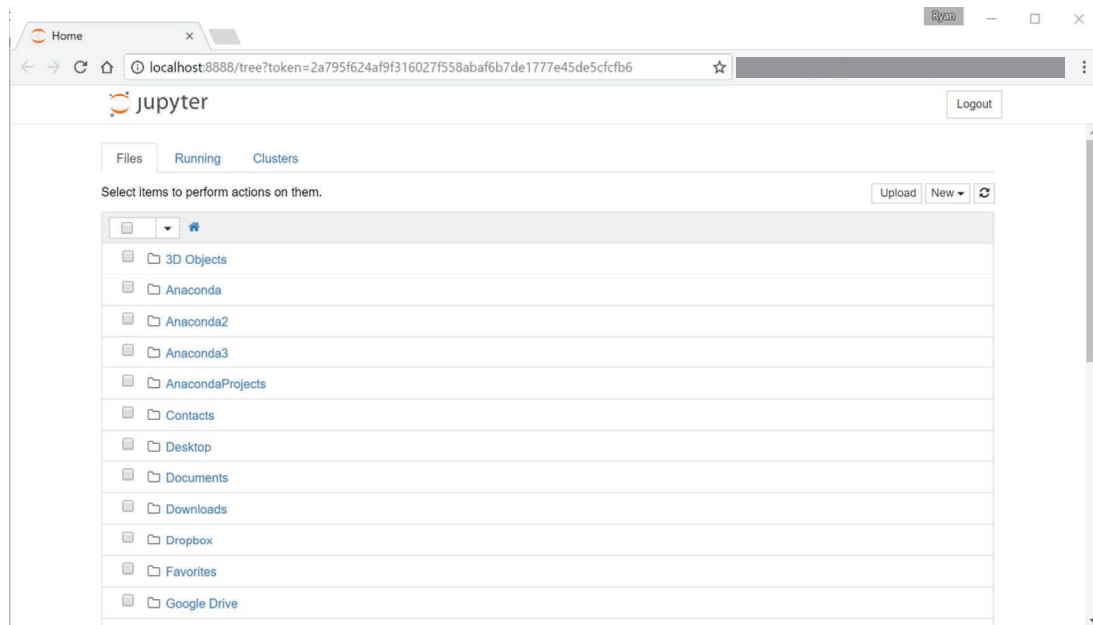


Figure 8 “Jupyter Notebook” dashboard

2.3. Run an example code（运行一个测试代码）

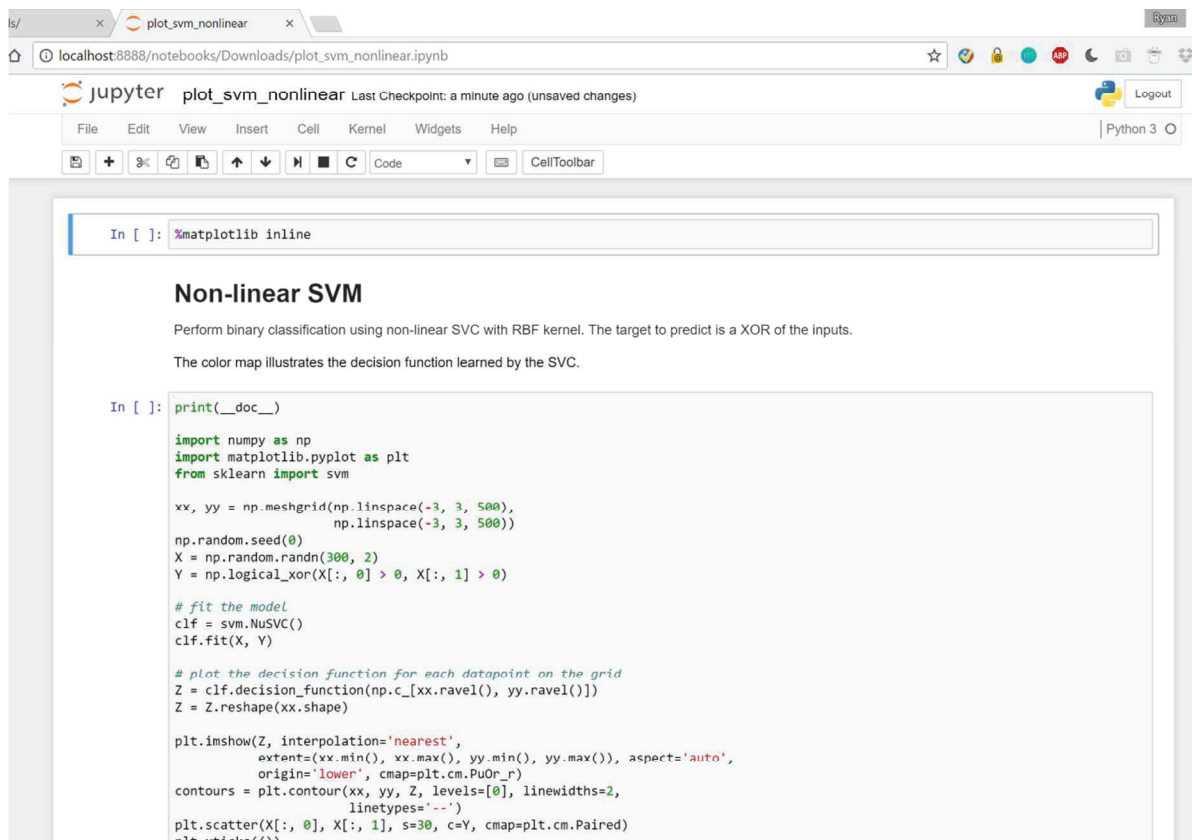
Download an example code from the link below and save it to “downloads” folder.

从以下地址下载一个测试代码，并保存到“下载”目录

http://scikit-learn.org/stable/downloads/plot_svm_nonlinear.ipynb

use the file browser to navigate and open the download source code above

通过网页内的文件浏览器找到并打开刚下载测试代码



```

In [ ]: %matplotlib inline

Non-linear SVM
Perform binary classification using non-linear SVC with RBF kernel. The target to predict is a XOR of the inputs.
The color map illustrates the decision function learned by the SVC.

In [ ]: print(__doc__)

import numpy as np
import matplotlib.pyplot as plt
from sklearn import svm

xx, yy = np.meshgrid(np.linspace(-3, 3, 500),
                    np.linspace(-3, 3, 500))
np.random.seed(0)
X = np.random.randn(300, 2)
Y = np.logical_xor(X[:, 0] > 0, X[:, 1] > 0)

# fit the model
clf = svm.NuSVC()
clf.fit(X, Y)

# plot the decision function for each datapoint on the grid
Z = clf.decision_function(np.c_[xx.ravel(), yy.ravel()])
Z = Z.reshape(xx.shape)

plt.imshow(Z, interpolation='nearest',
           extent=(xx.min(), xx.max(), yy.min(), yy.max()), aspect='auto',
           origin='lower', cmap=plt.cm.PuOr_r)
contours = plt.contour(xx, yy, Z, levels=[0], linewidths=2,
                       linetypes='--')
plt.scatter(X[:, 0], X[:, 1], s=30, c=Y, cmap=plt.cm.Paired)
plt.xticks(())

```

Figure 9 Opened example code in “Jupyter Notebook”

It should look like the screenshot above, and in “Cell” click “Run All” or run cells by clicking the .

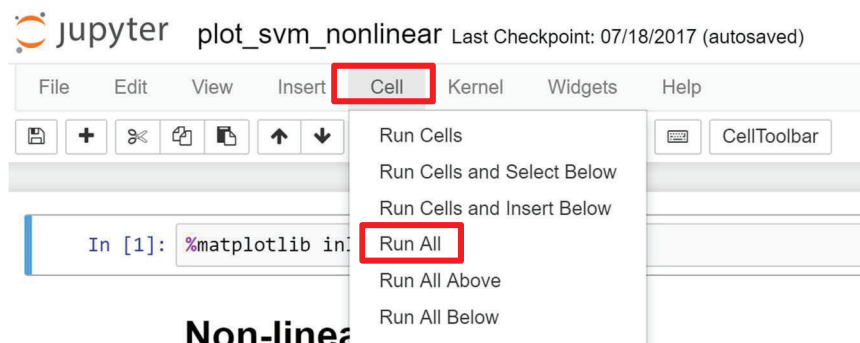


Figure 10 Run All cells to test the example code

打开后应该如上图的截屏一样。在“Cell”里点击“Run All”或者单个段落运行。

If it generated a figure like this, your software is good to go. Cheers!

如果它生成了下图，那么你的软件就没问题了！

```
plt.scatter(X[:, 0], X[:, 1], s=30, c=Y, cmap=plt.cm.Paired)  
plt.xticks()  
plt.yticks()  
plt.axis([-3, 3, -3, 3])  
plt.show()
```

Automatically created module for IPython interactive environment

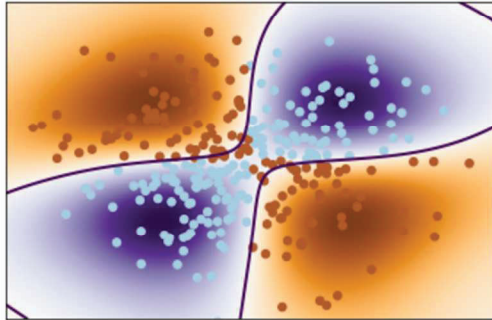


Figure 11 Expected output from example code

3. EIS data analysis with SVM machine learning (用支持向量机机器学习对电化学阻抗谱数据进行分析)

3.1. Data preparation (数据准备)

Raw EIS data usually includes frequency with real impedance (Z') and imaginary impedance (Z'') at that frequency.

电化学阻抗谱的原始数据通常由在特定频率的实阻抗和虚阻抗构成。

	A	B	C
	Frequency [Hz]	Z'_raw [Ohm]	Z''_raw [Ohm]
0	99999.99984	258.054229	-7.637512
1	85769.58917	255.299691	-17.882566
2	73564.22411	278.492955	-18.88002
3	63095.73291	275.258838	-15.963164
4	54116.95083	289.347566	-28.062849
5	46415.88639	287.247927	-26.796648
6	39810.71513	286.058176	-32.585536
7	34145.48673	296.438676	-33.791812
8	29286.44376	301.039143	-34.728174
9	25118.8625	300.781714	-35.632715
10	21544.34515	307.305851	-40.781186
11	18478.4963	308.219676	-39.220288
12	15848.93039	312.550444	-44.296644
13	13593.56249	311.666707	-50.051774
14	11659.14268	315.616756	-54.547519
15	9999.998792	318.54106	-58.196081
16	8576.957885	322.457927	-63.004504
17	7356.421543	326.558636	-69.321829
18	6309.57253	330.949427	-77.043239
19	5411.69444	336.52842	-84.527607
20	4641.588089	343.795531	-92.286639
21	3981.071029	352.501566	-102.064143
22	3414.548269	359.595675	-112.278786
23	2928.644022	372.104547	-122.381571
24	2511.885947	385.386363	-134.632903

Figure 12 A part of representative raw EIS data.

Make sure all you EIS test are using the same frequency range then **crate an excel sheet** as shown below, where first column are names, second column are labels, each following column is one feature which is either real impedance or imaginary impedance at a frequency.

确定你所有电化学阻抗谱的测试使用的都是相同的频率分布，并按下图建一个新的 excel 表格。

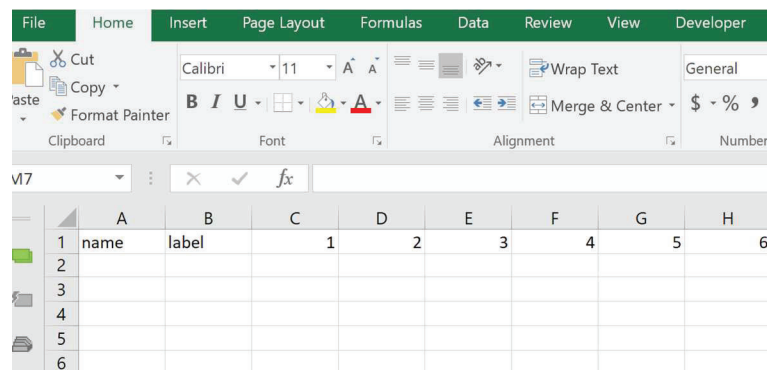


Figure 13 Excel template first step

第一列是名称，第二列是标签，之后的每一列是实阻抗护着虚阻抗。

Then, copy and transpose paste all real impedance (column B in Figure 12) to row 2 in Figure 13 starting at column C. (you may need to transpose paste the data in its original sheet then copy and paste to the template)

然后，把所有图 12 中 B 列的实阻抗数据，转置粘贴到图 13 中第二行，从第 C 列开始的位置（在原表格中先转置再复制粘贴可能更容易）

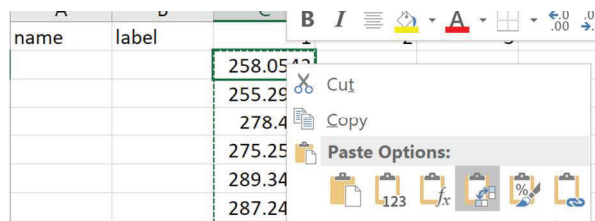


Figure 14 Using transpose paste option to paste all real impedance data in a row.

Then using similar method to copy all imaginary impedance (column C in Figure 12) to row 2 in Figure 13 starting at column CA (I have 76 frequencies in one EIS, I named row 1 from C as 1,2,3...76,77, to 152). Use your own naming system to give each EIS scan a unique name and put it in column A. Set a label (0 or 1 for binary classification) and put it in column B.

然后，用类似的方法，把所有虚阻抗的数据（图 12 中 C 列的数据）转置粘贴到图 13 中，第二行，CA 列开始的位置（在我的电化学阻抗谱中用了 76 个频率，所以第一行从 C 开始命名为 1,2,3 到 76，然后 77,78 一直到 152）。你可以使用你自己的命名系统，在 A 列中给每一个数据列命名，然后在 B 列中给每一个数据设置标签（二进制分类中就是 0 或者 1）

	A	B	C	BZ	CA	CB	EW	EX
1	name	label	1	76	77	78	151	152
2	4B2G1	0	258.054229	1621.41	-7.63751	-17.8826	-873.914	-939.174

Figure 15 Pasted imaginary impedance into row 2 from column CA to EX (columns D-BY and CC-EV are hidden). Name and label added

Transfer all you EIS data that you are interested in classification (usually with similar experimental setting and a single variable) to the template and save it as *.csv file

把那些你所有想要分类的的电化学阻抗谱数据（通常是相似的单变量实验）都用同样的方式粘贴到这个模板中，并另存为 csv 格式。

name	Label	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
4B2G1	0	258.0542	255.2997	278.493	275.2588	289.3476	287.2479	286.0582	296.4387	301.0391	300.7817	307.3059	308.2197	312.5504	311.6667	315.6168	318.5411
4B2G2	0	265.8894	268.0702	273.757	285.1902	278.4257	290.3433	291.5499	293.6509	302.0073	302.9377	307.6231	308.7262	312.3669	313.9265	315.5427	319.354
4B2G3	0	267.317	266.4577	276.3333	275.4226	286.8759	282.8898	294.9838	298.7177	299.2943	304.1186	306.9148	307.7466	312.0538	312.9816	315.566	318.3924
5B2G1	0	212.9031	210.1753	226.3933	227.7355	227.9052	226.8304	234.8648	238.0592	239.7823	242.3075	242.45	245.1441	246.9025	247.1612	249.6174	253.1013
5B2G2	0	221.8998	225.2367	231.5692	227.6233	227.1677	228.3944	234.2414	240.8749	242.4335	243.288	244.2544	247.5539	247.3955	248.675	250.9991	253.9048
5B2G3	0	220.5023	213.8915	224.6013	228.9741	225.4477	231.434	239.4562	239.4411	240.5017	244.0199	246.1277	246.6161	248.3261	249.4041	251.0594	253.8992
6B2G1	0	166.9949	173.7204	184.3192	169.5682	173.2099	176.5317	179.8662	179.617	183.9284	185.823	186.4487	188.3658	190.5809	191.4963	193.6587	196.2139
6B2G2	0	179.0694	182.0632	171.9485	169.2709	183.162	179.8637	183.721	182.0691	184.8741	185.6762	187.9043	189.6923	191.1944	191.7999	192.7237	196.459
6B2G3	0	168.6349	182.5261	178.646	174.2017	177.7401	179.4154	182.8754	184.3721	187.3621	184.121	186.3112	189.6721	191.2342	191.5679	193.5646	196.9216
4B2G5A1	1	259.9313	259.0188	266.8876	284.1592	285.0439	286.6123	294.9715	297.3411	304.1833	302.6753	305.6459	309.1808	311.1617	310.8451	313.0142	317.0626
4B2G5A2	1	263.466	266.4305	283.5566	278.298	285.1393	285.0858	289.288	298.2087	300.9645	302.7892	303.546	306.7226	309.8123	310.6402	311.6402	316.1097
4B2G5A3	1	265.7502	266.4175	272.3123	276.0552	276.7814	288.0103	291.8241	293.7257	299.5611	301.3291	303.3106	303.8075	308.4623	310.1837	312.8859	316.5454
5B2G5A1	1	214.0163	227.5339	223.9881	230.3015	225.7774	232.9494	236.9239	240.9703	242.9936	241.4223	245.6318	249.8173	249.9303	249.7395	251.7976	253.9502
5B2G5A2	1	221.6863	218.2461	224.2944	225.4269	234.8084	235.1881	237.1379	239.1588	242.6543	243.4588	245.48	247.0395	249.6863	250.0278	251.7821	254.6247
5B2G5A3	1	219.98	212.6655	217.8348	232.9979	229.0809	234.607	239.0655	242.7952	240.4469	246.9357	247.8388	248.3381	250.0531	249.12	250.7349	254.3541
6B2G5A1	1	186.333	178.2627	177.4258	185.1232	182.1481	184.8892	182.5009	183.927	188.007	190.4824	191.2653	190.0282	193.1123	193.4678	194.8699	196.8375
6B2G5A2	1	179.8914	173.6595	173.5661	180.1657	180.2534	182.6176	184.5293	184.7471	186.4101	187.6895	187.2631	189.8662	190.9922	191.2556	192.9192	194.9413
6B2G5A3	1	182.3292	179.924	177.2412	167.8647	180.4624	179.4651	185.4587	183.6399	188.3154	186.6553	189.5718	189.8636	191.809	191.5059	193.1888	195.5724
4B1G5A1	1	286.9791	291.5914	297.6871	292.363	306.4467	314.4559	308.4549	322.7986	324.8604	325.3788	325.2187	333.2716	331.9342	333.5523	336.6442	337.86
4B1G5A2	1	272.9672	281.8878	288.8579	313.4164	310.8411	312.8765	312.6907	309.6892	323.1059	325.5448	327.3001	327.981	332.406	333.0716	333.1723	337.3366
4B1G5A3	1	295.2762	283.1599	300.0213	297.0929	299.5606	307.4459	310.4039	321.0305	319.0035	325.234	326.0285	330.9777	332.898	331.6771	334.3737	338.3772

Figure 16 Example raw EIS dataset ready for SVM machine learning

This example file can be downloaded from:

我的实例文件可以从以下地址下载（国内可能需要翻墙）

<https://www.dropbox.com/s/7ftbm75mpyj6mc1/dataProject.csv?dl=0>

Each row is a data from one run of a sample (one EIS/CV scan)

The label column is used for supervised classification/regression. It could be binary or quantitative depends on your applications.

每一行代表一个完整的电化学阻抗谱。标签列用于有监督的分类或者回归。它可以是二进制的也可以是定量的。

For example:

In this dataset, "0" represent the blank/negative EIS results with no acetone in the samples; "1" represent the positive results with 5mM acetone concentration in the samples.

比如说:

在这个数据中, 0 代表了空白对照, 1 代表了有 5mM 丙酮的样本。

If you are testing glucose with 0, 1, 10 and 100 mM, you may label them as either "0,1,2,3" or "0,1,10,100" depending on doing classification or regression.

如果你要检测葡萄糖在 0,1,10 和 100mM 这几个浓度, 那你可以给对应数据加上 "0,1,2,3" 或者 "0,1,10,100" 的标签。取决于你是要分类分析还是回归分析。

Each column followed is called a "feature" that in EIS is the real or imaginary impedance at a certain frequency.

之后每一列都是一个机器学习中的“特征”, 它们都是电化学阻抗谱中某一频率下的实阻抗或者虚阻抗

3.2. SVM code for EIS data (支持向量机用于电化学阻抗谱的代码)

The code can be downloaded from:

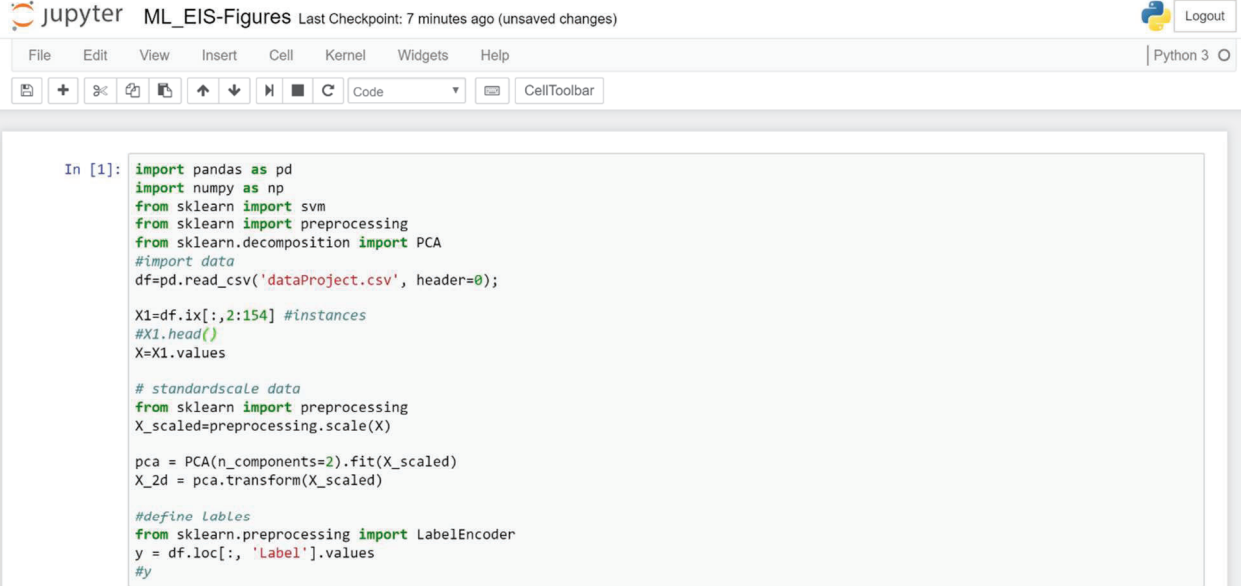
代码可以从以下地址下载（国内可能需要翻墙）

<https://www.dropbox.com/s/7ftbm75mpyj6mc1/dataProject.csv?dl=0>

Opened it in “Jupyter notebook” and put the datafile prepared as above in the same folder.

Run the code by cells.

用“Jupyter notebook”打开，并把之前的数据文件放到相同的目录。



```

In [1]: import pandas as pd
import numpy as np
from sklearn import svm
from sklearn import preprocessing
from sklearn.decomposition import PCA
#import data
df=pd.read_csv('dataProject.csv', header=0);

X1=df.ix[:,2:154] #instances
#X1.head()
X=X1.values

# standardscale data
from sklearn import preprocessing
X_scaled=preprocessing.scale(X)

pca = PCA(n_components=2).fit(X_scaled)
X_2d = pca.transform(X_scaled)

#define Labels
from sklearn.preprocessing import LabelEncoder
y = df.loc[:, 'Label'].values
#y

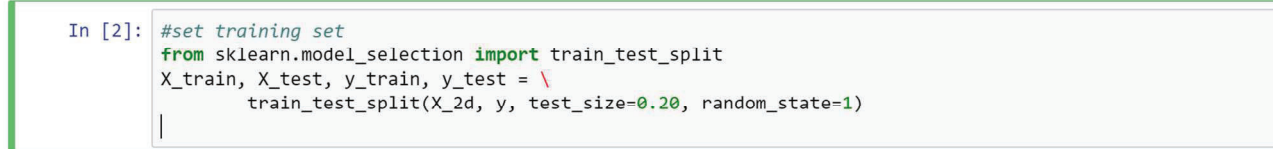
```

Figure 17 reading EIS dataset and data preprocessing

This cell read the EIS dataset from ‘dataProject.csv’

The data was scaled using `preprocessing.scale(X)`. And a principle component analysis (PCA) was performed to decompose the data into two dimensional.

这一个段落作用是从“dataProject.csv”读取数据。数据之后通过 `preprocessing.scale(X)` 标准化，通过主成分分析实现降维。



```


In [2]: #set training set
from sklearn.model_selection import train_test_split
X_train, X_test, y_train, y_test = \
    train_test_split(X_2d, y, test_size=0.20, random_state=1)

```

Figure 18 Split data into training and testing sets.

EIS data were split into 80% training and 20% testing.

电化学阻抗谱数据组被分为 80% 的训练组和 20% 的检验组



```

In [3]: import matplotlib.pyplot as plt

%matplotlib

Using matplotlib backend: Qt5Agg

```

Figure 19 pyplot from matplotlib package was imported and figures are set to appear in a new window.

Figures plotting tools was loaded. 制图工具载入

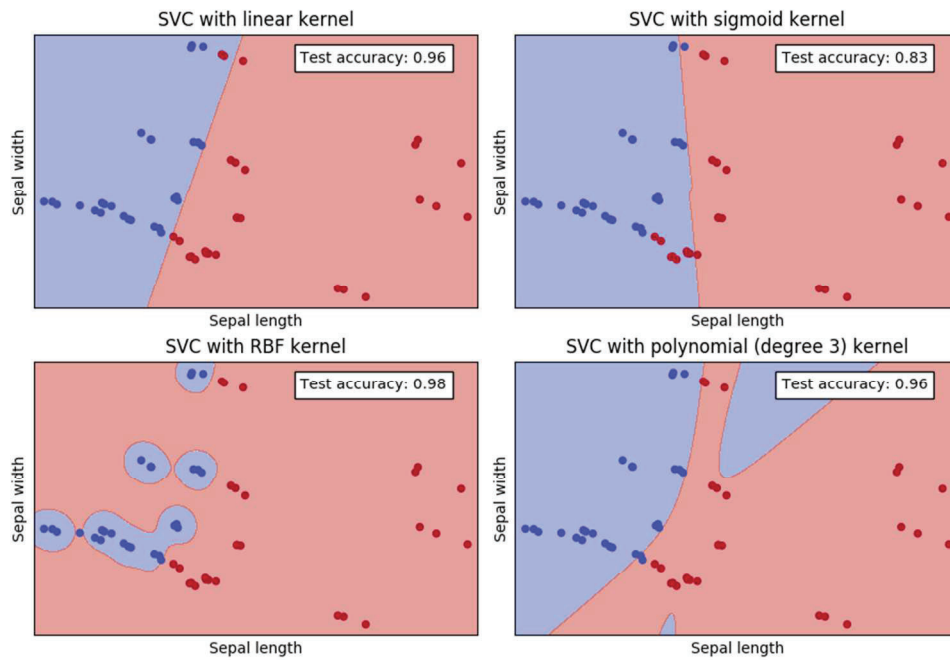


Figure 21 result figure from the kernel selection code 核选择代码的结果图

```
In [4]: #=====
#Fig 2
#=====
h = .02 # step size in the mesh
#C = 10 # SVM regularization parameter
svc = svm.SVC(kernel='linear').fit(X_train, y_train)
rbf_svc = svm.SVC(kernel='rbf').fit(X_train, y_train)
poly_svc = svm.SVC(kernel='poly').fit(X_train, y_train)
sigmoid_svc = svm.SVC(kernel='sigmoid').fit(X_train, y_train)

# create a mesh to plot in
x_min, x_max = X_train[:, 0].min() - 1, X_train[:, 0].max() + 1
y_min, y_max = X_train[:, 1].min() - 1, X_train[:, 1].max() + 1
xx, yy = np.meshgrid(np.arange(x_min, x_max, h),
                    np.arange(y_min, y_max, h))

# title for the plots
titles = ['SVC with linear kernel',
         'SVC with sigmoid kernel',
         'SVC with RBF kernel',
         'SVC with polynomial (degree 3) kernel']

for k, clf in enumerate((svc, sigmoid_svc, rbf_svc, poly_svc)):
    # Plot the decision boundary. For that, we will assign a color to each
    # point in the mesh [x_min, x_max][y_min, y_max].
    pl.subplot(2, 2, k + 1)
    pl.subplots_adjust(wspace=0.4, hspace=0.4)

    Z = clf.predict(np.c_[xx.ravel(), yy.ravel()])

    # Put the result into a color plot
    Z = Z.reshape(xx.shape)
    pl.contourf(xx, yy, Z, cmap=pl.cm.coolwarm, alpha=0.5)

    # Plot also the training points
    pl.scatter(X_2d[:, 0], X_2d[:, 1], c=y, cmap=pl.cm.coolwarm,s=20)

    #Plot score

    pl.text(0.6,0.9, ('Test accuracy: %.2f' % clf.score(X_2d, y)), transform=pl.gca().transAxes,
           bbox={'facecolor':'white'})

    pl.xlabel('Sepal length')
    pl.ylabel('Sepal width')
    pl.xlim(xx.min(), xx.max())
    pl.ylim(yy.min(), yy.max())
    pl.xticks(())
    pl.yticks(())
    pl.title(titles[k])

pl.show()
```

Figure 20 code cell for kernel selection 核选择的代码

```

1 In [7]: from matplotlib.colors import Normalize
2
3 from sklearn.svm import SVC
4 from sklearn.preprocessing import StandardScaler
5 from sklearn.datasets import load_iris
6 from sklearn.model_selection import StratifiedShuffleSplit
7 from sklearn.model_selection import GridSearchCV
8 %matplotlib
9
10 class MidpointNormalize(Normalize):
11
12     def __init__(self, vmin=None, vmax=None, midpoint=None, clip=False):
13         self.midpoint = midpoint
14         Normalize.__init__(self, vmin, vmax, clip)
15
16     def __call__(self, value, clip=None):
17         x, y = [self.vmin, self.midpoint, self.vmax], [0, 0.5, 1]
18         return np.ma.masked_array(np.interp(value, x, y))
19
20 C_range = np.logspace(-5, 8, 14)
21 gamma_range = np.logspace(-9, 4, 14)
22 param_grid = dict(gamma=gamma_range, C=C_range)
23 cv = StratifiedShuffleSplit(n_splits=10, test_size=0.2, random_state=12)
24 grid = GridSearchCV(SVC(), param_grid=param_grid, cv=cv)
25 grid.fit(X_train, y_train)
26
27 print("The best parameters are %s with a score of %0.2f"
28       % (grid.best_params_, grid.best_score_))
29
30 # Now we need to fit a classifier for all parameters in the 2d version
31 # (we use a smaller set of parameters here because it takes a while to train)
32
33 C_2d_range = [1,10, 100, 1000,10000]
34 gamma_2d_range = [1e-4,1e-3, 1e-2,1e-1,1]
35 classifiers = []
36 for C in C_2d_range:
37     for gamma in gamma_2d_range:
38         clf = SVC(C=C, gamma=gamma)
39         clf.fit(X_train, y_train)
40         classifiers.append((C, gamma, clf))
41
42 Using matplotlib backend: Qt5Agg
43 The best parameters are {'C': 10.0, 'gamma': 0.01} with a score of 0.99

```

Figure 23 Finding the best parameters for RBF kernel and its results 径向基函数核最佳参数选择的代码核

```

30 In [6]: from sklearn.model_selection import cross_val_score
31
32 scores = cross_val_score(estimator=svm.SVC(kernel='rbf', gamma=0.01, C=10),
33                          X=X_2d,
34                          y=y,
35                          cv=10,
36                          n_jobs=10)
37 print('CV accuracy scores: %s' % scores)
38 print('CV accuracy: %.3f +/- %.3f' % (np.mean(scores), np.std(scores)))
39
40 CV accuracy scores: [ 0.66666667  1.          0.83333333  1.          1.          1.          1.
41                    1.          1.          1.          ]
42 CV accuracy: 0.950 +/- 0.107

```

Figure 22 Cross validation and its result. 交叉验证的代码核结果



Figure 25 Effect of parameters for RBF kernel. 径向基函数核参数改变的效果

```
In [9]: import matplotlib.pyplot as plt
# plt.figure(figsize=(8, 6))
# xx, yy = np.meshgrid(np.linspace(-3, 3, 200), np.linspace(-3, 3, 200))
h=.1
x_min, x_max = X_train[:, 0].min() - 1, X_train[:, 0].max() + 1
y_min, y_max = X_train[:, 1].min() - 1, X_train[:, 1].max() + 1
xx, yy = np.meshgrid(np.arange(x_min, x_max, h),
                    np.arange(y_min, y_max, h))
for (k, (C, gamma, clf)) in enumerate(classifiers):
    # evaluate decision function in a grid
    Z = clf.decision_function(np.c_[xx.ravel(), yy.ravel()])
    Z = Z.reshape(xx.shape)

    # visualize decision function for these parameters
    plt.subplot(len(C_2d_range), len(gamma_2d_range), k + 1)
    plt.subplots_adjust(wspace=0.3, hspace=0.3)
    plt.title("gamma=10^%d, C=10^%d" % (np.log10(gamma), np.log10(C)),
             size='medium')

    # visualize parameter's effect on decision function
    Z = clf.predict(np.c_[xx.ravel(), yy.ravel()])
    Z = Z.reshape(xx.shape)
    plt.contourf(xx, yy, Z, cmap=plt.cm.coolwarm, alpha=0.5)
    # plt.pcolormesh(xx, yy, -Z, cmap=plt.cm.RdBu)
    # plt.scatter(X_train[:, 0], X_train[:, 1], c=y_train, cmap=plt.cm.coolwarm)
    # plt.scatter(X_test[:, 0], X_test[:, 1], y_test, cmap=plt.cm.RdBu_r)

    for i in range(0, X_train.shape[0]):
        if y_train[i] == 0:
            c1 = plt.scatter(X_train[i,0],X_train[i,1],c='r',marker='o', s = 20 )
        elif y_train[i] == 1:
            c2 = plt.scatter(X_train[i,0],X_train[i,1],c='g',marker='+', s = 30 )
    for i in range(0, X_test.shape[0]):
        if y_test[i] == 0:
            c3 = plt.scatter(X_test[i,0],X_test[i,1],c='b',marker='o', s = 20 )
        elif y_test[i] == 1:
            c4 = plt.scatter(X_test[i,0],X_test[i,1],c='m',marker='+', s = 30 )

    plt.xticks(())
    plt.yticks(())
    plt.axis('tight')

scores = grid.cv_results_['mean_test_score'].reshape(len(C_range),
                                                    len(gamma_range))
```

Figure 24 Code to visualize effect of parameters for RBF kernel. 径向基函数核参数效果展示的代码

1 If you have your dataset prepared like this you may easily modify my code or the codes available online
2 and test it out.

3 如果你的数据用这种方式预处理好了，那么你可以很容易的通过修改我的代码或者使用网上可用
4 的代码来进行测试
5

6 7 **3.3. Scikit-Learn**

8 <http://scikit-learn.org/stable/index.html>

9 If you have time, checkout this site.

10 Most of my code and knowledge is based on the information and example from this open source
11 project.

12 如果你有时间，请查阅以上网址，我的所有代码都是基于 Scikit-learn 这个开源项目。

13 Good Luck! 祝你好运!
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

10/23/2017



SNAPS

PART-1 & PART-2

Shoumen Datta

HAPHAZARD REALITY – IOT IS A METAPHOR





1 Sensor Analytics Point Solutions (SNAPS) for 2 Detection and Decision Support Systems (DSS)

3 Eric S. McLamore^{1*}, Shoumen Palit Austin Datta^{1,2,3**}, Victoria Morgan¹, Nicholas Cavallaro¹,
4 Greg Kiker¹, Daniel M. Jenkins⁴, Yue Rong¹, Carmen Gomes⁵, Jonathan Claussen⁵, Diana
5 Vanegas⁶, Sahar Bahramzadeh⁷, Evangelyn C. Alocilja^{8,9}

6 ¹ Agricultural and Biological Engineering, Institute of Food and Agricultural Sciences, University of Florida,
7 Gainesville, FL 32611

8 ² MIT Auto-ID Labs, Department of Mechanical Engineering, Massachusetts Institute of Technology, 77
9 Massachusetts Avenue, Cambridge, MA 02139

10 ³ MDPnP Labs, Biomedical Engineering Program, Department of Anesthesiology, Massachusetts General Hospital,
11 Harvard Medical School, 65 Landsdowne Street, Cambridge, MA 02139

12 ⁴ Molecular Biosciences and Bioengineering, University of Hawaii, Manoa, Honolulu, HI 96822

13 ⁵ Mechanical Engineering, Iowa State University, Ames, IA 50011

14 ⁶ Environmental Engineering and Earth Sciences, Clemson University, Clemson, SC 29634

15 ⁷ School of Computer Engineering, Azad University, Science and Research Branch, Saveh, Iran

16 ⁸ Global Alliance for Rapid Diagnostics, Michigan State University, East Lansing, MI 48824

17 ⁹ Nano-Biosensors Lab, Michigan State University, East Lansing, MI 48824

18

19 *Corresponding author: Eric S. McLamore [emclamor@ufl.edu] ☎ +1(352)294-6703]

20 **Corresponding co-author: Shoumen Palit Austin Datta [shoumen@mit.edu]

21 **Abstract:** We discuss the role of sensor analytics point solutions (SNAPS), a reduced complexity
22 machine-assisted decision support (MADS) tool. We summarize the approaches used for mobile
23 phone-based chemical/biological sensors, including general hardware and software requirements
24 for signal transduction and acquisition. We introduce SNAPS, part of a platform approach to
25 converge sensor data and analytics. The platform consists of a portfolio of modular tools which
26 may lend itself to dynamic composability by enabling context-specific selection of relevant units,
27 resulting in user-guided, context-specific, case-based working modules. SNAPS is an element of
28 this variant configuration mechanism, where, depending on need, data analytics, statistical
29 characterization and algorithms may be delivered to the data via embedded systems in devices, or
30 sourced, in near real-time, from mist, fog or cloud computing resources. Convergence of the
31 physical systems with the cyber components paves the path for SNAPS to progress to higher
32 levels of artificial reasoning tools (ART) and emerge as data-informed decision support as a
33 service (DIDA'S). Proof of concept examples of SNAPS are demonstrated for quantitative and
34 qualitative data, each operated using a mobile device (smartphone/tablet) for data acquisition and
35 analysis. We discuss the challenges and opportunities for SNAPS, centered around the value to
36 end-users as a key performance indicator (KPI), for generic machine-assisted tools (MAT).

37 **Keywords:** sensor; smart systems; data analytics; cyber-physical systems; artificial reasoning tools;
38 ART; drag and drop analytics; DADA; sensor-analytics packages; SNAP; machine-assisted tools;
39 MAT; machine-assisted platform; MAP; knowledge graphs; trans-disciplinary convergence;
40 machine-assisted decision support; MADS
41

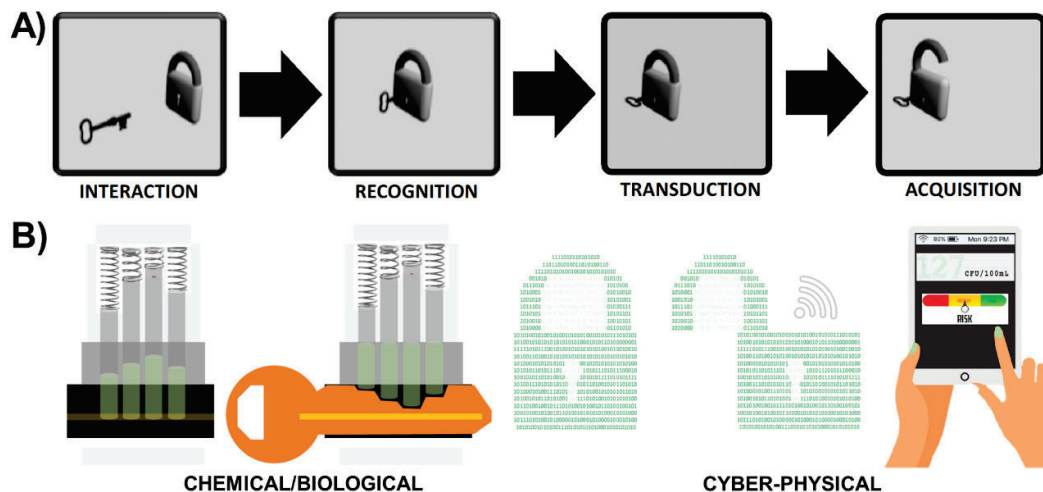
66 2. Sensor Engineering

67 *Chemosensing, biosensing, nanosensing may converge with partial autonomy*

68 A plethora of literature reviews describe the historical context [1], recent advances [2][3][4],
69 and futuristic ideas [5][6][7] related to development and application of chemosensors, biosensors,
70 and nanosensors [8][9]. These diagnostic tools have important applications across medical,
71 agricultural, and environmental domains. The sensor working mechanism established by the
72 International Union of Pure and Applied Chemistry in the 1990's serves as the design template.
73 The receptor coating on the sensor selectively binds target, a transduction event produces
74 measurable signal, the signal is acquired using specialty equipment. This sensing process, based on
75 the RTA triad, has been enhanced through the use of nanomaterials that improve detection limit,
76 speed and/or reversibility [10][11]. In addition, biomaterials are used to improve selectivity,
77 bandwidth, or facilitate actuation [12][13][14].

78
79 The primary application space for sensors/biosensors has been the analysis of unique targets
80 using relatively low cost, rapid detection platforms [15], including small molecules, viruses and
81 cells (amongst other targets). Recent works have focused on enhancing the mobility of sensors for
82 rapid on-site applications [16] by limiting the requirement for equipment or *post hoc* methods that
83 depend on formal labs. Most portable/handheld sensor efforts do not view chemo/bio/nanosensors
84 as a direct competitor for standard analytical laboratory diagnostics, but rather as a parallel tool to
85 trigger new questions or additional sampling to improve resolution and preserve data quality.
86 Attempting to use a handheld sensor to produce the accuracy and precision that is commonplace
87 in laboratory-based analytical techniques is in most cases a fool's errand, and a cost prohibitive
88 over-promise. What is realistic, on the other hand, is the development of low cost, light weight,
89 rapid diagnostic tools that can provide point solutions to match the specific context of the question
90 (the "low hanging fruit" from the tree of complex problems). Mobility of customized/personalized
91 sensors in an open-access format may prove to demystify the complexity of certain intractable
92 problems, raising the tide of knowledge, while providing service to communities in need and
93 enabling science to serve society (the masses, at large).

94
95 Mobile phone-based data acquisition systems are primary catalysts for mobility [17]. Smart
96 phone systems are available for optical transduction techniques such as fluorescence [18] and
97 surface plasmon resonance [19], in addition to electrochemical transduction techniques such as
98 voltammetry [20] and impedance spectroscopy [21]. While analytical capabilities have grown
99 exponentially in the last decade due to the rapid diffusion of tools such as machine learning
100 [22][23][24], there are only a few examples of mobile phone-based data analysis tools in the
101 literature [25] as most data analysis occurs on remote computers and not on mobile devices at the
102 point of contact. To maintain the integrity of end-user needs and ensure quality of service, mobile
103 phone-based sensors may be connected to remote analytics. Here, we introduce SeNsor-Analytics
104 Point Solutions (SNAPS), part of a platform approach for transforming sensor data into actionable
105 information using the mobile phone for data acquisition and performing near real-time, on-site,
106 edge analytics (Fig 1).



107

108 **Figure 1.** Sensor-Analytics Point Solutions (SNAPS) optimizes synergistic systems
 109 integration and connectivity between chemical/biological sensing with cyber-physical
 110 systems. A) Classical “lock and key” metaphor for sensor/biosensor part of the physical
 111 system in CPS. B) Sensor signal transduction (physical/chemical/biological component)
 112 and transmission to a mobile device coupled with in-network processing and on-site
 113 edge analytics (cyber component in CPS).

114 *The RTA triad is governed by material choice*

115 The affinity of the receptor for the target is the limiting factor for sensor function, and the
 116 importance of this first step in the RTA triad cannot be over-emphasized. Given that binding
 117 affinity and selectivity are the architects of the RTA triad, transduction is the platform for
 118 innovation. Intuitively, material choice dictates classification of device as either a sensor (use of
 119 abiotic materials), biosensor (biological or biomimetic materials), nanosensor (nanomaterials), or
 120 nanobiosensor (hybrid nano/biomaterials).

121

122 In addition to dictating these commonplace definitions, sensor material choice dictates critical
 123 factors such as performance, cost and quality of service (QoS). In its basic form, transduction is
 124 defined as a change in energy state, and there are two major classes of transduction that generates
 125 quantitative versus qualitative data, namely inherent and engineered transduction, respectively.

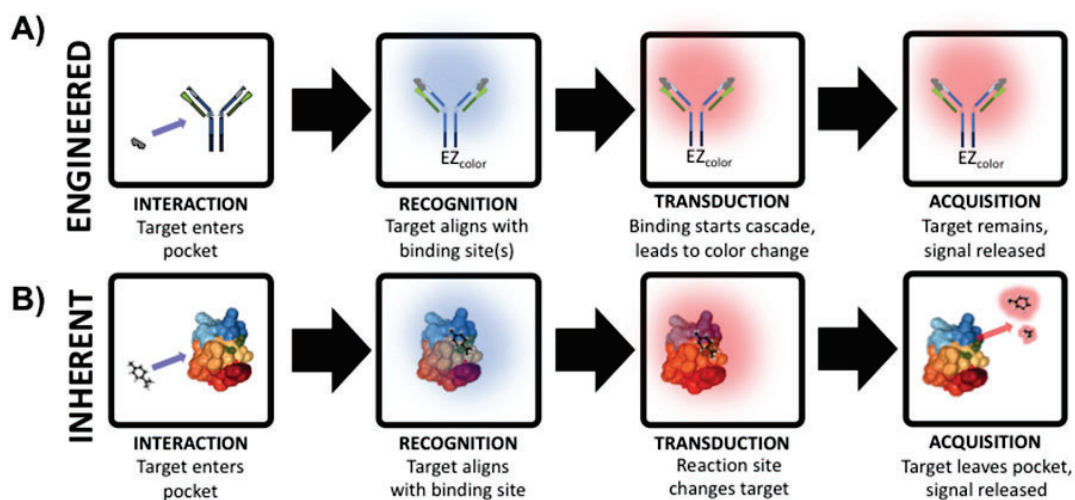
126

127 Engineered transduction involves specific binding between target and receptor but does not
 128 generate a measurable product without an extra “engineered” step. The thermodynamics of the
 129 system do not lead to favorable production of an active compound which can be directly quantified
 130 using acquisition equipment. An extra step is required such as addition of exogenous reagent(s)
 131 such as a label, or immobilization of a supporting material in close proximity to the recognition
 132 structure that results in a cascade which generates a measurable by-product. The most common
 133 example of engineered transduction is a lateral flow assay involving at least one binding protein
 134 (such as an antibody) (Fig 2A). This recognition structure is co-immobilized with a secondary
 135 structure that, upon binding of the target, undergoes a specific reaction and leads to a visible color

136 change [26]. In this type of transduction, the bonds between the target and recognition structure
137 are typically intact after the signal is acquired, leading to a significant amount of hysteresis (i.e.,
138 covalent antibody-epitope bonds). Due to the hysteric binding between target and receptor,
139 devices based on engineered transduction are typically not reusable as attempts to recover the
140 native binding chemistry of the receptor are uncommon. However, the latter may change and re-
141 usability may gain prominence if we can better appreciate the potential for engineering allosteric
142 triggers in the recognition mechanism [27][28]. At present, semi-quantitative data can be obtained
143 using engineered transduction approaches, if a sensor array is developed. The hysteric molecular
144 interactions restrict the data from being truly quantitative. Beyond color change, there are a host of
145 other transduction mechanisms that are not addressed in this paper (electrochemical, magnetic,
146 plasmonic, etc).

147
148 Sensors which autonomously produce quantitative data are classified as inherent
149 transduction. For example, an enzyme-ligand interaction is shown in **Fig 2B**. In this type of
150 transduction, binding of the target by the receptor leads to the production of a measurable by-
151 product with little or no hysteresis. No additional engineering is needed to obtain useful signal
152 correlated to the binding event, as the thermodynamics of the system indicate that the presence of
153 the target alone is the rate limiting step for energy state change. The formation of the product can
154 be directly correlated to the presence of a specific amount of target, with the causality of product
155 formation well described by system stoichiometry and thermodynamics. The most common
156 example of inherent transduction is the glucose biosensor for blood analysis. Glucose and oxygen,
157 present in blood, serve as activators of the enzyme catalyzed oxidation due to the enzyme GOx,
158 glucose-1-oxidase (beta-D-glucose:oxygen-1- oxidoreductase, EC 1.1.3.4). In this reaction, the
159 oxidation of glucose on the sensor surface results in the production of electrons, which are
160 measured using oxidative amperometry [29]. One major advantage of inherent transduction is that
161 the bonds between the target and receptor are typically destabilized during the transduction,
162 leading to diffusion of reaction by-products away from the binding site after formation. Reducing
163 sensor hysteresis facilitates development of reusable sensor chemistry, allowing continuous or in
164 line sensing.

165
166 Whether the recognition involves a biomaterial, abiotic, or nanophase material, in most cases
167 multiple chemical bonds occur between the target and the receptor material, and the strength of
168 these bonds governs the specificity, limit of detection (LoD), response time, and hysteresis of the
169 sensor. Mismatch of between material choice and intended application results in loss of quality of
170 service, and in some cases a complete lack of technology acceptance. Assays and sophisticated *post*
171 *hoc* analysis techniques can resolve some of this mismatch, within limits. To preserve and elevate
172 the quality of the outcome, selection of appropriate material(s) should be paired with optimized
173 sensing protocols and analytical techniques, discussed in the following section.



174

175 **Figure 2.** Development of chemical/biological sensor systems is based on either A)
 176 Engineered transduction, where a cascade of reactions must be developed for obtaining
 177 the signal that is specific to the interaction/recognition step, or B) Inherent transduction,
 178 where activation energy is supplied by target and ambient environment. Structure of
 179 protein in panel B courtesy of Mosbah et al [30].

180 3. Sensor-Analytics Point Solutions (SNAPS)

181 Overview

182 SNAPS consist of a biological/chemical/physical sensor directly interfaced with an analytical
 183 tool. The green box in Fig 3A summarizes the RTA triad and displays a choice between the two
 184 types of transduction discussed in the previous section. Once a receptor material is selected and the
 185 appropriate transduction scheme is engineered, the process is coupled with acquisition equipment
 186 to obtain signal (data). The blue box in Fig 3B shows the *post hoc* data analysis phase of SNAPS,
 187 which aims to extract actionable information from sensor data. Contrary to the standard used in
 188 sensor design, the analysis phase is less standardized, primarily due to lack of platform(s) for data
 189 diagnostics, data quality, context, problem space, and query semantics [31]. As an example of a
 190 common framework, Marr's framework is shown, which is a learning principle grounded in
 191 Bayesian inference. Marr's analysis process flow has three interconnected steps: a computational
 192 stage, an algorithmic or heuristic step, and an implementation step [32]. Analogous to the two
 193 types of transduction previously discussed, the choice of a heuristic or algorithmic approach
 194 should be directly linked to the problem context for maintaining quality of service. The
 195 implementation step deconvolutes processed data using a relevance filter for producing
 196 information.

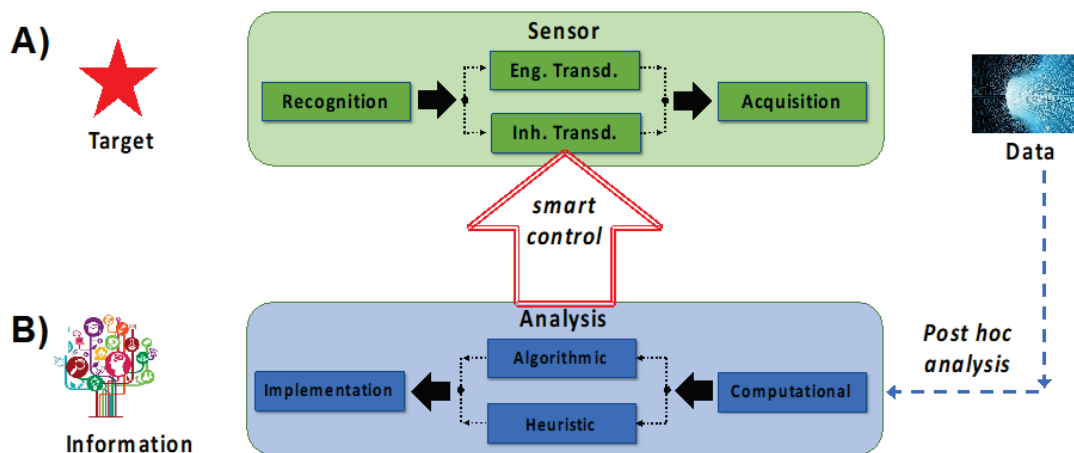
197

198 In advanced SNAPS, the analysis phase may have an optional feedback control loop with the
 199 sensor transduction step, which may be referred to as Smart SNAPS. For example, the temperature,
 200 pH, electrical potential, or light intensity can be modulated to influence the sensor transduction

201 step based on information obtained from the data analysis phase. Active control of any phase in
 202 the RTA triad qualifies as a Smart SNAPS, but interfacing with the transduction step is the most
 203 logical route for adding value.

204

205 In SNAPS, acquisition and analytical processing occurs at the edge by deploying a mobile
 206 platform of tools using a smartphone or a tablet, or other similar devices as mobile hosts. The next
 207 section demonstrates examples of these hardware and software tools in the current literature.



208

209 **Figure 3.** SNAPS attempts to transform data into information based on convergence of
 210 two distinct areas, namely sensing and analytics. The framework for these two areas is
 211 described by: A) standard sensor development guided by RTA logic, and B) data analysis
 212 using the usual tools (computational, algorithmic, statistical). Smart control can be
 213 achieved when data from the analysis step actively controls (auto-actuates) at least one
 214 process within the RTA sensor triad.

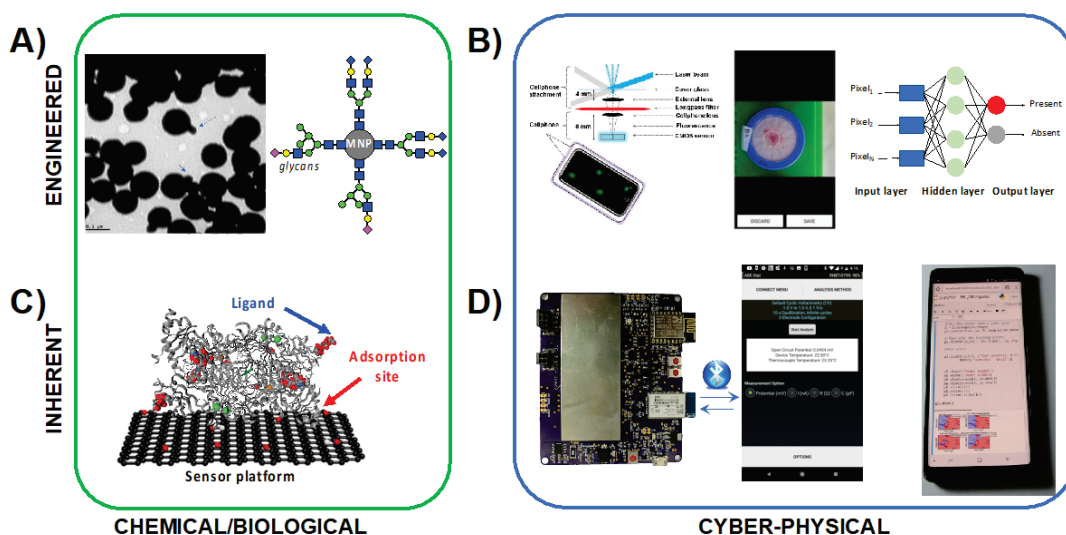
215 *SNAPS Hardware and Software*

216 **Fig 4** shows an example of the hardware and materials used for the development of SNAPS.
 217 The example of engineered transduction (top of **Fig 4**) demonstrates engineered transduction for
 218 diagnosis of tuberculosis (TB) via detection of acid-fast bacilli in sputum samples. Biorecognition
 219 is grounded in principles of glycobiology, where target cells are labeled by glycan-coated magnetic
 220 nanoparticles (GMNP) [33][34]. In this example, a neodymium magnet is used to separate the
 221 particle-cell aggregates to facilitate rapid determination of acid-fastness and cording properties of
 222 captured mycobacteria. The TB test also employs Gram staining to provide visual confirmation.
 223 Smartphone based optical systems [35] or complex microfluidic systems [36] may be used for on-
 224 site image analysis, and image processing algorithms [37][38][39][40], may be used for improving
 225 accuracy and providing decision support.

226

227 In another example (bottom of **Fig 4**), inherent transduction is demonstrated for approaches
 228 such as the graphene oxide-biogenic amine nanobiosensor recently developed by Vanegas et al
 229 [41]. In this example, an enzymatic biosensor was developed based on diamine oxidase, which was
 230 tethered to a laser scribed graphene (LSG) electrode decorated with nano-copper. Upon

231 recognition of the target ligand within the enzyme binding pocket, oxidation is carried out to
 232 produce hydrogen peroxide as a by-product. The peroxide is deprotonated under an operating
 233 potential of +500mV to produce electrons, measured using oxidative amperometry. Inherent
 234 transduction uses materials such as oxidase which contain both active binding site(s) for
 235 recognition and catalytic reaction site(s) for transduction, with the pockets remaining intact after
 236 reaction (limiting hysteresis). Signal acquisition utilizes a handheld potentiostat connected to a
 237 mobile phone such as the ABE-STAT tool [21]. The support vector machine (SVM) learning
 238 (SVML) classification system [25] may be also applied using the same mobile phone via the Jupyter
 239 notebook open source portfolio of machine learning tools. There are a myriad of other approaches
 240 for optical smartphone sensing [19][42][43] as well as electrochemical sensing [20][44].
 241



242

243 **Figure 4.** Examples of hardware/materials that may be used for SNAPS for engineered
 244 transduction (top) and inherent transduction (bottom). These select examples
 245 demonstrate the convergence of chemical/biological sensors with cyber-physical systems
 246 for delivering computational capabilities and *algorithms to sensor data* (rather than
 247 *sending* the data for analytics, in this paradigm the analytical tools are *sent* to the data at
 248 the edge, on a mobile device). **A)** Bacteria-specific magnetic nanoparticles provide dual
 249 functions of labeling and enhancing aggregation in detection of target cells. **B)** Cyber-
 250 physical tools for engineered transduction may include smartphone-based microscopes
 251 for cell imaging, the images are processed by embedded algorithms and the outcome
 252 “informs” the decision support system. **C)** Oxidase-based biosensors enable inherent
 253 transduction, limiting hysteresis and enabling reusability. **D)** Handheld potentiostats
 254 may be used to acquire electrochemical sensor signals, and embedded or cloud-based
 255 remote analytics such as SVML [25] may be used to provide analysis and decision
 256 support. Photograph of glycan-functionalized magnetic nanoparticles courtesy of Bhusal
 257 et al [33]. Crystal structure of diamine oxidase courtesy of McGrath et al [45].
 258 Fluorescent smartphone sensor platform courtesy of Wei et al [35]. Image of colorimetric
 259 *E. coli* test and machine learning knowledge graph from Gunda et al [40].

260 It is obvious that sensor data, and thus the hardware to collect the data, are core competencies
261 required to fuel SNAPS or any equivalent tool in the portfolio of machine-assisted tools (MAT).
262 Without data, subsequent progress from SNAPS to higher order decision support may be
263 impossible. A wide range of commercial and custom software are available for cloud-based
264 analytics [46][47][48]. Drag and drop analytics [49][50][51][52][53][54] is one such tool of
265 growing interest. One example of a drag and drop analytic software is the tool developed for
266 quantifying uncertainty in data exploration, or QUDE. QUDE automatically quantifies the
267 different types of uncertainty/errors within data exploration pipelines [55]. The automation feature
268 in this tool is based on the following workflow: data extraction, data integration, data processing,
269 exploratory queries, machine learning, and finally interpretation. QUDE is not intended to
270 represent a solution agnostic of all problems, but rather demonstrates an approach that may serve
271 as a starting point to connect chemical/biological sensors to analytics in real time. Evolution of
272 data analysis from extraction to visualization, even in a drag and drop *modus operandi*, requires a
273 deep understanding of the context and is highly problem specific. Visualization tools (such as the
274 volcano plots in Fig 5) are information-rich presentations of complex datasets which may facilitate
275 use of a tool in multiple application domains, but the information must be comprehensible to
276 users/stakeholders to provide any actionable information.

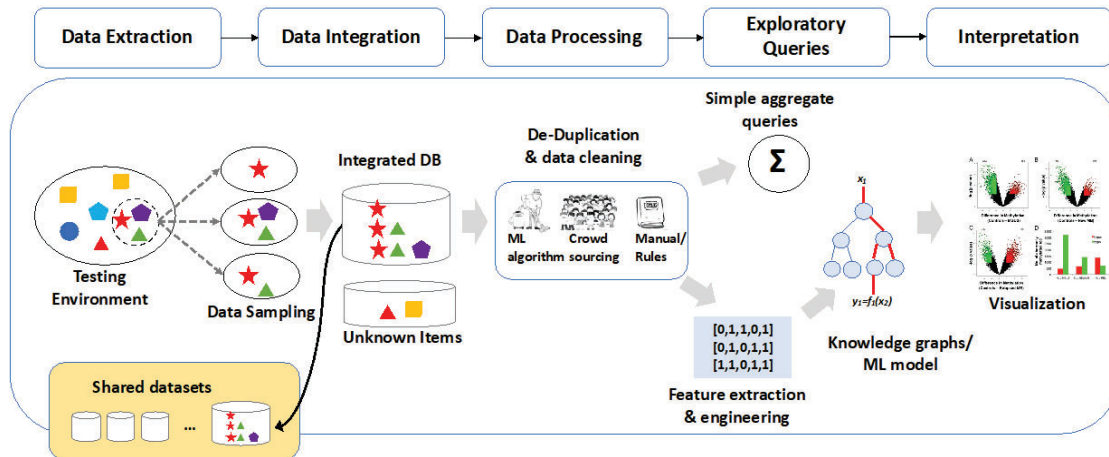
277

278 Knowledge graph algorithms, in combination with statistical analysis and machine learning
279 (for example, feature engineering, extraction and selection) [56][57], are elements likely to
280 improve the outcome from SNAPS and enable the gradual evolution of SNAPS to become a higher
281 order tool to facilitate data-informed decision as a service (DIDA'S), as discussed in the following
282 section.

283

284 The plethora of tools reviewed here and elsewhere may operate in harmony in specialized
285 facilities (such as academic research centers). However, the real value of the convergence is at the
286 hands of end-users who may lack specialized knowledge of software or systems. Without lucidity
287 as a guiding light in the design process, any meaningful application of these tools may remain an
288 utopian expectation. Adoption largely depends on creating user interfaces no more complicated
289 than a menu of choices, for example, the type of variant configuration that enables a customer to
290 customize a laptop. Thus, the paradigm of “plug and play” must be at the front and center of this
291 discussion in order to “hide” the complexity behind simple drag and drop features which may
292 empower end users to efficiently interact with these tools [58][59]. Simplified drag and drop tools
293 for SNAPS may exponentially accelerate global demand for these tools. Democratization of access
294 through Lego-esque modular drag and drop interfaces [60], may pave the way for “drag and drop
295 analytics” (DADA) for mobile decision support systems and partial autonomy. DADA and SNAPS
296 have enormous application potential, not only in the agro-ecosystem but in any domain, for
297 example, healthcare, manufacturing [61], finance, utilities, logistics, transportation and retail.

298



299

300 **Figure 5.** Software tools such as drag and drop analytics (DADA) may enable cloud-
 301 based analytics for SNAPS. The tool shown here automatically quantifies the different
 302 types of uncertainty/errors within data exploration pipelines (image from Chung et al
 303 [55] modified to match context of SNAPS). Diagram shows workflow (top) and an
 304 example of a pipeline (bottom).

305 4. Auto-actuation and partial levels of autonomy for low-risk automation (SARA Paradigm)

306 Autonomy is a framework that emerged from intelligent control and systems theory dating
 307 back at least a half century [62]. The specific technology need predicates the architecture of the
 308 system (including both hardware and software), and not all sensors or sensor systems are required
 309 to be involved in higher levels of autonomy [63][64]. For example, the purpose, architectural
 310 details, system functions, and characteristics for unmanned *terrestrial* vehicles are different
 311 compared to unmanned *space* vehicles [65]. One unifying attribute of these systems is the need to
 312 sense (sensors on the front end of the process) and then analyze (analytics on the back end) before
 313 the system can respond, i.e., SNAPS equivalent in the sense-analyze-response systems (SARS)
 314 paradigm. Lessons from higher level autonomous systems may inform how SNAPS may be better
 315 engineered and optimized to deliver value (albeit, in a very different context, when compared to
 316 the specifications for levels of autonomy in automobiles or the aerospace industry).

317

318 In the context of SNAPS, the traditional six levels of autonomy (*see supplemental Figure S1*),
 319 may inform design. In the lowest level of autonomy (simple), human interaction is required for
 320 direct control of the sensor system(s) and/or manual off-loading of data for *post hoc* analysis. For
 321 example, deployed buoy systems are common in environmental studies of aquatic chemistry [66],
 322 which represents the current state for most sensor data, which is simply a report of raw data. The
 323 latter may be referred to as simple user-guided activity report or the SUGAR paradigm.

324

325 In the 2nd level of autonomy (assisted), a high degree of human interaction is required, but at
 326 least one aspect of SNAPS (either sensing or analytics) is capable of performing task(s) without *de*
 327 *novo* synthesis of a map. These tasks may achieve prescribed objective(s), adapt to environmental
 328 changes, or develop new objectives. For example, Rong et al [25] recently developed an open

329 source mobile-phone based analytics protocol for analyzing impedance data acquired from a
 330 nanobiosensor. The primary objective of the tool is to perform the first layer of analysis in
 331 development of a SVM classifier to analyze impedance data (in lieu of equivalent circuit analysis).
 332 The mobile phone-based tool automates selection of classifier type using principal components
 333 analysis, and subsequently automates selection of hyperplane parameters (optimizes the support
 334 vector classifier and support vector regressor functions across the selected hyperplane). While this
 335 MAT does not perform decision support or provide validation layer(s), it may qualify as machine-
 336 assisted automation, particularly if the impedance data is acquired using the same hardware and
 337 the sensing/analysis processes are linked for on-site edge analytics (that is, analysis, at the edge).
 338

339 The classical 3rd level of automation, *partial autonomy*, may be achieved through remote
 340 control of SNAPS related features, including sensing, data download, and some form of data
 341 analytics such as heuristic risk assessment. The outcome may trigger a low-risk set of logic tools to
 342 execute workflow which sets into motion an auto-actuation function. By embracing and
 343 accomplishing auto-actuation, the concept of SNAPS evolves to address the SARA (sense, analyze,
 344 respond, actuate) paradigm. For example, SNAPS may auto-adjust water flow rate in irrigation
 345 pumps (by temporarily overriding a pre-set routine flow rate) based on updated moisture data
 346 (from field sensor) and refreshed external weather data predicting rapidly advancing thunderstorm
 347 with imminent rainfall. Hence, control systems like SNAPS, manifesting elements of the SARA
 348 paradigm are derived from principles of bio-mimicry. Feedback control (activation/inhibition) is
 349 the bed-rock of biological systems in maintaining homeostasis, cellular equilibrium and
 350 harmonization of physiological balance [67].
 351

352 Higher levels of automation are beyond the scope of this discussion. For partial automation,
 353 SNAPS shall increasingly rely on integration of logic structures, for example, integrating output
 354 from one or more artificial reasoning tools (ART) to support auto-actuation (SARA). Integration
 355 of logic and ART in the SNAPS architecture indicates a departure from simple point solutions
 356 (SNAPS) and an upstream march of ART, ushering new layers of convergence beyond SNAPS. In
 357 this description, we focus on two major categories: i) sensors with engineered transduction
 358 coupled with heuristic analysis of qualitative data (SNAPS-ART), and ii) sensors with inherent
 359 transduction coupled with algorithmic analysis of quantitative data (referred to as SNAPS-
 360 DIDA'S), summarized briefly, in the following section.

361 5. Design of SNAPS for Decision Support Systems

362 If auto-actuation or partial automation is expected as an outcome, then, according to the
 363 SARA paradigm, it is necessary to integrate elementary logic layers, relevant to performance/event,
 364 to enable SNAPS to execute actions by using/combining contextually relevant outputs from ART.
 365 The dynamic nature of ART elements may be sourced from a holding platform or repertoire for *ad*
 366 *hoc* composable machine-assisted tools (MAT), which applies basic pseudocode, with simple logic,
 367 to provide case-specific outputs, sufficient to execute low risk actions, which are (highly) fault
 368 tolerant. To provide guidance in development of future SNAPS, we may organize tools into two
 369 categories that are designed to meet user needs while maintaining an appreciable quality of service

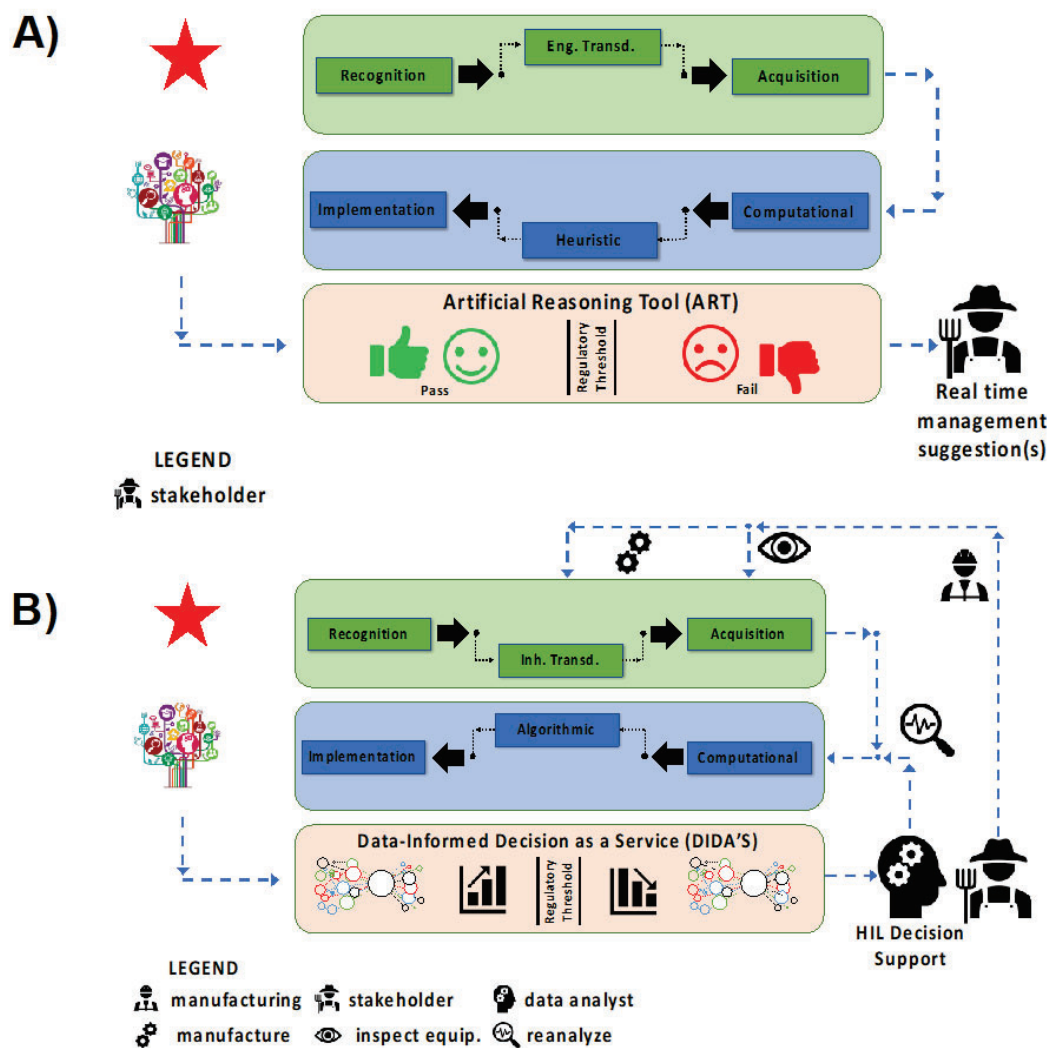
370 (QoS). The first category utilizes qualitative sensors based on engineered transduction coupled
371 together with heuristic analysis to produce a version of ART (**Fig 6A**). SNAPS-ART, is designed to
372 provide near real-time management suggestions, such as using (single) sensor data to determine
373 whether a particular sample is above or below a threshold value pre-set by a regulatory agency. The
374 assumption of high fault tolerance and low risk are pivotal to develop and deploy SNAPS-ART.
375

376 To optimize QoS versus development costs, acquisition of qualitative data for SNAPS-ART
377 uses engineered transduction techniques and heuristic classification to satisfy user expectations
378 with a binary output (rapid YES/NO test). In terms of active control features, SNAPS-ART is
379 rudimentary, with a few discrete/distinct actions (turn on/off a subsystem) determined by simple
380 non-overlapping binary outputs based on input from SNAPS. SNAPS-ART is not intended to be a
381 comprehensive diagnostic tool, but designed for triage or rapid screening, where additional testing
382 is required to confirm/validate results. It is possible to use ART for semi-quantitative purposes that
383 depends on other combinatorial factors (for example, controlling rate of flow), but within reason.
384

385 The 2nd category of SNAPS (**Fig 6B**) utilizes quantitative sensors based on inherent
386 transduction coupled with algorithmic analysis, collectively referred to as SNAPS-DIDA'S.
387 Contrary to SNAPS-ART, this category is designed for decision support under the assumption of
388 low fault tolerance and moderate risk. Rather than instantaneous results classified by heuristic data
389 analysis, SNAPS-DIDA'S involves a dynamic and/or reiterative analysis of streaming data from
390 sensors and feedback logic interfaces for processed data, for example, active control features using
391 a case-specific subset of tools from a super-set of MATs and MAPs (machine-assisted tools and
392 machine-assisted platforms). Optimization (from menu of choices and range of values) for each
393 variable requires computational rigor and resources to extract *context-specific* variant
394 configurations expected of SNAPS-DIDA'S. On the other hand, workflow middleware as the logic
395 application or control layer may suffice for SNAPS-ART. Sophisticated decision support software
396 with decision trees executing embedded logic is one option which may be user-directed [68][69].
397 The latter may be enabled by a drag and drop assembly from a portfolio of modular tools under the
398 umbrella of MAT and MAP. Another option is to present these choices to a human-in-the-loop
399 who may exercise some form of exclusion/reduction to narrow the search space (number of
400 choices) from the MAT/MAP menu based on experience and knowledge [70][71]. The preferred
401 option is the development of a parallel agent-based system (ABS) which may be part of a multi-
402 agent system (MAS) [72][73]. The agent is expected to specific for certain pre-determined
403 functions and able to replicate/reason a few key choices (select functions), in a manner
404 approximating the human-in-the-loop. ABS may be void of the human ability to handle exception
405 management. The range of options for the Agent may be restricted by its arsenal of information
406 and logic rules, due to limits of learning and training software Agents, especially about how and
407 when to use which tool. Because of the cognitive boundaries of deterministic design, it will be an
408 egregious error to expect any training tool or machine learning routine to educate an Agent to
409 deliver support in non-deterministic scenarios. The latter makes it mandatory to recognize
410 boundaries of "artificial" systems and maintain provisions for humans-in-the-loop, by design, for
411 non-deterministic instances.

412 In the context of SNAPS-DIDAS, agent-based systems begin to function upon receiving input
413 from SNAPS. Using logic capabilities (learned, trained), agent(s) determine which tool, or sets of
414 tools, may be necessary to execute the action or partial automation SNAPS expects to trigger.
415 Agents are limited by the tools contained within MAT and MAP, unless embedded logic provides
416 the option to place a remote function call (RFC) to a cloud repository to source other tools or
417 algorithms from different systems. Including and enabling this feature is vital for agent(s) to
418 “discover” contextually relevant elements suitable for the case at hand (perhaps enabling a
419 potential path to higher levels of automation). Unrestricted discovery demands interoperability
420 between systems to source tools and functions in a manner that is location (server) agnostic.
421 REST (representational state transfer) is a lightweight architectural alternative to mechanisms like
422 RPC (Remote Procedure Calls) which helps to connect between distributed hypermedia systems.
423 RESTful web services (conforms to REST architecture) facilitate interoperability between
424 computer systems and RESTful APIs (web service APIs that adhere to the REST architectural
425 constraints) are quintessential for “plumbing” the network to catalyze connectivity [74].
426

427 Knowledge discovery/search functions of machine-assisted systems (MAS) are key
428 performance indicators (KPI) which are inextricably linked with QoS. Synergistic integration with
429 external tools and modules calls for interoperability between platforms, which are influenced by
430 standards and architecture. Hence, automation of SNAPS-DIDA’S is far from trivial, and we are
431 only beginning to scratch the surface in terms of the confluence of ideas necessary to transform
432 this vision into reality.



433

434 **Figure 6.** Classification of SNAPS based on end-user expectations. A) SNAPS-ART
 435 produces qualitative, or semi-quantitative sensor data based on engineered transduction
 436 for analysis using heuristic analysis tools to provide management suggestions. B) SNAPS-
 437 DIDA'S produces quantitative, streaming data for algorithmic analysis to be
 438 implemented in a variety of decision support paradigms, which may include human-in-
 439 the loop and/or agent-based systems. The diagram provides a map for avoiding
 440 mismatch (i.e., loss of quality of service) between sensor chemistry and application needs
 441 but are not intended to be formulaic or dogmatic. Being dynamic and agile is essential.

442 The theoretical boundary between ART and DIDA'S is blurry, at best. The classification of the
 443 two systems into discrete boxes (**Fig 6**) is not intended to be reductionist. Perhaps it may trigger
 444 ideas about future improvements and innovations. The distinction between ART and DIDA'S may
 445 be made in terms of the data that must converge or the degree to which data fusion may be
 446 necessary when rendering the decision or recommendation. ART may assist a rapid-response
 447 system which aims to solve low risk problems, with a few data sources and data dependencies,

448 using either qualitative or quantitative sensors, matched with heuristic analysis. For example,
 449 *qualitative* SNAPS-ART may provide the instruction to turn off the irrigation water pump if [a]
 450 the rate of change of 80% of the soil moisture sensor readings fall above/below a given range of
 451 values or [b] if the data from sensor(s) indicates that the rainfall rate is above a certain value. For
 452 *quantitative* SNAPS-ART, the instruction may be to monitor and turn up/down the rate of
 453 irrigation water flow, by grids/zones, depending on the soil moisture sensor readings, if the sensor
 454 data falls above/below a range of values. The tool may refer to the logic instructions in a lookup
 455 table which recommends water flow rates which are recommended (appropriate context) for given
 456 soil moisture content and also integrates weather data.

457
 458 DIDA'S may be viewed as a mutiny of multiple ART units, each vying to contribute its data.
 459 At each gateway or node in the DIDA'S platform, there are Agents which are queueing, to be
 460 triggered by specific data strand/stream, to start its search and discovery process, to identify what
 461 tools must be used, which other databases or data resources must be accessed, in order to satisfy
 462 the context of dependencies and when/how to feed the results from the search and discovery to a
 463 higher level Agent. This situation is analogous to dynamic composability of tools, triggered by
 464 data, in a manner similar to application dependent networking (ADN), the underlying principle
 465 necessary to connect two mobile phone users in diverse environments [75].

466 6. Proof of concept SNAPS-ART

467 Fig 7 demonstrates an example of SNAPS-ART for heavy metal analysis coupled with risk
 468 assessment. In this design, a sensor with engineered transduction (qualitative data) is coupled with
 469 a heuristic risk analysis tool (hazard quotient [HQ] indicator) for monitoring and assessing risk of
 470 mercury exposure in drinking water in communities located near small scale artisanal gold mining
 471 regions [76]. In this example, a nanosensor was developed based on LSG electrodes decorated with
 472 anchored nanocopper for measuring ionic mercury (Hg^{2+}) via stripping voltammetry [77] (Fig
 473 7A). Rapid screening of water samples for mercury contamination is highly useful, but the value of
 474 sensor data is inconsequential without information on how compounded factors, such as body
 475 weight, ingestion rate, and length of exposure contribute to overall risk. A mobile app was
 476 developed in R language using the heuristic hazard quotient (HQ) method used by global
 477 regulatory agencies [78]. MIT App Inventor was used to create a smartphone app, using drag and
 478 drop techniques and Blockly modular tool (see supplemental section for code and details regarding
 479 app development). Fig 6B displays the graphic user interface and a sample output for the SNAPS-
 480 ART tool, where users input drinking water ingestion rate, body weight, length of exposure, and
 481 age. The app captures Hg^{2+} levels (ppm) obtained from the sensor, and uses the framework
 482 established by the US Environmental Protection Agency and the World Bank to calculate a HQ
 483 score [79][80][81]. Using the EPA standard HQ threshold [82], $\text{HQ} > 1.0$ indicates higher risk of
 484 potential adverse health effects increases, while a score < 1.0 indicates low risk.

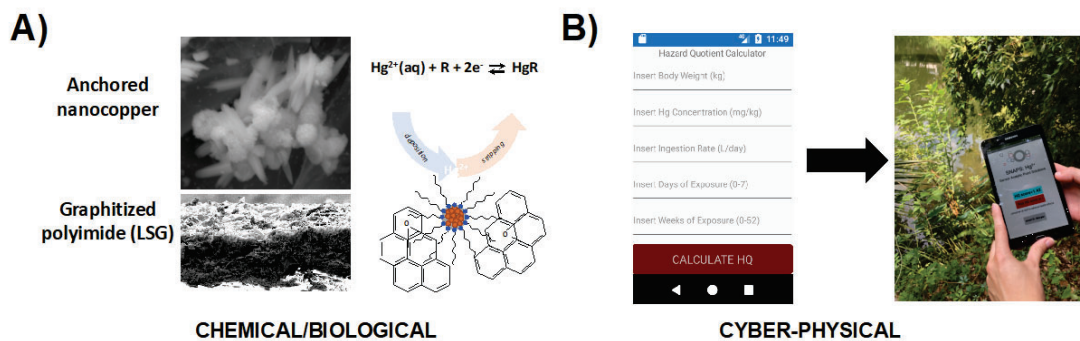
485
 486 It is significant to grasp that the suggestion offered to the end-user is *not* the raw sensor data
 487 output but a value (HQ) which *meaningfully integrates* other types of data to synthesize user-
 488 specific *information* which the user may choose to use, effectively (or not). Thus, SNAPS-ART

489 provides a real time *suggestion* to the user for health and wellness purposes as a result of
 490 convergence of data including international standards for heavy metals contamination of drinking
 491 water and healthcare statistics, relevant to the end-user and her environment. Detecting heavy
 492 metal in water [83] and access to data was facilitated when text messages (SMS) with geo-code
 493 (GPS location) were enabled to retrieve test data [84]. Improving the quality of raw data [85] is of
 494 paramount importance but the end-users are in quest of answers (information) rather than
 495 numbers (data). Simple and direct decision support using mobile devices is key for resource-
 496 limited populations [86].

497

498 This example of SNAPS-ART highlights this quintessential *transition* from *data* for experts to
 499 *information* for end-users. The HQ output significantly increases the *value* of the raw sensor data
 500 by *combining* data in context of human-specific factors and micro-environment, to provide
 501 actionable information relevant to precision public health. In addition, based on the HQ score, the
 502 embedded artificial reasoning tool (ART) provides options to seek additional screening at a
 503 verified laboratory, if the sample value triggers a set of logic/rules based on relationships between
 504 data, perhaps revealed due to data association and/or data fusion. The latter is a critical feature
 505 because the outcome has the potential to alert the user to recognize that the suggestion is not only
 506 displaying a number but requesting secondary validation (visit to a primary care, formal lab tests).

507

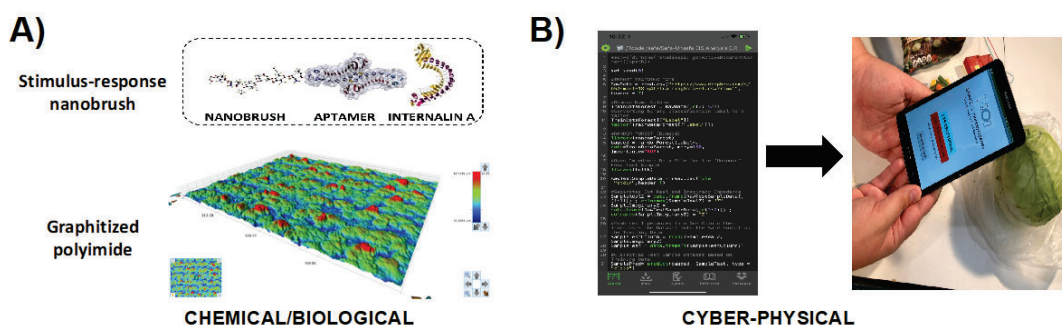


508

509 **Figure 7.** Proof of concept demonstration for SNAPS-ART in heavy metal analysis of
 510 water. **A)** Hg^{2+} -selective nanosensor based on LSG and nanocopper developed by
 511 Abdelbasir et al [77]. **B)** Photo of heuristic analysis tool for calculating risk of mercury
 512 exposure (hazard quotient calculator).

513 In another application (Fig 8) the SNAPS-ART platform aggregates impedimetric sensors for
 514 detection of pathogenic bacteria in food samples. The *Listeria monocytogenes* biosensor developed
 515 by Hills et al [87] is used as a demonstration (**Fig 8A**), and an ART tool was developed using
 516 machine learning (R programming language). The ART tool for *L. monocytogenes* detection is
 517 grounded in binary classification using bagged random forest written in R, with the smartphone
 518 app created using MIT App Inventor. The program (see supplemental section for code) reads a raw
 519 impedance data file from the biosensor, converts the data to the necessary form for machine
 520 learning classification, optimizes hyperparameter values, and then uses machine learning
 521 techniques to compare the sample to a training library; other methods are feasible as described by

522 Rong et al [25]. The tool is used for predicting whether the food sample (vegetable broth in this
 523 case) may be contaminated or is safe, and how an user may seek secondary validation, if sample is
 524 positive (**Fig 8B**); see supplemental section for details and screenshots of app. The major benefit of
 525 this tool is the avoidance of computationally expensive (and time intensive) analytical methods
 526 such as equivalent circuit analysis. While some equivalent circuit models, such as the Randles-
 527 Ershler circuit, provide some description of the physical meaning for each circuit element related
 528 to an impedimetric biosensor, in most cases more complex models are used and parameters are
 529 tuned with chi-squared (χ^2) fitting. If not used with expert guidance, equivalent circuit analysis
 530 leads to significant errors in both interpretation and accuracy. It may be cost prohibitive, too. For
 531 pathogens such as *L. monocytogenes*, the threshold for contamination is one live cell in a food
 532 sample, and thus speed and accuracy of the tool are pivotal for rapid screening. Use of machine
 533 learning (ML) tools to perform rapid screening, at the point of use, with a smartphone or tablet,
 534 increases the *value* of the biosensor data and offers near-real time actionable *information* to the
 535 end-user, agnostic of location or access to a laboratory test facility.



537

537 **Figure 8.** Proof of concept demonstration for SNAPS-ART in food safety analysis
 538 (vegetable broth). **A)** *Listeria monocytogenes* biosensor developed with stimulus-response
 539 polymers and DNA aptamers by Hills et al [70]. **B)** Screenshot and photograph of
 540 machine learning analysis tool for determining whether sample is contaminated based on
 541 an index score derived from machine learning analysis.

542 The benefits of the approach in **Fig 7-8** may be extended by adapting the sensor RTA scheme
 543 to allow the tool to detect and alert users about other targets (eg other heavy metal contaminants,
 544 such as lead, cadmium, and arsenic or other biomolecule targets, such as viruses). SNAPS-ART
 545 may be used for detection and diagnostics for a plethora of contaminating agents not only in liquid
 546 (as shown here), but in any other medium as long as the analyte is presented in a form that binds
 547 with the sensor material. The value of this approach increases exponentially if combined with
 548 mobility (smartphone). The latter enables sourcing sensor data for myriad of analytes from any
 549 environment where humans (citizen science) or drones may reach or interact with the sample. In
 550 our approach, we have eschewed the use of high cost sensors, to highlight the potential for
 551 diffusion of low-cost tools to enable democratization of data and distribute the dividends from
 552 decision support to serve community-specific needs. To acquire, curate, analyze and extract useful
 553 information from sensor and other data, we advocate synergistic integration with MAT and MAP.
 554 SNAPS is a tiny first step in that direction.

Table 1. Challenges and Opportunities for SNAPS

Challenges	Opportunities
Extraction of information from sensor data for real time decision support	<ul style="list-style-type: none"> • Development of SNAPS-ART tools using established regulatory standards as a guide
Controlling or modulating sensor hysteresis <i>in situ</i>	<ul style="list-style-type: none"> • Integration of smart materials on sensor surface (e.g., stimulus-response polymers) • Rudimentary control over system performance through the use of sense-analyze-respond-actuate (SARA) systems
Mobility and connectivity in agricultural and environmental systems	<ul style="list-style-type: none"> • Improvement of low latency communications • Deploy low power [a] sensor systems and [b] data management systems
Integrating SNAPS with standard platform	<ul style="list-style-type: none"> • Establishment of data management systems based on lessons learned from other systems such as integrated clinical environment (ICE) • Establishment of standards in architecture
Development of data informed decision as a service (DIDA'S)	<ul style="list-style-type: none"> • Establishment of SNAPS-ART as a common tool • Integration of drag and drop analytics (DADA) and agent-based systems (ABS) • Dynamic/reiterative analysis of streaming data from sensors • Demonstration of feedback logic that interfaces with processed data • Dynamic composability of tools triggered by data (application-dependent-networking) • Database discovery or data resource discovery by agents using embedded logic (e.g., remote function call, RESTful APIs) • Use of logic capabilities (learned, trained) and agent(s) to determine which tool, or sets of tools, are required for analyzing any given problem

558 7. The Path Forward?

559 The pivotal role of sensors, data, and information in decision support and partial automation
560 or auto-actuation is of critical importance in any field, including biosystems engineering. SNAPS
561 represents a confluence of ideas and is the foundation for making sense of data by adding value to
562 sensor data. Basic sensor design choices, described in this review, dictate the value and quality of
563 service for SNAPS. The lowest common denominator is to match the type of sensor transduction
564 (engineered or inherent) with an analytical approach (heuristic or algorithmic) to meet the needs
565 of the end user with respect to a baseline quality of service (QoS). In a more complex example,
566 sensor engineering for controlling or modulating hysteresis is required, if users expect real time, *in*
567 *situ*, sensor data connectivity to data analytics. SNAPS can offer design choices and suggest rules to
568 adopt (embedded logic) key performance indicators (KPI) which may be necessary to guide what
569 constitutes actionable information based on raw sensor data. However, it is essential to remain
570 cognizant of the fact that not all data may contain information and not all information may be
571 actionable or possess transactional value. Hence, the quality of data determines the quality of
572 service (QoS outcome).

573

574 SNAPS and ART are elements of the MAT and MAP trends, in terms of the quest to deliver
575 value from data analytics (in this case, with heuristic and qualitative sensors). Rudimentary control
576 over system performance through the use of SARA-driven Smart SNAPS, to auto-actuate select
577 system components, may be an example of emerging applications for agro-ecosystem,
578 environmental health, as well as public health and healthcare, especially remote diagnostics and
579 preventative health.

580

581 Beyond the SNAPS-ART paradigm, we hope to reach DIDA'S but its maturity is questionable,
582 at best. As these tools mature, the true value may be realized through the interaction of agents (i.e.,
583 an agency) which embraces the collective optimization of performance (P) in the context of the
584 environment (E) where processes may be influenced by actuators (A) that depend on information
585 from sensor (S) data (thus, PEAS).

586

587 PEAS is mnemonic borrowed from the literature on ABS designed (modeled) to address
588 systems performance [88] that is focused on the convergence of percepts, environment, actuators,
589 and sensors (PEAS). The principle of PEAS are supposed to be the pillars on which we may build
590 "machines that work for us" versus "cogs" in the wheel - SNAPS, ART, DIDA'S - which are
591 examples of "tools with which we work" [89].

592

593 PEAS are goal-dependent strategic perspectives arising from the conceptual pot of alphabet
594 soup each with its array of dynamic push-pull elements and user-directed levers, which may be
595 used in any combination, to accomplish short term tasks (SNAPS) versus long term attempts to
596 orchestrate systems performance (PEAS). This interrelationship may be analogous to components
597 of the engine (SUGAR, SNAPS, ART, DIDA'S) which are essential and dependent for the function
598 and performance of the "whole" vehicle (PEAS).

599

600 Aggregating data and information for systems performance (PEAS) is the Holy Grail. In some
601 instances the “whole” picture is the *only* relevant picture. One attempt in biomedical engineering
602 is referred to as the integrated clinical environment (ICE) effort [90], which strives to harmonize
603 data interoperability between all sub-systems to focus on the “whole patient” rather than isolated
604 parts. These concepts (PEAS, ICE) may serve as beacons for innovation in agriculture, energy,
605 environment, or other verticals areas, where a *tapestry* of solutions may be more valuable than
606 *point* solutions. Isolated solutions in the medical systems may lead to errors due to medical device
607 interoperability issues. The latter is often fatal, claiming as many as 250,000 lives per year, in the
608 US alone, and is the third leading cause of death in the US [91].
609

610 While no specific decision support framework is shown here, SNAPS is the first step toward
611 DIDA’S, which may rely on tools such as drag and drop analytics (DADA) and models using ABS.
612 One of the underlying themes in all cases is the use of mobility and low latency signal transmission
613 (for example, future potential for use of 5G) as key enablers for facilitating various levels of partial
614 autonomy within system of systems, which responds to remote instructions and signals, without
615 lag (latency may be fatal, for example in remote surgery or for pedestrians vs autonomous cars).
616

617 The excruciating struggle to extract information from sensor data (if there is information in
618 the data) is an indication that unleashing knowledge from information may be a mirage. The
619 anticipated evolution of data-science to knowledge-science is the central thrust of knowledge-
620 informed decision as a service (KIDS), an aspirational idea which may not be addressed by the use
621 of current tools and contemporary thinking. The broad spectrum of “data-informed” approaches
622 will vary by use cases, from simpler instances SNAPS may be a first step. For complex expectations,
623 DIDA’S may step in. Beyond DIDA’S we may be entering the domain of the unknown unknowns.
624

625 The mention of “unknown unknowns” cannot be left metaphorically hanging from the
626 rhetorical cliff of conclusion. The academic incentive to pontificate on this topic is inextricably
627 linked to the keystone factor of *knowledge discovery*. Unless we know what data to connect, the
628 extraction of information will be incorrect, insipid or incomplete, at best. Low level information is
629 akin to “the same and not the same” [92] where “whiskers” (outliers) far outweigh the central
630 substance (interquartile range) in a box plot. Using this information as knowledge bricks will be
631 tantamount to building a virtual house out of hollow cards.
632

633 Hence, knowledge discovery cannot be treated as a separate topic when discussing sensors
634 and sensor data. Without discovering the context and relevance of data to the bigger picture, the
635 outcome will remain narrow, retarded and half-baked. Sensors will be impotent without tools to
636 extract value from data fusion. This discussion is not peripheral but central, to all sensors.
637

638 The growing ubiquity of sensors, which are increasingly woven into almost every facet of our
639 daily lives, makes it imperative that sensor scientists consider the data science impact of their work.
640 Data scientists must take a closer look at sensor data and sensor engineering, to ask the correct
641 questions. Tools for knowledge discovery are not in short supply [93][94] but the rate limiting

642 factor preventing the diffusion of these tools are rooted in their complexity, lack of standards and
643 few common open platforms. If “open platforms” emerge, the race to adapt and adopt will not be
644 determined by its success due to technological strength or computational excellence. Rather the
645 economics of technology may be the single most important criteria which will influence and
646 determine feasibility [95][96] of mass adoption, the latter, in turn, will reduce cost of adoption due
647 to economies of scale. The latter is the catalyst to enable these benefits to reach the impoverished
648 communities and serve as a tool for democratization of data for the next billion users.

649

650 We are on the brink of change, albeit at a glacial pace. The advances in search and discovery of
651 data and information, are likely to improve if we can use tools based on graph theoretic
652 approaches, to establish relationships and dependencies between objects and subjects [97][98].
653 Currently, the tools from graph theory are few and far between, yet it is already being aggrandized
654 and referred to as knowledge graphs. Irrespective of the descriptive semantics and the professional
655 vernacular, knowledge graphs are potentially useful for knowledge discovery.

656

657 Scientific progress relies on the confluence of efficient assimilation of existing knowledge in
658 order to minimize re-invention. It appears that the graph theoretic approach may lead to the
659 creation of knowledge graph tools to plumb the depths of unknown unknowns, where catalysts for
660 scientific breakthroughs often reside. By using relationships between materials and their properties
661 [99] which may be organized as graphs with edges and nodes, a research team has developed a
662 methodology which may lend itself to exploring non-obvious relationships [100]. The authors are
663 incisive to point out an entity-relationship mode which remains the “bread and butter” of context-
664 awareness. The latter, in terms of knowledge representation, has evolved as RDF, the resource
665 description framework standard [101] and is a more general model of entities (nodes) and
666 relationships, albeit incomplete. Thus, the paper by Tshitoyan *et al* [99] provides tangible grounds
667 to extrapolate the methodology from material science to other domains. It strengthens the notion
668 that developing and implementing knowledge graph tools may aid in unleashing new ideas, reveal
669 unknown unknowns and enable context-aware knowledge discovery.

670

671 In another vein, a leap of progress was made when an unusual strategy was adopted to
672 organize and “number” the content (names, relationships from material science) in “preparation”
673 to use the tools of machine learning (ML) for analyzing the information and exploring
674 relationships [102][103][104][105]. Nandy *et al* **broke existing rules** and enabled analytical tools
675 to plumb the depths of the associations, generally not discovered by traditional rule-based
676 methods. It is a clear indication that the next step is to establish semantic associations [106]. We
677 propose an in-depth exploration of the tools that evolved from these materials science papers,
678 which *combined* data science with domain knowledge to explore uncharted waters [107]. The
679 principles behind these approaches may be in short supply (missing) in the domain of sensor
680 chemistry and engineering. The plethora of physico-chemical characteristics that govern the
681 attributes of sensors has little (if any) fundamental semantic association with basic science
682 (structure and properties of the molecules), which dictates functional interactions and
683 efficiency/efficacy.

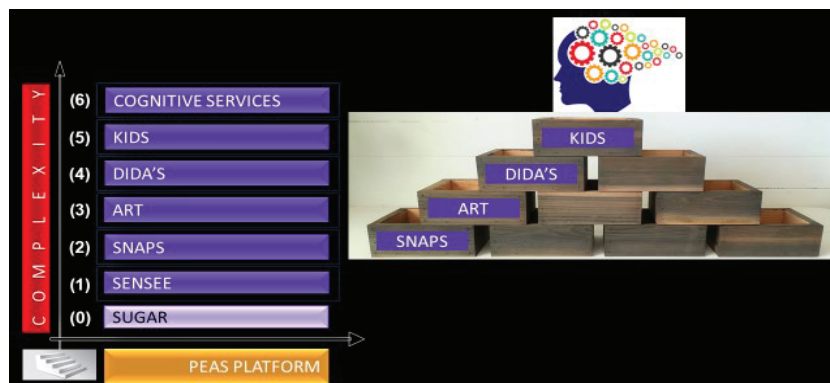
684 Interrelationships and dependencies are key to function, yet the reductionist approach must
 685 view components in isolation, for the sake of operational convenience. The ability to synthesize
 686 any graph theoretic approach (knowledge graphs) will depend on our ability to establish
 687 connections between nodes and sub-nodes. The ability to organize the knowledge in its semantic
 688 context (classification, taxonomy) may determine if we may extract *meaningful* relationships,
 689 between distant, apparently unrelated nodes/sub-nodes. The ability to adopt and use the semantic
 690 associations within the computational system will determine if we can use data related tools (for
 691 example, machine learning, artificial neural nets) to discover relationships yet to be discovered.
 692

693 Domain knowledge experts may help create nomological networks for sensor science [108]
 694 perhaps resembling taxonomic trees or biochemical cycles [109]. In the next step, basic sensor
 695 science must converge with the principles and practice of engineering, by learning from system
 696 dynamics [110]. From the user perspective, the ability to use natural language queries [111] may be
 697 beneficial. The latter unleashes the potential for neural machine reading comprehension [112].
 698 However, existing tools [113][114][115][116][117][118][119][120][121] are a smörgåsbord of
 699 word associations/representations [122] which may often use variations of nearest neighbor
 700 principles developed circa 1000 AD [123][124]. Although pockets of evolution to elementary
 701 semantic data type detection is in progress [125], almost all tools lack digital semantics [126].
 702 Knowledge discovery, knowledge graphs and graph neural networks [127] will remain reasonably
 703 impotent without the ability to use semantic associations, for example, semantic data catalogs
 704 [128]. Thus, there appears to be a vast chasm between sensor science and engineering and data
 705 science, which is in need of convergence, perhaps through a global group effort. The rejection of
 706 this idea [129] may serve as a badge of honor to those who may grasp its significance.

707
 708 The need for semantic tools is old news [130] but new research at the *nexus* of natural
 709 language processing, linguistics, semantics, and science, may fuel trans-disciplinary convergence
 710 necessary to advance knowledge discovery. Broad spectrum dissemination of this knowledge using
 711 simple and tangible user interfaces may be crucial [131]. Knowledge discovery appears to be at the
 712 heart of sensor research and sensor engineering, if we wish to extract value from sensors, already
 713 deployed in enterprises, and aspire to deploy sensors as global public goods, for the next trillion
 714 use-cases in the global supply chain [132]. For global supply chain and value network dynamics,
 715 the "sense" table principle (circa 1997) using tangible user interfaces (TUI) is an useful idea, that
 716 can display how data can change decisions in near real-time ([133][134][135][136][137] [138]).
 717 However, TUI applications remains unexplored, in practice. Synergistic integration of tools based
 718 on tangible user interfaces may be useful to simulate or display real-world potential for dynamic
 719 changes and variant configurations (alternatives, options) if the operating logic of these TUI tools
 720 are informed by (guided, advised, shaped) the convergence of semantically relevant curated data
 721 (perishability, time sensitivity, time series), location-aware contextual information and meaningful
 722 correlations which may uncover cryptic relationships (obvious, non-obvious, reinforced, learned),
 723 which may influence the outcome or expectation or prediction. Information-informed tangible
 724 user interface tools (iiTUIT) may be another higher order plane for combinatorial thinking and a
 725 task for a new breed of creative thinkers who may invest in exploring *confluence* of ideas.

726 8. Concluding Remarks

727 Ubiquity of sensor data makes it crucial that sensor data offers semantically sensible
 728 value, preferably at every instance, starting with less complex point solutions, referred to as
 729 SNAPS, in this discussion. SNAPS and other layers in the layer cake (0-6) illustrated as steps
 730 are not discrete stages but represents tool sets and or decision sub-platforms which can
 731 combine, re-combine and co-exist in various forms. For example, artificial reasoning tools
 732 (ART) is a sub-platform where the output may use various types of logic or rules which may
 733 guide/shape rational/irrational decisions. ART is not only its own layer but may be viewed as a
 734 mobile layer (repertoire of tools) which can work with various other layers to modulate the
 735 output (decision). For example, SUGAR (simple user guided activity report) only delivers raw
 736 data based on user command. If the output from SUGAR feeds ART, the tools may offer a
 737 preliminary processing of data generated by SUGAR and offer an output (decision support)
 738 which is a level above SUGAR (yet, not SNAPS). The “empty boxes” (indicated on the right)
 739 in the illustration represents these potential combinations which may be case specific and
 740 offers room for innovation as the evolution of decision science continues. ART may be one
 741 occupant of these “boxes” if necessary, in a certain scenario (use case). ART may work with
 742 any layer and in any stage (in any “box”). In this bio-inspired “McClintock”-esque paradigm
 743 [139], ART (or something similar or equivalent) may be viewed as a cross-pollinator of
 744 SUGAR, SNAPS, PEAS (hence “jumping genes” may be a suitable analogy [140] as well as the
 745 related “mobile transposon” concept [141]). The threads of these ideas advocate the potential
 746 of cross-platform mobile elements (tools) which may be designed to act as dynamic cross-
 747 fertilizing “influenza” {(the term “influenza” is Italian for “influence” and used [142] since
 748 circa 1357 (circa 1504 in English) to describe the illness, due to its perceived association with
 749 cold weather (influenza di freddo)} agents capable of improving and/or influencing, as well as
 750 linking, various domains of decision support systems.



751
 752 **Figure 9.** The challenge for a new breed of thinkers is to pave the path with value
 753 extracted from data and information from SUGAR (simple user guided activity report) to
 754 SERVICES (layer 6), and the layers and sub-layers, which may be necessary or
 755 mandatory but still remains to be discovered and/or identified. In the distant future,
 756 perhaps, someday, the system may legitimately claim to integrate the use of cognitive
 757 tools even beyond knowledge (KIDS, knowledge informed decision as a service) to
 758 introduce and promote bold new frontiers in the realm of decision science.

759 **Author Contributions:**

760 Conceptualization: ESM, SPAD

761 Data curation: YR

762 Formal analysis: YR

763 Funding acquisition: ESM

764 Formatting: ESM, SB

765 Investigation: VM, NC

766 Methodology: ESM

767 Project administration: ESM, DV

768 Resources: ESM, DV

769 Software: VM, NC, YR, SB

770 Supervision: ESM

771 Visualization: ESM, SPAD

772 Writing – original draft: ESM, SPAD

773 Writing – review and editing: ALL

774

775 **Funding:** This project was supported by AFRI Grant no. 2018-67016-27578 awarded as a Center of
 776 Excellence from the USDA NIFA. The authors also acknowledge NSF project 1805512
 777 (Biosensing) and NSF project 1511953 (Nanobiosensing) for financial support.

778

779 **Conflicts of Interest:** “The authors declare no conflict of interest.”

780

781 **References**

782 1. Wang, J., 2001. Glucose biosensors: 40 years of advances and challenges. *Electroanalysis: An*
 783 *International Journal Devoted to Fundamental and Practical Aspects of*
 784 *Electroanalysis*, 13(12), pp.983-988.

785 2. Wang, B. and Anzai, J.I., 2015. Recent progress in lectin-based biosensors. *Materials*, 8(12),
 786 pp.8590-8607..

787 3. Song, Y., Luo, Y., Zhu, C., Li, H., Du, D. and Lin, Y., 2016. Recent advances in electrochemical
 788 biosensors based on graphene two-dimensional nanomaterials. *Biosensors and*
 789 *Bioelectronics*, 76, pp.195-212.

790 4. Yang, L. and Bashir, R., 2008. Electrical/electrochemical impedance for rapid detection of
 791 foodborne pathogenic bacteria. *Biotechnology advances*, 26(2), pp.135-150.

792 5. Brolo, A.G., 2012. Plasmonics for future biosensors. *Nature Photonics*, 6(11), p.709.

- 793 6. Scheller, F.W., Yarman, A., Bachmann, T., Hirsch, T., Kubick, S., Renneberg, R., Schumacher,
794 S., Wollenberger, U., Teller, C. and Bier, F.F., 2013. Future of biosensors: a personal view.
795 In *Biosensors Based on Aptamers and Enzymes* (pp. 1-28). Springer, Berlin, Heidelberg.
- 796 7. Li, R., Feng, Y., Pan, G. and Liu, L., 2019. Advances in molecularly imprinting technology for
797 bioanalytical applications. *Sensors*, 19(1), p.177.
- 798 8. Murphy, L., 2006. Biosensors and bioelectrochemistry. *Current opinion in chemical*
799 *biology*, 10(2), pp.177-184.
- 800 9. Bogue, R., 2009. Nanosensors: a review of recent research. *Sensor Review*, 29(4), pp.310-315.
- 801 10. Li, C., Bai, H. and Shi, G., 2009. Conducting polymer nanomaterials: electrosynthesis and
802 applications. *Chemical Society Reviews*, 38(8), pp.2397-2409.
- 803 11. Bonanni, A., Loo, A.H. and Pumera, M., 2012. Graphene for impedimetric biosensing. *TrAC*
804 *Trends in Analytical Chemistry*, 37, pp.12-21.
- 805 12. Zhu, C., Yang, G., Li, H., Du, D. and Lin, Y., 2014. Electrochemical sensors and biosensors
806 based on nanomaterials and nanostructures. *Analytical chemistry*, 87(1), pp.230-249.
- 807 13. Ekinici, K.L., 2005. Electromechanical transducers at the nanoscale: actuation and sensing of
808 motion in nanoelectromechanical systems (NEMS). *small*, 1(8-9), pp.786-797.
- 809 14. Collins, B.E. and Anslyn, E.V., 2007. Pattern-Based Peptide Recognition. *Chemistry–A*
810 *European Journal*, 13(17), pp.4700-4708.
- 811 15. Turner, A.P., 2013. Biosensors: sense and sensibility. *Chemical Society Reviews*, 42(8),
812 pp.3184-3196.
- 813 16. Thakare, V. and Khire, G., 2014. Role of emerging technology for building smart hospital
814 information system. *Procedia Economics and Finance*, 11, pp.583-588.
- 815 17. Quesada-González, D. and Merkoçi, A., 2017. Mobile phone-based biosensing: An emerging
816 “diagnostic and communication” technology. *Biosensors and Bioelectronics*, 92, pp.549-562.
- 817 18. Wei, Q., Luo, W., Chiang, S., Kappel, T., Mejia, C., Tseng, D., Chan, R.Y.L., Yan, E., Qi, H.,
818 Shabbir, F. and Ozkan, H., 2014. Imaging and sizing of single DNA molecules on a mobile
819 phone. *ACS nano*, 8(12), pp.12725-12733.
- 820 19. Guner, H., Ozgur, E., Kokturk, G., Celik, M., Esen, E., Topal, A.E., Ayas, S., Uludag, Y.,
821 Elbuken, C. and Dana, A., 2017. A smartphone based surface plasmon resonance imaging
822 (SPRi) platform for on-site biodetection. *Sensors and Actuators B: Chemical*, 239, pp.571-577.
- 823 20. Rowe, A.A., Bonham, A.J., White, R.J., Zimmer, M.P., Yadgar, R.J., Hobza, T.M., Honea, J.W.,
824 Ben-Yaacov, I. and Plaxco, K.W., 2011. CheapStat: an open-source, “Do-It-Yourself”
825 potentiostat for analytical and educational applications. *PloS one*, 6(9), p.e23783.
- 826 21. Jenkins, D.M., Lee, B.E., Jun, S., Reyes-De-Corcuera, J. and McLamore, E.S., 2019. ABE-Stat, a
827 Fully Open-Source and Versatile Wireless Potentiostat Project Including Electrochemical
828 Impedance Spectroscopy. *Journal of The Electrochemical Society*, 166(9), pp.B3056-B3065..
- 829 22. Moraru, A., Pesko, M., Porcius, M., Fortuna, C. and Mladenic, D., 2010. Using machine
830 learning on sensor data. *Journal of computing and information technology*, 18(4), pp.341-347.
- 831 23. Ghahramani, Z., 2015. Probabilistic machine learning and artificial
832 intelligence. *Nature*, 521(7553), p.452.
- 833 24. Saeb, S., Lonini, L., Jayaraman, A., Mohr, D.C. and Kording, K.P., 2016. Voodoo machine
834 learning for clinical predictions. *Biorxiv*, p.059774.

- 835 25. Rong, Y., Padron, A.V., Hagerty, K.J., Nelson, N., Chi, S., Keyhani, N.O., Katz, J., Datta,
836 S.P.A., Gomes, C. and McLamore, E.S., 2018. Post hoc support vector machine learning for
837 impedimetric biosensors based on weak protein–ligand interactions. *Analyst*, 143(9),
838 pp.2066-2075.
- 839 26. Koczula, K.M. and Gallotta, A., 2016. Lateral flow assays. *Essays in biochemistry*, 60(1),
840 pp.111-120.
- 841 27. Olsman, N. and Goentoro, L., 2016. Allosteric proteins as logarithmic sensors. *Proceedings of*
842 *the National Academy of Sciences*, 113(30), pp.E4423-E4430.
- 843 28. Nussinov, R., Tsai, C.J. and Ma, B., 2013. The underappreciated role of allostery in the cellular
844 network. *Annual review of biophysics*, 42, pp.169-189.
- 845 29. Taguchi, M., Ptitsyn, A., McLamore, E.S. and Claussen, J.C., 2014. Nanomaterial-mediated
846 biosensors for monitoring glucose. *Journal of diabetes science and technology*, 8(2), pp.403-
847 411.
- 848 30. Mosbah, A., Campanacci, V., Lartigue, A., Tegoni, M., Cambillau, C. and Darbon, H., 2003.
849 Solution structure of a chemosensory protein from the moth *Mamestra brassicae*. *Biochemical*
850 *Journal*, 369(1), pp.39-44.
- 851 31. Vámos, T., 1992. Judea pearl: Probabilistic reasoning in intelligent systems. *Decision Support*
852 *Systems*, 8(1), pp.73-75.
- 853 32. Marr, D. and Poggio, T., 1979. A computational theory of human stereo vision. *Proceedings of*
854 *the Royal Society of London. Series B. Biological Sciences*, 204(1156), pp.301-328.
- 855 33. Bhusal, N., Shrestha, S., Pote, N. and Alocilja, E., 2019. Nanoparticle-Based Biosensing of
856 Tuberculosis, an Affordable and Practical Alternative to Current Methods. *Biosensors*, 9(1),
857 p.1.
- 858 34. Gordillo-Marroquín, C., Gómez-Velasco, A., Sánchez-Pérez, H., Pryg, K., Shinnors, J.,
859 Murray, N., Muñoz-Jiménez, S., Bencomo-Alarm, A., Gómez-Bustamante, A., Jonapá-Gómez,
860 L. and Enríquez-Ríos, N., 2018. Magnetic Nanoparticle-Based Biosensing Assay
861 Quantitatively Enhances Acid-Fast Bacilli Count in Paucibacillary Pulmonary
862 Tuberculosis. *Biosensors*, 8(4), p.128.
- 863 35. Wei, Q., Qi, H., Luo, W., Tseng, D., Ki, S.J., Wan, Z., Göröcs, Z., Bentolila, L.A., Wu, T.T.,
864 Sun, R. and Ozcan, A., 2013. Fluorescent imaging of single nanoparticles and viruses on a
865 smart phone. *ACS nano*, 7(10), pp.9147-9155.
- 866 36. Zheng, L., Cai, G., Wang, S., Liao, M., Li, Y. and Lin, J., 2019. A microfluidic colorimetric
867 biosensor for rapid detection of *Escherichia coli* O157: H7 using gold nanoparticle
868 aggregation and smart phone imaging. *Biosensors and Bioelectronics*, 124-125, pp.143-149.
- 869 37. Yetisen, A.K., Martinez-Hurtado, J.L., Garcia-Melendrez, A., da Cruz Vasconcellos, F. and
870 Lowe, C.R., 2014. A smartphone algorithm with inter-phone repeatability for the analysis of
871 colorimetric tests. *Sensors and Actuators B: Chemical*, 196, pp.156-160.
- 872 38. Lopez-Ruiz, N., Curto, V.F., Erenas, M.M., Benito-Lopez, F., Diamond, D., Palma, A.J. and
873 Capitan-Vallvey, L.F., 2014. Smartphone-based simultaneous pH and nitrite colorimetric
874 determination for paper microfluidic devices. *Analytical chemistry*, 86(19), pp.9554-9562.
- 875 39. Thompson, R.E., Larson, D.R. and Webb, W.W., 2002. Precise nanometer localization
876 analysis for individual fluorescent probes. *Biophysical journal*, 82(5), pp.2775-2783.

- 877 40. Gunda, N.S.K., Gautam, S.H. and Mitra, S.K., 2019. Artificial Intelligence Based Mobile
878 Application for Water Quality Monitoring. *Journal of The Electrochemical Society*, 166(9),
879 pp.B3031-B3035.
- 880 41. Vanegas, D., Patiño, L., Mendez, C., Oliveira, D., Torres, A., Gomes, C. and McLamore, E.,
881 2018. Laser Scribed Graphene Biosensor for Detection of Biogenic Amines in Food Samples
882 Using Locally Sourced Materials. *Biosensors*, 8(2), p.42.
- 883 42. Yoo, S.M. and Lee, S.Y., 2016. Optical biosensors for the detection of pathogenic
884 microorganisms. *Trends in biotechnology*, 34(1), pp.7-25.
- 885 43. Liu, L., Zhang, D., Zhang, Q., Chen, X., Xu, G., Lu, Y. and Liu, Q., 2017. Smartphone-based
886 sensing system using ZnO and graphene modified electrodes for VOCs detection. *Biosensors
887 and Bioelectronics*, 93, pp.94-101.
- 888 44. Lane, N.D., Miluzzo, E., Lu, H., Peebles, D., Choudhury, T. and Campbell, A.T., 2010. A
889 survey of mobile phone sensing. *IEEE Communications magazine*, 48(9), pp.140-150.
- 890 45. McGrath, A.P., Hilmer, K.M., Collyer, C.A., Shepard, E.M., Elmore, B.O., Brown, D.E.,
891 Dooley, D.M. and Guss, J.M., 2009. Structure and inhibition of human diamine
892 oxidase. *Biochemistry*, 48(41), pp.9810-9822.
- 893 46. Babiceanu, R.F. and Seker, R., 2016. Big Data and virtualization for manufacturing cyber-
894 physical systems: A survey of the current status and future outlook. *Computers in Industry*, 81,
895 pp.128-137.
- 896 47. C. Wu, R. Buyya, and K. Ramamohanarao, 2016 . “Big Data Analytics = Machine Learning +
897 Cloud Computing,” in Buyya, R., Calheiros, R.N. and Dastjerdi, A.V. eds. *Big Data: Principles
898 and Paradigms*. Elsevier, pp. 1-27.
- 899 48. Ravi, K., Khandelwal, Y., Krishna, B.S. and Ravi, V., 2018. Analytics in/for cloud-an
900 interdependence: A review. *Journal of Network and Computer Applications*, 102, pp.17-37.
- 901 49. J Heer, J. and Perer, A., 2014. Orion: A system for modeling, transformation and visualization
902 of multidimensional heterogeneous networks. *Information Visualization*, 13(2), pp.111-133.
- 903 50. Kim, J., Levy, E., Ferbrache, A., Stepanowsky, P., Farcas, C., Wang, S., Brunner, S., Bath, T.,
904 Wu, Y. and Ohno-Machado, L., 2014. MAGI: a Node. js web service for fast microRNA-Seq
905 analysis in a GPU infrastructure. *Bioinformatics*, 30(19), pp.2826-2827.
- 906 51. Nolte, H., MacVicar, T.D., Tellkamp, F. and Krüger, M., 2018. Instant Clue: a software suite
907 for interactive data visualization and analysis. *Scientific reports*, 8(1), p.12648.
- 908 52. Ko, G., Kim, P.G., Yoon, J., Han, G., Park, S.J., Song, W. and Lee, B., 2018. Closha:
909 bioinformatics workflow system for the analysis of massive sequencing data. *BMC
910 bioinformatics*, 19(1), p.43.
- 911 53. Shang, Z., Zraggen, E., Buratti, B., Kossmann, F., Eichmann, P., Chung, Y., Binnig, C., Upfal,
912 E. and Kraska, T., 2019, June. Democratizing data science through interactive curation of ml
913 pipelines. In *Proceedings of the 2019 International Conference on Management of Data* (pp.
914 1171-1188). ACM.
- 915 54. Binnig, C., Buratti, B., Chung, Y., Cousins, C., Kraska, T., Shang, Z., Upfal, E., Zeleznik, R. and
916 Zraggen, E., 2018, June. Towards interactive curation & automatic tuning of ml pipelines.
917 In *Proceedings of the Second Workshop on Data Management for End-To-End Machine
918 Learning* (p. 1). ACM.

- 919 55. Chung, Y., Servan-Schreiber, S., Zraggen, E. and Kraska, T., 2018. Towards Quantifying
920 Uncertainty in Data Analysis & Exploration. *IEEE Data Eng. Bull.*, 41(3), pp.15-27.
- 921 56. Tou, J.T. and Gonzalez, R.C., 1972. Automatic recognition of handwritten characters via
922 feature extraction and multi-level decision. *International Journal of Computer & Information*
923 *Sciences*, 1(1), pp.43-65.
- 924 57. Zeng, W., Meng, X., Yang, C. and Huang, L., 2006. Feature extraction for online handwritten
925 characters using Delaunay triangulation. *Computers & Graphics*, 30(5), pp.779-786.
- 926 58. COMSOL, "Introduction to COMSOL Multiphysics 5.3," *Manual*, 2014.
- 927 59. P. Roger W. Pryor, *Multiphysics Modeling Using COMSOL®: A First Principles Approach*. 2009.
- 928 60. Hamada, M. and Sato, S., 2010, June. Lego NXT as a learning tool. In *Proceedings of the*
929 *fifteenth annual conference on Innovation and technology in computer science education* (pp.
930 321-321). ACM.
- 931 61. Datta, S.P.A., 2017. Emergence of Digital Twins-Is this the march of reason?. *Journal of*
932 *Innovation Management*, 5(3), pp.14-33.
- 933 62. Meystel, A., 1989. Intelligent control: A sketch of the theory. *Journal of Intelligent & Robotic*
934 *Systems*, 2(2), pp.97-107.
- 935 63. Stephanopoulos, G. and Han, C., 1996. Intelligent systems in process engineering: A
936 review. *Computers & Chemical Engineering*, 20(6-7), pp.743-791.
- 937 64. Meystel, A., 1993, August. Architectures for intelligent control systems: The science of
938 autonomous intelligence. In *Proceedings of 8th IEEE International Symposium on Intelligent*
939 *Control* (pp. 42-48). IEEE.
- 940 65. Antsaklis, P.J., Passino, K.M. and Wang, S.J., 1991. An introduction to autonomous control
941 systems. *IEEE Control Systems Magazine*, 11(4), pp.5-13.
- 942 66. Albaladejo, C., Soto, F., Torres, R., Sánchez, P. and López, J.A., 2012. A low-cost sensor buoy
943 system for monitoring shallow marine environments. *Sensors(Switzerland)*, 12(7), pp.9613-
944 9634.
- 945 67. Pardee, A.B., Jacob, F. and Monod, J., 1959. The genetic control and cytoplasmic expression of
946 "inducibility" in the synthesis of β -galactosidase by *E. coli*. *Journal of Molecular Biology*, 1(2),
947 pp.165-178.
- 948 68. Quinlan, J.R., 1986. Induction of decision trees. *Machine learning*, 1(1), pp.81-106.
- 949 69. "Introduction to Decision Trees," 2014.
- 950 70. Forstmann, B.U., Dutilh, G., Brown, S., Neumann, J., Von Cramon, D.Y., Ridderinkhof, K.R.
951 and Wagenmakers, E.J., 2008. Striatum and pre-SMA facilitate decision-making under time
952 pressure. *Proceedings of the National Academy of Sciences*, 105(45), pp.17538-17542.
- 953 71. Gold, C., Damböck, D., Lorenz, L. and Bengler, K., 2013, September. "Take over!" How long
954 does it take to get the driver back into the loop?. In *Proceedings of the Human Factors and*
955 *Ergonomics Society Annual Meeting* (Vol. 57, No. 1, pp. 1938-1942). Sage CA: Los Angeles,
956 CA: SAGE Publications..
- 957 72. Cabri, G., Leonardi, L. and Zambonelli, F., 2000. MARS: A programmable coordination
958 architecture for mobile agents. *IEEE Internet Computing*, 4(4), pp.26-35.
- 959 73. E. Jean, 2011. "Sensor network interoperability and reconfiguration through mobile agents,".

- 960 74. Fielding, R.T. and Taylor, R.N., 2000. *Architectural styles and the design of network-based*
961 *software architectures*. Doctoral dissertation: University of California, Irvine.
- 962 75. Willinger, W., Paxson, V., Riedi, R.H. and Taqqu, M.S., 2003. Long-range dependence and
963 data network traffic. *Theory and applications of long-range dependence*, pp.373-407.
- 964 76. Vélez-Torres, I., Vanegas, D.C., McLamore, E.S. and Hurtado, D., 2018. Mercury pollution
965 and artisanal gold mining in Alto Cauca, Colombia: woman's perception of health and
966 environmental impacts. *The Journal of Environment & Development*, 27(4), pp.415-444.
- 967 77. Abdelbasir, S.M., El-Sheikh, S.M., Morgan, V.L., Schmidt, H., Casso-Hartmann, L.M.,
968 Vanegas, D.C., Velez-Torres, I. and McLamore, E.S., 2018. Graphene-anchored cuprous oxide
969 nanoparticles from waste electric cables for electrochemical sensing. *ACS Sustainable*
970 *Chemistry & Engineering*, 6(9), pp.12176-12186.
- 971 78. Nakazawa, K., Nagafuchi, O., Kawakami, T., Inoue, T., Yokota, K., Serikawa, Y., Cyio, B. and
972 Elvince, R., 2016. Human health risk assessment of mercury vapor around artisanal small-
973 scale gold mining area, Palu city, Central Sulawesi, Indonesia. *Ecotoxicology and*
974 *environmental safety*, 124, pp.155-162.
- 975 79. Saleem, M., Iqbal, J. and Shah, M.H., 2014. Dissolved concentrations, sources, and risk
976 evaluation of selected metals in surface water from mangla lake, Pakistan. *The Scientific World*
977 *Journal*, 2014.
- 978 80. Xiao, J., Wang, L., Deng, L. and Jin, Z., 2019. Characteristics, sources, water quality and health
979 risk assessment of trace elements in river water and well water in the Chinese Loess
980 Plateau. *Science of the Total Environment*, 650, pp.2004-2012.
- 981 81. Takabe, Y., Tsuno, H., Nishimura, F., Tanii, N., Maruno, H., Tsurukawa, M., Suzuki, M. and
982 Matsumura, C., 2012. Bioaccumulation and primary risk assessment of persistent organic
983 pollutants with various bivalves. *Water Science and Technology*, 66(12), pp.2620-2629.
- 984 82. U. S. E. P. a Oppt, "Quantitative Risk Assessment Calculations," *EPA Sustain. Futur. Framew.*
985 *Man. 2012 EPA-748-B12-001*, 2012.
- 986 83. Smith, A.H., Lingas, E.O. and Rahman, M., 2000. Contamination of drinking-water by arsenic
987 in Bangladesh: a public health emergency. *Bulletin of the World Health Organization*, 78,
988 pp.1093-1103.
- 989 84. Van Geen, A., Trevisani, M., Immel, J., Jakariya, M., Osman, N., Cheng, Z., Gelman, A. and
990 Ahmed, K.M., 2006. Targeting low-arsenic groundwater with mobile-phone technology in
991 Araihasar, Bangladesh. *Journal of health, population, and nutrition*, 24(3), p.282.
- 992 85. Wan, X., Volpetti, F., Petrova, E., French, C., Maerkl, S.J. and Wang, B., 2019. Cascaded
993 amplifying circuits enable ultrasensitive cellular sensors for toxic metals. *Nature chemical*
994 *biology*, 15(5), p.540.
- 995 86. Haque, F., Ball, R.L., Khatun, S., Ahmed, M., Kache, S., Chisti, M.J., Sarker, S.A., Maples, S.D.,
996 Pieri, D., Korrapati, T.V. and Sarnquist, C., 2017. Evaluation of a smartphone decision-
997 support tool for diarrheal disease management in a resource-limited setting. *PLoS neglected*
998 *tropical diseases*, 11(1), p.e0005290.
- 999 87. Hills, K.D., Oliveira, D.A., Cavallaro, N.D., Gomes, C.L. and McLamore, E.S., 2018. Actuation
1000 of chitosan-aptamer nanobrush borders for pathogen sensing. *Analyst*, 143(7), pp.1650-1661.

- 1001 88. Shirude, S.B. and Kolhe, S.R., 2018. Agent-Based Architecture for Developing Recommender
1002 System in Libraries. In *Knowledge Computing and its Applications* (pp. 157-181). Springer,
1003 Singapore.
- 1004 89. Ellul, J. (1964). *The technological society*. New York: Knopf.
- 1005 90. Subcommittee: F29.21 (ASTM), “ASTM F2761 - 09(2013) Medical Devices and Medical
1006 Systems - Essential safety requirements for equipment comprising the patient-centric
1007 integrated clinical environment (ICE),” 2013.
- 1008 91. Makary, M.A. and Daniel, M., 2016. Medical error—the third leading cause of death in the
1009 US. *Bmj*, 353, p.i2139.
- 1010 92. R. Hoffmann and F. J. Dyson, "The Same and Not the Same" *Phys. Today*, 2008.
- 1011 93. W. E. McCarthy, “Knowledge Representation: Logical, Philosophical, and Computational
1012 Foundations,” *Account. Rev.*, 2002.
- 1013 94. Bergman, M.K., 2018. *A Knowledge Representation Practitioner: Guidelines Based on Charles*
1014 *Sanders Peirce*. Springer.
- 1015 95. P. A. David, and G. Wright (2012) General Purpose Technologies and Surges in Productivity:
1016 Historical Reflections on the Future of the ICT Revolution, in *The Economic Future in*
1017 *Historical Perspective*, 2012.
- 1018 96. *The Economic Future in Historical Perspective*. 2012.
- 1019 97. Bullmore, E. and Sporns, O., 2009. Complex brain networks: graph theoretical analysis of
1020 structural and functional systems. *Nature reviews neuroscience*, 10(3), p.186.
- 1021 98. Fornito, A., Zalesky, A. and Breakspear, M., 2013. Graph analysis of the human connectome:
1022 promise, progress, and pitfalls. *Neuroimage*, 80, pp.426-444.
- 1023 99. Tshitoyan, V., Dagdelen, J., Weston, L., Dunn, A., Rong, Z., Kononova, O., Persson, K.A.,
1024 Ceder, G. and Jain, A., 2019. Unsupervised word embeddings capture latent knowledge from
1025 materials science literature. *Nature*, 571(7763), p.95.
- 1026 100. J. Jonas, 2005. Non-Obvious Relationship Awareness (NORA), in *IBM Entity Analytic*
1027 *Solutions*, pp. 1–78.
- 1028 101. G. Bartolomeo and T. Kovacikova. (2013). “Resource Description Framework”, in G.
1029 Bartolomeo and T. Kovacikova. *Identification and Management of Distributed Data*, Boca
1030 Raton: CRC Press, pp. 205-211.
- 1031 102. Janet, J.P., Chan, L. and Kulik, H.J., 2018. Accelerating chemical discovery with machine
1032 learning: simulated evolution of spin crossover complexes with an artificial neural
1033 network. *The journal of physical chemistry letters*, 9(5), pp.1064-1071.
- 1034 103. Janet, J.P. and Kulik, H.J., 2017. Predicting electronic structure properties of transition metal
1035 complexes with neural networks. *Chemical science*, 8(7), pp.5137-5152.
- 1036 104. Janet, J.P. and Kulik, H.J., 2017. Resolving transition metal chemical space: Feature selection
1037 for machine learning and structure–property relationships. *The Journal of Physical Chemistry*
1038 *A*, 121(46), pp.8939-8954.
- 1039 105. Nandy, A., Duan, C., Janet, J.P., Gugler, S. and Kulik, H.J., 2018. Strategies and software for
1040 machine learning accelerated discovery in transition metal chemistry. *Industrial &*
1041 *Engineering Chemistry Research*, 57(42), pp.13973-13986.

- 1042 106. Barati, M., Bai, Q. and Liu, Q., 2017. Mining semantic association rules from RDF
1043 data. *Knowledge-Based Systems*, 133, pp.183-196.
- 1044 107. Lee, J., Yoon, W., Kim, S., Kim, D., Kim, S., So, C.H. and Kang, J., 2019. Biobert: pre-trained
1045 biomedical language representation model for biomedical text mining. *arXiv preprint*
1046 *arXiv:1901.08746*.
- 1047 108. Cronbach, L.J. and Meehl, P.E., 1955. Construct validity in psychological tests. *Psychological*
1048 *bulletin*, 52(4), p.281.
- 1049 109. Krebs, H.A. and Johnson, W.A., 1937. The role of citric acid in intermediate metabolism in
1050 animal tissues. *Enzymologia*, 4, pp.148-156.
- 1051 110. Forrester, J.W., 1995. The beginning of system dynamics. *McKinsey Quarterly*, pp.4-17.
- 1052 111. Guo, J., Zhan, Z., Gao, Y., Xiao, Y., Lou, J.G., Liu, T. and Zhang, D., 2019. Towards Complex
1053 Text-to-SQL in Cross-Domain Database with Intermediate Representation. *arXiv preprint*
1054 *arXiv:1905.08205*.
- 1055 112. Liu, S., Zhang, X., Zhang, S., Wang, H. and Zhang, W., 2019. Neural machine reading
1056 comprehension: Methods and trends. *Applied Sciences*, 9(18), p.3698.
- 1057 113. Devlin, J., Chang, M.W., Lee, K. and Toutanova, K., 2018. Bert: Pre-training of deep
1058 bidirectional transformers for language understanding. *arXiv preprint arXiv:1810.04805*.
- 1059 114. Shen, Y., Huang, P.S., Gao, J. and Chen, W., 2017, August. Reasonet: Learning to stop reading
1060 in machine comprehension. In *Proceedings of the 23rd ACM SIGKDD International*
1061 *Conference on Knowledge Discovery and Data Mining* (pp. 1047-1055). ACM.
- 1062 115. Wang, W., Yang, N., Wei, F., Chang, B. and Zhou, M., 2017, July. Gated self-matching
1063 networks for reading comprehension and question answering. In *Proceedings of the 55th*
1064 *Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers)* (pp.
1065 189-198).
- 1066 116. Tan, C., Wei, F., Yang, N., Du, B., Lv, W. and Zhou, M., 2017. S-net: From answer extraction
1067 to answer generation for machine reading comprehension. *arXiv preprint arXiv:1706.04815*.
- 1068 117. Yang, Z., Dai, Z., Yang, Y., Carbonell, J., Salakhutdinov, R. and Le, Q.V., 2019. XLNet:
1069 Generalized Autoregressive Pretraining for Language Understanding. *arXiv preprint*
1070 *arXiv:1906.08237*.
- 1071 118. Wang, Y., Wang, S., Tang, J., O'Hare, N., Chang, Y. and Li, B., 2016. Hierarchical attention
1072 network for action recognition in videos. *arXiv preprint arXiv:1607.06416*.
- 1073 119. Yang, Z., Yang, D., Dyer, C., He, X., Smola, A. and Hovy, E., 2016, June. Hierarchical
1074 attention networks for document classification. In *Proceedings of the 2016 conference of the*
1075 *North American chapter of the association for computational linguistics: human language*
1076 *technologies* (pp. 1480-1489).
- 1077 120. Jain, S. and Wallace, B.C., 2019. Attention is not explanation. *arXiv preprint*
1078 *arXiv:1902.10186*.
- 1079 121. Nie, D., Trullo, R., Lian, J., Petitjean, C., Ruan, S., Wang, Q. and Shen, D., 2017, September.
1080 Medical image synthesis with context-aware generative adversarial networks. In *International*
1081 *Conference on Medical Image Computing and Computer-Assisted Intervention* (pp. 417-425).
1082 Springer, Cham.

- 1083 122. Mikolov, T., Chen, K., Corrado, G. and Dean, J., 2013. Efficient estimation of word
1084 representations in vector space. *arXiv preprint arXiv:1301.3781*.
- 1085 123. Chen, G.H. and Shah, D., 2018. Explaining the success of nearest neighbor methods in
1086 prediction. *Foundations and Trends® in Machine Learning*, 10(5-6), pp.337-588.
- 1087 124. Pelillo, M., 2014. Alhazen and the nearest neighbor rule. *Pattern Recognition Letters*, 38,
1088 pp.34-37.
- 1089 125. Hulsebos, M., Hu, K., Bakker, M., Zraggen, E., Satyanarayan, A., Kraska, T., Demiralp, Ç.
1090 and Hidalgo, C., 2019. Sherlock: A Deep Learning Approach to Semantic Data Type Detection
1091 In *25TH ACM SIGKDD CONFERENCE ON KNOWLEDGE DISCOVERY AND DATA*
1092 *MINING*, Anchorage, Alaska, 4-8 August.
- 1093 126. Datta, S.P.A., 2007. Unified theory of relativistic identification of information in a systems
1094 age: Proposed convergence of unique identification with syntax and semantics through
1095 Internet protocol version 6.
- 1096 127. Xu, K., Li, J., Zhang, M., Du, S.S., Kawarabayashi, K., & Jegelka, S., 2019. What Can Neural
1097 Networks Reason About? *ArXiv, abs/1905.13211*.
- 1098 128. www.schema.org
- 1099 129. Borrell, B., 2010. Foundations-Nature Rejects Krebs's Paper, 1937. *Scientist*, 24(3), p.88.
- 1100 130. Datta, S., 2008. Potential for improving decision support catalysed by semantic
1101 interoperability between systems.
- 1102 131. Patten, J., Ishii, H., Hines, J. and Pangaro, G., 2001, March. Sensetable: a wireless object
1103 tracking platform for tangible user interfaces. In *Proceedings of the SIGCHI conference on*
1104 *Human factors in computing systems*. ACM, pp. 253-260.
- 1105 132. Datta, S., Betts, B., Dinning, M., Erhun, F., Gibbs, T., Keskinocak, P., Li, H., Li, M. and
1106 Samuels, M., 2004. Adaptive value networks. In *Evolution of supply chain management* (pp. 3-
1107 67). Springer, Boston, MA.
- 1108 133. Ullmer, B. and Ishii, H., 1997. The metaDESK: models and prototypes for tangible user
1109 interfaces. In *Proceedings of Symposium on User Interface Software and Technology (UIST???*
1110 *97)*, ACM.
- 1111 134. Ishii, H., 2004, lecture notes, Tangible Media Group MIT Media Laboratory, Tokyo, delivered
1112 February 2004.
- 1113 135. Maquil, V., Leopold, U., De Sousa, L.M., Schwartz, L. and Tobias, E., 2018. Towards a
1114 framework for geospatial tangible user interfaces in collaborative urban planning. *Journal of*
1115 *Geographical Systems*, 20(2), pp.185-206.
- 1116 136. Ullmer, B. and Ishii, H., 2000. Emerging frameworks for tangible user interfaces. *IBM systems*
1117 *journal*, 39(3.4), pp.915-931.
- 1118 137. Ullmer, B.A., 1997. *Models and mechanisms for tangible user interfaces* (Master Thesis,
1119 Massachusetts Institute of Technology).
- 1120 138. <https://tangible.media.mit.edu/papers/>
- 1121 139. Pray, L. & Zhaurova, K. 2008. Barbara McClintock and the discovery of jumping genes
1122 (transposons). *Nature Education* 1(1):169.

- 1123 140. Creighton, H.B. and McClintock, B., 1931. A correlation of cytological and genetical crossing-
1124 over in *Zea mays*. *Proceedings of the National Academy of Sciences of the United States of*
1125 *America*, 17(8), p.492.
- 1126 141. Ravindran, S., 2012. Barbara McClintock and the discovery of jumping genes. *Proceedings of*
1127 *the National Academy of Sciences*, 109(50), pp.20198-20199.
- 1128 142. Prince, T. 2019, 'The Definitive History of the Flu', *Champagne remedies, sneezing ferrets, and*
1129 *thousands of years of havoc*. [https://elemental.medium.com/the-definitive-history-of-the-flu-](https://elemental.medium.com/the-definitive-history-of-the-flu-b975432f9fc5)
1130 [b975432f9fc5](https://elemental.medium.com/the-definitive-history-of-the-flu-b975432f9fc5)
- 1131



© 2019 McLamore et al. Submitted for open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).

1132

Beginnings

Thresholded Logic Unit (1943)

Perceptron (1957)

Adaline (1960)

1st Neural Winter

XOR Problem (1969)

2nd Neural Winter

Multilayer Backprop (1982)

CNNs (1986)

LSTMs (1989)

GPU Era

SVMs (1995)

Deep Nets (2006)

Alex Net (2012)

1940 1950 1960 1970 1980 1990 2000 2010



S. McCulloch - W. Pitts



R. Rosenblatt



B. Widrow - M. Hoff



M. Minsky - S. Papert



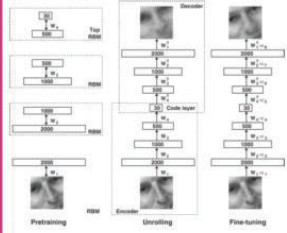
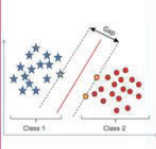
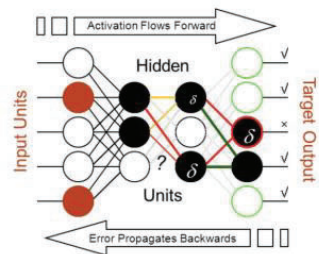
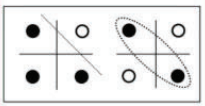
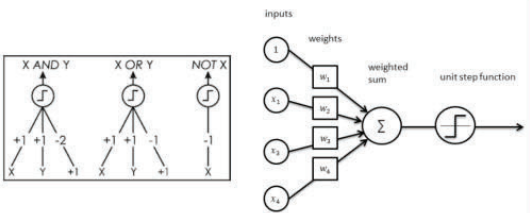
P. Werbos D. Rumelhart - G. Hinton - R. Williams Y. Lecun - J. Schmidhuber



C. Cortes - V. Vapnik



R. Salakhutdinov - J. Hinton - A. Krizhevsky - I. Sutskever



1 review

2 **Sensor-as-a-Service: Convergence of Sensor** 3 **Analytic Point Solutions (SNAPS) and Pay-A-** 4 **Penny-Per-Use (PAPPU) Paradigm as a Catalyst for** 5 **Democratization of Healthcare in Underserved** 6 **Communities**

7 **Victoria Morgan¹, Lisseth Casso-Hartman^{2,3}, David Bahamon-Pinzon⁴, Kelli McCourt⁴, Robert**
8 **G. Hjort⁵, Sahar Bahramzadeh⁶, Irene Velez-Torres^{2,3}, Eric McLamore¹, Carmen Gomes⁵,**
9 **Evangelyn C. Alocilja^{7,8}, Nirajan Bhusal^{7,9,10}, Sunaina Shrestha¹⁰, Nisha Pote¹⁰, Ruben Kenny**
10 **Briceno^{11,12,13,7}, Shoumen Palit Austin Datta^{1,14,15,16}, Diana C. Vanegas^{4,3*}**

11 ¹ Agricultural and Biological Engineering, Institute of Food and Agricultural Sciences, University of
12 Florida, Gainesville, FL, 32611, USA

13 ² Natural Resources and Environmental Engineering, Universidad del Valle, Cali, Colombia

14 ³ Interdisciplinary Group for Biotechnological Innovation and Ecosocial Change -BioNovo, Universidad
15 del Valle, Cali, Colombia

16 ⁴ Biosystems Engineering, Department of Environmental Engineering and Earth Sciences, Clemson
17 University, Clemson, SC 29631, USA

18 ⁵ Mechanical Engineering, Iowa State University, Ames, IA, 50011, USA

19 ⁶ School of Computer Engineering, Azad University, Science and Research Branch, Saveh, Iran

20 ⁷ Global Alliance for Rapid Diagnostics, Michigan State University, East Lansing, MI 48824, USA

21 ⁸ Biosystems and Agricultural Engineering, Michigan State University, East Lansing, MI 48824, USA

22 ⁹ School of Medical Sciences, Kathmandu University, Kathmandu, Nepal

23 ¹⁰ Dhulikhel Hospital, Kathmandu University, Kavrepalanchok, Nepal

24 ¹¹ Instituto de Investigacion en Ciencia y Tecnologia, Universidad Cesar Vallejo, Trujillo 13100, Peru

25 ¹² Hospital Victor Lazarte Echegaray, Trujillo 13100, Peru

26 ¹³ Institute for Global Health, Michigan State University, East Lansing, MI 48824, USA

27 ¹⁴ MIT Auto-ID Labs, Department of Mechanical Engineering, Massachusetts Institute of Technology, 77
28 Massachusetts Avenue, Cambridge, MA, 02139, USA

29 ¹⁵ MDPnP Interoperability and Cybersecurity Labs, Biomedical Engineering Program, Department of
30 Anesthesiology, Massachusetts General Hospital, Harvard Medical School, 65 Landsdowne Street,
31 Cambridge, MA 02139, USA

32 ¹⁶ NSF Center for Robots and Sensors for Human Well-Being, Purdue University, 156 Knoy Hall, Purdue
33 Polytechnic, West Lafayette, IN 47907, USA

34 * Correspondence: dvanega@clemson.edu; Tel.: (+1)864-656-1001

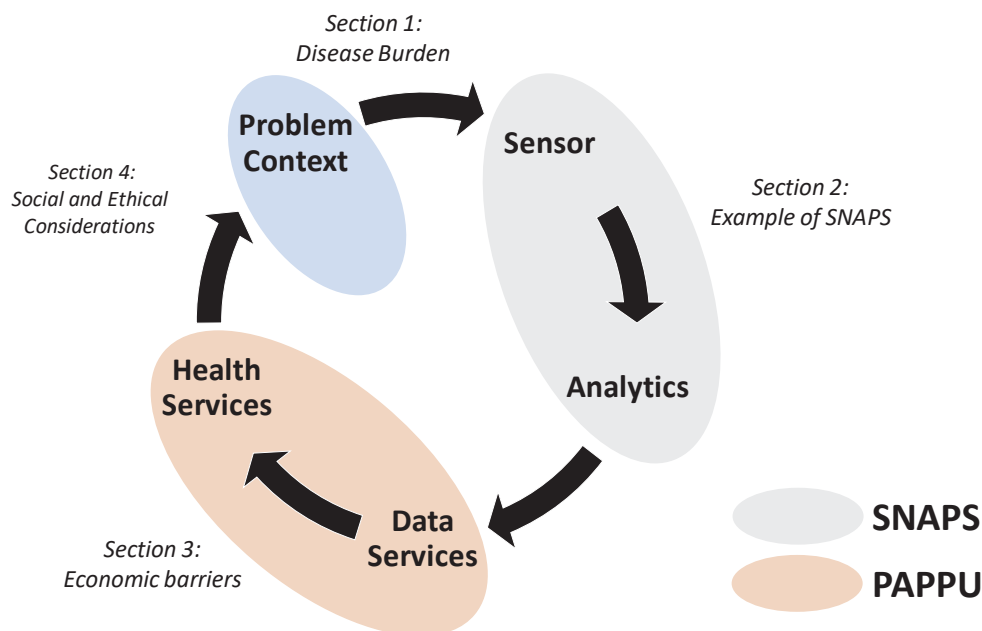
35 Received: date; Accepted: date; Published: date

36 **Abstract:** In this manuscript, we discuss relevant socioeconomic factors for developing and
37 implementing Sensor Analytic Point Solutions (SNAPS) as point-of-care tools to serve
38 impoverished communities. The distinct economic, environmental, cultural, and ethical
39 paradigms that affect economically disadvantaged users, adds complexity to the process of
40 technology development and deployment beyond the science and engineering issues. We begin
41 by contextualizing the environmental burden of disease in select low-income regions around
42 the world, including environmental hazards at work, home, and broader community
43 environment, where SNAPS may be helpful in prevention and mitigation of human exposure to
44 harmful biological vectors and chemical agents. We offer examples of SNAPS designed for
45 economically disadvantaged users, specifically for supporting decision-making in cases of
46 tuberculosis (TB) infection and mercury exposure. We follow-up by discussing the economic
47 challenges involved in phased implementation of diagnostic tools in low-income markets and
48 describe a micropayment-based systems-as-a-service approach (PAPPU), which may be

49 catalytic for adoption of low-end, low-margin, low-research and development SNAPS. Finally,
 50 we provide some insights into the social and ethical considerations for the assimilation of
 51 SNAPS to improve health outcomes in marginalized communities.

52 **Keywords:** sensor analytic point solutions (SNAPS); environmental health; poverty, pay-a-
 53 penny-per-use (PAPPU), public health

54
 55



56

57 **Graphical Abstract.** We suggest a framework for using SNAPS (sensor-analytic point solutions)
 58 in combination with the financial instrument PAPPU (Pay-A-Penny-Per-Use) for providing
 59 health care services for low-income communities. Distinct economic, environmental, and
 60 cultural, issues must be taken into consideration. In this review we summarize the environmental
 61 burden of disease (section 1), then provide two examples of SNAPS that are at various stages of
 62 maturity (section 3) and discuss PAPPU as a potential mechanism to overcome economic barriers
 63 (section 4). We close the review by discussing the opportunities and challenges of this approach
 64 through the lens of social acceptance.

65 1. Environmental Burden of Disease

66 According to the World Health organization, environmental factors including unsafe water,
 67 poor sanitation, air pollution, and unintentional exposure to hazardous chemical and biological
 68 agents, are root causes for the burden of disease, disability, and death in the developing world
 69 [1, 2] Impoverished communities living in polluted and crowded environments are much more
 70 susceptible to the double burden of infective and non-communicable diseases, and this situation
 71 is often compounded by the lack of adequate infrastructure, weak environmental policy, and
 72 deficient or inequitable healthcare systems that disfavor economically challenged users [3-8].
 73 Despite the global efforts to reduce poverty, indicators of health disparities between
 74 disadvantaged and affluent populations continue to persist. For instance, the 2018 World Bank
 75 estimates show that on average, there is a 12-fold difference in mortality rate of infants between
 76 low- and high- income populations [9], but in countries experiencing extreme deprivation such
 77 as Somalia and Sierra Leone, this rate is nearly 20-fold higher than the average rate in wealthy
 78 nations. In 2016, diarrheal diseases linked to poor sanitation and consumption of contaminated

79 food and water were responsible for 1.6 million deaths, 90% of which occurred in South Asia and
80 sub-Saharan Africa [10, 11] The per capita burden of disease from inhalation exposure to airborne
81 polycyclic aromatic hydrocarbons (by-products of fuel combustion) is nearly 33-fold higher in
82 India compared to the USA [12, 13].

83 Nonetheless, it is important to note that due to the myriad ways in which socioeconomic and
84 environmental factors interact, it is very difficult to establish highly detailed associations of single
85 environmental risk factors with epidemiological outcomes [14-17]. Moreover, environmental
86 factors rarely occur in isolation; for example, a population can be exposed to a combination of
87 pollutants from different sources, which could result in additive or synergistic effects and
88 symptoms, making medical diagnostic processes extremely cumbersome (Briggs, 2003). In
89 addition to the limited access to healthcare systems, the problem is compounded by the relatively
90 high cost of clinical testing and may cause many illnesses to go under-reported or mis-diagnosed
91 [18] in economically challenged populations. Despite the complexities involved in linking
92 environmental and socioeconomic factors to epidemiological outcomes, there is no question that
93 such factors can result in serious public health problems, particularly in low-income communities
94 which bear the largest proportion of the burden of environmentally related diseases [19, 20].

95 Undoubtedly, much of the economic strain from both infectious and non-communicable
96 diseases associated with unhealthy environments could be effectively diminished through
97 preventive strategies that tackle associated risk factors [18, 21]. One promising approach for
98 addressing health risk factors in low-income communities is the deployment of integrated
99 technologies for data-informed decision support such as Sensor Analytic Point Solutions
100 (SNAPS). The concept of SNAPS has been recently introduced as part of a platform approach to
101 converge sensor data and analytics to deliver data-informed decision support for a number of
102 applications, including healthcare [21]. Even though thousands of sensors and point-of-care
103 diagnostic tools have been developed in research labs around the world during the past decades,
104 the large majority of these technologies have not yet translated into implementable solutions due
105 to different obstacles including unsuitability of operation under real-world conditions, high
106 fabrication and operation costs (which limits market penetration and profitability), and a lack of
107 convergence with other technologies to yield actionable information for the user [22].

108 Consider for instance the case of diarrheal diseases associated with *E. coli* infection from
109 ingestion of contaminated food or water, which contributes significantly to mortality and
110 morbidity of children under 5 years of age in African and Eastern Mediterranean countries [23].
111 By conducting a literature search on the Web of Science, we found that in the past 10 years 303
112 research articles have been published in peer-reviewed journals portraying the development of
113 *E. coli* biosensors. However, only a small fraction of these papers includes claims such as real-
114 sample testing (~29%), low-cost fabrication (~10%), portability (~9%), and user-friendly operation
115 (~2%) (the complete report from this search is available in the Supplemental Section S1).

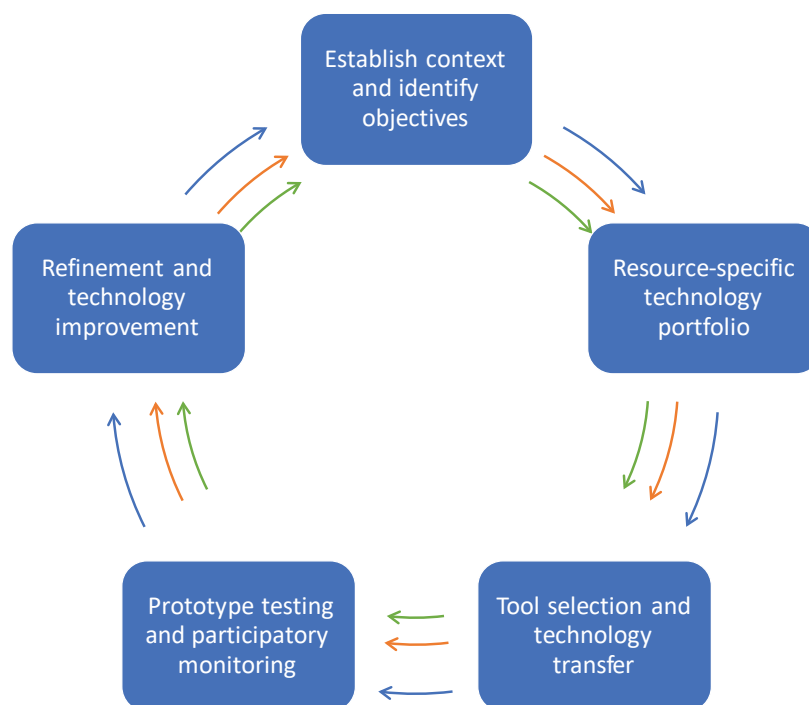
116 In this manuscript, we provide examples of SNAPS that have been tested in field conditions,
117 within the context of low-income communities. The first example was developed for assisting
118 early diagnosis of infectious disease and prevention of public health outbreaks, and the second
119 example supports decision making in cases of human exposure to an environmental pollutant.
120 We also propose the concept of Pay-A-Penny-Per-Use (PAPPU) as a potential paradigm to reduce
121 economic barriers to implement SNAPS in economically-deprived regions. The two examples of
122 field-tested SNAPS are at different stages of maturity, which provides insight into the design
123 process and logic flow. Finally, we provide some insights on the social and ethical considerations
124 for the effective use of SNAPS in assisting the users and improving health outcomes in
125 underserved communities.

126 2. Examples of SNAPS-ART

127 Near real-time qualitative decisions are often key for rapid response. SNAPS is a tool that
128 uses sensor data to provide response at the point of use with minimal analytics. If two or more
129 factors must be considered by the human-in-the-loop to take a decision, artificial reasoning tools
130 (ART) is implemented. ART is a data fusion layer that combines sensor data and display
131 suggestions or information, on the user's mobile device. In principle, SNAPS is designed to offer
132 "point solutions", which implies a rapid binary output (yes/no) based on the data captured from
133 the sensor signal (for example, sensor binds to an analyte). However, even in rudimentary
134 scenarios, a single source of binary data may fail to provide basic information. Hence, the need
135 for artificial reasoning tools (ART) which are light-weight middleware (software which sits in the
136 "middle") embedded with preliminary logic to decide what is the *meaning* of the data and what
137 information may be conveyed (displayed) for the end-user. By introducing a modular ART tool,
138 the user takes advantage of combinatorial variant configuration menu to change, adapt or
139 introduce new reasoning/logic in the middleware by re-programming the logic "buckets" simply
140 by re-shuffling and inserting the user's preferred choices from a repertoire of pre-programmed
141 logic.

142 There are many complex layers to system-level solution to ease the environmental burden
143 on impoverished communities. Velez-Torres et al [24] recently developed a circular system
144 framework for integrating analytic tools (such as SNAPS) with social action research (CLISAR).
145 The CLISAR framework is a transdisciplinary approach that involves analytical tools such as
146 sensors for informing community action related to public health, environmental issues, or food
147 security, for example. Beyond simple commercial colorimetric detection strips used in
148 development of CLISAR, information derived from SNAPS can transform this system by
149 supporting decision-making processes aimed at improving the health outcomes of marginalized
150 communities.

151 Herein, we suggest a conceptual approach for selecting and implementing the type of
152 diagnostic tools for implementation of SNAPS (see **Fig 1**). The examples that follow in the
153 subsequent section used a five-step process that followed a closed-loop approach similar to
154 CLISAR and other circular economic models [25]. The first step is to understand the specific
155 problem as well as the social and economic context where decision-support technology may be
156 needed. The next step is to identify readily available resources and design diagnostic tools for
157 creating a technology portfolio (sensors, analytics software, portable hardware, etc.). The third
158 step involves selection of the most appropriate tools to create SNAPS based on technical
159 capabilities as well as interactive feedback from stakeholders. In step four scientists and end-
160 users test technology prototypes in field conditions using established participatory
161 methodologies. Finally, results from proof-of-concept testing should be used to evaluate and
162 refine the technology. Below, we present two examples of how this conceptual model is applied
163 in real-world settings. The first example is in advanced stage field-testing (refinement and
164 technology improvement, with some elements in the second circular phase), while the second
165 example is in early phase of development (tool selection and technology transfer).



166
167
168
169
170

Figure 1. Overview of process in development of SNAPS for the examples shown below. The blue, orange, and green arrows indicate technology evolution using established principles of circular feedback systems. The blue, orange, and green arrows indicate convergence toward a systems-level solution through feedback/refinement pathways.

171

2.1 Early assessment of tuberculosis in vulnerable populations

172
173
174
175
176
177
178
179

In 2017, 1.6 million people died from tuberculosis (TB) globally and there were 10 million new TB cases that occurred in the same year [26]. TB has surpassed HIV as the leading infectious disease killer worldwide since 2014 [27]. Furthermore, multidrug-resistant and extensively drug-resistant TB (MDR/XDR-TB) are current global public health threats. The 2017 Moscow Ministerial Declaration on ending TB, involving 120 countries and over 800 partners, identified “to advance research and development of new tools to diagnose, treat and prevent TB” as one of four action items [28]. This meeting was followed in 2018 by a United Nations (UN) General Assembly first-ever high-level meeting to accelerate efforts on ending TB [29].

180
181
182
183
184
185
186
187
188
189
190
191
192
193
194

Care of TB patients starts with accessible and affordable diagnosis. The majority of TB patients live in poor conditions and in geographically remote areas. Culture-based techniques are the gold standard for diagnosis, but this is relatively expensive and results take 6-8 weeks [30]. For decades, TB diagnosis has relied on direct sputum smear microscopy (SSM) in many countries [31]. SSM is fast, inexpensive, facile, and specific for detecting *Mycobacterium tuberculosis* (Mtb) in high incidence areas [30, 32, 33]. It does not require complex laboratory equipment and is therefore very suitable for low-resource settings especially in populations with varying socio-economic situations [30, 32]. However, SSM’s sensitivity is only about 25%-65% compared to culture, with a detection limit of about 10,000 colony forming units per milliliter (CFU/mL) [33, 34]. A study comparing culture, SSM, and Xpert MTB/RIF system involving hundreds of specimens showed that SSM had 54% sensitivity for respiratory samples and 50% for non-respiratory samples [35]. Furthermore, smear sensitivity varies with the type of lesion, type and number of specimens, mycobacterial species, staining technique, and the alertness and persistence of the microscopist [34]. In a 2014 survey, 22 high-burden countries (HBCs) conducted 77.6 million sputum smears valued at 137 million USD in 42,827 microscopy centers [36]. Of these,

195 61% were performed in the BRICS countries (Brazil, Russian Federation, India, China and South
196 Africa) [36]. On average, 79% of the smears were performed for initial diagnosis in these
197 countries. When converted to 2012 USD, the unit cost for a smear, including materials, labor, and
198 overhead expenses, was 1.77 USD [34]. Studies have shown that the sensitivity of SSM improved
199 significantly when specimens were subjected to liquefaction followed by the concentration of the
200 mycobacteria by overnight sedimentation or centrifugation [33, 37-41]. However, the increased
201 sensitivity provided by these processing methods may not be sufficient to offset their increased
202 cost, complexity, and potential biohazards.

203 Recently, several methods have been developed for the diagnosis and concentration of TB
204 and multi-drug resistant tuberculosis (MDR-TB), such as Xpert MTB/RIF, TB beads, liquid
205 culture, centrifugation, filtration, and line probe assays [42-46]. However, they are not necessarily
206 accessible or affordable for those who need them the most [47]. For example, the World Health
207 Organization recommended the Xpert MTB/RIF in 2010 to diagnose all persons with signs and
208 symptoms of TB. In many studies, the Xpert system was shown to have a sensitivity of 96.8% and
209 a specificity of 99.3% compared to culture as the reference standard [35]. However, if the Xpert
210 MTB/RIF assay (cartridge price of US\$9.98) were to be used for all people with presumed TB, the
211 cost would exceed 80% of the total TB spending in countries such as India, Bangladesh, Indonesia
212 and Pakistan [48]. In 2014 and 2015, there were 32.6 and 9.1 SSM for every Xpert MTB/RIF test
213 procured [49]. While these new diagnostic methods are more sensitive and/or specific than SSM,
214 they are oftentimes prohibitively expensive and not easily accessible for those living in low-
215 resource countries where Mtb has a high prevalence.

216 An important aspect of TB is the substantial financial burden placed on patients and their
217 families, not only for treatment costs but also associated costs, such as TB patients who are
218 required to take a leave of absence from work leading to the risk of impoverishment [50].
219 Tanimura et al. reported that on average, 20% of the total cost was due to direct medical costs,
220 20% to direct non-medical costs, and 60% to income loss [51]. On average, the total cost was
221 equivalent to 58% of reported annual individual income and 39% of reported household income
222 [51]. Cost as percentage of income was particularly high among poor people and those with
223 multidrug-resistant TB [51].

224 Accurate, rapid, and cost-effective diagnostic tests are crucial to reducing TB's unacceptably
225 high infection and mortality rates especially for a treatable disease [52]. The ambitious goal of the
226 global "End TB Strategy" to reduce TB incidence by 90% and reduce TB mortality by 95% by the
227 year 2035 will not be achieved without new tools to fight TB [53]. These tools include improved
228 point-of-care diagnostic tests that are delivered to low-income communities and at the first point-
229 of-contact by patients in the healthcare system. These tests should be performed on an easily
230 accessible sample and results be provided in a timely manner, allowing for a quick turnaround
231 time for treatment in a single clinical encounter, hence avoiding loss of patient follow up [53].

232 Thus, our strategy was to develop low-cost biosensing assay for rapid TB detection by
233 employing modern advances in nanoparticle science and glyco-chemistry resulting in sensitivity
234 matching the performance of Xpert MTB/RIF and standard culture. The nanoparticle-based
235 colorimetric biosensing assay (NCBA) is based on the concept of magnetically activated cell
236 enrichment (MACE) technique. In this technique the Mtb cells are isolated and enriched by
237 applying a magnetic field to activate nanoparticle-bound Mtb cells, without using any expensive
238 antibodies and energy-consuming centrifuge instruments and eliminating the need for time-
239 consuming growth of Mtb. The novelty of NCBA includes the utilization of iron oxide
240 nanoparticles with superparamagnetic properties. The use of magnetic nanoparticles (MNPs)
241 offers major advantages due to their unique size and physicochemical properties. The MNP
242 solution is colloidal in nature and it provides stability, which gives rise to both steric and

243 coulombic repulsions. Their nanoscale size results in their higher effective surface areas, lower
 244 sedimentation rates, and minimal precipitation due to gravitation forces. The MNPs are coated
 245 with glycan to facilitate attachment on the bacterial cell wall through carbohydrate-binding
 246 protein sites, providing specificity to the biosensing mechanism.

247 NCBA was validated in 500 sputum samples in Nepal and Mexico [54, 55]. In Nepal, 500
 248 sputum samples were tested for TB using SSM, Xpert MTB/RIF, and NCBA. Results showed that
 249 for the SSM test, 32 were positive (32+) and 468 were negative (468-); for the Xpert test, 80 were
 250 positive (80+) and 420 were negative (420-); and, for the NCBA test, 80 were positive (80+) and
 251 420 were negative (420-). The 32+ SSM samples were all positive in Xpert and NCBA. Of the 468-
 252 (negative) SSM samples, 48 were positive in both Xpert and NCBA. Table 1 presents the results
 253 from SSM test (not shaded) and NCBA test (shaded) using Xpert MTB/RIF as the standard in
 254 defining the number of true TB cases and non-TB cases. Statistical analysis of the diagnostic
 255 comparison between SSM and NCBA using Xpert MTB/RIF results as gold standard for true
 256 cases, and are presented in Table 2. At 95% confidence interval, the results show that SSM has a
 257 sensitivity of only 40% (29%–52%), while NCBA has a sensitivity matching that of the Xpert
 258 system (95%–100%). Probably because sputum samples were from suspected TB patients, the
 259 specificity, positive predictive value (PPV), and negative predictive value (NPV), for SSM and
 260 NCBA are very high close to 100%. The accuracy of SSM is 90% (87%–93%), while the accuracy
 261 of NCBA is 100% (99%–100%). Given the sample size and nature of the collected samples, the
 262 calculated prevalence for this cohort of patients is 16% (80 out of 500).

Table 1. Results using Xpert MTB/RIF as the gold standard for true tuberculosis (TB) cases and non-TB cases.

SSM Test	True TB	Non-TB	NCBA Test	True TB	Non-TB
	cases	cases		cases	cases
Positive test	32	0	Positive test	80	0
Negative test	48	420	Negative test	0	420

263

264

Table 2. Comparison of diagnostic performance.

Technique	Xpert MTB/RIF as the gold standard, % (95% CI)				
	Sensitivity	Specificity	PPV	NPV	Accuracy
SSM Test	40 (29–52)	100 (99–100)	100	90 (88–91)	90 (87–93)
NCBA Test	100 (95–100)	100 (99–100)	100	100	100 (99–100)

265

266

267

268

269

270

271

272

The Xpert MTB/RIF system reports bacterial load as very low, low, medium, and high. These categories were used to estimate the bacterial load in SSM and NCBA by matching the corresponding samples with the Xpert system. Table 3 shows a comparison of the detection limit and dynamic range of detection of the two techniques with respect to the Xpert system. Results from NCBA match well with the results from the Xpert MTB/RIF at all levels. On the other hand, SSM could not detect at very low level, detecting only 14% at low level, 48% at medium level, and 79% at high level. Sensitivity of NCBA matches well with the Xpert system at all bacterial loads, while SSM increases linearly with increasing bacterial load ($y = 0.27x - 0.33$, $R^2 = 0.97$). TB positive

273 samples are normally distributed around the medium level. SSM has 48% detection at the
 274 medium level, which is very close to the calculated sensitivity of 40% (29%-52%) in Table 2.

Table 3. Detection limit and dynamic range of detection of the two techniques with respect to the Xpert MTB/RIF categories.

Xpert MTB/RIF Categories	Very				Total
	Low	Low	Medium	High	
Xpert MTB/RIF	10	22	29	19	80
NCBA	10	22	29	19	80
SSM	0	3	14	15	32
% Detection (NCBA/Xpert)	100%	100%	100%	100%	
% Detection (SSM/Xpert)	0%	14%	48%	79%	

275 Thus, with the Xpert system as the standard, the sensitivity of NCBA is in accordance with
 276 the Xpert system (100%), while SSM's sensitivity is only 40%. NCBA could detect very low AFB
 277 concentrations at 102 CFU/mL, two orders of magnitude lower than SSM. This nanotechnology-
 278 based detection is rapid (10–20 min), inexpensive (0.10 USD/test), simple, and easily scalable
 279 (Figure 1). According to Nepal's Ministry of Health, a TB diagnostic test with 70% sensitivity (and
 280 treatment cure of 85%) would save 300,000 lives over the next five years [56]. This NCBA
 281 technique has a high potential to support and transform the TB control program in Nepal and in
 282 other high-prevalence low-resource countries. Implementation in rural areas would help to
 283 increase case finding and case notification, and would support programs targeted against drug-
 284 resistant TB. Nepal has close to 600 microscopy centers that can support the immediate
 285 implementation of this technology in the country. Similarly, it is applicable in many of the high
 286 TB-burden countries. This technique can be performed in rural communities and at the first point-
 287 of-contact by patients in the healthcare system. Results are obtained in less than 30 min, allowing
 288 for a quick turnaround time for treatment in a single clinical encounter. Desikan 2013
 289 hypothesized that a universally accessible and rapid detection method with a sensitivity of 85%
 290 and specificity of 97% could potentially save 392,000 lives annually worldwide [32]. Thus, the
 291 developed NCBA technology may enhance the "End TB Strategy" towards a TB-free world.

292

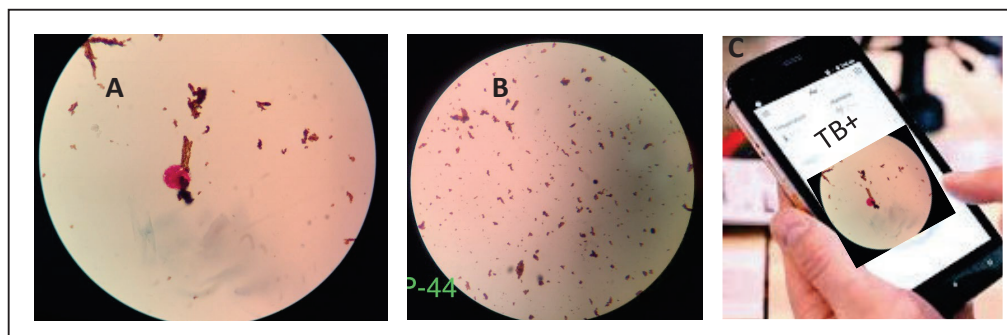
293

294

295

296

297



298 **Figure 2.** typical NCBA results for TB+ and TB- sputum samples, as viewed through the eyepiece
 299 of the bright field microscope. A) TB positive sample (clumped red GMNP-AFB complex
 300 surrounded by brown GMNPs). B) TB negative sample (dispersed brown GMNP). C) Schematic
 301 of smartphone app for image processing and display of test results.

302

2.2 Alerting mercury exposure in artisanal gold mining communities

303

304

In South America, Africa, and Asia, millions of individuals are exposed to dangerous levels of mercury concentrations as a result of Artisanal Small-Scale Gold Mining (ASGM) [57]. ASGM

305 is a rudimentary gold mining approach performed by individuals or groups with little or no
306 mechanization, often in informal (illegal) operational settings with toxic chemicals [58]. ASGM is
307 composed of three main steps: crushing the ore into fines, mixing the fines with liquid mercury,
308 and separating the mercury from gold by evaporating the mercury [59]. Often in unregulated
309 occupational conditions, workers perform mercury evaporation using open pit, which not only
310 has severe adverse health effects for the workers that inhale the mercury vapor but also releases
311 the toxic vapor into the environment. ASGM recently exceeded combustion of coal as the leading
312 anthropogenic source for mercury emissions globally [60]. Risk of exposure to mercury can lead
313 to detrimental effects on the nervous, immune, reproductive, and digestive systems, induce
314 infertility, reduce mental function, and kidney failure [61-65].

315 The global responsibility for reducing mercury emissions was recognized by the Minamata
316 Convention in Switzerland in 2013. At the convention, over 140 countries signed a treaty
317 committing to protect human health from mercury exposure [60]. The signatory countries
318 pledged to “ban new mercury mines, phase-out existing mines, ensure the phase out and phase
319 down of mercury use in a number of products and processes, develop control measures for
320 emissions, and regulate the informal sector of ASGM” [60]. In order to mitigate mercury exposure
321 and regulate mining operations, it is prudent for marginalized communities to monitor the
322 presence of mercury in their water through low-cost, rapid, and facile devices.

323 Several analytical methods have been developed for mercury determination in water.
324 Standard laboratory techniques include cold vapor atomic absorption spectroscopy (CV-AAS)
325 [66, 67], cold vapor-atomic fluorescence spectrometry (CV-AFS) [68, 69] and inductively coupled
326 plasma mass spectrometry (ICP-MS) [70, 71]. These spectroscopic techniques are highly sensitive
327 and accurate but are often impractical for environmental applications due to the high cost of
328 analysis. In addition, these standard methods require extensive user training, and the results
329 often require days or even weeks to produce results, making them less suitable for rural
330 communities [72-74]. Some field capable units are commercially available, namely based on direct
331 mercury analysis (DMA) and handheld nanosensors/biosensors [75, 76]. DMA is based on the
332 principle of thermal decomposition (vaporization), followed by amalgamation and subsequent
333 atomic absorption spectroscopy. While extremely accurate, DMA is cost prohibitive for low-
334 income communities since commercial prices of US-manufactured equipment range between
335 \$13k and \$30k USD. Perhaps inexpensive nanosensors/biosensors coupled with low-cost
336 electrochemical techniques on portable devices are likely to be more suitable as a tool for on-site
337 analysis of mercury, especially where ASGM is in practice.

338 While there are many types of transduction methods for low-cost determination of mercury,
339 electrochemical methods are sensitive and quantitative, and may be the mechanism of choice for
340 cost-effective rapid detection in the field [77]. The most common electrochemical method for ionic
341 mercury detection is anodic linear stripping voltammetry (ASV) techniques [72, 78]. ASV is a two-
342 step method of deposition/accumulation during reduction of mercury ions and stripping during
343 oxidation of mercury ions along the surface of the electrode. As the mass transfer limit is reached
344 in the reaction, the oxidative current forms a well-defined peak, which can be used to calculate
345 the concentration of mercury in the sample [79]. The efficiency of any electrochemical stripping
346 test can be determined by calculating the percent change in oxidative current relative to baseline.

347 Carbon-based nanomaterials are a popular choice for improving electrochemical detection
348 of mercury, as this type of materials exhibit high surface area, strong mechanical strength,
349 excellent thermal conductivity, and high conductivity [80-81]. Some of the carbon nanomaterials
350 in recent literature include glassy carbon [83, 84], carbon nanotubes [85], graphene [86], and
351 reduced graphene oxide [87]. While each of these nanocarbon materials is efficient for mercury
352 detection via stripping voltammetry, some of the materials are complicated to fabricate and

353 exhibit poor water solubility [88]. Among carbon nanomaterials, graphene and reduced graphene
354 oxide (rGO) have the highest water solubility, and one of the lowest fabrication costs. For these
355 reasons, there is a growing trend to develop disposable, low-cost, graphene-based electrodes for
356 field applications.

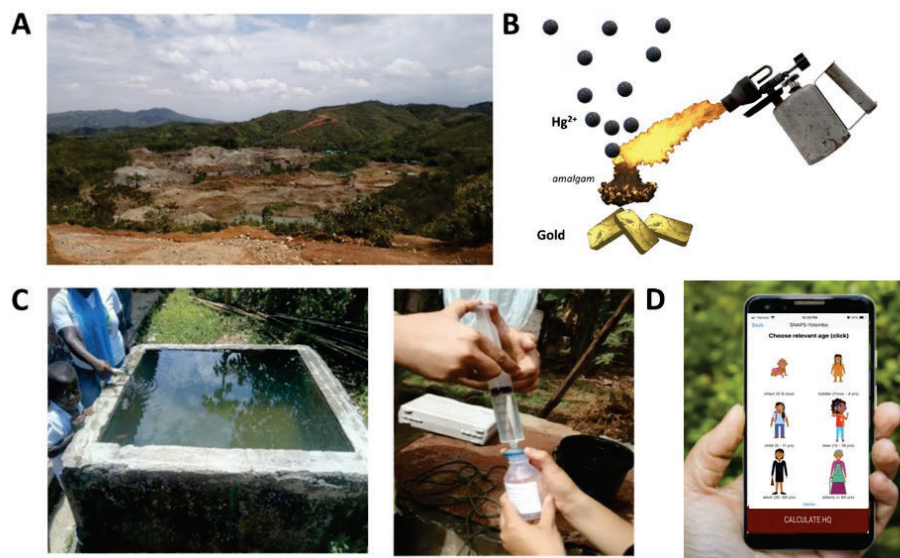
357 Examples of low-cost graphene electrodes include screen-printed electrodes and conductive
358 paper and plastic [72, 89]. In 2014, Lin et al. (2014) [90] discovered a low-cost, one-step,
359 conductive material when reducing graphene on a commercial polymer with a carbon dioxide
360 infrared laser. Since then, multiple researchers have shown that laser scribing could be used for
361 designing electrodes to sense biomolecules using infrared and ultra-violet light lasers [91-94].
362 While graphene is indeed a useful material in sensing, one of the problems is the tendency of
363 graphene and graphene oxide for binding a host of materials in aqueous phase [95]. For this
364 reason, sensor labs typically metallize graphene electrodes with a noble metal that has a specific
365 interaction with mercury ions. These metals can be deposited using simple electrodeposition
366 methods, or advanced techniques such as pulsed sonoelectrodeposition [96]. Recently,
367 Abdelbasir et al. 2018 [97] showed that copper nanoparticles recovered from waste cables can be
368 used to detect ionic mercury using linear sweep stripping voltammetry (LSSV).

369 Low-cost, portable, mobile phone-based acquisition systems have been developed for
370 mercury analysis in the field [98]. While this is significant for deploying sensors in low-income
371 regions, the inexpensive-portable sensor-systems lack data analytics capability to transform the
372 data into *meaningful information* which could be useful for the user. For example, the maximum
373 concentration level for inorganic mercury in drinking water is 6 ppb [99]. However, bodyweight,
374 ingestion rate, length of exposure, form and pathway of the contaminant, health of the individual,
375 and concentration of mercury influences the degree of mercury toxicity [101-102]. Thus, a SNAPS
376 tool may assist communities in acquiring data and extracting actionable information for decision
377 support.

378 Our group is currently working on developing the SNAPS platform for estimating the
379 toxicity risk associated with the ingestion of mercury-contaminated water. This SNAPS platform
380 is composed of a disposable graphene-nanocopper sensor coupled with a low-cost handheld
381 potentiostat, and a smartphone. The working mechanism of the platform starts with the detection
382 of mercury present in the sample using the graphene-nanocopper sensor. Next, selective
383 electrochemical interactions between mercury and the electrode generates an electrical signal.
384 The electrical signal is acquired and processed by the potentiostat to produce a current output.
385 Then, computer software records the current output and transforms it into concentration data via
386 calibration curves. Finally, a smartphone app is used by the user to enter the data for the
387 following parameters: mercury concentration in water (from the sensor), bodyweight of the user,
388 water ingestion rate, and length of exposure. Based on these parameters, the app runs an
389 algorithm that includes a hazard quotient formula to generate an estimation of the risk of toxicity
390 for the user [103-106].

391 We recently conducted a proof-of-concept demonstration of this SNAPS platform in a rural
392 area that has been dramatically impacted by ASGM, known as La Toma in Cauca, Colombia.
393 Even though this SNAPS platform is in an early stage of development, it represents an example
394 of how rural communities in developing countries may use sensors as a service to access data on
395 mobile devices and extract actionable information to help make informed decisions. Figure 3
396 shows the progression of the proof-of-concept demonstration of the technology.

397 Mercury enters natural aquatic systems primarily due to the burning of mercury amalgam during
398 the extraction of gold from raw ore.



399

400 **Figure 3.** Demonstration of SNAPS tool for assessing risk due to inadvertent consumption
 401 of mercury in drinking water for gold mining communities in Colombia. The first step was to (A)
 402 characterize the local socioeconomic dynamics and (B) identify related routes of mercury
 403 exposure (in this case from smelting of amalgam). (C) Together with community members, we
 404 collected samples from local water sources. (D) These samples were tested with nanomaterial-
 405 enabled sensors. (D) Concentration data derived from sensors was transformed into customized
 406 information about toxicity risk for specific user groups using a mobile app.

407 3. Can we overcome the economic barriers for distributing diagnostic tools in low-income 408 settings?

409 Framing the issue of diagnostic tools in the context of technology leads us to recognize a vast
 410 spectrum. On one hand, ideas about telemedicine proposed about 100 years ago [107], and on the
 411 other hand, milestones in computational speed from about 100 days ago [108]. It may be
 412 justifiable to suggest that technological barriers may not be the primary reason why many
 413 diagnostic tools are still absent from communities under economic constraint. The powerful
 414 incentive of lucrative profitability, in the short term, may not be realized by serving impoverished
 415 regions.

416 Transaction cost [109] may be the over-arching factor which may have multiple
 417 interpretations [110] but appears to be the economic barrier with respect to the reasons why
 418 accelerating the rate of diffusion of diagnostic tools in distressed communities continues to pose
 419 difficult challenges [111-113]. We must focus on value to the user or the extent of the benefit to
 420 the beneficiary's environment and/or ecosystem (for example, early diagnosis of tuberculosis in
 421 a patient may save the entire village from infection and epidemic). However, delivery of value is
 422 inextricably linked to cost, unless it is aimed to deliver philosophical or mythical messages [114].

423 In over-simplified terms, the convergence of the cost of the product and the cost to deliver
 424 the service contributes to transaction cost [115]. A plethora of costs and cost-incurring processes
 425 are involved but we shall bypass the details. The physical product (in this case is the sensor) and
 426 the service is the solution delivery (SNAPS). Academics cannot control cost, but their contribution
 427 can impact implementation and use. A low-cost sensor from a lab must be manufactured,
 428 calibrated, evaluated and sufficiently scaled if the outcome can still be claimed as a "low-cost"
 429 sensor, capable of delivering value with respect to maintaining a certain pre-agreed quality of

430 service (QoS) in keeping with the key performance indicators (KPI) that the users desire, demand
431 or deem necessary.

432 In addition, a working sensor delivered to a user is useless without a visualization system to
433 capture the data from the sensor. Stand-alone visualization devices (for example, blood glucose
434 home monitors with dedicated devices to read the blood glucose strip and deliver data readout)
435 will add inordinate cost to the system. The alternative is to use a mobile phone as a platform to
436 visualize the data from the sensor. Signal transduction from the sensor to the mobile phone calls
437 for multiple layers of tools, technology and software (middleware), in addition to the functional
438 use of a mobile phone. The presence of a mobile phone in any environment is contingent upon
439 available cellular and/or wireless infrastructure to support its use. It may not be prudent to
440 assume the presence of telecommunications infrastructure despite the penetration of such
441 services, globally [116-119]. Thus, even if a working sensor is at hand, the obvious process of
442 signal to data transition and visualization of the data involves multiple layers of capital expenses
443 (infrastructure cost) as well as associated technologies and software.

444 Assuming that the above layers are in working order, the sensor data meets a “dead end”
445 upon data visualization. A number (with units) is only meaningful if there is a relevant
446 framework for interpreting such data, for example, the combination of sensor data from mercury
447 contamination expressed in terms of a hazard quotient score, which uses other vital pieces of
448 information to assess health risk. It is the *delivery of information* based on sensor data that drives
449 value. Taken together, the physical product is no longer the focal point of value. Information
450 pertaining to the health of the user is the service which delivers value to the user. Transaction
451 cost, therefore, is no longer a product-based entity but the cost of service which must be feasible
452 for the service to be delivered, disseminated, and adopted by a community.

453 Overcoming the economic barriers to deliver SNAPS will be virtually impossible if the
454 chasm between product and service continues to overshadow the concept of value delivery to the
455 user. The economic principle, which may work in impoverished nations, is rooted in micro-
456 finance and micro-payments with low transaction costs [120, 121]. The paradigm shift from
457 “product sales” to delivery of “service” involves combining the product with resources
458 (including retail mobile banking, infrastructure, telecommunications, cybersecurity, customer
459 service). Users pay only when they use the service. The latter lowers the transaction cost and
460 hence the barrier to entry into vast markets of low-income users. Not the product, but the *user*
461 *experience* is the pivotal fulcrum for the inversion of traditional business models in the era of the
462 internet of things (IoT) [122].

463 The PAPPU model was epitomized by the plain old telephone system (POTS), where the
464 user paid only the “charge per call” which was reasonably affordable even if the per capita
465 income was low. In this paper we advocate for PAPPU as a metaphor for ethical profitability
466 through social business models. In principle, the user may pay a penny for each use of a SNAP
467 (suggested but not restricted to one penny). The “penny” is a placeholder for the financial design
468 of an ultra low-cost nano-payment model, which, in the real world may represent one Rupee
469 (INR), one Yuan (CNY, RMB) or one Peso (COP). The PAPPU metaphor may evolve to become
470 the *generalized* monetization mantra signifying pay-a-price-per-unit wherever the principles of
471 IoT may be deployed or embedded as a digital by design metaphor including ubiquitous sensing.
472 The diffusion of connectivity may serve as a tool and IoT may be catalytic as a platform to better
473 facilitate the practice of equality, equity and égalité. PAPPU offers *an economic instrument* for
474 businesses to build a profit model based on economies of scale to serve low-income communities
475 and abide by ethical profitability. PAPPU offers an alternative strategy for enterprises and
476 businesses who are seeking to engage with the next billion users, albeit profitably, but within the

477 realms of ethical profitability which can be *sustained* by the per capita income of these
478 communities.

479 The concomitant growth of infrastructure (for example, affordable access to low latency,
480 reduced jitter, high bandwidth wireless telecommunications, 5G, trusted mobile banking) may
481 be necessary to pave the road for pursuit of PAPPU. The ability to escape the dead weight of old
482 technology in the developing world may accelerate the implementation of PAPPU as an integral
483 part of the socio-economic fabric of a product-less, service-based economy where payment per
484 unit of service (1 liter of municipal water, 1 kilo-watt hour of energy, 1 gallon of sanitation waste)
485 may become the new normal.

486 Implementing PAPPU may require alliances or public-private partnerships or global
487 consortia with an altruistic fervor to pay and pave for the synergistic integration necessary, to
488 promote SNAPS as a service in low-income communities. The challenge is to bring to the table
489 global organizations, benevolent individuals and thoughtful governments, who may choose to
490 lead this effort to channel science to serve society, for the less fortunate. We need new eyes,
491 unbridled imagination and moral fabric of synergistic solutions that can wrap around, not to
492 isolate, but to protect, provide and promote acceptable solutions for remediable injustices.

493 **4.Social and ethical considerations for the development and implementation of SNAPS**

494 Cultural and ethical considerations are inextricably linked with the transformation of SNAPS
495 from an academic vision to real-world implementations which may actually help people.
496 Academics must remain cognizant of their ethical responsibility to discourage misapplication and
497 dissemination of misinformation about their inventions. In this section, we attempt to analyze
498 some potential interactions between the social and technological domains, as well as how
499 democratic approaches for technology creation and diffusion could favor the improvement of
500 health outcomes for disadvantaged communities.

501 Since the introduction of the technology acceptance model (TAM) decades ago, several extended
502 versions of this archetype have been proposed to elaborate a more comprehensive framework for
503 predicting people's intention to use a particular product or service [123-125]. TAM and its
504 variants have served as the guiding rationale behind R&D for a variety of commercial
505 technologies that are mass-produced, including healthcare devices [126]. However, it may be
506 inadequate in the context of technology development for low-income communities [127]. It is
507 worth noting that the ultimate goal of TAM and related models is to forecast user behavior across
508 a broad range of consumer populations, which means that the model focuses on highly generic
509 predictors of technology acceptance. For instance, TAM does not explicitly include any cultural
510 or social variables, which is a significant limitation since social constructs may contribute
511 significantly to the variance in users' attitudes towards technology [125, 128]. However, the goal
512 of the SNAPS with PAPPU concept is to provide an affordable sensor-analytics service platform
513 to support decision-making and enhancement of health outcomes for economically challenged
514 groups. Thus, a useful model to guide the development of SNAPS should include bi-directional
515 communication between researchers and users, and perhaps motivate researchers and users to
516 change or adapt or better inform their behavior [129].

517 Trust in the technology [130] is quintessential for adoption and continued use because
518 technology could be equally euphemistic for a double-edged sword [131, 132]. Driving positive
519 impacts from the introduction of SNAPS in low-income regions may involve not only the
520 transfer of fully functional technology but also the empowerment of the beneficiary
521 communities by enabling local mastery of the technology along with the possibility to
522 reproduce and even adapt the technology to the local conditions. We believe this open-source

523 approach to technology adoption is auspicious for supporting marginalized communities,
524 especially when trying to avoid the known failures of the charitable approach of technology
525 leapfrogging. For example, the WHO estimates that only 10-30% of the medical devices donated
526 to developing countries are used as intended; the remaining 70-90% end-up being dumped in
527 landfills, thus contributing to more pollution problems and environmental health risks [133].
528 This situation is explained not only by the incompatibility of the technology with the locally
529 available infrastructure, but also to the lack of local capacity to adapt or fix the donated devices
530 once they break [134]. Additionally, dependence on foreign technologies could lead to an
531 imbalance of power in which the users have no option other than relying on the willingness of
532 external entities to continue to deliver much-needed technology in their regions. Thus, if the
533 goal is to make technology work effectively on behalf of society, we must divert from the
534 mainstream *handed-down from the top* approach and enable society to create and transform
535 technology in meaningful ways, in dispersed regions, and from the bottom-up.

536 Engaging the community through operational transparency may prevent public anxiety and
537 may also facilitate proper implementation of the technology. Users' understanding of the
538 limitations and potential risks associated with SNAPS could be vital for setting clear expectations
539 about SNAPS-assisted testing while avoiding misapplications of the technology. As Wallace et
540 al. point out, misuse of many direct-to-consumer screening tests could have caused an
541 unnecessary increase in healthcare costs due to people's overreaction to inaccurate readings from
542 direct-to-consumer screening tests, and their subsequent demand for further testing with
543 advanced clinical technology [130]. However, this concern is mostly relevant for developed
544 countries in which people have access to healthcare systems where clinical testing is readily
545 available for patients. In low-income settings, such as remote rural areas in developing countries,
546 health care services are often dysfunctional or completely inaccessible. For marginalized
547 communities, information from SNAPS could instead drive actions aimed at limiting the
548 exposure to harmful biological vectors and chemical agents. Thus, communities living in
549 territories that suffer from prolonged government abandonment could greatly benefit from the
550 democratic adoption of SNAPS to make informed decisions and solve their problems with more
551 autonomy. Nonetheless, we agree that transparency and accountability in technology
552 deployment are paramount for protecting the users' rights and integrity.

553 5. Conclusions

554 Monitoring environmental contamination is essential to protect the public from diseases and
555 other health issues. This monitoring requires accurate and accessible detection technologies to
556 ensure quality control and early warning capabilities for users to minimize negative impacts
557 (Figure 4). The framework of SNAPS with PAPUU have the potential to pave the way for
558 economically viable systems that can potentially be applied as tools for reducing local
559 environmental risks and mitigate health problems that derive from them. We envision that the
560 use of SNAPS will increase low-income communities' participation in the public/government
561 planning process by providing data they can use to fight for their right to public health care,
562 clean water and adequate sanitation. By bridging smart technology with basic needs and public
563 health, SNAPS will advance our understanding of how information can change public
564 participation, having low-income communities' representatives as 'change agents' that
565 influence public policies and planning. These communities' representatives benefit from rights-
566 based arguments, evidence-based research, and effective data analyses. SNAPS have the
567 potential to serve as an illustration of how empowering impoverished communities in their
568 local context, can strengthen democratic practice in their region. Grounded on an integrated
569 perspective that takes into account cultural and ethical considerations, we foresee that SNAPS
570 will shed some light to improve implementation of public health plans in underserved
571 communities by increasing public participation in planning. Moreover, SNAPS could

572 potentially become a new approach to achieve the United Nations Sustainable Development
 573 Goals 3 and 6: ensure healthy lives and promoting the well-being at all ages and ensure access
 574 to water and sanitation for all, respectively. Furthermore, it would also help empower
 575 impoverished communities to obtain the rights they have been promised such as basic
 576 sanitation, clean water, and adequate health care services.

577



578

579 **Figure 4.** SNAPS converges with PAPPU to establish a framework for sensor-as-a-service. The
 580 paradigm is rooted in economic, ethical, cultural, and environmental core values that
 581 synergistically act as a catalyst for the democratization of healthcare in underserved
 582 communities,

583 **Supplementary Materials:** The following are available online at www.mdpi.com/xxx/s1, Figure S1: title,
 584 Table S1: title, Video S1: title.

585 **Acknowledgments:** We would like to acknowledge the support from the Department of Environmental
 586 Engineering and Earth Sciences at Clemson University. Many thanks to the DUPC2-IHE program at Delft
 587 University for funding the project entitled “Synoptic and participatory assessment of environmental
 588 pollution and health effects due to exposure to mercury from artisanal gold mining in the Alto Cauca basin,
 589 Colombia. First steps towards local development of sustainable solutions (P: 1084731:111;
 590 Ref:2019/061/108473/EWH). Additional funding was provided by the Agriculture and Food Research
 591 Initiative Competitive Grant no. 2018-67016-27578 awarded as a Center of Excellence from the USDA
 592 National Institute of Food and Agriculture.

593 **Conflicts of Interest:** The authors declare no conflict of interest.

594 **References**

595

- 596
597
598
599
600
601
602
603
604
605
606
607
608
609
610
611
612
613
614
615
616
617
618
619
620
621
622
623
624
625
626
627
628
629
630
631
632
633
634
635
636
637
638
639
640
641
642
643
644
645
646
647
648
649
650
651
652
1. Briggs, D., Environmental pollution and the global burden of disease. *British medical bulletin* **2003**, *Volume 68*, pp. 1-24. 10.1093/bmb/ldg019.
 2. World Health Organization and United Nations Environment Programme, Health and environment: tools for effective decision-making: review of initial findings. 2004.
 3. Cureton, S., Environmental victims: environmental injustice issues that threaten the health of children living in poverty. *Reviews on environmental health* **2011**, *Volume 26*, pp. 141-147.
 4. Boutayeb, A., The double burden of communicable and non-communicable diseases in developing countries. *Transactions of The Royal Society of Tropical Medicine and Hygiene* **2006**, *Volume 100*, pp. 191-199. 10.1016/j.trstmh.2005.07.021 %J Transactions of The Royal Society of Tropical Medicine and Hygiene.
 5. Gwatkin, D.R.; Bhuiya, A.; Victora, C.G., Making health systems more equitable. *The Lancet* **2004**, *Volume 364*, pp. 1273-1280.
 6. Marmot, M., Social determinants of health inequalities. *The lancet* **2005**, *Volume 365*, pp. 1099-1104.
 7. Evans, G.W.; Kantrowitz, E., Socioeconomic status and health: the potential role of environmental risk exposure. *Annual review of public health* **2002**, *Volume 23*, pp. 303-331.
 8. Waller, L.A.; Louis, T.A.; Carlin, B.P., Environmental justice and statistical summaries of differences in exposure distributions. *Journal of Exposure Science Environmental Epidemiology* **1999**, *Volume 9*, pp. 56.
 9. Mortality rate, infant (per 1,000 live births). Available online: <https://data.worldbank.org/indicator/SP.DYN.IMRT.IN?end=2018&start=2018&type=points&view=bar> (accessed on September 27 2019).
 10. Moraga, P.; Collaborators, G.C.o.D., Global, regional, and national age-sex specific mortality for 264 causes of death, 1980-2016: a systematic analysis for the Global Burden of Disease Study 2016. *The Lancet* **2017**, *Volume 390*, pp. 1151-1210.
 11. Collaborators, G.D.D., Estimates of the global, regional, and national morbidity, mortality, and aetiologies of diarrhoea in 195 countries: a systematic analysis for the Global Burden of Disease Study 2016. *Lancet Infect Dis* **2018**, *Volume 18*, pp. 1211-1228.
 12. Etchie, A.T.; Etchie, T.O.; Shen, H.; Pillariseti, A.; Popovicheva, O., Burden of disease at the same limit of exposure to airborne polycyclic aromatic hydrocarbons varies significantly across countries depending on the gap in longevity. *Ecotoxicology environmental safety* **2019**, *Volume 180*, pp. 420-429.
 13. Schraufnagel, D.E.; Balmes, J.R.; Cowl, C.T.; De Matteis, S.; Jung, S.-H.; Mortimer, K.; Perez-Padilla, R.; Rice, M.B.; Riojas-Rodriguez, H.; Sood, A., Air pollution and noncommunicable diseases: a review by the Forum of International Respiratory Societies' Environmental Committee, Part 2: air pollution and organ systems. *Chest* **2019**, *Volume 155*, pp. 417-426.
 14. Valdivia-Rivera, S.; Martínez-Cano, A.; Aguirre-García, G.; Lizardi-Jiménez, M., Hydrocarbon water-pollution related to chronic kidney disease in Tierra Blanca, a perfect storm. *Environment international* **2018**, *Volume 121*, pp. 1204-1209.
 15. Kumar, V.; Parihar, R.D.; Sharma, A.; Bakshi, P.; Sidhu, G.P.S.; Bali, A.S.; Karaouzas, I.; Bhardwaj, R.; Thukral, A.K.; Gyasi-Agyei, Y., Global evaluation of heavy metal content in surface water bodies: a meta-analysis using heavy metal pollution indices and multivariate statistical analyses. *Chemosphere* **2019**, *Volume* pp. 124364.
 16. Johannson, K.A.; Balmes, J.R.; Collard, H.R., Air pollution exposure: a novel environmental risk factor for interstitial lung disease? *Chest* **2015**, *Volume 147*, pp. 1161-1167.
 17. Hu, C.-Y.; Gao, X.; Fang, Y.; Jiang, W.; Huang, K.; Hua, X.-G.; Yang, X.-J.; Chen, H.-B.; Jiang, Z.-X.; Zhang, X.-J., Human epidemiological evidence about the association between air pollution exposure and gestational diabetes mellitus: Systematic review and meta-analysis. *Environmental research* **2019**, *Volume* pp. 108843.
 18. Stanaway, W.D.; GBD 2017 Risk Factor Collaborators, Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. *The Lancet* **2018**, *Volume 392*, pp. 1923-1994.
 19. Prüss-Ustün, A.; Wolf, J.; Bartram, J.; Clasen, T.; Cumming, O.; Freeman, M.C.; Gordon, B.; Hunter, P.R.; Medlicott, K.; Johnston, R., Burden of disease from inadequate water, sanitation and hygiene for selected adverse health outcomes: An updated analysis with a focus on low-

- 653 and middle-income countries. *International journal of hygiene environmental health* **2019**, Volume
654 222, pp. 765-777.
- 655 20. Ostro, B.; Spadaro, J.V.; Gumy, S.; Mudu, P.; Awe, Y.; Forastiere, F.; Peters, A., Assessing the
656 recent estimates of the global burden of disease for ambient air pollution: methodological
657 changes and implications for low-and middle-income countries. *Environmental research* **2018**,
658 Volume 166, pp. 713-725.
- 659 21. Bauer, U.E.; Briss, P.A.; Goodman, R.A.; Bowman, B.A., Prevention of chronic disease in the
660 21st century: elimination of the leading preventable causes of premature death and disability
661 in the USA. *The Lancet* **2014**, Volume 384, pp. 45-52.
- 662 22. From the lab to real-world use. *Nature Sustainability volume* **2019**, Volume 2, pp. 989.
663 <https://doi.org/10.1038/s41893-019-0435-7>.
- 664 23. Anderson IV, J.D.; Bagamian, K.H.; Muhib, F.; Amaya, M.P.; Laytner, L.A.; Wierzba, T.;
665 Rheingans, R., Burden of enterotoxigenic Escherichia coli and shigella non-fatal diarrhoeal
666 infections in 79 low-income and lower middle-income countries: a modelling analysis. *The
667 Lancet Global Health* **2019**, Volume 7, pp. e321-e330. [https://doi.org/10.1016/S2214-
668 109X\(18\)30483-2](https://doi.org/10.1016/S2214-109X(18)30483-2).
- 669 24. Vélez-Torres, I.; Vanegas, D.C.; McLamore, E.S.; Hurtado, D., Mercury pollution and artisanal
670 gold mining in Alto Cauca, Colombia: woman's perception of health and environmental
671 impacts. *The Journal of Environment Development* **2018**, Volume 27, pp. 415-444.
672 <https://doi.org/10.1177/1070496518794796>.
- 673 25. World Health Organization (WHO), Circular Economy and Health: Opportunities and Risk.
674 1.52. 2018.
- 675 26. Tuberculosis (TB). Available online: [https://www.who.int/news-room/fact-
676 sheets/detail/tuberculosis](https://www.who.int/news-room/fact-sheets/detail/tuberculosis) (accessed on November 13 2019).
- 677 27. Yang, T.; Zhong, J.; Zhang, J.; Li, C.; Yu, X.; Xiao, J.; Jia, X.; Ding, N.; Ma, G.; Wang, G., Pan-
678 genomic study of Mycobacterium tuberculosis reflecting the primary/secondary genes,
679 generality/individuality, and the interconversion through copy number variations. *Frontiers in
680 microbiology* **2018**, Volume 9, pp. 1886. <https://doi.org/10.3389/fmicb.2018.01886>.
- 681 28. Dias, H.M.Y.; Pai, M.; Raviglione, M.C., Ending tuberculosis in India: A political challenge &
682 an opportunity. *The Indian journal of medical research* **2018**, Volume 147, pp. 217.
683 https://doi.org/10.4103/ijmr.IJMR_660_18.
- 684 29. WHO | UN General Assembly High-Level Meeting on ending TB. Available online:
685 http://www.who.int/tb/features_archive/UNGA_HLM_ending_TB/en/ (accessed on
686 November 15 2019).
- 687 30. Oлару, I.D.; Heyckendorf, J.; Grossmann, S.; Lange, C., Time to culture positivity and sputum
688 smear microscopy during tuberculosis therapy. *PloS one* **2014**, Volume 9, pp. e106075.
689 <https://doi.org/10.1371/journal.pone.0106075>.
- 690 31. Hobby, G.L.; Holman, A.P.; Iseman, M.D.; Jones, J.M., Enumeration of tubercle bacilli in
691 sputum of patients with pulmonary tuberculosis. *Antimicrobial agents chemotherapy* **1973**,
692 Volume 4, pp. 94-104.
- 693 32. Desikan, P., Sputum smear microscopy in tuberculosis: is it still relevant? *The Indian journal of
694 medical research* **2013**, Volume 137, pp. 442.
- 695 33. Steingart, K.R.; Ng, V.; Henry, M.; Hopewell, P.C.; Ramsay, A.; Cunningham, J.; Urbanczik, R.;
696 Perkins, M.D.; Aziz, M.A.; Pai, M., Sputum processing methods to improve the sensitivity of
697 smear microscopy for tuberculosis: a systematic review. *The Lancet infectious diseases* **2006**,
698 Volume 6, pp. 664-674. [https://doi.org/10.1016/S1473-3099\(06\)70602-8](https://doi.org/10.1016/S1473-3099(06)70602-8).
- 699 34. Demers, A.-M.; Verver, S.; Boulle, A.; Warren, R.; Van Helden, P.; Behr, M.A.; Coetzee, D.,
700 High yield of culture-based diagnosis in a TB-endemic setting. *BMC infectious diseases* **2012**,
701 Volume 12, pp. 218. <https://doi.org/10.1186/1471-2334-12-218>.
- 702 35. Afsar, I.; Gunes, M.; Er, H.; Sener, A.G., Comparison of culture, microscopic smear and
703 molecular methods in diagnosis of tuberculosis. *Revista Española de Quimioterapia* **2018**, Volume
704 31, pp. 435.
- 705 36. Kik, S.V.; Denkinger, C.M.; Chedore, P.; Pai, M., Replacing smear microscopy for the diagnosis
706 of tuberculosis: what is the market potential? *European Respiratory Journal* **2014**, Volume 43, pp.
707 1793-1796. <https://doi.org/10.1183/09031936.00217313>.

- 708 37. Allen, V.; Nicol, M.; Tow, L., Sputum processing prior to Mycobacterium tuberculosis
709 detection by culture or nucleic acid amplification testing: a narrative review. *Res Rev J Microbiol*
710 *Biotechnol* **2016**, *Volume 5*, pp. 96-108.
- 711 38. Das, S.; Narang, P.; Nagamiah, S.; Mishra, P.; Deotale, V.; Mendiratta, D., Evaluation of
712 variants of carbol fuchsin solution to stain acid-fast bacilli in-situ by the pot method. *The*
713 *International Journal of Tuberculosis Lung Disease* **2015**, *Volume 19*, pp. 1470-1475.
714 <https://doi.org/info:doi/10.5588/ijtld.15.0272>.
- 715 39. Ho, J.; Marks, G.; Fox, G., The impact of sputum quality on tuberculosis diagnosis: a systematic
716 review. *The International Journal of Tuberculosis Lung Disease* **2015**, *Volume 19*, pp. 537-544.
717 <https://doi.org/10.5588/ijtld.14.0798>.
- 718 40. Munir, M.; Shabbir, I.; Iqbal, R.; Khan, S.U., Comparison of detection of acid fast bacilli in
719 clinical samples by AFB smear microscopy and culture in the diagnosis of tuberculosis in a
720 tertiary care setting. *Pakistan Journal of Chest Medicine* **2015**, *Volume 15*, pp.
- 721 41. Shea, Y.R.; Davis, J.L.; Huang, L.; Kovacs, J.A.; Masur, H.; Mulindwa, F.; Opus, S.; Chow, Y.;
722 Murray, P.R., High sensitivity and specificity of acid-fast microscopy for diagnosis of
723 pulmonary tuberculosis in an African population with a high prevalence of human
724 immunodeficiency virus. *Journal of clinical microbiology* **2009**, *Volume 47*, pp. 1553-1555.
725 <https://doi.org/10.1128/JCM.00348-09>.
- 726 42. Cudahy, P.; Sheno, S.V., Diagnostics for pulmonary tuberculosis. *Postgraduate medical journal*
727 **2016**, *Volume 92*, pp. 187-193. <https://doi.org/10.1136/postgradmedj-2015-133278>.
- 728 43. Dunn, J.J.; Starke, J.R.; Revell, P.A., Laboratory diagnosis of Mycobacterium tuberculosis
729 infection and disease in children. *Journal of clinical microbiology* **2016**, *Volume 54*, pp. 1434-1441.
730 <https://doi.org/10.1128/JCM.03043-15>.
- 731 44. Nyendak, M.R.; Lewinsohn, D.A.; Lewinsohn, D.M., New diagnostic methods for tuberculosis.
732 *Current opinion in infectious diseases* **2009**, *Volume 22*, pp. 174.
- 733 45. Ryu, Y.J., Diagnosis of pulmonary tuberculosis: recent advances and diagnostic algorithms.
734 *Tuberculosis respiratory diseases* **2015**, *Volume 78*, pp. 64-71.
735 <https://doi.org/10.4046/trd.2015.78.2.64>.
- 736 46. Singhal, R.; Myneedu, V.P., Microscopy as a diagnostic tool in pulmonary tuberculosis.
737 *International journal of mycobacteriology* **2015**, *Volume 4*, pp. 1-6.
738 <https://doi.org/10.1016/j.ijmyco.2014.12.006>.
- 739 47. Engel, N.; Wachter, K.; Pai, M.; Gallarda, J.; Boehme, C.; Celentano, I.; Weintraub, R.,
740 Addressing the challenges of diagnostics demand and supply: insights from an online global
741 health discussion platform. *BMJ Global Health* **2016**, *Volume 1*, pp. e000132.
742 <https://doi.org/10.1136/bmjgh-2016-000132>.
- 743 48. Pantoja, A.; Fitzpatrick, C.; Vassall, A.; Weyer, K.; Floyd, K., Xpert MTB/RIF for diagnosis of
744 tuberculosis and drug-resistant tuberculosis: a cost and affordability analysis. *European*
745 *Respiratory Journal* **2013**, *Volume 42*, pp. 708-720. <https://doi.org/10.1183/09031936.00147912>.
- 746 49. Cazabon, D.; Pande, T.; Kik, S.; Van Gemert, W.; Sohn, H.; Denking, C.; Qin, Z.Z.; Waning,
747 B.; Pai, M., Market penetration of Xpert MTB/RIF in high tuberculosis burden countries: a
748 trend analysis from 2014-2016. *Gates open research* **2018**, *Volume 2*, pp.
749 <https://doi.org/10.12688/gatesopenres.12842.2>.
- 750 50. Sakamoto, H.; Lee, S.; Ishizuka, A.; Hinoshita, E.; Hori, H.; Ishibashi, N.; Komada, K.; Norizuki,
751 M.; Katsuma, Y.; Akashi, H., Challenges and opportunities for eliminating tuberculosis–
752 leveraging political momentum of the UN high-level meeting on tuberculosis. *BMC public*
753 *health* **2019**, *Volume 19*, pp. 76. <https://doi.org/10.1186/s12889-019-6399-8>.
- 754 51. Tanimura, T.; Jaramillo, E.; Weil, D.; Raviglione, M.; Lönnroth, K., Financial burden for
755 tuberculosis patients in low- and middle-income countries: a systematic review. *European*
756 *Respiratory Journal* **2014**, *Volume 43*, pp. 1763-1775. <https://doi.org/10.1183/09031936.00193413>.
- 757 52. Reed, J.L.; Basu, D.; Butzler, M.A.; McFall, S.M., XtracTB Assay, a Mycobacterium tuberculosis
758 molecular screening test with sensitivity approaching culture. *Scientific reports* **2017**, *Volume 7*,
759 pp. 3653. <https://doi.org/10.1038/s41598-017-03930-3>.
- 760 53. García-Basteiro, A.L.; DiNardo, A.; Saavedra, B.; Silva, D.; Palmero, D.; Gegia, M.; Migliori,
761 G.B.; Duarte, R.; Mambuque, E.; Centis, R., Point of care diagnostics for tuberculosis.
762 *Pulmonology* **2018**, *Volume 24*, pp. 73-85. <https://doi.org/10.1016/j.rppnen.2017.12.002>.

- 763 54. Bhusal, N.; Shrestha, S.; Pote, N.; Alocilja, E., Nanoparticle-Based Biosensing of Tuberculosis,
764 an Affordable and Practical Alternative to Current Methods. *Biosensors* **2019**, Volume 9, pp. 1.
765 <https://doi.org/10.3390/bios9010001>.
- 766 55. Gordillo-Marroquín, C.; Gómez-Velasco, A.; Sánchez-Pérez, H.; Pryg, K.; Shinnars, J.; Murray,
767 N.; Muñoz-Jiménez, S.; Bencomo-Alerm, A.; Gómez-Bustamante, A.; Jonapá-Gómez, L.,
768 Magnetic Nanoparticle-Based Biosensing Assay Quantitatively Enhances Acid-Fast Bacilli
769 Count in Paucibacillary Pulmonary Tuberculosis. *Biosensors* **2018**, Volume 8, pp. 128.
770 <https://doi.org/10.3390/bios8040128>.
- 771 56. Floyd, K.; Glaziou, P.; Houben, R.; Sumner, T.; White, R.; Raviglione, M., Global tuberculosis
772 targets and milestones set for 2016–2035: definition and rationale. *The international journal of*
773 *tuberculosis lung disease* **2018**, Volume 22, pp. 723-730. <https://doi.org/10.5588/ijtld.17.0835>.
- 774 57. Kristensen, A.K.B.; Thomsen, J.F.; Mikkelsen, S., A review of mercury exposure among
775 artisanal small-scale gold miners in developing countries. *International archives of occupational*
776 *environmental health* **2014**, Volume 87, pp. 579-590.
- 777 58. Hentschel, T.; Hruschka, F.; Priester, M. *Artisanal and Small-Scale Mining: Challenges and*
778 *Opportunities*, 1st ed.; International Institute for Environment and Development (IIED) and
779 World Business Council for Sustainable Development: London, United Kingdom, 2003.
- 780 59. Cordy, P.; Veiga, M.M.; Salih, I.; Al-Saadi, S.; Console, S.; Garcia, O.; Mesa, L.A.; Velásquez-
781 López, P.C.; Roeser, M., Mercury contamination from artisanal gold mining in Antioquia,
782 Colombia: The world's highest per capita mercury pollution. *Science of the Total Environment*
783 **2011**, Volume 410, pp. 154-160.
- 784 60. United Nations Environment Programme, Global mercury assessment 2013: Sources,
785 emissions, releases and environmental transport. *UNEP Chemicals Branch, Geneva, Switzerland*.
786 2013.
- 787 61. Sengupta, P.; Banerjee, R.; Nath, S.; Das, S.; Banerjee, S., Metals and female reproductive
788 toxicity. *Human experimental toxicology* **2015**, Volume 34, pp. 679-697.
- 789 62. Pizent, A.; Tariba, B.; Živković, T., Reproductive toxicity of metals in men. *Archives of industrial*
790 *hygiene toxicology* **2012**, Volume 63, pp. 35-46.
- 791 63. Matta, G.; Gjyli, L., Mercury, lead and arsenic: impact on environment and human health.
792 *Journal of chemical Pharmaceutical Sciences* **2016**, Volume 9, pp. 718-725.
- 793 64. Mahurpawar, M., Effects of heavy metals on human health. *Int. J. Res. Granthaalayah* **2015**,
794 Volume 530, pp. 1-7.
- 795 65. Bridges, C.C.; Zalups, R.K., The aging kidney and the nephrotoxic effects of mercury. *Journal*
796 *of Toxicology Environmental Health, Part B* **2017**, Volume 20, pp. 55-80.
- 797 66. Ghaedi, M.; Reza Fathi, M.; Shokrollahi, A.; Shajarat, F., Highly selective and sensitive
798 preconcentration of mercury ion and determination by cold vapor atomic absorption
799 spectroscopy. *Analytical Letters* **2006**, Volume 39, pp. 1171-1185.
- 800 67. Yavuz, E.; Tokaloğlu, Ş.; Patat, Ş., Magnetic dispersive solid phase extraction with
801 graphene/ZnFe₂O₄ nanocomposite adsorbent for the sensitive determination of mercury in
802 water and fish samples by cold vapor atomic absorption spectrometry. *Microchemical Journal*
803 **2018**, Volume 142, pp. 85-93.
- 804 68. Jones, R.; Jacobson, M.; Jaffe, R.; West-Thomas, J.; Arfstrom, C.; Alli, A., Method development
805 and sample processing of water, soil, and tissue for the analysis of total and organic mercury
806 by cold vapor atomic Fluorescence spectrometry. *Oceanographic Literature Review* **1996**, Volume
807 2, pp. 192.
- 808 69. Yu, L.-P.; Yan, X.-P., Flow injection on-line sorption preconcentration coupled with cold vapor
809 atomic fluorescence spectrometry and on-line oxidative elution for the determination of trace
810 mercury in water samples. *Atomic spectroscopy* **2004**, Volume 25, pp. 145-153.
- 811 70. Rodríguez-Reino, M.P.; Rodríguez-Fernández, R.; Peña-Vázquez, E.; Domínguez-González,
812 R.; Bermejo-Barrera, P.; Moreda-Piñeiro, A., Mercury speciation in seawater by liquid
813 chromatography-inductively coupled plasma-mass spectrometry following solid phase
814 extraction pre-concentration by using an ionic imprinted polymer based on methyl-mercury-
815 phenobarbital interaction. *Journal of Chromatography A* **2015**, Volume 1391, pp. 9-17.
- 816 71. Ma, S.; He, M.; Chen, B.; Deng, W.; Zheng, Q.; Hu, B., Magnetic solid phase extraction coupled
817 with inductively coupled plasma mass spectrometry for the speciation of mercury in
818 environmental water and human hair samples. *Talanta* **2016**, Volume 146, pp. 93-99.

- 819 72. Barton, J.; García, M.B.G.; Santos, D.H.; Fanjul-Bolado, P.; Ribotti, A.; McCaul, M.; Diamond,
820 D.; Magni, P., Screen-printed electrodes for environmental monitoring of heavy metal ions: a
821 review. *Microchimica Acta* **2016**, Volume 183, pp. 503-517.
- 822 73. Kabir, K.M.; Sabri, Y.M.; Lay, B.; Ippolito, S.J.; Bhargava, S.K., A silver electrode based surface
823 acoustic wave (SAW) mercury vapor sensor: a physio-chemical and analytical investigation.
824 *RSC Advances* **2016**, Volume 6, pp. 36362-36372.
- 825 74. Lai, C.; Qin, L.; Zeng, G.; Liu, Y.; Huang, D.; Zhang, C.; Xu, P.; Cheng, M.; Qin, X.; Wang, M.,
826 Sensitive and selective detection of mercury ions based on papain and 2, 6-
827 pyridinedicarboxylic acid functionalized gold nanoparticles. *RSC Advances* **2016**, Volume 6, pp.
828 3259-3266.
- 829 75. Noël, M.; Christensen, J.R.; Spence, J.; Robbins, C.T., Using laser ablation inductively coupled
830 plasma mass spectrometry (LA-ICP-MS) to characterize copper, zinc and mercury along
831 grizzly bear hair providing estimate of diet. *Science of the Total Environment* **2015**, Volume 529,
832 pp. 1-9.
- 833 76. Habte, G.; Hwang, I.M.; Kim, J.S.; Hong, J.H.; Hong, Y.S.; Choi, J.Y.; Nho, E.Y.; Jamila, N.;
834 Khan, N.; Kim, K.S., Elemental profiling and geographical differentiation of Ethiopian coffee
835 samples through inductively coupled plasma-optical emission spectroscopy (ICP-OES), ICP-
836 mass spectrometry (ICP-MS) and direct mercury analyzer (DMA). *Food chemistry* **2016**, Volume
837 212, pp. 512-520.
- 838 77. Cui, L.; Wu, J.; Ju, H., Electrochemical sensing of heavy metal ions with inorganic, organic and
839 bio-materials. *Biosensors Bioelectronics* **2015**, Volume 63, pp. 276-286.
- 840 78. Bansod, B.; Kumar, T.; Thakur, R.; Rana, S.; Singh, I., A review on various electrochemical
841 techniques for heavy metal ions detection with different sensing platforms. *Biosensors*
842 *Bioelectronics* **2017**, Volume 94, pp. 443-455.
- 843 79. Gao, C.; Huang, X.-J., Voltammetric determination of mercury (II). *TrAC Trends in Analytical*
844 *Chemistry* **2013**, Volume 51, pp. 1-12.
- 845 80. Mauter, M.S.; Elimelech, M., Environmental applications of carbon-based nanomaterials.
846 *Environmental science technology* **2008**, Volume 42, pp. 5843-5859.
- 847 81. Crevillen, A.G.; Escarpa, A.; García, C.D. *Carbon-based Nanomaterials in Analytical Chemistry*, 1st
848 ed.; Royal Society of Chemistry: United Kingdom, 2018.
- 849 82. Xie, F.; Yang, M.; Jiang, M.; Huang, X.-J.; Liu, W.-Q.; Xie, P.-H., Carbon based nanomaterials-
850 A promising electrochemical sensor toward persistent toxic substance. *Trends in Analytical*
851 *Chemistry* **2019**, Volume pp. 115624.
- 852 83. Gong, J.; Zhou, T.; Song, D.; Zhang, L.; Hu, X., Stripping voltammetric detection of mercury
853 (II) based on a bimetallic Au- Pt inorganic- organic hybrid nanocomposite modified glassy
854 carbon electrode. *Analytical chemistry* **2009**, Volume 82, pp. 567-573.
- 855 84. Ghanei-Motlagh, M.; Taher, M.A.; Heydari, A.; Ghanei-Motlagh, R.; Gupta, V.K., A novel
856 voltammetric sensor for sensitive detection of mercury (II) ions using glassy carbon electrode
857 modified with graphene-based ion imprinted polymer. *Materials Science Engineering: C* **2016**,
858 Volume 63, pp. 367-375.
- 859 85. Pokhrel, L.R.; Ettore, N.; Jacobs, Z.L.; Zarr, A.; Weir, M.H.; Scheuerman, P.R.; Kanel, S.R.;
860 Dubey, B., Novel carbon nanotube (CNT)-based ultrasensitive sensors for trace mercury (II)
861 detection in water: a review. *Science of the Total Environment* **2017**, Volume 574, pp. 1379-1388.
- 862 86. Xing, H.; Xu, J.; Zhu, X.; Duan, X.; Lu, L.; Wang, W.; Zhang, Y.; Yang, T., Highly sensitive
863 simultaneous determination of cadmium (II), lead (II), copper (II), and mercury (II) ions on N-
864 doped graphene modified electrode. *Journal of Electroanalytical Chemistry* **2016**, Volume 760, pp.
865 52-58.
- 866 87. Choi, S.-M.; Kim, D.-M.; Jung, O.-S.; Shim, Y.-B., A disposable chronocoulometric sensor for
867 heavy metal ions using a diaminoterthiophene-modified electrode doped with graphene
868 oxide. *Analytica chimica acta* **2015**, Volume 892, pp. 77-84.
- 869 88. Huang, X.-J.; Chen, X.; Yang, M. *Persistent Toxic Substance Monitoring: Nanoelectrochemical*
870 *Methods*, 1st ed.; John Wiley & Sons: Weinheim, Germany, 2018.
- 871 89. Duarte, K.; Justino, C.I.; Freitas, A.C.; Gomes, A.M.; Duarte, A.C.; Rocha-Santos, T.A.,
872 Disposable sensors for environmental monitoring of lead, cadmium and mercury. *TrAC Trends*
873 *in Analytical Chemistry* **2015**, Volume 64, pp. 183-190.

- 874 90. Lin, J.; Peng, Z.; Liu, Y.; Ruiz-Zepeda, F.; Ye, R.; Samuel, E.L.; Yacaman, M.J.; Yakobson, B.I.;
875 Tour, J.M., Laser-induced porous graphene films from commercial polymers. *Nature*
876 *communications* **2014**, *Volume 5*, pp. 5714.
- 877 91. Tehrani, F.; Bavarian, B., Facile and scalable disposable sensor based on laser engraved
878 graphene for electrochemical detection of glucose. *Scientific reports* **2016**, *Volume 6*, pp. 27975.
- 879 92. Nayak, P.; Kurra, N.; Xia, C.; Alshareef, H.N., Highly efficient laser scribed graphene
880 electrodes for on - chip electrochemical sensing applications. *Advanced Electronic Materials*
881 **2016**, *Volume 2*, pp. 160085. 10.1002/aelm.201600185.
- 882 93. Vanegas, D.; Patiño, L.; Mendez, C.; Oliveira, D.; Torres, A.; Gomes, C.; McLamore, E., Laser
883 Scribed Graphene Biosensor for Detection of Biogenic Amines in Food Samples Using Locally
884 Sourced Materials. *Biosensors* **2018**, *Volume 8*, pp. 42.
- 885 94. Garland, N.T.; McLamore, E.S.; Cavallaro, N.D.; Mendivelso-Perez, D.; Smith, E.A.; Jing, D.;
886 Claussen, J.C., Flexible Laser-Induced Graphene for Nitrogen Sensing in Soil. *ACS applied*
887 *materials interfaces* **2018**, *Volume 10*, pp. 39124-39133.
- 888 95. Yang, K.; Wang, J.; Chen, X.; Zhao, Q.; Ghaffar, A.; Chen, B., Application of graphene-based
889 materials in water purification: from the nanoscale to specific devices. *Environmental Science:*
890 *Nano* **2018**, *Volume 5*, pp. 1264-1297.
- 891 96. Taguchi, M.; Schwalb, N.; Rong, Y.; Vanegas, D.; Garland, N.; Tan, M.; Yamaguchi, H.;
892 Claussen, J.; McLamore, E., Pulsed: Pulsed sonoelectrodeposition of fractal nanoplatinum for
893 enhancing amperometric biosensor performance. *Analyst* **2016**, *Volume 141*, pp. 3367-3378.
- 894 97. Abdelbasir, S.; El-Sheikh, S.; Morgan, V.; Schmidt, H.; Casso-Hartmann, L.; Vanegas, D.; Velez-
895 Torres, I.; McLamore, E., Graphene-anchored cuprous oxide nanoparticles from waste electric
896 cables for electrochemical sensing. *Sustainable Chemistry Engineering* **2018**, *Volume 6*, pp. 12176-
897 12186.
- 898 98. Jenkins, D.M.; Lee, B.E.; Jun, S.; Reyes-De-Corcuera, J.; McLamore, E.S., ABE-Stat, a Fully
899 Open-Source and Versatile Wireless Potentiostat Project Including Electrochemical Impedance
900 Spectroscopy. *Journal of The Electrochemical Society* **2019**, *Volume 166*, pp. B3056-B3065.
- 901 99. World Health Organization, Mercury in Drinking-water: Background document for
902 development of WHO Guidelines for Drinking-water Quality. 2005.
- 903 100. World Health Organization, Exposure to mercury: a major public health concern. *WHO, Public*
904 *Health Environment international*. 2007.
- 905 101. Taueg, C.; Sanfilippo, D.; Rowens, B.; Szejda, J.; Hesse, J., Acute and chronic poisoning from
906 residential exposures to elemental mercury-michigan, 1989–1990. *Journal of Toxicology: Clinical*
907 *Toxicology* **1992**, *Volume 30*, pp. 63-67.
- 908 102. Bernhoft, R.A., Mercury toxicity and treatment: a review of the literature. *Journal of*
909 *environmental public health* **2012**, *Volume 2012*.
- 910 103. Castilhos, Z.C.; Rodrigues-Filho, S.; Rodrigues, A.P.C.; Villas-Bôas, R.C.; Siegel, S.; Veiga,
911 M.M.; Beinhoff, C., Mercury contamination in fish from gold mining areas in Indonesia and
912 human health risk assessment. *Science of the Total Environment* **2006**, *Volume 368*, pp. 320-325.
- 913 104. Castilhos, Z.; Rodrigues-Filho, S.; Cesar, R.; Rodrigues, A.P.; Villas-Bôas, R.; de Jesus, I.; Lima,
914 M.; Faial, K.; Miranda, A.; Brabo, E., Human exposure and risk assessment associated with
915 mercury contamination in artisanal gold mining areas in the Brazilian Amazon. *Environmental*
916 *Science Pollution Research* **2015**, *Volume 22*, pp. 11255-11264.
- 917 105. Nakazawa, K.; Nagafuchi, O.; Kawakami, T.; Inoue, T.; Yokota, K.; Serikawa, Y.; Cyio, B.;
918 Elvince, R., Human health risk assessment of mercury vapor around artisanal small-scale gold
919 mining area, Palu city, Central Sulawesi, Indonesia. *Ecotoxicology environmental safety* **2016**,
920 *Volume 124*, pp. 155-162.
- 921 106. Petroczi, A.; Naughton, D., Mercury, cadmium and lead contamination in seafood: A
922 comparative study to evaluate the usefulness of Target Hazard Quotients. *Food Chemical*
923 *Toxicology* **2009**, *Volume 47*, pp. 298-302.
- 924 107. Telemedicine Predicted in 1925. Available online:
925 <https://www.smithsonianmag.com/history/telemedicine-predicted-in-1925-124140942/>
926 (accessed on November 20 2019).
- 927 108. Arute, F.; Arya, K.; Babbush, R.; Bacon, D.; Bardin, J.C.; Barends, R.; Biswas, R.; Boixo, S.;
928 Brandao, F.G.; Buell, D.A., Quantum supremacy using a programmable superconducting
929 processor. *Nature* **2019**, *Volume 574*, pp. 505-510.

- 930 109. Coase, R., The Nature of the Firm. *Economica*, New Series, 4 (16), 386-405. *Article first published*
 931 *online 1937, Volume 19*, pp. 10.1111/j.1468-0335.1937.tb00002.x.
- 932 110. Kay, N.M., Coase and the Contribution of 'The Nature of the Firm'. *Managerial Decision*
 933 *Economics 2015, Volume 36*, pp. 44-54.
- 934 111. Kim, J.Y., Rich and poor: opportunities and challenges in an age of disruption. *World Bank*
 935 2018. 10.1596/31119.
- 936 112. Tonda, E.; Susan, C., Technology Challenges and tools for the implementation of the water-
 937 related sustainable development goals and targets. *2015 UN-Water Annual International*
 938 *Zaragoza Conference 2015*.
- 939 113. Banerjee, A.V. and Duflo, E. *Poor economics: A radical rethinking of the way to fight global poverty*.
 940 1st ed.; Public Affairs: New York, United States of America, 2011. ISBN: 978-1-58648-798-0
- 941 114. Mikami, M., Methodological divergence between coase and williamson in the history of
 942 transaction cost economics. *Economic Journal of Hokkaido University 2011, Volume 40*, pp. 41-57.
- 943 115. Klein, S.; Frazier, G.L.; Roth, V.J., A transaction cost analysis model of channel integration in
 944 international markets. *Journal of Marketing research 1990, Volume 27*, pp. 196-208.
- 945 116. Pentland, A.; Fletcher, R.; Hasson, A., Daknet: Rethinking connectivity in developing nations.
 946 *Computer 2004, Volume 37*, pp. 78-83. 10.1109/MC.2004.1260729.
- 947 117. Martinez, A.; Villarroel, V.; Seoane, J.; del Pozo, F., Analysis of information and
 948 communication needs in rural primary health care in developing countries. *IEEE transactions*
 949 *on Information Technology in Biomedicine 2005, Volume 9*, pp. 66-72. 10.1109/TITB.2004.842411.
- 950 118. Pimenidis, E.; Sideridis, A.B.; Antonopoulou, E., Mobile devices and services: bridging the
 951 digital divide in rural areas. *International Journal of Electronic Security Digital Forensics 2009,*
 952 *Volume 2*, pp. 424-434.
- 953 119. James, J., Mechanisms of access to the Internet in rural areas of developing countries. *Telematics*
 954 *Informatics 2010, Volume 27*, pp. 370-376. <https://doi.org/10.1016/j.tele.2010.02.002>.
- 955 120. Llanto, G.M.; Fukui, R., Innovations in Microfinance in Southeast Asia, PIDS Discussion Paper
 956 Series, No. 2003-11, Philippine Institute for Development Studies (PIDS), Makati City. 2003.
 957 *PIDS Discussion Paper Series*
- 958 121. Nenova, T.; Niang, C.T. *Bringing Finance to Pakistan's poor: Access to Finance for Small enterprises*
 959 *and the Underserved*, 1st ed.; The World Bank: Washington DC, United States of America, 2009.
- 960 122. Bernardi, L.; Sarma, S.; Traub, K. *The inversion factor: How to thrive in the IoT economy*, 1st ed.;
 961 MIT Press: London, England, 2017.
- 962 123. Davis, F.D., A technology acceptance model for empirically testing new end-user information
 963 systems: Theory and results. Ph.D. thesis. Ph.D. in Management-Massachusetts Institute of
 964 Technology, Massachusetts, United States of America, December 20 1985.
- 965 124. Rogers, E.M., A prospective and retrospective look at the diffusion model. *Journal of health*
 966 *communication 2004, Volume 9*, pp. 13-19.
- 967 125. Williams, M.D.; Rana, N.P.; Dwivedi, Y.K., The unified theory of acceptance and use of
 968 technology (UTAUT): a literature review. *Journal of Enterprise Information Management 2015,*
 969 *Volume 28*, pp. 443-488. 10.1108/JEIM-09-2014-0088.
- 970 126. Johnson, M.P.; Zheng, K.; Padman, R., Modeling the longitudinality of user acceptance of
 971 technology with an evidence-adaptive clinical decision support system. *Decision Support*
 972 *Systems 2014, Volume 57*, pp. 444-453. 10.1016/j.dss.2012.10.049.
- 973 127. Campbell, J.I.; Aturinda, I.; Mwesigwa, E.; Burns, B.; Haberer, J.E.; Bangsberg, D.R.; Holden,
 974 R.J.; Ware, N.C.; Siedner, M.J., The Technology Acceptance Model for Resource-Limited
 975 Settings (TAM-RLS): a novel framework for mobile health interventions targeted to low-
 976 literacy end-users in resource-limited settings. *AIDS Behavior 2017, Volume 21*, pp. 3129-3140.
 977 10.1007/s10461-017-1765-y.
- 978 128. Sunny, S.; Patrick, L.; Rob, L., Impact of cultural values on technology acceptance and
 979 technology readiness. *International Journal of Hospitality Management 2019, Volume 77*, pp. 89-
 980 96. <https://doi.org/10.1016/j.ijhm.2018.06.017>.
- 981 129. Mathieson, K., Predicting user intentions: comparing the technology acceptance model with
 982 the theory of planned behavior. *Information systems research 1991, Volume 2*, pp. 173-191.
- 983 130. Wallace, E.A.; Schumann, J.H.; Weinberger, S.E., Ethics of Commercial Screening Tests. *Annals*
 984 *of Internal Medicine 2013, Volume 158*, pp. 500-500. doi:10.231/JIM.0b013e318210eeb0.
- 985 131. Hersh, M., Technology change, technology transfer and ethics. University of Glasgow, Vienna,
 986 Austria. 2001.

- 987 132. Street, J. *Politics and technology*, 1st ed.; The Guilford Press: New York, United States, 1992.
- 988 133. Guidelines for health care equipment donations. Available online:
989 https://www.who.int/medical_devices/publications/en/Donation_Guidelines.pdf (accessed
990 on November 05 2019).
- 991 134. Perry, L.; Malkin, R., Effectiveness of medical equipment donations to improve health systems:
992 how much medical equipment is broken in the developing world? *Medical & Biological*
993 *Engineering & Computing* **2011**, Volume 49, pp. 719-722. [https://doi.org/10.1007/s11517-011-0786-](https://doi.org/10.1007/s11517-011-0786-3)
994 3.
- 995
- 996



© 2019 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).

997



Can “SNAPS” and/or “PAPPU”
make a difference for the masses?

Economic Incentives Don't Always Do What We Want Them To

By Esther Duflo and Abhijit Banerjee

The authors were just awarded the Nobel Prize in economics.

Oct. 26, 2019



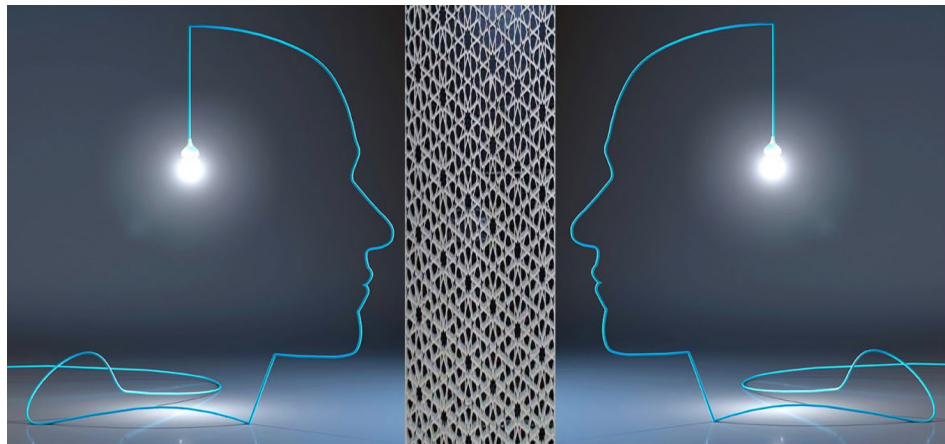
Running Title: Unsustainable and Misaligned Economics of Technology triggers a Porous Pareto Partition Between the Haves and the Have Nots: Can Democratization of Distributed Data act as a Catalyst for the Dissemination of Digital Dividends?

P₃

Porous Pareto Partition:

₁Democratization of ₂Distributed ₃Data may or may not catalyze the global ₄Dissemination of ₅Digital ₆Dividends

D₆ is an unfinished essay (op-ed) by Shoumen Palit Austin Datta *et al* ♦ Massachusetts Institute of Technology and Massachusetts General Hospital, Harvard Medical School (shoumen@mit.edu & sdatta8@mgh.harvard.edu)



Opinions expressed in this essay are solely due to the primary author and do not reflect the views of the institutions with which the author is affiliated. Listed co-authors are not responsible and may not endorse any/all comments and criticisms in this essay. This essay is not based on any scholastic research, it does not contain any new concepts and perhaps best categorized as a blog.

ABSTRACT

P3 is a petri dish brimming with questions. This essay does not provide answers but suggestions to explore. This essay may not instruct, educate or teach, but may swing the proverbial pendulum with sufficient motion to discuss business to consumer services. The reader may ponder about the amorphous questions or wonder in confusion, ambiguity and uncertainty. This essay breaks with the *status quo* and indulges orthogonal, non-linear and asymmetric information arbitrage. This essay is not an attempt to be correct or right. This essay is a seed, sterile unless cultivated or you can bury it (but it may grow). This essay aspires to inform that tools and data related to the affluent world are *not* a template to be “copied” or applied to systems in the remaining (80%) parts of the world with economic constraints and cultural preferences. We need different thinking that resists the inclination of the affluent 20% of the world to treat the rest of the world (80% of the population) just as a market. The 80/20 distribution evokes the Pareto¹ theme in this essay. On reflection (see “END NOTE”), it is unclear what this essay contributes.

CONTEXT

Since 1999, the concept of the internet of things (IoT) was nurtured as a marketing term² which may have succinctly captured the idea of data about objects stored on the internet³ in the networked physical world. The idea evolved while transforming the use of RFID (radio frequency identification) where an alphanumeric unique identifier (64-bit EPC⁴ or electronic product code) was stored on the chip (tag⁵) but the volume of raw data was stored on the internet, yet inextricably and uniquely linked via the EPC, in a manner resembling the structure of internet protocols⁶ (64-bit IPv4 and 128-bit IPv6⁷). IoT and later, *cloud of data*⁸, were metaphors for ubiquitous connectivity and concepts originating from ubiquitous computing, a term introduced by Mark Weiser⁹ in 1998. The underlying importance of data from connected objects and processes usurped the term big data¹⁰ and then twisted the sound bites to create the artificial myth of “Big Data” sponsored and accelerated by consulting companies. The global drive to get ahead of the “Big Data” tsunami, flooded both businesses and governments, big and small. The chatter about big data garnished with dollops of AI became parlor talk among fish mongers¹¹ and gold miners, inviting the sardonicism of doublespeak, peppered in this essay.

Much to the chagrin of the thinkers, the laissez-faire approach to IoT percolated by the tinkerers over-shadowed hard facts. The “quick & dirty” anti-intellectual chaos adumbrated the artefact-fueled exploding frenzy for new revenue from “IoT Practice” which spawned greed in the consulting¹² world. The cacophony of IoT in the market¹³ is a result of that unstoppable transmutation of disingenuous tabloid fodder to veritable truth, catalyzed by pseudo-science hacks, social gurus and glib publicity campaigns to drum up draconian “dollar-sign-dangling” predictions¹⁴ about “trillions of things connected to the internet” to feed mass hysteria, to bolster consumption. Few ventured to correct the facts and point out that *connectivity without discovery* is a diabolical tragedy of egregious errors. Even fewer recognized that the idea of IoT is *not a point* but an *ecosystem*, where collaboration adds value.

The corporate orchestration of the digital by design metaphor of IoT was warped solely to create demand for sales by falsely amplifying the lure of increasing performance, productivity and profit, far beyond the potential digital transformation could deliver by embracing the rational principles of IoT.

Ubiquitous connectivity is associated with high cost of products (capex or capital expense) but extraction of "value" to generate ROI (return on investment) rests on the ability to implement SARA, a derivative of the PEAS paradigm (see Fig 6 and 7). SARA - **S**ense, **A**nalyze, **R**espond, **A**ctuate – is not a linear concept. Data and decisions necessary for SARA makes the conceptual illustration more akin to The Sara Cycle, perhaps best illustrated by the analogy to the Krebs¹⁵ Cycle, an instance of bio-mimicry. Data and decisions constantly influence, optimize, re-configure, and change the parameters associated with, *when* to sense, *what* to analyze, *how* to respond and *where* to actuate or auto-actuate. Combining SARA with the metaphor of IoT by design may help to ask these questions, with precision and accuracy.

It is hardly necessary to over-emphasize the value of the correct questions for each element of SARA in a matrix of connected objects, relevant entities which can be discovered, distributed nodes, related processes and desired outcomes. Strategic inclusion of SARA guides key performance indicators. Lucidity and clarity of thoughtful integration of digital by design idea is key to reconfiguring operations management. Execution and embedding SARA is not a systems integration task but rather a fine-tuned *synergistic* integration based on the *weighted combination of dependencies* in the SARA matrix. Failure to grasp the role of data and semantics of queries, in the context of KPI (key performance indicators) may increase transaction costs, reduce the value proposition for customers and obliterate ROI or profitability.



Figure 0 - From the annals¹⁶ of the march of unreason: *Internet of things*: \$8.9 trillion market in 2020, 212 billion connected things. It is blasphemous and heretical to suggest that this a *research*¹⁷ outcome.

This essay meanders, not always aimlessly, around discussions involving data and decision. It also oscillates, albeit asynchronously, between a broad spectrum of haphazard realities or “dots” which may be more about esoteric analysis rather than focusing on delivering real-world value. In part, this discussion questions the barriers to the rate of diffusion of technologies in underserved communities. Can implementing *simple* tools act as affordable catalysts? Can it lift the quality of life, in less affluent societies, by enabling meaningful use of data, perhaps small data, at the right time, at the lowest cost?

The extremely non-linear business of delivering tools and technologies makes it imperative to consider the trinity of systems integration, standards and interoperability. We advocate that businesses may wish to gradually dis-engage with the product mind-set (sensors, hardware, software) and engage in the *ecosystem* necessary to deliver *services* to communities. The delivery of service to the end-user must be synergized. Hence, system integration may be a subset of synergistic integration. But, before we can view this “whole” it is better to understand the coalition of cyber (data) with the physical (parts). In many ways, this discussion is about cyberphysical systems (CPS) but not for lofty purposes, such as landing on Mars, but for simple living, on Earth.

MODELS IN THE BACKGROUND

Because it may be difficult to grasp the whole, we tend to focus on the part, and parts, closest to our comfort zone, in our area of interest. This reductionist approach may be necessary *ab initio* but rarely yields a solution, *per se*. Reconstruction requires synthesis and synergy, the global glue which underlies mass adoption and diffusion, of tools, in an age of integration, which, itself, is a khichuri¹⁸ of parts, some known (industrial age, information age, systems age) and others, parts unknown.

Divide and conquer still remains a robust adage. It may be the philosophical foundation of reductionism. The latter has rewarded us with immense gains in knowledge and the wisdom as to why this *modus operandi* is *sine qua non*. For example, the pea plant (*Pisum sativum*) unleashed the cryptic principles of genetics¹⁹ and unicellular bacteria shed light on normal physiological underpinnings of feedback control²⁰ common in genetic circuits as well as regulatory networks for maintenance and optimization of biological homeostasis, quintessential for health and healthcare in humans and animals. Cancer biology was transformed by Renato Dulbecco²¹ by *reducing* the multi-factorial complexity of human cancer research to focus on a *single gene model* (SV40 large T-antigen) from Papova viruses.

Biomimicry also inspired the creation of better machines and systems²², using the principles and practice of control theory borrowed from science, strengthened by mathematics and successfully integrated with design and manufacturing, by engineers. An early convergence²³ of control theory with communication may be found in the 1948 treatise “Cybernetics” by Norbert Wiener²⁴ (who may have borrowed²⁵ the word “cybernétique” proposed by the French physicist and mathematician André-Marie Ampère²⁶ to design the then non-existent science of process control).

In other examples of ‘divide and conquer’ the theoretical duo “Alice and Bob” is at the core²⁷ of cryptography²⁸ as well as the game theoretic²⁹ approach³⁰ to “prisoner’s dilemma” which has influenced business strategies³¹ and now it is spilling over to knowledge graph³² databases. The simple concept of a lone travelling salesman proposed by Euler in 1759 appears to have evolved³³ as the bread and butter of most optimization engines, which, when considered together with data and information, continues to improve decision support systems (DSS) in manufacturing, retail, transportation, logistics³⁴ and omnipresent supply chain³⁵ networks, almost in every vertical.

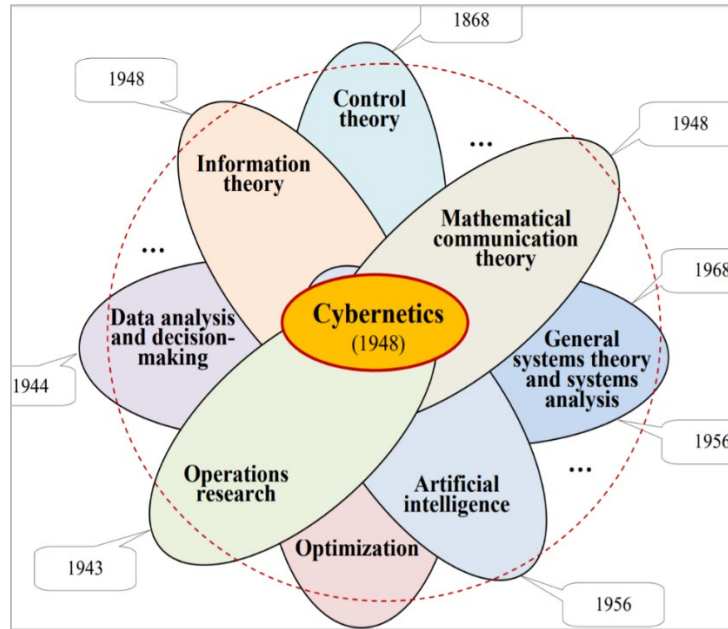


Figure 1 - A Century of Convergence ◆ The Composition and Structure of Cybernetics [22]

The purpose of these disparate examples are to emphasize the notion that there are fundamental units of activity or models or set(s) of patterns or certain basic behavioral criteria (for lack of a better descriptive term) that underlie most actions and reactions. When taken apart or sufficiently reduced, we may observe these as isolated units or patterns or models of rudimentary entities. When combined, these simple models/units/patterns/elements can generate an almost unlimited variety of system behaviors observed on grand scales. When viewing the massive scale of systems from the “top” it may be quite counter-intuitive to imagine that the observed manifestations are due to a few or a relatively small group of universal ‘truths’ which we refer to as models, units, rules, logic, patterns, elements or behaviors. To further illustrate this perspective, consider petals (flowers), pineapple (fruit) and pyramids. The variation between and within these three very different examples may boil down to Fibonacci³⁶ numbers, fractal³⁷ dimensions and the Golden³⁸ Ratio³⁹ in some form, or the other. In another vein, the number, eight, seems to be central to atoms (octet) and an integral part of the Standard Model in physics (octonions⁴⁰). Number 8 is revered by the Chinese due to its link with words synonymous with wealth and fortune (fa).

If one is still unconvinced and remain skeptical that small sets of underlying elements, generally, may be responsible, albeit in part, for the “big things” we consider diverse, then the “killer” example is that of nucleic acids, deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), made up of only five sub-units or molecules (Adenine, Guanine, Cytosine, Thymine, Uracil). DNA and RNA serves as the blueprint for all humans, animals, plants, bacteria and viruses, that may ever exist. The infinite diversity of multi-cellular⁴¹ and uni-cellular organisms, whose creation is instructed by a *combination of these 5 molecules* in DNA and RNA, may vastly exceed 5×10^{30} (5,000,000,000,000,000,000,000,000,000⁴²). The known exception to the DNA-RNA dogma may be the case for prions⁴³ which uses proteins⁴⁴ as the transmissible macromolecule.

Parallel examples can be drawn from physical sciences. Large scale system behaviors can be reduced and mapped to simple models. Combination of these simple models, with widely different microscopic details, applies to, and generates, large set of possible systems⁴⁵ and system of systems. Another example of “hidden complementarities” emerged from cryptic mathematical bridge embedded in natural sciences. It is now established that eigenvectors may be computed⁴⁶ using information about eigenvalues. Students are still taught that eigenvectors and eigenvalues are independent, and must be calculated separately starting from rows and columns of the matrix. Mathematicians authored papers in related fields⁴⁷ yet none “connected the dots” between eigenvectors and eigenvalues. The insight that eigenvalues of the minor matrix encode hidden information may not be entirely new⁴⁸ but was neither understood nor articulated. The relationship of centuries-old mathematical objects⁴⁹ ultimately came from physicists. Nature inspires mathematical thinking because mathematics thrives when connected to nature. Grasping these connections enables humans to create tools to mimic nature (bio-mimicry).

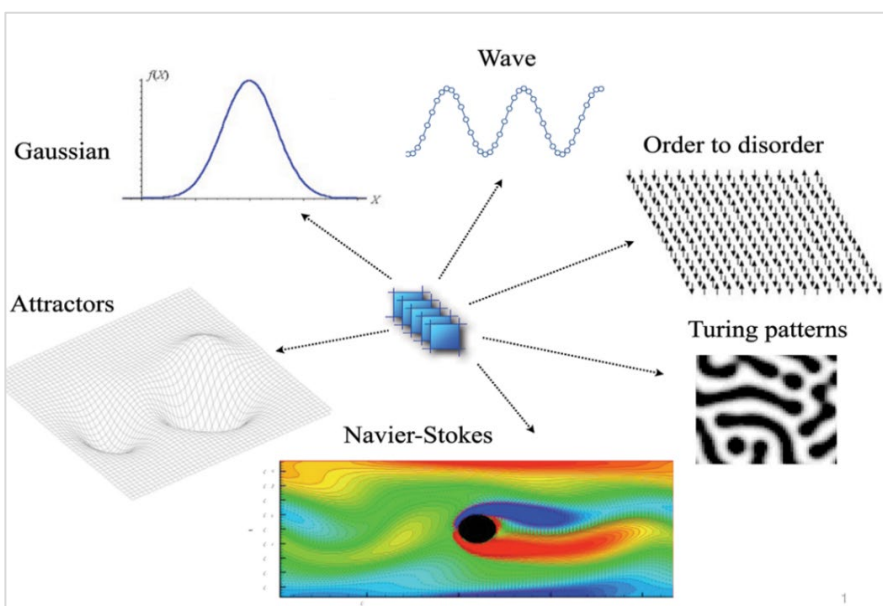


Figure 2 – Only a few models may capture the behavior of a wide range of systems, underlies the idea of universality²⁶ (models illustrated in this figure: Gaussian distribution, wave motion, order to disorder transitions, Turing patterns, fluid flow described by Navier-Stokes equations, and attractor dynamics).

PROBLEM SPACE: ARE WE ASKING THE CORRECT QUESTIONS?

The lengthy and winding preface [to the problem at hand (D₆)] is presented to substantiate the opinion that there may be a disconnect between the volume of data we have generated as a result of the “information age” versus the lack lustre gains in performance, as estimated by the productivity⁵⁰ index. Currently, we may have ~2.7 zettabytes⁵¹ (2.7 billion terabytes) of data, but some estimates claim as much as 33 zettabytes⁵² of data at hand (2018), and predicts it to reach 175 zettabytes circa 2025.

The deluge of data as a result of “information technology” is far greater in magnitude than the diffusion of electricity⁵³ a century ago. Productivity increases due to the introduction of electricity and IT offer economic parallels⁵⁴ but based on the magnitude of change, the short fall (in productivity) cannot be brushed aside by attributing the blame to mismeasurement explanations⁵⁵ for the sluggish⁵⁶ pace. Extrapolating measurements using the tools of classical productivity⁵⁷ to determine the impact of IT and influence of data is certainly fraught with problems⁵⁸ yet the incongruencies alone cannot explain the shrinkage. In socio-economic terms, there is a growing chasm between IT and data/information versus productivity, improvement in quality of life, labor, compensation⁵⁹ and increases in living standards.

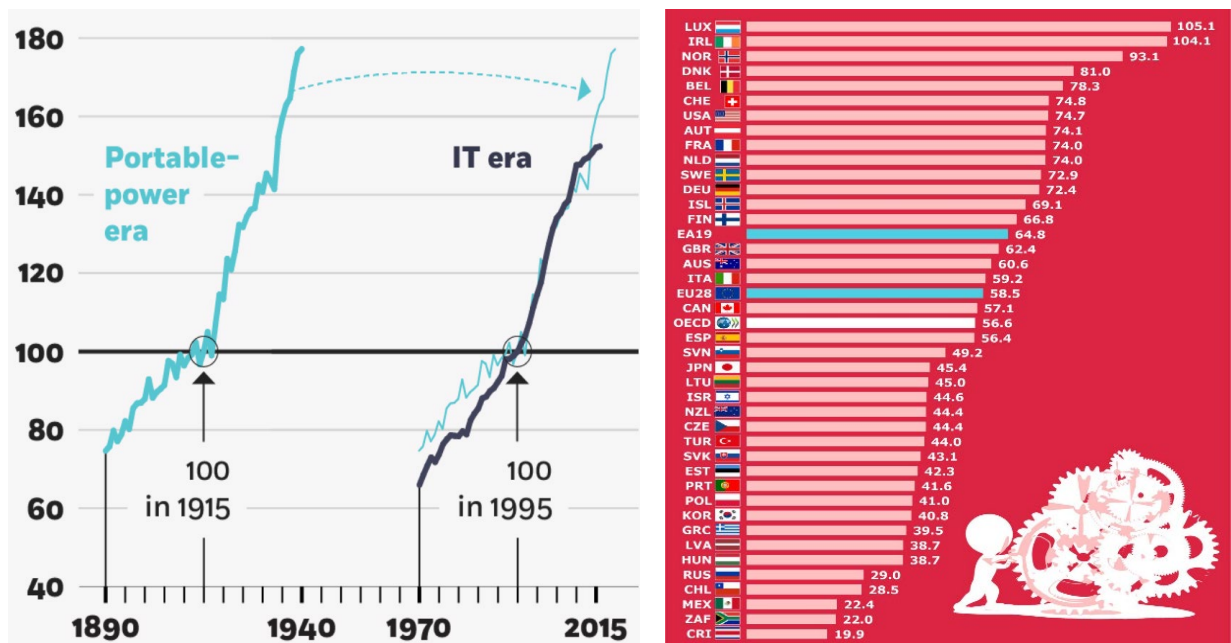


Figure 3 – (LEFT) Labor-Productivity Index [60]: Has data failed to deliver? IT was billed as the bridge between *the haves* and *the have-nots*. General process technologies takes ~25 years to reach market adoption [51]. (RIGHT) Labor Productivity⁶¹ (OECD, 2018) is yet another example how the arithmetic of productivity (ratio between volume of output vs input) is misguided, misdiagnosed, mismeasured and misused as a metric of economic realities. Making Mexico (22.4) appear to be one fifth as “productive” as Ireland (104.1) suggests formulaic manipulations⁶² (GDP per hour worked, current prices, PPP).

Despite trillions of dollars invested in data, digital transformation and other IT tools⁶³ (big data, AI, blockchain) the perforated return on investment⁶⁴ increasingly points to massive⁶⁵ waste. One reason for this “waste” may be due to use of models of data where errors are aggregated under a generalized⁶⁶ form or variations⁶⁷ of the normal (homoskedastic) distribution.

Heteroskedasticity was addressed⁶⁸ using ARCH⁶⁹ (autoregressive conditional heteroskedasticity⁷⁰) and GARCH⁷¹ models⁷² (generalized ARCH). The use⁷³ of these proven techniques⁷⁴ for time series data (for example, sensor data showing water temperature in marine aquaponics⁷⁵ or cold chain⁷⁶ temperature log of vaccine package during transportation) in financial⁷⁷ econometrics⁷⁸ may be extended. Applications in predictive⁷⁹ modeling and forecasting⁸⁰ techniques may wish to adopt these econometric tools (GARCH) as a standard, whenever time series data is used (for example, supply chain⁸¹ management, sensor data in health), but only *if* there is sufficient data (volume) to meet the statistical rigor necessary for successful error correction.

Perhaps it is best to limit the post-mortem analysis of IT failures, snake-oil sales of AI⁸² and other debacles. Let us observe from this discussion that in the domain of data, and extraction of value from data to inform decisions, the tools of transforming data to inform decision may benefit from re-viewing the processes and technologies with “new” eyes. Above all, we must ask, often, if we are pursuing the correct questions, if the tools are appropriate and rigorous. The productivity gap and reports of corporate waste are “sign-posts” on the road ahead, except that the signage is in the incorrect direction, with respect to the intended destination, that is, profit and performance.

SOLUTIONS APPROACH – THE ELUSIVE QUEST TO BUILD BRIDGES BETWEEN DATA AND DECISIONS

There are no novel proposed solutions in this essay, only new commentary about *approaches* to solutions. The violent discord between volume of data versus veracity of decisions appears to be one prominent reason why the productivity gap may widen to form a chasm. The “background” section discussed how the reductionist approach points to simple models or underlying units or key elements, which, when combined, in some form, by some rules or logic, may generate large scale systems.

Data models⁸³ for DBMS are very different from models in data. Pattern mining⁸⁴ from data⁸⁵ is a time-tested tool. What new features can we uncover or learn about data, from patterns? What simpler models or elements are cryptic in data? Are these the correct questions? *If* there are simpler models or patterns in some types of data, can we justify extrapolating these models and *patterns* as a *general feature* of the data?

We have been mining for patterns and models (clustering, classification, categorization, principal component analysis) for decades, why haven’t we found simpler models or patterns, yet? Are we using the wrong tools or wrong approaches or looking at the wrong places? How rational are we in our search for these general/simple models in view of the fact that models of data from retail or manufacturing or health clinics *should* be quite different?

The lowest common denominator of simple/general models/patterns may not be an ingredient for building that experimental “thought” bridge. Increasing volume of data could help GARCH tools but appears to be on a slippery slope in terms of quality with respect to *informing* decision support systems and/or the veracity of decisions (output). Baseline data models/patterns as denominators from grocery shopping or dry wall manufacturing or mental health clinics *should* be different. In lieu of “universal” common denominators, we may create repertoires of domain-specific common denominators. Then, a comparative analysis between common denominators of retail grocery shopping model from Boston versus Beijing may reveal the spectrum of nutritional behaviors. If linked to eating habits, perhaps we can extrapolate its *influence* on health/mental health (additional mental health comments on page 28).

Domain-specific denominator models (DSDM) aren’t new. It requires an infrastructure approach to data analytics which needs multi-talented teams to explore almost every cross-section and combination of very large volumes of data, from specific domains, to identify obvious correlations as well as unknown/non-obvious relationships. If there is any doubt about the quality of the raw data, then quality control may mandate data curation. The latter alone, makes the task exponentially complex. Curation may introduce reasonable doubt in evaluating any outcome because the possibility exists that curation algorithms and associated processes were error-prone or untrustworthy (post-curation jitters).

Another demerit for DSDM and the idea of denominator models, in general, may be rooted in the “apples vs oranges” dilemma. Denominator models that underlie science and engineering systems are guided by natural laws, deemed *rational*. The quest for denominator models in data (retail, finance, supply chain, health, agriculture) are influenced, infected and corrupted by irrational⁸⁶ human behavior. Rational models of irrational behavior⁸⁷ may co-exist elsewhere but remains elusive for data science due to volatility and the vast *spectrum of irrationality* that may be introduced in data by human interference.

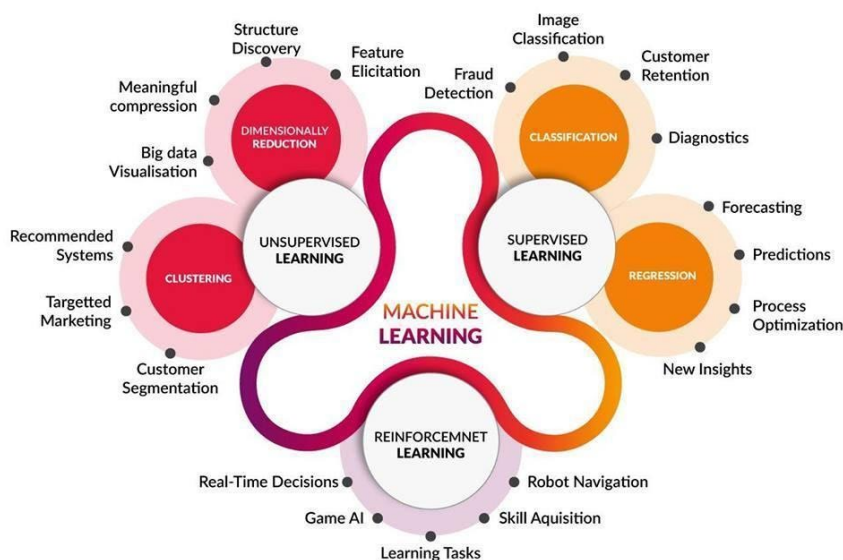


Figure 4 – It appears that we have been mining for patterns and other simpler models (such as clustering, classification, categorization, regression, principal component analysis). But, have we found a set(s) of simpler models or patterns, yet, to test the concept of domain-specific denominator models (DSDM)?

Perhaps the concept of DSDM, ignoring its obvious caveats, may be applied to select domains for specific purposes, for example, healthcare, where deliberate human interference to introduce errors in data is a criminal offense. Case-specific model building, and pattern recognition, may benefit from machine learning (ML) approaches. The latter fueled a plethora of false⁸⁸ claims but real success is still a *work in progress* because the bridge between data and decisions will be perpetually *under construction*. Productivity gap and corporate waste are indicators that existing approaches (see Figure 4) are flawed, failing or have⁸⁹ failed. We need new roads. The boundary of our thought horizon ‘map’ is in Figure 4. The tools are incremental variations⁹⁰ garnished with gobbledygook alphabet soup. Unable⁹¹ to create any breakthrough, the return of seasonal “winters of AI” indicates the struggle to shed new light in this field since the grand edification⁹² during the 1950’s. Unable to cope with data challenges, hard facts⁹³ and difficult progress, the field offered a perfect segue for con artists and hustlers to inculcate falsehoods and deceive⁹⁴ the market. Machine learning was substituted⁹⁵ by mindless drivel from ephemeral captains of industry and generated hype⁹⁶ from corporate⁹⁷ marketing machines.

AVOID THIS SPACE – THE DECEPTION SPACE

Data consumers have been led astray by vacuous buzz words manufactured mostly by consulting groups. Part of the productivity gap may be due to fake news, propaganda⁹⁸ and glib strategy from smug consultants to coerce large contracts with cryptic “billable hours” to help “monetize” false promises due to “big” data, fabricated⁹⁹ claims¹⁰⁰ of “intelligence” in artificial intelligence¹⁰¹ and deliberately conniving misrepresentations¹⁰² of “blockchain” as a panacea¹⁰³ for all problems¹⁰⁴ including basic food safety and security. Callous and myopic funding agencies invested billions in academic¹⁰⁵ industry partnerships to fuel banal R&D efforts orchestrated by corporate collusion¹⁰⁶ and perhaps¹⁰⁷ criminal¹⁰⁸ practices. Abominable predatory practices on display in Africa are disguised under the “smart cities” marketing campaign to mayors of *African cities, which cannot even provide clean drinking water to its residents*. Vultures from the industry¹⁰⁹ are selling mayors of African cities surveillance technology and AI in the name of cameras for smart city safety and security. These behemoths are cognizant as to how autocrats use data as an ammunition to plan and justify abuse of its citizens, through algorithms of repression.

EXPLORE THE SOLUTION SPACE – NECESSARY TO ASK QUESTIONS THAT MAY NOT HAVE ANSWERS, YET

Uploading data from nodes along a variety of supply chains is an enormous undertaking given trillions of interconnected processes and billions of nodes with extraordinarily diverse categories of potential data streams, with different security mandates, for example, [a] sensor data about heavy metal (mercury) contamination in water used for irrigation, [b] near real-time respiratory rate of patient with COPD (chronic obstructive pulmonary disease) under remote monitoring telemedicine in rural nursing home, and [c] automated check-out scan data from retail grocery store sales, of fast moving consumer goods, contracted for replenishment (penalty for out of stock) under vendor managed inventory (VMI). The *e-tail* revolution is creative supply chain optimization and reducing retail information asymmetry.

Transforming data and data analytics to inform decision support for *small* cross-sections of examples cited, here, may be theoretically easy in “*power point*” diagrams which “connects” nodes and integrate decisions which circle back to optimize processes, *using pixels*. The reality may be different.

Aggregating data, from various nodes, sub-nodes, devices and processes, on a platform, to enable collective evaluation of dependencies, which could influence outcomes/decisions, may be not only beneficial, but must be mandatory for certain domains, for example, healthcare¹¹⁰ and clinical¹¹¹ environments where patient safety¹¹² must be of paramount importance.

Any *one* standard platform approach is unlikely to succeed. But a platform approach is probably rational. Multiple segments, on standard (open) platforms, with secure, yet selective interoperable data exchange, between platforms, may address a few challenges. Bringing together various options with respect to data acquisition and analytics, begins to catalyze information flow, decision support and *meaningful*¹¹³ use of data¹¹⁴. This suggestion is a few decades old, but not yet a trend, in practice. The drive to connect data was accelerated by the introduction of the concept of the internet of things¹¹⁵ (IoT). Platform¹¹⁶ efforts¹¹⁷ are addressing data¹¹⁸ upload from devices and sensors¹¹⁹ (Figure 5).

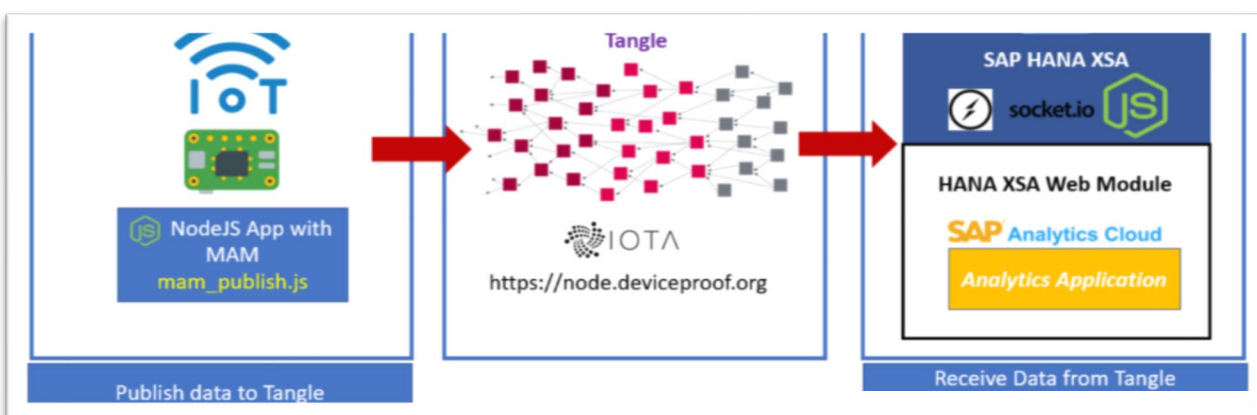


Figure 5 – National and international consortiums, in partnership with large and small software companies, are addressing data acquisition and aggregation. In this example, Tangle appears to be a data aggregation platform (example shows data from a temperature sensor) which can serve data analytics engines to extract information (if data contains information). Replication of “Tangle” for various verticals (retail, health, logistics) and the ability to use open data distribution services¹²⁰ may facilitate interoperability between data “holding” services like Tangle. When coupled with supply chain track and trace systems, a retail store (Target, Tesco, Metro, Ahold) can use Tangle data to inform a customer that the One-Touch blood glucose testing strip (healthcare product manufactured by J&J) will arrive at the store (3rd party logistics provider and distribution transportation service) on Monday by 2am and placed on store shelf by 530am (retail store replenishment planning) or delivered to the customer on Tuesday before 9am (online fulfillment services). Any data can be uploaded/downloaded from Tangle.

SOLUTION ECONOMY – WILL WE EVER GET THERE?

There aren't any silver bullets and one shoe doesn't fit¹²¹ all. If we focus on the data to decision process, alone, in any vertical or domain, the variations of analysis and analytics may be astronomical. Initial investments necessary for these endeavors almost guarantees that the extracted value from data (and relevant information) may not be democratized or made functionally available to the less fortunate. In principle, the outcome from data to decisions, when appropriate, must be sufficiently distributed and democratized to provide value for communities under economic constraints. Any *meaningful* solution, therefore, is not a scientific or engineering outcome, alone, but must be combined with the economics of technology¹²² which must be a catalyst for implementation and adoption by the masses, if transaction costs¹²³ can be sustained by the community of users.

The economic principle for impoverished environments may be rooted in micro-finance¹²⁴ and micro-payments¹²⁵ with *low* transaction costs (*the downside*: misinformation¹²⁶ can be propagated and disseminated at *low* cost, too). By eliminating classical "product sales" the focus shifts to delivery of "service" which is a *package* of the product plus other resources (retail mobile banking, infrastructure, telecommunications, cybersecurity¹²⁷, security¹²⁸, customer service). Users pay (pennies) *only when they use the service*. PAPPU¹²⁹ (pay-a-penny-per-use or pay-a-price-per-unit) is a *metaphor* for economic instruments to lower the barrier to entry into markets with billions of users.

The economic incentive for democratization of data is the potential to unleash/create new markets for data, information and decision support, for billions of new consumers (users). The **reward** in the lucrative service economy model depends on harvesting the economies of scale where each user (market of billions) may pay one or more "pennies" (micro-payment for pay-per-use services). The **risk** in the service economy is the collection of that "penny" (per use) at the last step of the *seamless* service delivery process, if the user is satisfied with the quality of service (QoS) metrics. The plethora of partners necessary to create and sustain the ecosystem to deliver the *seamless* service is a herculean task. Sharing a fraction of that "penny" with the partners in the ecosystem is not a trivial challenge. If the QoS delivery metrics suffer due to poor performance of any one partner (component), the end-user "penny" may be unpaid if the QoS metric fails to reach a pre-determined value (time, duration, speed, rate, volume). The inability of one provider (weakest link) in the service supply chain can be financially detrimental to all other supply chain partners due to loss of that penny, *albeit, only for that transaction* (unless the partner has a chronic problem, then, it must be excluded from the ecosystem and the entire value network¹³⁰). Delivery of service is a real-time convergence of operations management which includes (but is not limited to) multiple value chains which must integrate¹³¹ the physical supply chain and the financial supply chain with the service supply chain and customer relationship management (brand expectation).

Determining the cost of execution, to deploy, the example in Figure 5, may be an effective way to study feasibility. By simulating models to explore "what if" scenarios, it may be possible to predict the potential for adoption of services in the context of various economies of scale and PAPPU models which could unchain the economics of technology adoption.

IS THIS FAUX NAÏVETÉ IN ITS PUREST DISTILLATE?

Decision scientists must build a compass to help extract value from data. One compass will not suffice to guide domain-specificity. Existing tools may limp along with *snail-ish* advances (Figure 4) yet it may remain inaccessible to the masses because the tools may not be feasible for mass adoption. The struggle to transform data into information is still in quest of a Renaissance.

The path from *data-informed* to *information-informed* decision remains amorphous. The grand “highway” from information to knowledge is still in the realm of unknown unknowns. Making sense of data is handicapped due to [i] an apparently insurmountable semantic barrier, [ii] scarcity of tools to facilitate location-aware and context-aware discovery of data at the edge or point of use, [iii] lack of standards and interoperability between platforms and mobile devices for data and analytics sharing.

Users in non-OECD nations may not want to idle away while the architects of Renaissance are still in short supply. In the near term, it is necessary that we continue to work on dissemination of data which can deliver at least some value, sooner, rather than later. Decision support based on sensor data analytics may provide economic benefits¹³² and incentives, if we can share the digital dividends with the masses, for example, in health¹³³ and agriculture, including every facet of food, required, daily, globally.

Tangle, a tool¹³⁴ to share sensor data using MAM¹³⁵ (masked authenticated messaging) may offer hope. Can nano-payments for sensor data address some of the feasibility challenges¹³⁶ and pave the way for human-centric economy of things¹³⁷ using IoT as a design metaphor? SNAPS¹³⁸ is a tiny step in that general direction: distributing low cost tools to enable data-informed decision support for less complex problems. Assuming the Pareto principle is working, perhaps 80% of the problems may be addressed, and even resolved, with simple tools to deliver solutions as a *service*, at the right-time, at the point of use.

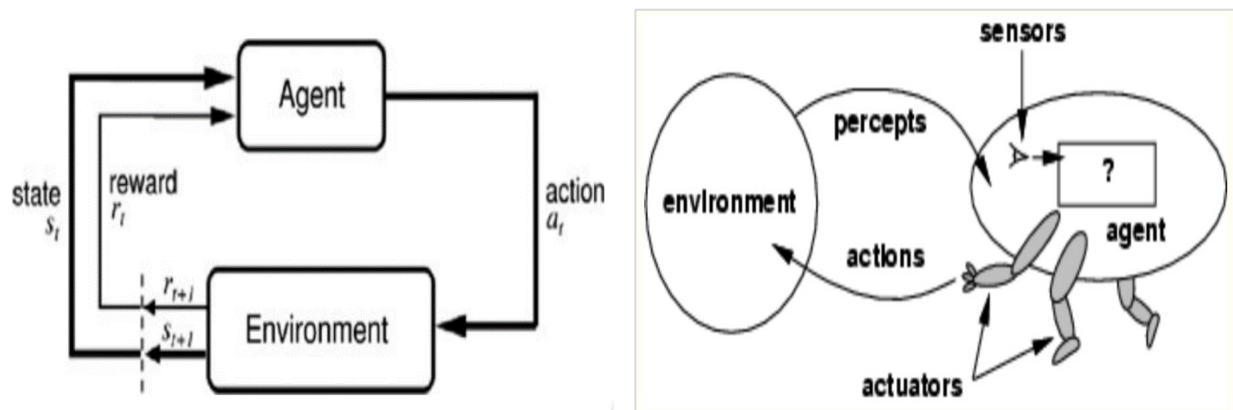


Figure 6 - SNAPS is one layer in a proposed analytics platform (layer cake) which consists of a portfolio of tools aligned with the concept of PEAS¹³⁹, a mnemonic borrowed from agent-based systems (R), to address systems performance through convergence of percepts, environment, actuators, and sensors. (L) Reinforcement Learning¹⁴⁰ (Figure 4), a machine learning technique, compared with PEAS.

REALITY CHECK – DATA FUSION

The inflated view of the sensor-based economy¹⁴¹ is carefully¹⁴² crafted¹⁴³ to create¹⁴⁴ new markets¹⁴⁵ and momentum¹⁴⁶ for sales¹⁴⁷ of sensors and data services¹⁴⁸ aimed to amplify the IoT¹⁴⁹ hype to fortify the deception game. It is promoting the desired effect by spawning mass hysteria and skillfully obfuscating the hard facts which then paves the ground for hordes of consultants to act as “trusted advisors” to make sense of this “revolution” which is supposedly going to change the future of work, life and living. One glaring outcome of delusional¹⁵⁰ propaganda¹⁵¹ is the near trillion dollar³⁹ waste related to investment in technology with a failed ROI. Trillions of sensors and devices that *could* connect to the internet (basis for the cosmic scale of IoT) is due to the scale of unique identification¹⁵² made possible by adopting a 128-bit structure in the internet protocol. The unique address spaces in IPv6¹⁵³ is **29 orders of magnitude higher** than IPv4 if one compares¹⁵⁴ 4.3×10^9 address spaces for the 64-bit IPv4 versus 3.4×10^{38} unique address spaces for the 128-bit IPv6. New possibilities¹⁵⁵ and applications¹⁵⁶ may arise due to the flexibility of IPv6 to directly connect to the internet (rather than sub-nesting under/via gateway nodes).

The difference between promise and perils in deploying the concept of IoT as a design metaphor is rooted in grasping the difference between connectivity, discovery and actionable insight. Just because something is *connected* does not mean value emerges, automatically, without a *connected ecosystem*. If a visitor’s tablet can discover the printer in an office and use it to print a meeting agenda, then we have extracted some type of value between the connectivity of the tablet and the printer, which were able to “discover” each other, and that discovery enabled the gain in efficiency (printing the agenda). In its basic form, this is an example of very simple data fusion which leads to an actionable output and provides “information” for the meeting attendees in terms of the printed agenda. Connecting trillions of entities to the internet is an exercise in futility unless discovery and data fusion enables meaningful extraction of data to move up the DIKW¹⁵⁷ value chain¹⁵⁸ where data precedes information, knowledge and wisdom.

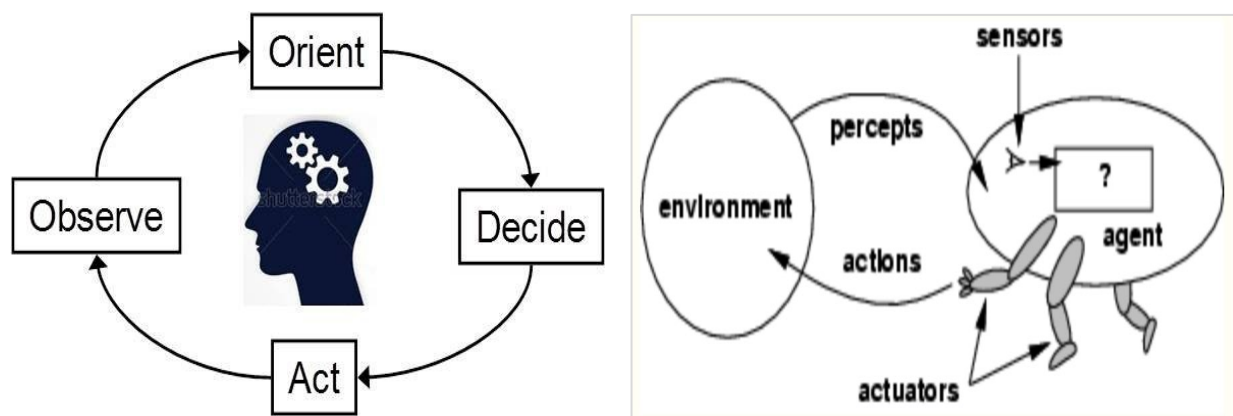


Figure 7 - PEAS, a mnemonic borrowed from agent-based systems (R), addresses systems performance through convergence of percepts, environment, actuators, sensors. The OODA¹⁵⁹ loop (L) and PEAS¹³³ contribute to advance DIKW (data, information, knowledge, wisdom), which begins with data fusion¹⁶⁰.

The PEAS paradigm resembles OODA (Figure 7) because “observations” refer to scanning (sensing) the environment and “orientation” informs the image of the environment by encapsulating both descriptive and predictive analytics (“decide” includes prescriptive analytics). The integration of data fusion and analytics with agent-based systems is critical in the era of IoT. The networked society faces a deluge¹⁶¹ of data yet the human ability to deal with data, analytics, and synthesis of information may be inefficient. How can devices discover data and facilitate processes without intervention by humans? Automated on/off action taken by a domestic thermostat and HVAC based on temperature sensors may be quite primitive when considering autonomous objects in air (UAV), land and water.

Raw sensor data unless discovered and combined with “perceptions” from the environment, may be context-deprived and over/under utilized, which lowers the value of the data with respect to the desired goals. The perception from the environment is not unique but a “learning” task for the system. It may re-use the experience (learning), when relevant and appropriate, at a different instance (Figure 6). Can this “learning” become mobility-enabled and “teach” other devices, for example, by transmitting a *tutor* virion to another computer or drive or system? Can this device communicate in natural language and/or respond/understand the semantics in human queries?

Taken together, unleashing the value of data may require coordination of ABS (agent-based systems) in every facet of our interaction with machines, objects, and processes which may benefit from feedback. ABS is an old¹⁶² concept¹⁶³ but resistant to succinct definition¹⁶⁴ because agent activity must remain agile and adapt to the operating objective (PEAS) and problem context (OODA). Equation-based models create rigid, hard-coded software. Agent-based system design induces agility, may enable “drag & drop” variant configuration to adjust (on-demand) to volatility, uncertainty and ambiguity, inherent in most environments. In the context of democratization of data and benefits for the masses, agents can be highly personalized and “belong” to people, for example, personal agents, as discussed¹⁶⁵ elsewhere, with respect to cybersecurity. A similar modus operandi can be adopted for other use cases where data fusion¹⁶⁶ can be dynamic and composable (composed when necessary, depends on context) not only for use-cases but also for individual user-specific cases/applications.

Agent Characteristics	Definition
Autonomy	Operates without the direct intervention of humans or others
Sociability	Interacts with other agents, that is, communicates with external environment such as sensors, fusion systems and human operators
Reactivity	Perceives its environment and responds in a timely fashion
Pro-activity	Exhibits goal-directed behavior by taking the initiative
Learnability	Learns from the environment over time to adjust knowledge and beliefs
Mobility	Moves with code to a node where data resides
Anthromorphicity	Externally behaves like human

Table 1 – Generally, Agents are computational entities (software) designed to perform specific tasks, autonomously. Agents embedded in devices (sensors) may have logic capabilities to perform artificial reasoning tasks (ART) and/or optimization¹⁶⁷ in multi-agent systems (MAS)

The role of software agents to “discover” and then determine which data and/or data fusion may be meaningful or relevant (user-specific), is an old idea, waiting to be effectively applied. Connecting data must be contextual. The *established* contextual relationship must be discovered and “understood” by agents or group of agents. Another old idea is to *pre-establish* the context based on knowledge graphs. The common thinking that W3C standard RDF¹⁶⁸ (resource description framework) triples are the solution for knowledge graphs is incomplete. This myopia, is, in part, one reason why the semantic web¹⁶⁹ failed to flourish. The brilliant idea of representing subject-predicate-object (SPO) as a relational RDF graph is certainly useful and applicable in many instances but the approach *bites the dust* when the reductionist 1:1 granular relationship fails to represent reality. The latter is painfully obvious, especially in medicine and healthcare, where the rigidity of the RDF standard structure and RDF schema may be an anathema. The “force-fitting” of RDF to healthcare applications¹⁷⁰ oversimplifies scenarios to the point where it may, inadvertently, introduce errors, simply due to exclusion, which may prove to be fatal.

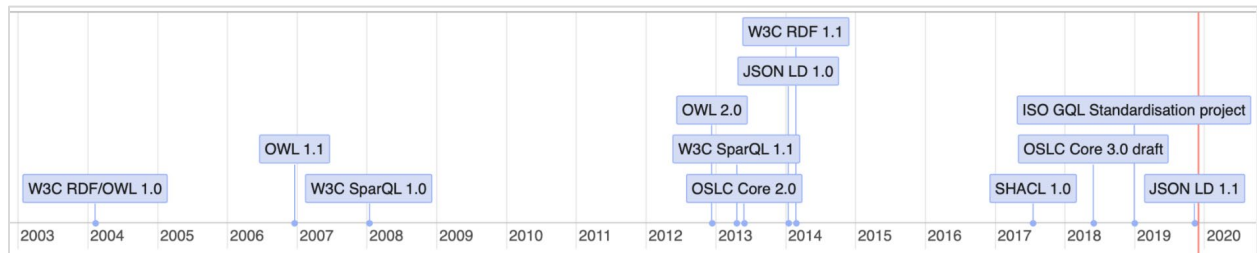
One proposal suggests adapting¹⁷¹ RDF by creating relationships between sets/subsets (rather than points and vertices as in classical SPO) using the set theoretic¹⁷² approach. It is easy to grasp why “set” of symptoms and potential set of causes may make more sense in medicine and healthcare. The overlapping (Venn diagram) subset of relationships may be indicative of likely causes for symptoms. Generic symptoms, for example, fever, can be due to a plethora of causes and why a rigid 1:1 relationship in RDF could turn lethal in healthcare applications. The finer granularity of RDF is a disadvantage yet it is key to merging attribute lists about an entity sourced from different data sources. The latter enables better search and discovery across diverse domains, the hallmark of globalization of enterprise systems.

An even older idea¹⁷³ which is recently¹⁷⁴ enjoying scientific¹⁷⁵ as well as public attention¹⁷⁶ is the labeled property graph (LPG). It is suitable for use cases which may be focused on providing stores for single applications and single organizations, such as, domain-specific denominator models (DSDM). LPG proponents are less committed to standardization, interoperability and sharing. It is in contrast to the W3C ethos and RDF which favors standardization, interoperability and sharing, which makes it useful in discovery using graph pattern searches. Optimization of local (domain specific) searches¹⁷⁷ using graph-traversal algorithms¹⁷⁸ are better suited for property graph (PG) databases. Knowledge graph networks embedded between sets/subsets may give rise to amorphous “linked” clouds, which could be industry¹⁷⁹ specific and may be domain specific¹⁸⁰ as well as user specific. Imagine if data from each patient could be used by an **automated knowledge graph engine** to create precision, patient-specific and personalized knowledge graphs. Extracting the relationships and contextualizing the relevance of symptoms may influence the accuracy of diagnosis. When viewing knowledge graphs in a population study (epidemiology), it may be easier to detect outlier events or cases that did not fit expected patterns.

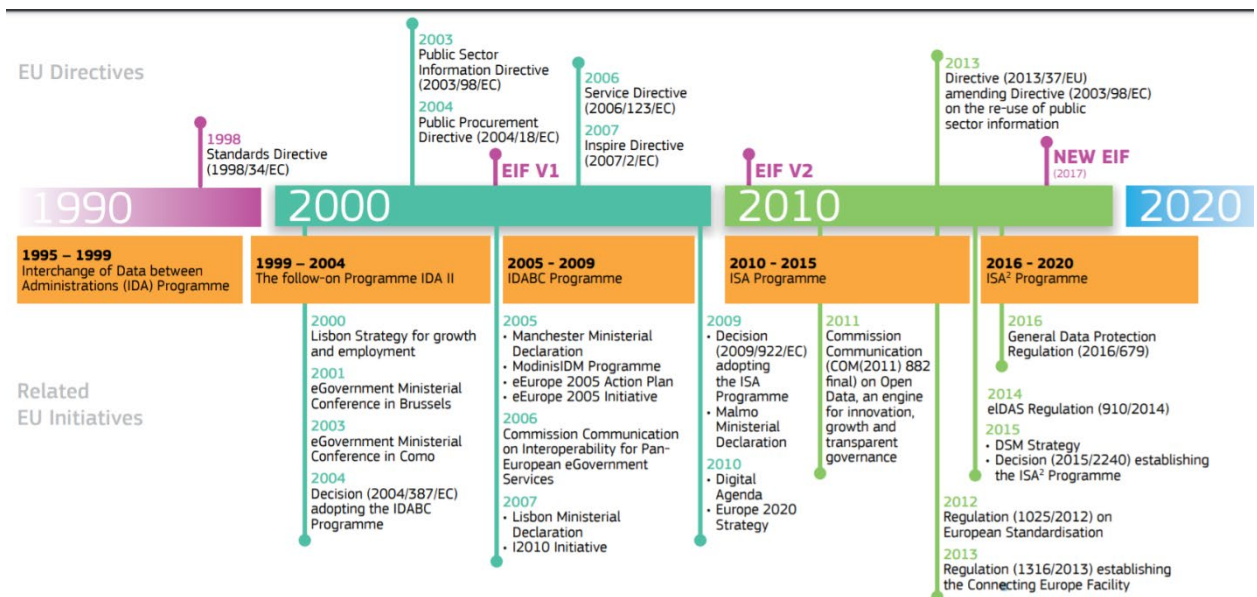
Therefore, domain specific denominator models (DSDM) may be represented as a domain/user specific knowledge graph networks. Agents may be invaluable in working within this environment to discover relationships and contexts (specificity reduces search space), as well as discover data sources, and perhaps, based on embedded logic, decide whether the features or attributes calls for data fusion.

Running Title: Unsustainable and Misaligned Economics of Technology triggers a Porous Pareto Partition Between the Haves and the Have Nots: Can Democratization of Distributed Data act as a Catalyst for the Dissemination of Digital Dividends?

For any agent-based approach to succeed, it is critical that the agent framework and standards are interoperable with the knowledge graph network and the data domains where the agent is searching. The opposing tendencies of RDF vs LPG in terms of standardization, interoperability and sharing may limit agent mediated “cross-investigation” of domains, discovery and data. Therefore, it begs to question the expectation why one agent must perform in all domains. Perhaps, the success of agent search and discovery depends on semantically annotated structured data. The latter depends on ontological structure. W3C proposed¹⁸¹ OWL standard web ontology language¹⁸² and recent variations (VOWL¹⁸³) may contribute to interoperability. The old idea of Internationalized Resource Identifier (IRI), as a complement to the Uniform Resource Identifier (URI)¹⁸⁴ to identify resources (to facilitate discovery) is a valid principle but yet to be adopted in practice. The plethora of old ideas (referred here) suggests that the value of these ideas may have to be revisited. This field needs new “blood” and new “eyes” to imagine new ways to address interoperability. But, in reality, today, on top of this wobbly incompatible infrastructure, we are layering the “snake oil AI” and unleashing an incorrigible torrent of half-truths.



Timeline 1: Long march of graph related¹⁸⁵ specifications. Is standardization a sufficient solution?



Timeline 2: EU’s Elusive¹⁸⁶ Quest for Interoperability: Is 30 years not enough?

“DOUBLE A” PERSPECTIVE OF DATA AND TOOLS vs THE HYPOTHETICAL POROUS PARETO (80/20) PARTITION

If combined, Africa (1+ billion) and Asia (4+ billion) approximates 75% of the world’s current (2019-2020) population. The corporate view of 75% of the world’s market is driven by the promise of new markets, new customers and new wave of consumerism. It has little to do with lifting the lives of people. Our discussion about the physics and mathematics of data, therefore, is *a tempest in a tea cup*. For 5+ billion people, the trial and tribulations of data and data analytics, we have discussed here, can be dismissed with an eye roll. It is useless for most pressing daily applications in the “double A” world.

Thus far, what we have discussed, on one hand, may be an exploration of the tessellated facets in our search for meaning, and on the other hand, it is a discussion which may find parallels with the “six blind men and the elephant” syndrome¹⁸⁷ apparently divorced from complementarity¹⁸⁸ or synergy. It is as if the outcome from 20% of the global population, relevant or not, is thrust upon the remainder of the world market. In 80% of the cases for 80% of the global population the daily decisions about FEWSH (bare necessities of life: food, energy, water, sanitation, healthcare) do not require artificial intelligence, machine learning algorithms or optimization of ‘state space’ for hundreds of variables.

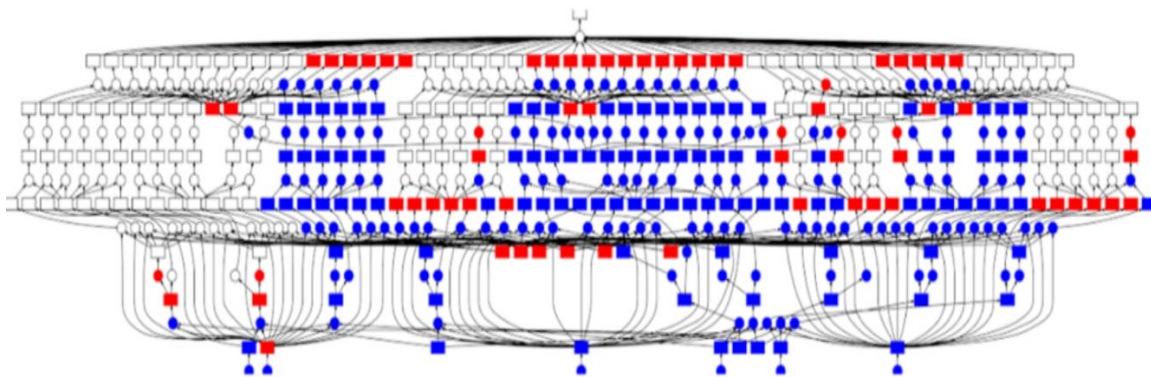


Figure 8 - Blind men and elephant. Each man guesses his own part of the elephant but blinded by hype¹⁸⁹ they cannot perceive the “whole” elephant. A metaphor for focus on parts, which occludes the system. Cartoon (bottom): penchant for decision trees by *power-point* rather than search for low hanging fruits.

In 80% of the cases for 80% of the global population the daily decisions about FEWSH require data, *small data*, data in near real time and data that only impacts and enhances the user. In that context, jumping up and down about *democratization of data* is tantamount to chest-thumping. The data in these use cases may be related to a subset of FEWSH (food, farm, agriculture, water, healthcare). If the tools are there to acquire this data, then the data is available. Therefore, is democratization really an issue? Is it a politically correct word that the 20% world prefers to use as a hand-waving advocacy of problems that are divorced from reality on the ground? Is “democratization” a “theme” song for advocacy groups in OECD nations who may display the symptoms of the *six blind men and elephant syndrome*?

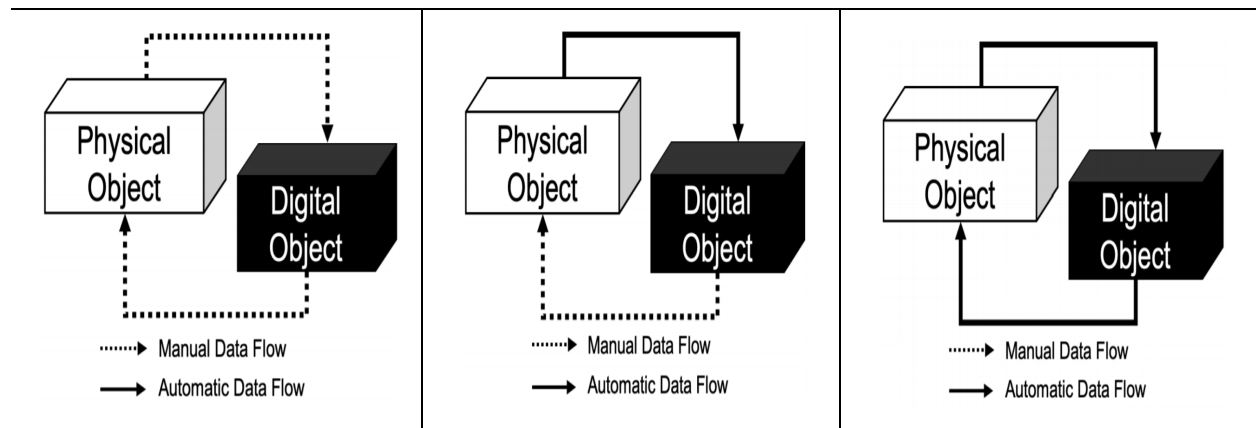
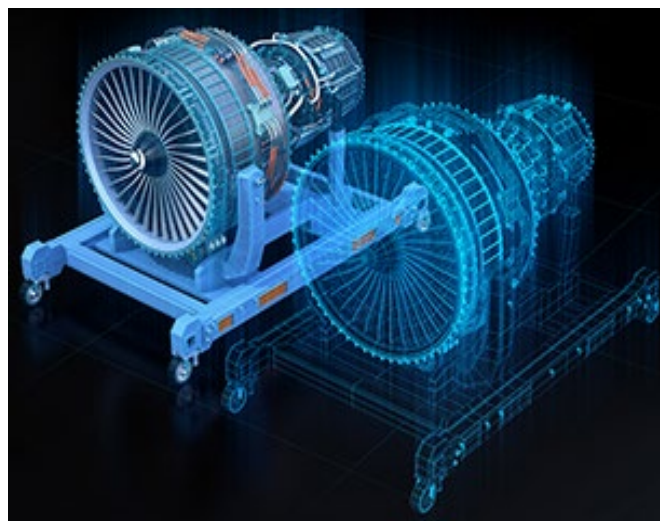


Figure 9 – Digital Duplicate (left), Digital Shadow¹⁹⁰ (center), Digital Proxy (right) and Digital Twin (bottom) are variations of digital models of physical objects, integrated with data flow. But, do we know if it is *meaningful* for data related needs for 80% of the world? It is unlikely to be solved by Digital Twins¹⁹¹ or flamboyant gimmicks peddled by fake pundits on the pages¹⁹² of *Forbes*. However, the R&D related to these tools may trickle through the “pores” from the 20% side of the partition to the other side (80%) of the *porous* Pareto¹⁹³ partition and occasionally¹⁹⁴ may be helpful.



The number and provision of central DXA units available in the EU27 (Data on reimbursement and waiting time [10])

	DXA units/million	Waiting time (d)	Cost (€)	Reimbursement
Austria	28.7	14	30 [11]	yes
Belgium	53	14	34 [12]	partial
Bulgaria	1.2	0	59 [9]	none
Cyprus	23.9	20	75 [9]	yes (depending on income)
Czech Republic	5.2	40*	32 [9]	yes
Denmark	14.6	30	187 [13]	yes
Estonia	8.9	14	14 [14]	yes
Finland	16.8	1	146 [15]	yes
France	29.1	14	41 [9]	yes (conditional)
Germany	21.1	0	36 [9]	yes
Greece	37.5	11*	115 [9]	yes
Hungary	6.0	15*	7 [16]	yes
Ireland	10.0	140* ^a	99 [17]	yes (conditional)
Italy	18.6	83*	81 [9]	yes (conditional)
Latvia	4.9	10*	18 [18]	yes
Lithuania	3.4	6*	28 [19]	no
Luxembourg	2.0	30	59 [20]	yes
Malta	9.7	105*	184 [21]	yes
Netherlands	10.7	14*	84 [22]	yes
Poland	4.3	1	10 [9]	yes (conditional)
Portugal	26.9	8	5 [23]	yes
Romania	2.4	7	5[24]	yes
Slovakia	10.7	18*	32 [9]	yes
Slovenia	27.1	11*	29 [25]	yes (conditional)
Spain	8.4	105*	109 [9]	yes
Sweden	10.0	60	152 [26]	yes
UK	8.2	11*	51 [27]	yes ^d

Table 2 – Availability¹⁹⁵ of DEXA (dual energy x-ray absorptiometry) scan machines to measure bone mineral density (BMD), a fair prognosticator for osteoporosis. The European standard¹⁹⁶ is 11 (DEXA) DXA units/million. In an updated estimate, the poorest country in EU27 offers 4 machines/million¹⁹⁷ whereas Bulgaria’s neighbor Greece boasts 37.5 DXA units/million. In comparison, Indonesia¹⁹⁸ has only 0.13, India¹⁹⁹ 0.18 and Morocco²⁰⁰ 0.6 DXA units/million. For the health of the people in these nations, how can democratization of data lower their risk of osteoporosis? Are we asking the correct questions? Are we pursuing the wrong reasons? Are we arm-chair analysts helping the (BMD) medical device industry²⁰¹ accelerate their sales campaigns to AA nations? Can data provide relevant answers?

Table 2 offers a glimpse of one problem in healthcare. The tools to acquire the data are in short supply. Measuring the risk of osteoporosis is a prerequisite for prevention and treatment, if affordable. Arm-chair “scenarios” of medical IoT will want to connect DEXA (DXA) scan data with sales of milk and exposure to sunlight as a “wellness” indicator. From the “double A” perspective, it may be a futile “power point” exercise because milk *may not be available* for the age group²⁰² generally at high risk of osteoporosis in the AA nations. In most parts of Africa and Asia there is an opulence of sunlight.

Just because there is an “IoT” scenario, does not mean it is worthwhile or valid for users in “double A” nations. Just because there is data also does not result in information. Can we reduce incidence rates of osteoporosis simply by adding more DXA machines per capita? A recent (2013) study using seven national electronic healthcare records (EHR) databases revealed that Denmark (14.2 DXA units per million) showed age- and sex-standardized incidence rates (IRs) of hip/ femur fractures 2X higher than those observed in UK (8.2 DXA units/million), Netherlands (10.7 DXA units/million), and Spain (8.4 DXA units/million), while Germany (21.1 DXA units/million) yielded IRs in the middle range.

DRUG	PRESCRIBED FOR	UK PRICE	US PRICE	PRICE RISE
NEXIUM per 20mg tablet	Acid reflux	£0.66	£7.40	1120%
ACTIMMUNE, 12 vials	Genetic diseases, osteopetrosis	£5,400	£42,990	800%
DARAPRIM per tab	HIV, cancer, malaria patients	£2.30	£619	26,900%
NASONEX, 50mg	Nasal allergies	£7.68	£224	2,900%
CINRYZE, 2 vials	HAE, genetic disorder	£1,336	£3,645	200%
HARVONI per tab	Hepatitis C virus	£464	£928	270%
SOVALDI per 400mg tab	Hep C in children under 12	£416	£855	200%
DIAZEPAM, per tab	anxiety, relaxation, muscle spasms	£0.02	£3.05	15,200%
OVEX, 100mg tablet	Threadworm parasite	£2.54	£300	11,800%
LIPITOR, per 10mg tab	Statin	£0.46	£4.50	980%
VIAGRA, per 25mg tab	Male impotency	£4	£61	1,500%
ZOCOR per 10mg tab	Statin	£0.64	£4.20	656%
CYMBALTA per 30mg capsule	Anti-depressant	£0.80	£9.48	1,200%
EPIPEN, 300mg	Allergies	£52.90	£523	1000%
HUMALOG INSULIN	Diabetes	£16.61	£215.30	1300%
HIP REPLACEMENT OPERATION		£7,313	£26k-£37k	350%
KNEE REPLACEMENT OPERATION		£6,315	£24,801	390%
CATARACT OPERATION		£803	£5,780	720%

Table 3 – Plague of unethical profitability makes US pharmaceutical²⁰³ business model in healthcare an abomination which is inappropriate for mimicry in any part of the world. Source: Dr James Nolan²⁰⁴

CONUNDRUMS

On one extreme we have presented sophisticated ideas for making sense of data. On the other hand, we doubt whether the toothless call for *democratization of data* from the affluent 20% of the world can help to lift the lives of people on the other side of the porous Pareto partition (80% of the world). It is not a true “Pareto” scenario, but the 80/20 nature of this problem evokes the Pareto principle as an analogy, hence, Pareto partition. The R&D outcome of the 20% may contribute certain elements to the 80% side. The “partition” is a metaphorical porous membrane, with bidirectional porosity, if necessary.

Often, it may not be necessary. For example, is it necessary to deal with data and data models in this scholastic²⁰⁵ manner (Figure 10) for all problems? The 80/20 global partition may be prominent in agriculture, healthcare and energy. In case of the latter, what is the value of smart metering or load balancing algorithms when there isn’t enough energy, at an affordable cost, to supply the basic tenets of economic growth? How many farmers in the “80%” world can afford to use the drone-on-demand²⁰⁶ system? Why should people from the majority sector (80%) need useless marketing tools²⁰⁷ when daily healthcare for the less fortunate can solve a myriad of problems with *just-in-time little bits of data*, for example, daily blood glucose level from a diabetic (versus the *always-on* real-time monitoring of blood glucose) or monitoring individuals for silent myocardial ischemia²⁰⁸, a leading contributor to death. This is the debate where the economics of technology and its *relevance to the community* are crucial issues which may *enable* adoption or *disable* the dissemination of technology, which could have contributed to economic growth, workforce development and sustainable job creation.

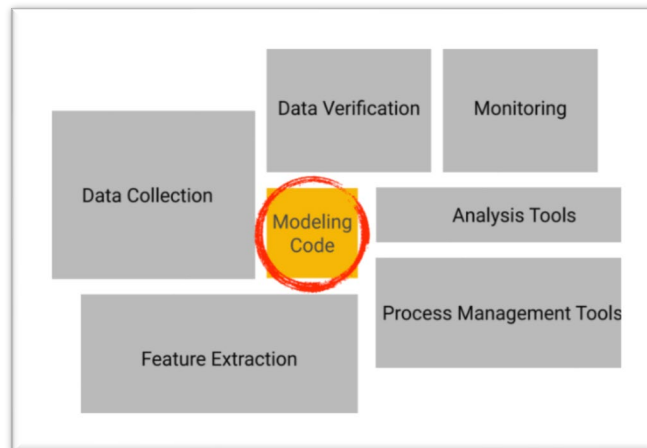


Figure 10 – From monitoring an event to using the data to inform a decision, there are a plethora of steps²⁰⁹ in the standard operating procedure (SOP) for the “20%” deploying data to drive decisions. However, irrespective of socio-economic issues, in future, all aspects of feature selection and feature engineering may emerge as a pivotal or rate limiting step in dealing with diverse data sources. In this context, automated feature extraction and other feature related steps may be a very significant step. *In combination, automated feature engineering and automated knowledge graph engines (see page 16) may usher new dimensions in data and data analytics, if automated data curation could improve data quality.*

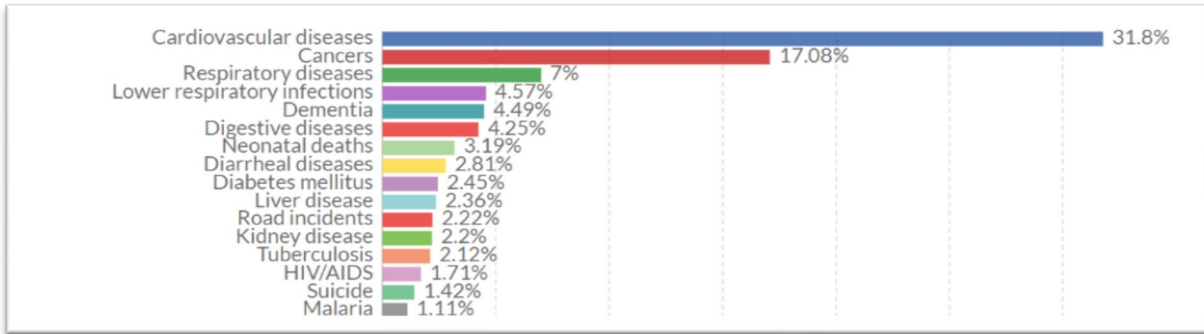


Figure 11 – Share of deaths, by cause (2017) percent of total deaths²¹⁰. Data refers to specific cause of death, which is distinguished from risk²¹¹ factors for death (water and air pollution, diet, sanitation).

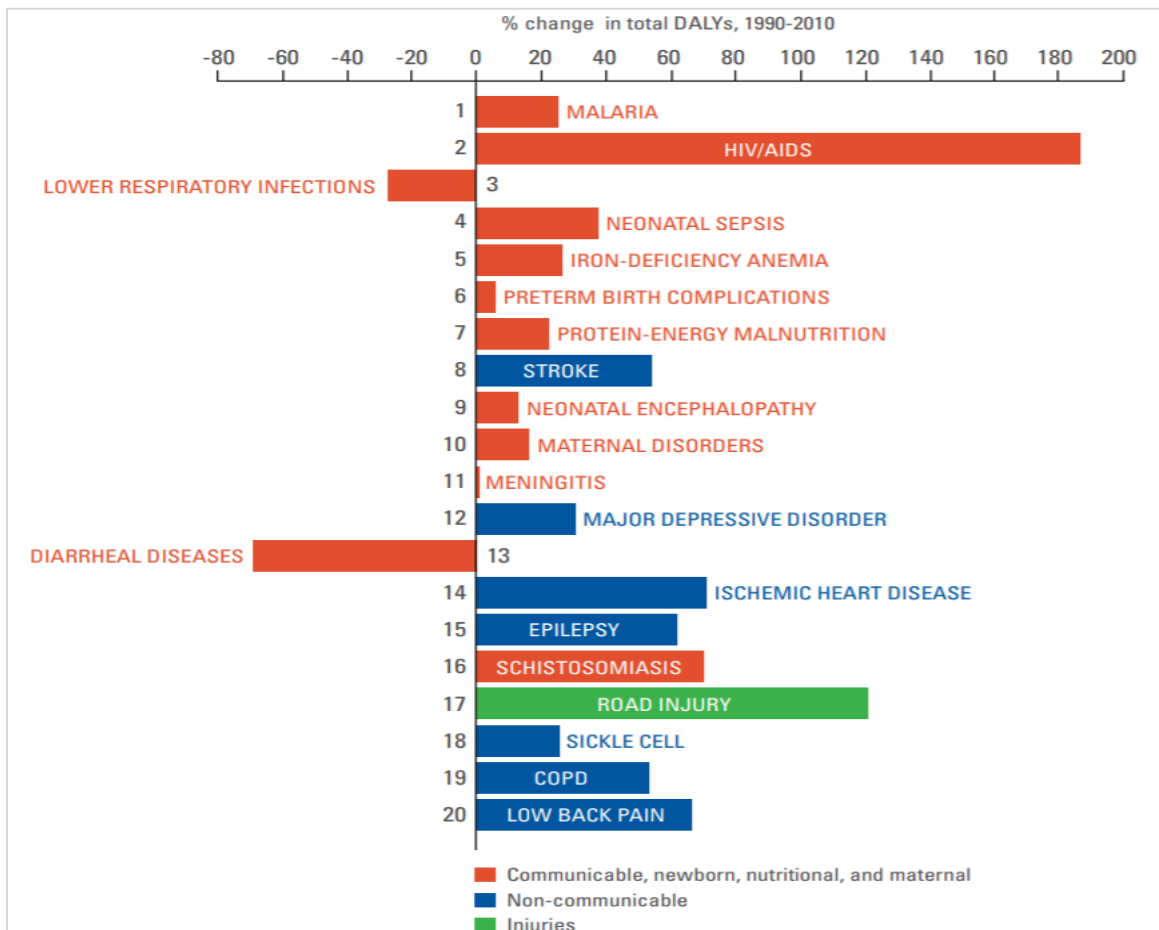


Figure 12 - Shifts²¹² in leading causes of DALYs for females, Ghana (1990-2010). The leading 20 causes of DALYs are ranked from top to bottom in order of the number of DALYs they contributed in 2010. DALYs (Disability-adjusted life years): The sum of years lost due to premature death (YLLs, Years of life lost due to premature mortality) and years lived with disability (YLDs, Years of life lived with any short-term or long-term health loss causing disability.). DALYs are also defined as years of healthy life lost.

Worldwide, Africa²¹³ accounts for 9 out of every 10 child deaths due to malaria, for 9 out of every 10 child deaths due to AIDS, and for half of the world's child deaths due to diarrhoeal disease and pneumonia. More than one billion children are severely deprived of at least one of the essential goods and services they require to survive, grow and develop²¹⁴ - these include nutrition, water, sanitation facilities, access to basic health-care services, adequate shelter, education and information. As a result, almost 9.2 million children under-five die every year and 3.3 million babies are stillborn. Most of the 25,000 children under five that die each day are concentrated in the world's poorest countries in sub-Saharan Africa and South Asia. There, the child mortality rate is 29 times greater than in industrialized countries: 175 deaths per 1000 children compared with 6 per 1000 in industrialized countries.

These facts (paragraph above) and Figure 12 offers a vastly contrasting view to that of data tools and democratization of data as essential for lifting the lives of the people living on the majority side of the porous Pareto partition. Simple forms of small amount of data, sufficiently informing ordinary tasks, may be suitable for delivery of global public goods and services to the majority of the 80% world. It is absolutely ludicrous to think that "big" data, AI/ML, blockchain or smarmy publicity²¹⁵ stunts may help, in this context. What we need is the concept²¹⁶ of "bit dribbling" perhaps coupled with pay-a-penny-per-use (PAPPU) systems to help people improve their quality of life without the constant need for charity.

Technology may play a central role to reach the billions who need service but not in the form of business²¹⁷ which is staple in the West and copied by the thoughtless Eastern schools, especially in India. Technical tools will generate data. The ability to use that data, judiciously, may be key to the value of data, for impoverished nations. Coupling social need with technical catalysts must be optimized in the context of the community and not according to *Wired* or *MIT Tech Review* or *HBR*. Advanced R&D is the bread and butter of progress, but the application of advanced tools must be contextual to the services that the community can sustain. Just because auto maker Koenigsegg claims the *Agera* model was built with a "less is more" philosophy does not mean it is the pragmatic standard of transportation suitable for Calcutta, India. In the realm of systems engineering courses and education, dynamic optimization (DO, Figure 13) illustrates a similar perspective. The principle is worth teaching, worldwide, but the practice must be relevant to the case. Do we all need DO in everyday life and living? Is it necessary for all types of edge analytics to process data using convolutional neural networks (CNN) on a mobile device or phone?

The conundrum of *not* applying the tools we think we have mastered is counterintuitive to the problem-solving ethos in the 20% world. We are ever ready to use the latest and greatest knowledge from the bleeding edge to derive and drive the best possible 99.99% perfection and performance. The quagmire of lies aside, we do have real tools which offers notable advantages. But, the volume of the 80% of the world and the economic handicap in these communities must be assimilated in order to change our thinking. The acronym KPI (key performance indicator) is for "performance" which is euphemistic for profit in the 20% world. It may or may not be in the best interest of the people. For 80% of the world perhaps KPI should stand for "key people indicator" and ascertain whether we improved lives of people.

Improving lives, however, is relative to the life you aim to improve, a life with disabilities²¹⁸ versus life with social²¹⁹ void are active domains in robotics. Indeed, robotics is key for the 21st century but the robot propaganda, written mostly by hacks²²⁰ and driven by media²²¹ sales, is a sign of the times. Essential robotics and robots for tasks that are dangerous, dirty and dull (repetitive) are progressing in various domains.

The idea of the automated robotic factory was popularized by Philip K. Dick's fiction "Autofac" published²²² in 1955 (*Galaxy* magazine). The "lights-out" automated manufacturing facility FANUC²²³ (factor automated numerical control) is in operation since 2001, in Japan. But FANUC is an exception. Even though "lights-out" robotics made significant strides in heavy industry, it is far from the Orwellian scenarios promoted through chicanery²²⁴ and buffoonery²²⁵ aimed for profit from book sales by discombobulating the masses. In reality, the promise of robotics must be balanced with the degree of *trust*²²⁶ *in automated execution*, especially when humans are involved, directly.

In other instances where human life is at risk (for example, transportation, manufacturing, mining) the trust in automated action (robot) is as good as the planning for "what ifs" *when* the auto execution goes awry. But, that is a deterministic perspective where what could go wrong is anticipated, albeit with some degree of uncertainty. However, if a mobile robot crashes with a holonic manufacturing podium, it may generate a cascade of events where the outcome may be non-deterministic. The critical question in such a scenario is the extent to which a non-deterministic outcome can be tolerated and the *acceptable* cost of risk despite the 'open-ended' uncertainty. Few can even approach to answer this/these questions²²⁷ because it verges on the domain of unknown unknowns.

But, that may not deter simulation aficionados from pursuing stochastic (*what if*) models to capture distribution of randomness in non-deterministic outcomes. Heuristics approaches may surface to suggest contingency measures. This is "video gaming" of automation²²⁸ which could turn deadly in reality. The *executive* robot may be suited for "3D" tasks (dull, dirty, dangerous) but unsuitable for relinquishing human oversight and control if lives are at risk. However, even worse are evil acts perpetrated by humans to bury²²⁹ and ignore²³⁰ the failure of automation, in the pursuit of profit.

Robotic tools in the 20% world are engaged in sophisticated activity which may be subjected to high oversight. In general, the 80% world is not a customer for such implementations in terms of mass consumption. Automation replacing or reorganizing jobs is not a new event (for example, auto industry) because technology²³¹ shifts the cycle of jobs and with it, the economy. Rapid changes in skill sets and the volatility of job categories influence other domains, namely, K-16 education, training, skills development (capital, labor market, employment) and communication (hopefully, the truthful variety). The rate of change in certain ecosystems are dreadfully slow (for example, education system) whereas the evolution of the job market may resemble the rapid pace of bacterial growth, albeit slower than viral growth rates. The diffusion of robotics will take time and only if the building blocks of automation can be popularized, globally, in a manner that Lego blocks may have inspired young minds to compose, create and construct.

The 80% world can benefit from robotics, for example, by reducing global disease²³² burden in emerging economies and developing nations. If sewer system cleaners (mostly young children who are flexible enough to reach cramped spaces) are replaced by robotic tools to do the “dirty” work, then the health risk to the young workers and public health risk to the community (from unsafe or unhygienic sewers) may be reduced. One must balance between improving lives versus affordable robots to perform such tasks. Robotics (tools) are an ally for the underserved by helping to improve lives, enabling health and wellness, rather than fear-mongering and flagrant deception²³³ how robots will replace human jobs.

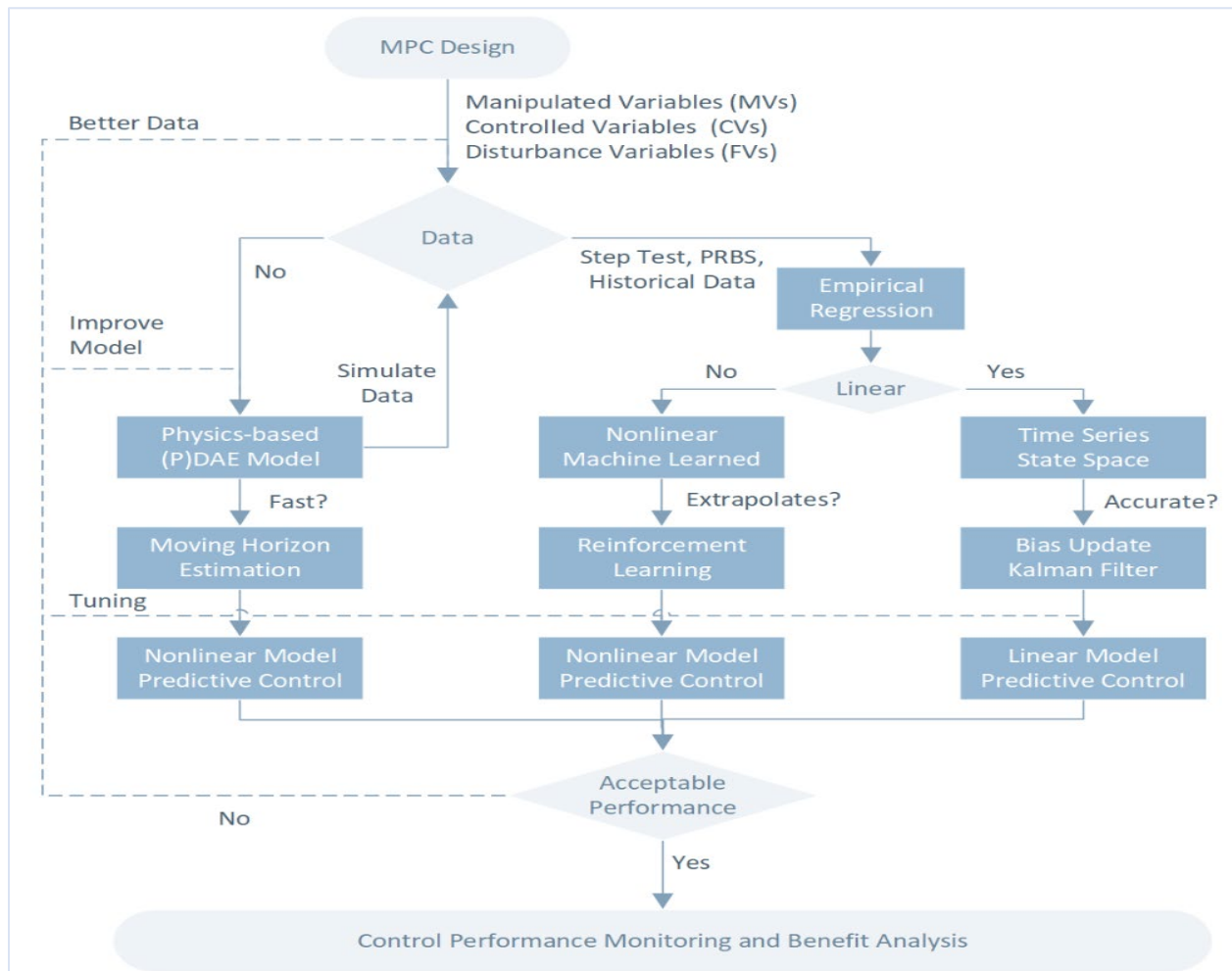


Figure 13 – Dynamic Optimization²³⁴ is a central component of systems engineering where applications of numerical methods for solution of time-varying systems are used to improve performance and precision of engineering design and real-time control applications, which may have a broad spectrum of use, for example, from optimizing the artificial pancreas to fuel cells. Principles of DO may be taught²³⁵ worldwide but DO, systems level data science²³⁶ and Bayesian²³⁷ statistics are excellent tools yet, often, less useful for 80% of the tasks for 80% of the world on the other side of the porous Pareto partition.

REFLECTION

The protagonists of the “open source” movement may be dismayed by “partition” suggestion which does not disguise an “ours” vs “theirs” view of a divided world. It is unfortunate but necessary to serve as a constant thorn in our conscience and sow discomfort. The “partition” thinking originates from the corporate pursuit of developing a smörgåsbord of bleeding edge tools in the 20% world and then coerce 80% of the world to buy such products and services (“next billion users”). To add insult to injury, corporations from the 80% world are salivating to acquire rights to these products and bring it to their market (for example, Tata (TCS), TechMahindra, Wipro, Infosys, “body-shops” in India²³⁸). There exists a *nano-cosm* of people in the 80% world who could be a part of the 20% world. Because they are an influential minority and holds the financial power in the 80% world, they are aligning their “profit” objectives with the 20% world.

This mismatch may be at the heart of this global dilemma and creates the necessity to consider the porous Pareto partition in terms of people and service for the end-user. People in AA nations are not the consumers for facial recognition software systems. The abuse²³⁹ is perpetrated by governments. People in the 80% world are not seeking quantum computing to process exabytes of data. People are seeking simple information, for example, for their health (data for blood cholesterol level) or from their farm (data about concentration of heavy metal contaminants in irrigation water used for fresh produce, such as, tomatoes). These services help people, the end user, the consumer. This discussion is about what science, engineering and technology businesses can do for people where the key performance indicator is user-centricity and human-centric²⁴⁰ well-being.

This mismatch between the business to consumer (B2C) services versus the business to business (B2B) services is not new. The 80% world is always looking to the 20% world when planning strategic moves for climbing “up” the supply chain. The fact that the tools from the 80% of the world may not fit in the 20% world is obvious from “frugal innovation” calls²⁴¹ by others. Yet, the type of imagination, invention²⁴² and innovation²⁴³ from the 20% world R&D is quintessential for all and a few are immensely helpful in the lives of the 80% world. What may be often lost, is the *translation* of the advances from the 20% world, for people-centric applications, in the 80% world. This discussion is not singing the praises about the investment in research that only the 20% of the world can afford to push forward because we know²⁴⁴ the facts. The world is indebted for the strides made possible due to entrepreneurial innovation in such havens such as Massachusetts and California. This discussion is about exposing the lies²⁴⁵ but not slowing the leaps of vision from the 20% world which may help create low cost²⁴⁶ tools to serve the 80% world. The world needs R&D from the 20% world, hence, “porous” partition may facilitate the flow of innovation. Not “as is” but with contextual modifications to better serve communities in the 80% world, at a self-sustaining cost (for example, the PAPPU model, pay-a-penny-per-use or pay-a-price-per-unit).

Mental health is one problem where “porosity” is most welcome because most of the world are affected by generic²⁴⁷ as well as specific issues, which contributes to economic²⁴⁸ drain. Inherited bipolar and unipolar disorders²⁴⁹ do not discriminate on the basis of race, color, religion or national origin. The neurochemical, neuroendocrine and autonomic abnormalities associated with these disorders need biomedical research to elucidate the neurobiological basis of these diseases. The latter is not feasible for the 80% world. Harvesting data²⁵⁰ from external symptoms and pattern analysis²⁵¹ may offer a low-cost substitute, to inform the nature of treatment required. People in the 80% world may find it useful.

However, this discussion is not a *to-do* list. It is not a roadmap. It may be a compass, oscillating asynchronously from esoteric thoughts to bare necessities. We are immersed in this duality. One cannot exist without the other. The role of the “partition” is to help focus on the issues that are unique to the environment and community that we wish to serve. It is not a partition of R&D or people or products but a partition for *delivery of service*.

The idea of democratization of data is a bit buzzy but gimmicks are key to marketing. August institutions, including MIT, are complicit in sponsoring potentially puffy pieces to keep the hype²⁵² alive. But, the fact remains that enabling data to inform decision is a bedrock of measurement, central to all, irrespective of economic status. The porous Pareto partition is a catalyst to focus on services for the 80% world, where less could be more and serves our sense of *égalité*.

Dribbling a bit of data to inform a person that her respiratory rate (RR) is fluctuating, too often, may be a preventative measure (think of the proverb *a stitch in time saves nine*). Informing the person that her RR data is not copasetic, may reduce future morbidity due to COPD (chronic obstructive pulmonary disease). Providing data and information may be *without* impact on the quality of life in the absence of follow-up (clinic). In terms of data and information, alone, by enabling something simple and even mundane, the people-centric application of technology and data, preferably at the edge²⁵³ (point of use), may help to do more, with less. Unbeknownst to us, we are attempting to use the pillars of science, engineering, data, information and knowledge to build bridges which may serve as a platform to provide service to billions of users. Rather than *gilding the lily* we are offering a “bare bones” bridge which serves a rudimentary purpose and still may exclude a few. The volume and demand for such low cost services [pay-a-penny-per-use (PAPPU) service business] may also be profitable for the business ecosystem.

Supporting a sustainable effort, to lift the quality of life, will depend on the extent of the product *ecosystem* and many other “things” in addition to technical and sensor data (see “disclaimer”) as well as the *cohesion of the service supply chain*. Socio-economic data²⁵⁴ and related factors are equally significant. Core elements are education of women²⁵⁵ and trust²⁵⁶ in women, followed by civic honesty²⁵⁷, social value²⁵⁸ as well as inculcating the practice of ethical profitability in social business and entrepreneurial innovation to accelerate the pace of creating pragmatic tools and solutions for remediable²⁵⁹ injustices.

DISCLAIMER – THE ILLUSION OF DATA, DELUSION OF BIG DATA AND THE ABSENCE OF INTELLIGENCE IN AI

Neither data nor AI²⁶⁰ is a panacea. The acquisition of data and analysis of data is not a guarantee that there is information in the data or that the information is actionable in terms of delivering value for the user. This essay about data in its various forms is *not* the life-blood but a contributor. Global public goods that define “life-blood” are food, energy, water, sanitation and healthcare (FEWSH). Separately, and in combination, the 80% world need advanced and affordable array of tools and technologies to leapfrog the conventional practices of FEWSH in the 20% world.

In this context energy is the rate limiting entity and in a “tie” with food and water, in terms of human existence and life. The “hand-me-downs” from the 20% world of energy may not be sustainable and perhaps not even good. Perhaps the Sahara Desert may be a source of energy for creating a global “battery” - an idea²⁶¹ triggered by an 1877²⁶² proposal, in a different context (it was, too, subjected to misrepresentation²⁶³ and mockery²⁶⁴). Whether this is a “good” idea or not is *not exclusively* a matter of technological feasibility of implementation or transaction cost of service delivery. The question is, if it is *good for people*. Global public goods are a matter of context for the community as well as the continent. Exploring the cleavage between entrepreneurial engineering innovation and complexities of social egalitarianism requires willingness to recognize, and adapt, among many *different conceptions of a sense of the future*. Not the future deemed appropriate by the 20% world experts. The future is non-linear.

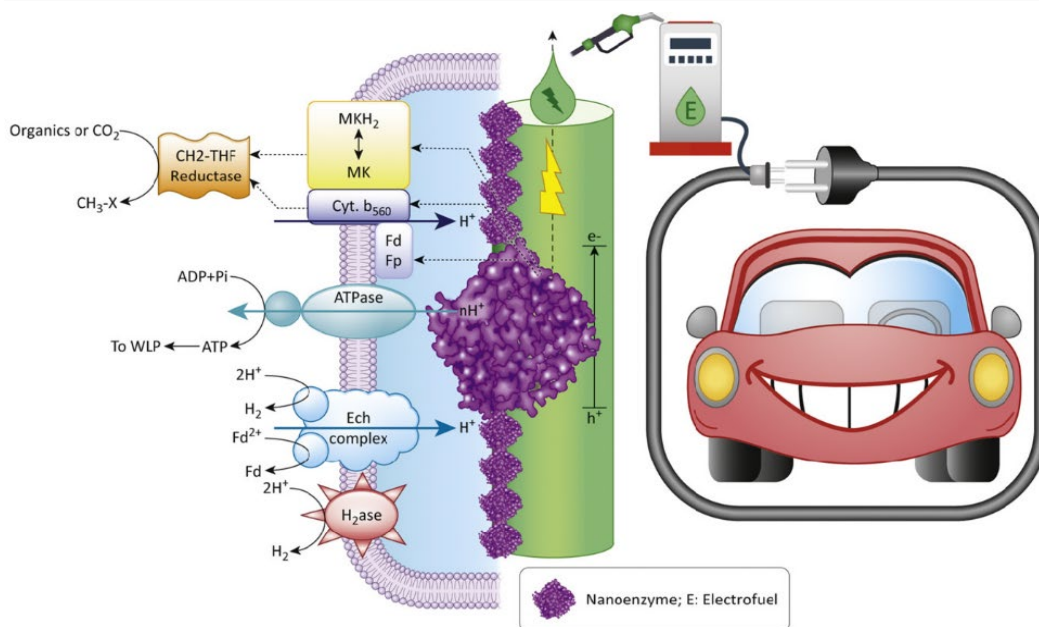


Figure 14 – The trinity of imagination, invention and innovation is central for the 80% world to leapfrog the dead weight of old technology and conventional wisdom from the 20% world. *Nanoenzyme-microbe interaction for clean and affordable bio-electrofuel production (Fig 1 from Singh et al [ref 271]).*

It may be a non-binary future with multiple paths and unequal connectivity between amorphous nexus of networks representing non-linear choices, aspirations and outcomes. “Good” decisions are relative to *that mix* which defies definition yet works as a catalyst for economic rejuvenation. Even this *type* of “good” will (must) change with time and culture because no one version of good can fit all the world²⁶⁵. A binary *outcome*, with exceptions, must not be confused with binary *decision making* because a plethora of non-binary factors can influence the outcome, which may appear as a simple output.

An oversimplified and cherubic example of the latter may resonate with residents of the Boston area. The choice between Mike’s²⁶⁶ and Modern²⁶⁷, famed confectioners located almost opposite each other on Hanover Street in Boston’s North End, is far from binary. The filling in the cannoli, taste of java and the length of the queue, are factored in the decision-making process, which generally presents itself cloaked in a binary-esque outcome.

Thus, the creativity and imagination necessary from science, engineering, technology and medicine (STEM) to address FEWSH must extract solutions sustainable under economic constraints. They will vary in their need to connect a few or many ‘dots’ to inform the solution delivery system. It is true “porosity” may contribute to solutions in the 80% world, and perhaps, less is more, but it will be remiss to leave the reader with the impression that invention/innovation may have to take a second place in the 80% world. In some cases, the latter rings true. In most instances we must seek *out-of-the-world* or counterintuitive ideas²⁶⁸ and blend it with incisive insight. Far reaching *convergence* of bio, nano, info and eco²⁶⁹ is not an alternative but an imperative to stitch practical solutions, which can satisfy, survive, and surpass, the criteria dictated by the economics of technology and technology policy²⁷⁰, which may be necessary to transform grand visions²⁷¹ into everyday reality (and uncover new²⁷² tools, in the process).

But “grand visions” are often manufactured²⁷³ as incremental mediocrity. Patents for using quantum²⁷⁴ computing²⁷⁵ are as absurd as the use of “cognitive” and the accompanying belligerence²⁷⁶ in marketing. Those who throw around the term “cognition” may not have consulted a credible expert²⁷⁷ or explored its meaning/definition {*cognition [n] mental action or process of acquiring knowledge and understanding through thought, experience, and the senses*}. Neither neurology nor modern computational neuroscience comprehends the *combined* electrochemical, cellular and molecular nature of what it may mean to “acquire knowledge” by animals or humans. Any model, equation, algorithm or hand-waving is simply false if it claims anything more than a vague impression of what “*acquire knowledge*” may mean. The other key words in the definition (*thought, experience*) are at depths we do not even dare to know how to measure. The mindless drivel that we can decipher “processes” because of functional nuclear magnetic resonance imaging (fMRI “activation” maps of real time blood flow) are constrained by spatio-temporal resolution and limited ability of fMRI²⁷⁸ to reliably detect functional activation. At the current state of instrumentation, resolution is inversely proportional to the ability to detect functional activation. Optimizing both is essential before fMRI data may be considered precise.

The infinite absurdity cryptic in the claims about cognition, learning, experience and thought is neither coloured by cognitive dissonance nor a figment of our uninformed imagination. Table 4²⁷⁹ captures the duration of so-called “deep learning” training over “days” on a TPU²⁸⁰ (tensor processing unit) scale with vast amounts of data (GB) only to generate undifferentiated²⁸¹ rubbish. By comparing row number 1 vs 10 (bottom), the scores of the relevant match (#1, 0.892) between learning (saved query) vs challenge (new query) is unimpressively different (#10, 0.765). In other words, according to Google BERT, after several days of “deep learning” “*Blah blah blah blah*” when challenged with the query “*Does this integrate with gmail?*” generates 0.765, suggesting **76.5% similarity** between the two.

	BERT	RoBERTa	DistilBERT	XLNet
Size (millions)	Base: 110 Large: 340	Base: 110 Large: 340	Base: 66	Base: ~110 Large: ~340
Training Time	Base: 8 x V100 x 12 days* Large: 64 TPU Chips x 4 days (or 280 x V100 x 1 days*)	Large: 1024 x V100 x 1 day; 4-5 times more than BERT.	Base: 8 x V100 x 3.5 days; 4 times less than BERT.	Large: 512 TPU Chips x 2.5 days; 5 times more than BERT.
Performance	Outperforms state-of-the-art in Oct 2018	2-20% improvement over BERT	3% degradation from BERT	2-15% improvement over BERT
Data	16 GB BERT data (Books Corpus + Wikipedia). 3.3 Billion words.	160 GB (16 GB BERT data + 144 GB additional)	16 GB BERT data. 3.3 Billion words.	Base: 16 GB BERT data Large: 113 GB (16 GB BERT data + 97 GB additional). 33 Billion words.
Method	BERT (Bidirectional Transformer with MLM and NSP)	BERT without NSP**	BERT Distillation	Bidirectional Transformer with Permutation based modeling

	Saved Query	New Query	BERT Score	USE Score	ELMO Score	XLNet Score
1	How much will this cost?	Is this expensive?	0.892	0.803	0.742	0.720
2	Where is your data stored?	How secure is your product	0.890	0.625	0.765	0.705
3	What temperature is it today?	What time is the game on?	0.880	0.677	0.746	0.730
4	How do I change my password	I can't find the settings page	0.868	0.671	0.717	0.706
5	Can I sign up for a free trial	Do I need a credit card to get started?	0.868	0.736	0.753	0.759
6	Where can I view my settings	Does this integrate with gmail?	0.866	0.620	0.717	0.691
7	I really do not like this product	I really like this product	0.865	0.747	0.864	0.870
8	What is the Capital of Ireland?	What time is the film in the cinema	0.865	0.578	0.663	0.778
9	Hello, is there anyone there?	What time is the game on?	0.832	0.594	0.680	0.723
10	Blah blah blah blah	Does this integrate with gmail?	0.765	0.519	0.585	0.688

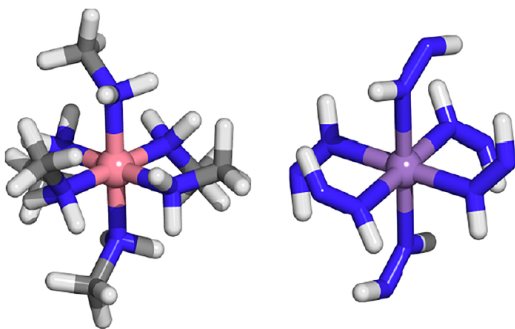
Table 4 – Google BERT thinks “*blah blah blah*” is **76.5% similar** to “*Does this integrate with gmail?*” The laughable outcome is not at all surprising despite the hordes of brilliant scientists working to create tools (RNet, XLNet, ELMO, BERT, ALBERT, DILBERT, ROBERTA) over the past 20 years because it is gnarly to capture *semantics* of language which has evolved over the past 200,000 years.

The much-ballyhooed *context-awareness* of ELMo²⁸², BERT²⁸³, and its cousin ALBERT²⁸⁴, due to permutations and combinations of including masked language model (MLM) and next sentence prediction (NSP), is left in the dust, based on examples in Table 4. Except for those feigning ignorance and *blind-to-reason-fanatics*, observers may not be incorrect in thinking that throwing data (please see “Data” row in the upper part of Table 4) or using generic high volume of data for training (BERT claims to use “Wikipedia” in column 1 row 4) is ineffective. To be effective, these tools (ELMo, BERT, ALBERT, DILBERT, ROBERTA, etc) must use training data *relevant to the context* of target (search). Context-awareness in the absence of data curation is as fake as claiming that a marble bowl is made of gold. Nevertheless, these advances in search techniques are immense strides²⁸⁵ but the tools still aren’t “intelligent” but dumb as doorknobs. The doorknob does not turn unless one turns it or actuates it, manually or mechanically. Wikipedia as an experimental *control* is a plausible idea. Using curated data for training (ANN) may improve accuracy of search and better guide *informed users* to extract notions of connections and relationships with BERT-esque tools as *supplementary aids* (Tshitoyan *et al*²⁸⁶ provides supporting evidence, Table 5). These tools are of limited value for non-mission critical applications, for example, recommendations (movies, books, restaurants), weather for entertainment (IBM’s Weather Channel) and fault tolerant uses (open garage door, on/off sprinklers). Non-essential human-centric uses (congestion routing, temperature control, voice message to email) may qualify if the outcome is almost correct in 80% of the cases. Actual use with humans-in-the-loop (healthcare, emergency response, security) may be scuppered if based on any credible risk versus reward analytics, except for offering *non-binding and non-executable* suggestions or alerts for human decision makers.

Text corpus	Materials	Grammar	All	Corpus size
Wikipedia	2.6	72.8	51.0	2.81B words
Wikipedia elements	2.7	72.1	41.4	1.08B words
Wikipedia materials	2.2	72.8	41.3	781M words
All abstracts	43.3	58.3	51.0	643M words
Relevant abstracts	48.9	54.9	52.0	290M words
Pre-trained model	10.4	47.1	30.8	640k papers

Table 5 (from Tshitoyan *et al* Extended Data Table 4) – Analogy scores (%) for materials science versus ‘grammar’ from different sources. Training using Wikipedia for – metals – is grammatically rich (>72%) but content poor even when using select Wikipedia for materials (2.2% analogy). The smallest corpus (290M words) used for training using continuous bag of words (CBOW) offers the best performance (48.9%) on materials-related analogies when *curated* for “relevant” abstracts. The best performance for grammar may turn out to be profitable by enabling ELMo, BERT, ALBERT, ROBERTA and DILBERT (DistilBERT) to be the voices of artificial trainers for the standardized twaddle marketed with impunity and known as *Test of English as a Foreign Language* (TOEFL). The contextual enrichment in this table is similar to the example of enrichment shown in Figure 16, suggesting the need for relevance / curation.

The paramount significance of curated contextual data in training any model (including ANNs, artificial neural networks) cannot be overemphasized. Individuals and institutions in possession of less than lofty ideals may revert to trickery in an attempt to sow doubt or discombobulate or disqualify the type of outcomes, for example, presented in Table 5. It is the age-old deception due to over-fitting²⁸⁷ which can be also applied to ANN during training and the “fit” may be driven to precision using tools such as recursive feature addition²⁸⁸ (RFA). For readers seeking a simpler analogy may wish to re-visit what we discussed as the “force-fitting” of RDF to healthcare applications (reference 170). The erudition necessary to train ANN with curated data is not easily gleaned from a cursory review. Extensive perusal of scholastic research²⁸⁹ begins to reveal a few of the minutiae with respect to the nature of the domain specific data and the context of data curation (see sections 3 and 4 in Nandy *et al*, reference 289) that forms the bulk of the *preparatory* work based on rigor and strength of broad spectrum²⁹⁰ knowledge. In an earlier section we referred to *domain specific* models in a “macro” sense (pages 9-10) whereas the domain specificity of this example (Nandy *et al*) is at the molecular (atomic and/or sub-atomic) scale.



	[Co(NH ₂ CH ₃) ₆] ³⁺	[Mn(HNNH) ₆] ³⁺
DFT	-20.00 eV	-18.64 eV
ANN	-19.91 eV	-23.55 eV

Table 6 – Even after extensive training using precision data enriched for features using RFA, it is not surprising when gross errors are found in the outcome (analysis). Figure 7 (from page 13981 in Nandy *et al*) is one example how artificial neural networks (ANN) used in machine learning (ML) exercises and analytics generate erroneous results. ΔE_g data (LEFT) shows ANN error (0.09 eV) with respect to DFT (density functional theory²⁹¹) in a singlet [Co(NH₂CH₃)₆]³⁺ transition metal complex.

(Right) Data shows large ANN error (−4.91 eV) with respect to DFT for a quintet [Mn(HNNH)₆]³⁺ transition metal complex. The quintet [Mn(HNNH)₆]³⁺ complex highest occupied molecular orbital (HOMO) level is underestimated by 4.9 eV, which is almost **double** the mean absolute error (MAE). This ANN was specifically trained using ΔE_g data models on a set of 64 octahedral homoleptic complexes (OH64). The discrepancy (ANN error) is significant because frontier molecular orbital energetics provide essential insight into chemical reactivity and dictate optical and electronic properties. Small errors could make an immense difference in terms of chemistry of the transition metal complex. In this illustration, the metals are shown as spheres and coordinating atoms as sticks (C atoms, gray; N atoms, blue; H atoms, white). ***If your healthcare diagnosis and treatment was based on such an ANN outcome, would you trust, accept and abide by the direction of the treatment suggested by such results? If this outcome is based on data from your electronic health records (EHR) which is known to be erroneous, would you trust poor data quality to inform a poorly performing ANN engine to design your healthcare?***

The third piece of evidence that also dispels the marketing myths of AI in favor of viewing through the lens of **artificial reasoning** tools (ART, referring to ANN, CNN, RNN, DL, RL), is another variety of neural network²⁹² with credible capabilities. MPNN²⁹³ (message passing neural network) for molecules²⁹⁴ is a tool²⁹⁵ to unleash data²⁹⁶ for human-centric applications in health and medicine. This example centers on uncovering and repurposing a previously known molecule as an antibiotic²⁹⁷ using a plethora of tools including MPNN and collectively referred to as deep learning (DL). This paper (297) by Stokes *et al* and the two other papers by Tshitoyan *et al* as well as Nandy *et al*, emphasize data curation and learning, without once mentioning the term AI or “artificial intelligence” in any shape or form in the scientific papers. Unfortunately, the marketing and news item²⁹⁸, as expected, did not shy away from fake sensationalism to bolster the false appeal of AI.

The *learning* that generated the antibiotic (renamed Halicin), is nauseatingly detailed and the *training* (MPNN) was excruciatingly structured, optimized and re-optimized (using hyperparameter²⁹⁹ optimization). The old idea of ensembling³⁰⁰ was applied to improve outcomes *in silico* but predictions were *biologically* tested through rigorous experiments. Even after repeated steps to minimize errors, the authors (reference 297) remain cognizant of the pitfalls: “*It is important to emphasize that machine learning is imperfect. Therefore, the success of deep neural network model-guided antibiotic discovery rests heavily on the coupling of these approaches to appropriate experimental designs.*” (Stokes *et al*, page 698)

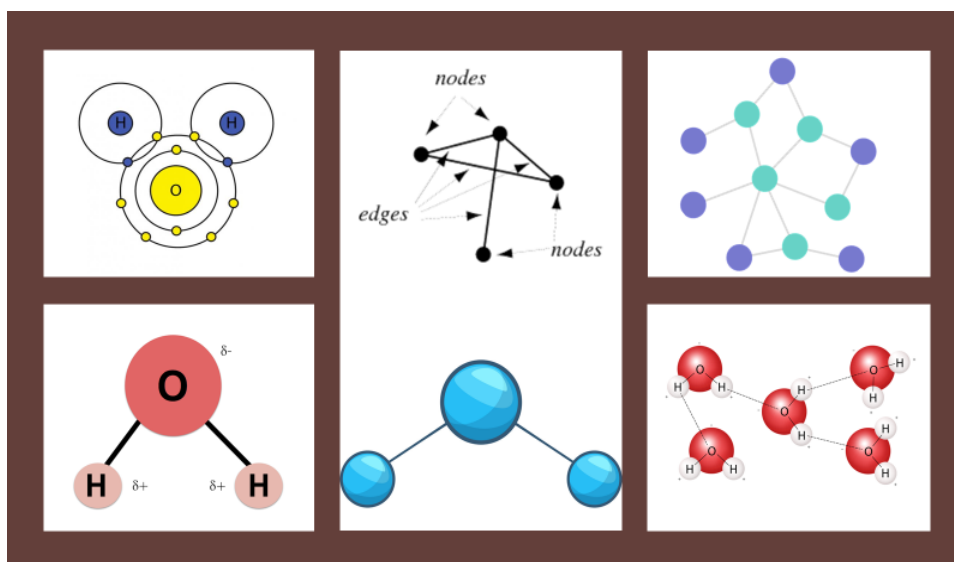


Figure 15 – Training a neural network to recognize molecules relies on the fact that every molecule may be represented as a *graph* (or a collage of connected graphs, eliciting the idea of a *knowledge graph*). The water molecule may be viewed as a graph with oxygen (O) as the node (vertex). Bonds between oxygen and hydrogen (O–H) serves as the “side” or edge. Most molecule (within reason) may be transformed to a molecular graph and is at the heart of MPNN training to recognize different types of molecules. Then, the *trained* neural network, MPNN, is used to search for similar or *dissimilar* molecules in a repository.

A curated set of 2335 molecules were used as the training set for new antibiotic molecules. The 2335 training data set were chosen, including FDA library of 1,760 molecules pre-selected based on their ability to inhibit microbial (*E. coli* BW25113) growth. In other words, molecules with structure and function *known* to possess anti-microbial activity. Training MPNN with this data set enables the neural network to *learn* the structures in order to select similar (or dissimilar) structures from a larger library of structures. The expectation is that when a “challenge” library is presented to the MPNN, the degree of similarity or dissimilarity, in terms of the output from the MPNN, can be *tuned* by modifying selection parameters. For example, using prediction scores (PS) to categorize molecules from a larger library (in this case, the ZINC database with ~1.5 billion molecules). By selecting higher PS value (>0.7, >0.8, >0.9), the outcome is “enriched” and a sub-set of molecules (in this case, 107,349,223, reductionism at work) is further subjected to other selection criteria, for example, nearest neighbor analysis (Tanimoto score). Finally, potential molecules (in this case, 23) are biologically screened (microbial assay) to identify the “new” antibiotic candidate(s). One such candidate is Halicin (Stokes *et al*), previously identified as the c-Jun N-terminal kinase inhibitor SU3327 and re-discovered as a broad-spectrum antibiotic, re-named Halicin but still the same molecule as SU3227, albeit repurposed, based on function.

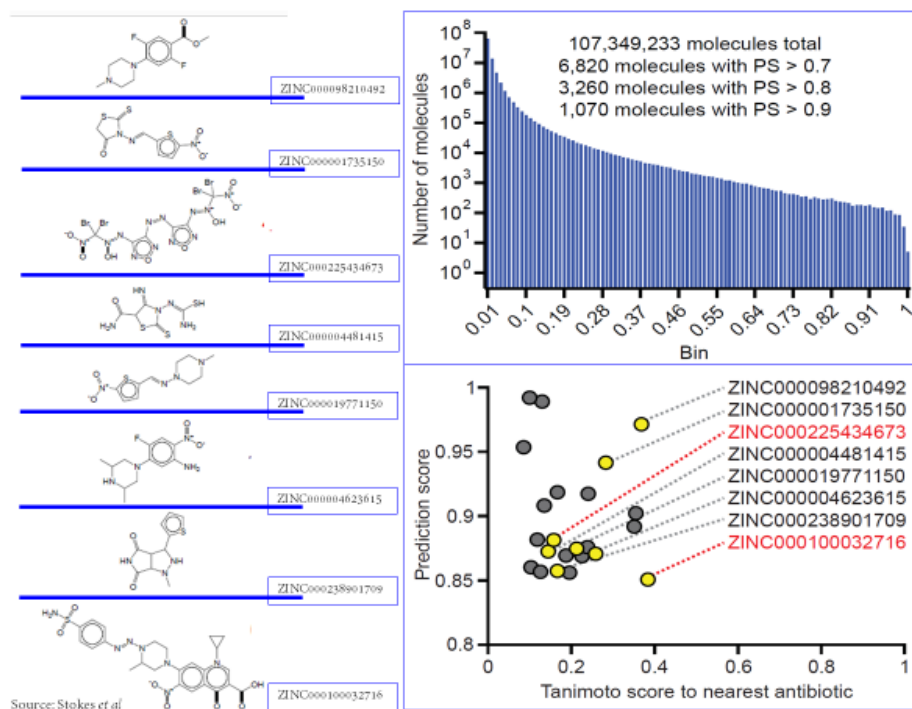


Figure 16 – Potential candidates (8 molecules) from ZINC database (structures on the left) were scored using nearest neighbor (NN) analysis (yellow circles, bottom right). NN is based on principles derived a thousand years ago³⁰¹ (circa 1030). Data is curated at successive steps by enriching for *context* (selecting higher prediction scores, PS, top right) in a manner similar to Table 5 (wikipedia vs relevant abstracts).

In combination, these three examples offers preliminary evidence that artificial reasoning tools (ART) such as ANN, MPNN, DL (deep learning), RL (reinforcement learning), etc. are *excellent* tools. However, ART and related tools are not intelligent, they do not self-operate and the outcome is solely due to the skill and sophistication of the human operators. The steps must be designed with cautious intellectual strategy embracing the *breadth* of diverse knowledge, often dismissed by many institutions. Execution demands *depth* of erudition and incisive foresight to weigh the pros and cons of the criteria used to assess the *quality of curated data* prior to commencing training neural networks with such data.

It is essential to learn the *meaning of context* in order to sufficiently inform the “artificial” part of ART. Models and patterns are like chicken playing tic-tac-toe³⁰² without context and semantics. Human *knowledge* to equip ART is almost impossible to transfer because we do not have a clue how to abstract continuous knowledge and use discrete processes to *build* it into an artificial system. Hence, ART may not “possess” an internal model of the external world. The immense variability in terms of features and which features may be *relevant* in which environment makes it difficult to model a state by claiming that feature selection will address all relevant and discrete contexts that the item or object may experience. Even if feature engineering was automated to levels of precision continuity that could encapsulate all possible permutations and combinations of the behavior of an entity or object, the model may be inadequate in the hands of different users who may not feature in the feature catalog, without bias. It is not trivial yet not impossible to model behavior and optimize for some features in a retail environment (for example, who may shop at Whole Foods, who may return to Andronico’s versus Mollie Stone’s).

If reason could inform common sense then one may prefer ART over AI and the observe the value of reasoning in machine learning techniques using neural networks. Neural networks and machine learning tools are amplifying, modifying and regurgitating whatever humans have programmed into the tool. It cannot *learn* beyond the range of data or information provided, until humans decide to change, adjust or add/subtract parameters/attributes which will influence the *learning* and the output from ART. The obstreperous zeal to move away from the misnomer of modern³⁰³ AI³⁰⁴ and adopt ART as a generic term may be a *back to the future* moment for rule-based³⁰⁵ expert systems³⁰⁶ and principles³⁰⁷ but coupled with new ML tools³⁰⁸. Marketing panders to creators of unstructured data but the zettabytes of data anarchy occasionally offers value irrespective of the clamor for general AI or ambient AI or intuitive AI or cognitive AI. Isn’t it possible to deliver value using ART?

But, does the acronym matter? Perhaps only to a few (or less). AI is a false trigger for technology transitions³⁰⁹ but it is cheaper³¹⁰ and cheaper³¹¹ to promote. It is profitable for conference organizers, narcissistic speakers, greedy social gurus and other forms of eejits. Irresponsible computation may be draining the energy³¹² economy yet the marketing world is oblivious to the grave socio-economic incongruencies in terms of the thermodynamics³¹³ of computation, which is absent from daily discussions. Perpetrating the myth of intelligence in AI is a moral anathema. ART lacks the cachet and panache, but promotes the rational idea of *learning* tools, which are, and will be, helpful for society.

The state of artificial learning is analogous to receiving a map of the world on a postage stamp and expect the bearer of the map (stamp) to arrive at 77 Massachusetts Avenue, Cambridge, MA, using that postage-stamp-sized map as the only guide. Neurologists shudder³¹⁴ at AI, the public are ignorant of the evidence of sham (Tables 4-6 and Figure 16) while marketing accelerates the “show” over substance. Sensationalism amplifies attention and siphon funds away from real world issues, making it harder for elements of FEWSH³¹⁵ to move forward, for the 80% world. The task ahead is to be creative, more than expected, and avoid the oxymoronic implementation of *innovation as usual*. Dynamic combinations³¹⁶ and cross-pollination of counterintuitive connections may be worth exploring³¹⁷ to find many *different* ways to lift billions of boats, not just a few yachts. Future needs égalitarian resistance to our “default” state of society where we allow, acquiesce and accept greed³¹⁸ as a price and penalty we pay for progress.

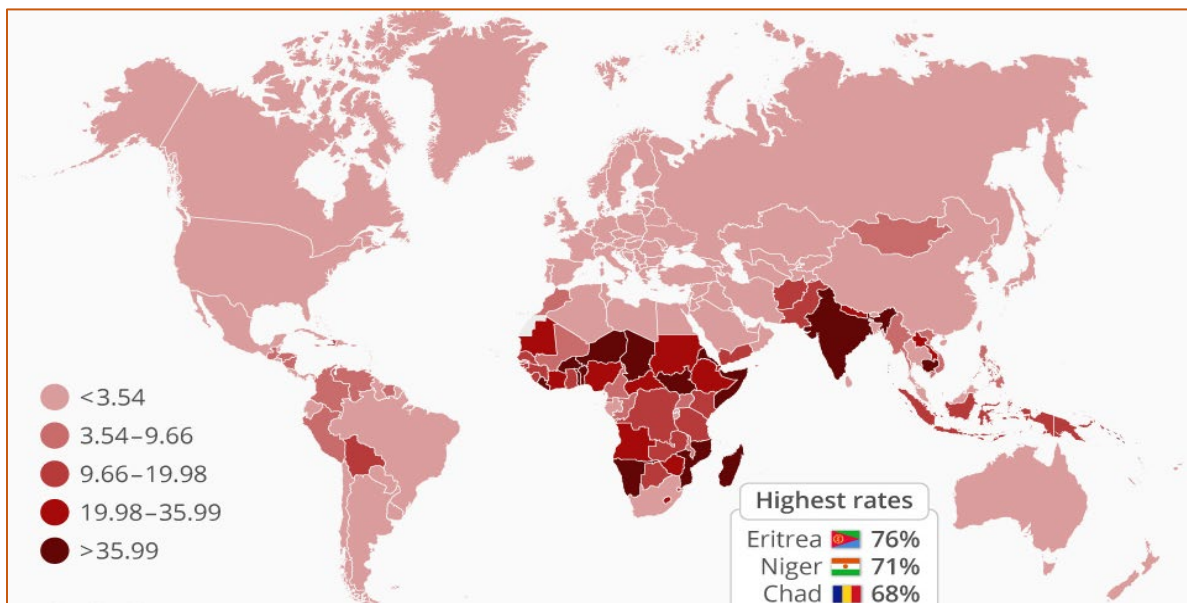


Figure 17 – Is GINI coefficient³¹⁹ a non-stationary end-goal for economic redistribution through ethical social entrepreneurial innovation? Nearly a billion³²⁰ people³²¹ defecate outdoors (percent of population who are forced to defecate outdoors). It appears that the pay-a-penny-per-unit (PAPPU) model could rake in billions if managed sanitation services were developed as a business. If a billion people paid one penny (US) per use per day for their “leased” sanitation service (at home) then the global gross earning for pay-per-use sanitation may be US\$3.65 billion annually, an indication of earnings potential and wealth from the business of the poor. The primary assumption is that the individual will choose to pay one penny per day even if their income is only \$2 per day (lowest per capita average earnings). This social business model depends on different domains³²² of infrastructure necessary to offer home sanitation as an e-commerce³²³ service. The return on investment will be realized gradually because earnings will not be US\$3.65 billion in the first year. Is the inclination to invest, and wait, too much to expect from global organizations which could help facilitate delivery of global public goods?

Running Title: Unsustainable and Misaligned Economics of Technology triggers a Porous Pareto Partition Between the Haves and the Have Nots: Can Democratization of Distributed Data act as a Catalyst for the Dissemination of Digital Dividends?

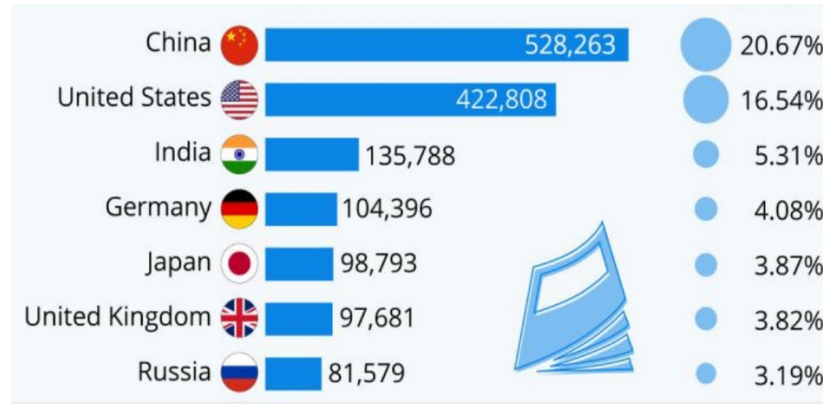


Figure 18 – Publications in peer-reviewed journals (2018). Face-saving feel-good false positives? Propaganda³²⁴ (does *not* exclude scientists³²⁵) masks facts³²⁶ and analyses, by ignoring the quality of publications, citations and investment in R&D (% GDP). Dubious research³²⁷ output tarnishes the image and publications. Are we pointing fingers at a quarter (25.98% = 20.67% + 5.31%) of the global share?



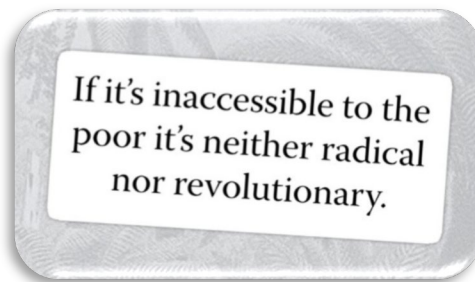
Photograph 0 – GINI coefficient gone awry? Vast slums, adjacent to high rise residential buildings in a section of Mumbai (photograph by Prashant Waydande³²⁸), contradicts the notion that India may be an emerging leader in credible scientific research³²⁹ (Figure 18). Are these a few symptoms stemming from grave gender bias, discrimination³³⁰ against females and inequity of women in science and society?

PERSONAL END NOTE

Thoughtful readers have asked about the audience³³¹ that this essay intends to reach. I am unable to answer. This essay flows from convergence of a broad spectrum of chatter. Certain segments originate from personal observations and others are a mix of intent, content, context and relevance from social network of users as well as decision makers³³². Most people prefer focus and a *take home message*. The former is less obvious but the latter is less unclear from the cartoon at the bottom of this page. It may be uninteresting for most adults to read about an array of haphazard realities, an extrapolation from my exchanges (or lack thereof) with a few hundred selected professionals in academia and industry. But, what is more painful is the absence of engagement with young minds and students. Isn't it tragic to be young and cynical? Has the person gone from knowing little to exploring even less? Ruminations in this essay may not reach more than a few people. The fabric of this essay was spun with many threads, not all of them are digital. To arrive at the conjectures in this essay consumed part of my life in their acquisition and formation, irrespective of the fact that they be incorrect, flippant, vacant or just rubbish. Thus, one may conclude, perhaps the essay exposes my stupidity³³³, perhaps it is irrelevant and serves no real purpose, perhaps *it is a tale³³⁴, told by an idiot, full of sound and fury, signifying nothing*.

Les savants des autres nations, à qui nous avons donné l'exemple, ont cru avec raison qu'ils écriraient encore mieux dans leur langue que dans la nôtre. L'Angleterre nous a donc imités; l'Allemagne, où le latin semblait s'être réfugié, commence insensiblement à en perdre l'usage; je ne doute pas qu'elle ne soit bientôt suivie par les Suédois, les Danois et les Russes. Ainsi, avant la fin du dix-huitième siècle, un philosophe qui voudra s'instruire à fond des découvertes de ses prédécesseurs, sera contraint île charger sa mémoire de sept à huit langues différentes, et, après avoir consume à les apprendre le temps le plus précieux de sa vie, il mourra avant de commencer à s'instruire.³³⁵

The scholars of other nations, to whom we have provided an example, believed with reason that they would write even better in their language than in ours. England has thus imitated us; Germany, where Latin seems to have taken refuge, begins insensibly to lose the use of it: I do not doubt that it will soon be followed by the Swedes, the Danes and the Russians. Thus, before the end of the 18th century, a philosopher who would like to instruct himself about his predecessor's discoveries will be required to load his memory with 7 to 8 different languages; and after having consumed the most precious time of his life in acquiring them, he will die before having begun to instruct himself.³³⁶



IN CONCLUSION – THE PRINCIPLES AND PRACTICE OF P3 – IS IN NEED OF PEOPLE WHO ARE TRUE LEADERS

Concluding sections ought to be labeled “temporary” because we are perpetually immersed in an ocean of unknown unknowns. This essay and our discussion is not an exception. Nevertheless, it will be remiss to leave the discussion without an attempt to share clues with entrepreneurial innovators who may be interested in social businesses and, in parallel, the pursuit of ethical profitability. Perusal of the PDF documents “Practice of P3” will reveal a broader context and perhaps a few ideas related to food and water (01FW), healthcare (02H) and energy (03E) - <https://dspace.mit.edu/handle/1721.1/123984>

As the name implies, social businesses are “*businesses*” and not academic experiments or lab projects. The convergence of concepts, tools and technologies necessary to deliver the business of social business is not trivial and the most important element is that of *leadership*. Convergence implies that collaboration between domains rich in ideas, integration and implementation are, more or less, essential for end-to-end service delivery. No *one* business can synthesize the entire tapestry required to deliver a certain quality of service. Each business (and academic partners) must contribute to the ecosystem and relinquish certain elements of control the business executives assume. The service delivery ecosystem is comprised of many types of businesses and some may be inclined to conclude that they are the “pillars” in this new process. Too often one forgets that pillars are useless unless we can build bridges over pillars. This *forgetfulness* is buoyed by hubris, mostly at the CxO level, where individuals designated “chief officers” are ill-equipped to navigate the paradigm shift to *service* delivery. In particular, *people* who are CTO or CSO or CIO or CDO may think that they possess all the tools and resources to provide what is best. They may know what is best for their domain or company but it may not be the same as what is best for the end user in the ecosystem and the service supply chain partners in the delivery network.

The CxO roles must evolve to keep pace with emerging spectrum of models where products are pariahs and service is the new slogan. Management roles ought to change (CEO, COO, CFO). Urgent changes are overdue for CTO, CSO, CIO, CDO roles (excludes people who maintain IT plumbing). In the world of the “outcome economy” selling a trainer or a sneaker is no longer the end point. The trainer or sneaker is now a “service” where the consumer pays for duration of the service (life cycle) provided by the trainer or sneaker. It may seem tad obsequious but the service economy is here to stay, especially for the 80% world. The *nano-fee pay-a-penny-per-use* (PAPPU) model may unlock markets of billions who may have non-zero amounts of disposable income. Wealth of the poor may fuel ethical profitability for social business by tapping into markets of the next billion users. Current shades of ‘western’ business ethos, roles and models are unlikely to serve as pillars for the bridge to the future of service economies. The insurmountable resistance to reducing *western* business barriers is comparable to the resistance from the American Medical Association to universal healthcare. *However, exceptions may be found in cases where the CEO or CTO is/are the primary inventors (creating start-ups). The question for them is whether can they successfully and seamlessly integrate their contribution with the service supply chain.*

In general, one of many errors in the current CxO model is the focus on specialization, which is highly relevant to CTO, CSO, CIO, CDO, because the company values the skills the person contributes. While that skill is certainly useful and valuable to a segment of the business, it may be less applicable when that skill is only a part of the solution. The outcome economy does not care if the CTO is skilled in millimeter wavelets or the CDO is an expert in backpropagation algorithms. The *delivery of value* at the end of the tunnel is not about a skill, but a synergistic integration of a *variety of skills*, most of which may be missing in any one person and in any one company. The idea of a generalist gently rises to the surface.

The future is about fusion. The rate limiting nodes are due to the nature of the CxO roles who are, traditionally, prefer to drown in their own knowledge, even if the facts are out of sync. The new world CxO roles may emphasize coordination and *cross-pollination*. The CxO must be a dynamic *node* who can connect the company to access knowledge as well as resources from a wide cross-section of academic, industry and government sources, depending on the case. This is important, immediately, to CTO, CSO, CIO, CDO roles because of the complex and inextricably linked dependencies, at the core of service delivery solutions. This change is not only for social businesses but for every business, especially small and medium businesses, where resources are limited yet the solutions demand increasing degrees of sophistication. This change is neither a silver bullet nor is it fitting for all intents and purposes.

Part of the disconnect, in Fortune 500 type companies, may be related to the salaries of CxO's. For example, if a half-million-dollar CTO seeks outside help for a project, the CEO may wonder why the company should yet again pay for external experts when it has already paid half-million for the "know-it-all" CTO. The depth of the in-house talent may be inadequate. At the end, a half-baked outcome is served to the customer, who is brain-washed to believe that the innovation delivered exceed all others.

For human resources, hiring a CTO, CSO, CIO, CDO as a "learn-it-all" *node* for knowledge connectivity may be heretic. The constant need for creating liaison may be unacceptable. Most CxO individuals may not have the correct network or may not know who knows what, where. Composing and re-composing solution teams through agile combinations of internal and external relationships are rarely in practice. Yet, it is the latter that is poised to deliver exponential value, if explored. Few *leaders* have the incisive foresight to lead beyond their comfort zone. Even fewer possess the courage to take the road less travelled. The system appears to reward the *risk-averse* managers (albeit, with exceptions).

Businesses will benefit from people/nodes of connectivity who can act as *coordinators*. Social businesses who aim to be profitable will require immense connectivity. Coordination must be the daily mantra. Perusal of "Practice of P3" will reveal that trans-disciplinarity is the norm. The definition of CxO roles must be deconstructed and reconstructed as an amalgam of parts, if we are serious about service delivery of global public goods, for example, food, water (01FW), healthcare (02H) and energy (03E) - the crucial elements of our haphazard reality (<https://dspace.mit.edu/handle/1721.1/123984>).

REFERENCES

- ¹ https://en.wikipedia.org/wiki/Pareto_principle
- ² <https://www.postscapes.com/iot-history/>
- ³ Sanjay Sarma, David Brock and Kevin Ashton (1999) “*The Networked Physical World - Proposals for Engineering the Next Generation of Computing, Commerce, and Automatic-Identification*,” MIT Auto-ID Center White Paper. MIT-AUTOID-WH001, 1999. <https://autoid.mit.edu/publications-0>
<https://pdfs.semanticscholar.org/88b4/a255082d91b3c88261976c85a24f2f92c5c3.pdf>
- ⁴ Sarma, S., Brock, D. and Engels, D. (2001) “Radio Frequency Identification and the Electronic Product Code,” *IEEE Micro*, vol. 21, no. 6, Dec. 2001, pp. 50–54. doi:10.1109/40.977758.
- ⁵ Sarma, Sanjay (2001) “Towards the 5 cents tag,” Auto-ID Center. MIT-AUTOID-WH-006, 2001
- ⁶ <https://www.rfc-editor.org/rfc/pdf/rfc791.txt.pdf>
- ⁷ Deering, S. and Hinden, R (2017) Internet Protocol, Version 6 (IPv6) Specification. Internet Engineering Task Force (IETF) <https://www.rfc-editor.org/rfc/pdf/rfc8200.txt.pdf>
- ⁸ <https://www.bizjournals.com/boston/blog/mass-high-tech/2012/11/mit-aims-to-harness-cloud-data-on-consumer.html>
- ⁹ Max Mühlhäuser and Iryna Gurevych (2008) Introduction to Ubiquitous Computing. IGI Global. <https://pdfs.semanticscholar.org/ab0e/b44c7c81a1af3fc2d23fa03f8f04f9e4ca2d.pdf>
- ¹⁰ <https://www.bigdataframework.org/short-history-of-big-data/>
- ¹¹ Melina Kourantidou (2019) *Artificial intelligence makes fishing more sustainable by tracking illegal activity*. <https://theconversation.com/artificial-intelligence-makes-fishing-more-sustainable-by-tracking-illegal-activity-115883>
- ¹² <https://www.postscapes.com/iot-consulting-research-companies/>
- ¹³ Which market view? The imperfect categories are consumer and industrial IoT. Definitions proposed by domestic and foreign governments (US DHS, US FTC, EU ENISA) are (not surprisingly) neither systematic nor in sync. According to DHS, IoT is defined as “connection of systems and devices (with primarily physical purposes e.g. sensing, heating/cooling, lighting, motor actuation, transportation) to information networks (internet) via interoperable protocols, often built into embedded systems.” (page 2 in “Strategic Principles for Securing the Internet of Things (IoT)”, Version 1.0, Nov 15, 2016) https://www.dhs.gov/sites/default/files/publications/Strategic_Principles_for_Securing_the_Internet_of_Things-2016-1115-FINAL_v2-dg11.pdf.
European Union Agency for Network and Information Security (ENISA) defines IoT as “a cyber-physical ecosystem of interconnected sensors and actuators, which enable intelligent decision making.” Internet viewed as a subset not the whole set. (Page 18 in “Baseline Security Recommendations for IoT” https://www.enisa.europa.eu/publications/baseline-security-recommendations-for-iot/at_download/fullReport). One version of IoT is in H.R.1668 “Internet of Things Cybersecurity Improvement Act of 2019” (<https://www.congress.gov/116/bills/hr1668/BILLS-116hr1668ih.pdf>).

H.R. 4792 “U.S. Cyber Shield Act of 2019” mentions “internet-connected products” and stipulates that the term ‘covered product’ means a consumer-facing physical object that can (a) connect to the internet or other network; and (b) (i) collect, send, or receive data; or (ii) control the actions of a physical object or system (<https://www.congress.gov/116/bills/hr4792/BILLS-116hr4792ih.pdf>).

¹⁴ Cisco CEO at CES 2014: *Internet of Things is a \$19 trillion opportunity*.

https://www.washingtonpost.com/business/on-it/cisco-ceo-at-ces-2014-internet-of-things-is-a-19-trillion-opportunity/2014/01/08/8d456fba-789b-11e3-8963-b4b654bcc9b2_story.html

¹⁵ <https://www.the-scientist.com/uncategorized/nature-rejects-krebss-paper-1937-43452>

¹⁶ www.zdnet.com/article/internet-of-things-8-9-trillion-market-in-2020-212-billion-connected-things/

¹⁷ https://machinaresearch.com/static/media/uploads/machina_research_press_release_-_m2m_global_forecast_&_analysis_2012-22_dec13.pdf

¹⁸ <https://www.npr.org/sections/thesalt/2017/07/20/527945413/khichuri-an-ancient-indian-comfort-dish-with-a-global-influence>

¹⁹ Mendel, Gregor. 1866. Versuche über Pflanzhybriden. Verhandlungen des naturforschenden Vereines in Brünn, Bd. IV für das Jahr 1865, Abhandlungen, 3–47.

<http://www.esp.org/foundations/genetics/classical/gm-65.pdf>

²⁰ F. Jacob and J. Monod, “Genetic regulatory mechanisms in the synthesis of proteins,” *Journal of Molecular Biology*, vol. 3, no. 3, pp. 318–356, 1961. [https://doi.org/10.1016/S0022-2836\(61\)80072-7](https://doi.org/10.1016/S0022-2836(61)80072-7)

²¹ Dulbecco, Renato. “The Induction of Cancer by Viruses.” *Scientific American*, vol. 216, no. 4, Apr. 1967, pp. 28–37 doi:10.1038/scientificamerican0467-28

<http://calteches.library.caltech.edu/230/1/cancer.pdf>

²² Novikov, D. A. “Systems Theory and Systems Analysis. Systems Engineering.” *Cybernetics*, by D.A. Novikov, vol. 47, Springer International Publishing, 2016, pp. 39–44. doi:10.1007/978-3-319-27397-6_4 www.researchgate.net/publication/300131568_Systems_Theory_and_Systems_Analysis_Systems_Engineering

²³ <http://web.mit.edu/esd.83/www/notebook/Cybernetics.PDF>

²⁴ Wiener, Norbert. *Cybernetics, or Control and Communication in the Animal and the Machine (2nd Ed.)*. MIT Press, 1961. doi:10.1037/13140-000.

https://uberty.org/wp-content/uploads/2015/07/Norbert_Wiener_Cybernetics.pdf

²⁵ https://www.sissa.it/fa/workshop_old/DCS2003/reading_mat/zuazuaDivSEMA.pdf

²⁶ Williams, L. Pearce. “André-Marie Ampère.” *Scientific American*, vol. 260, no. 1, 1989, pp. 90–97.

<https://www.jstor.org/stable/24987112>

²⁷ <https://www.americanscientist.org/article/alice-and-bob-in-cyberspace>

²⁸ Rivest, R. L., et al “A Method for Obtaining Digital Signatures and Public-Key Cryptosystems.” *Communications of the ACM*, vol. 21, no. 2, Feb. 1978, pp. 120–26

doi:10.1145/359340.359342. <https://dl.acm.org/citation.cfm?id=359342>

²⁹ Nash, J. F. (1950) “Equilibrium Points in N-Person Games.” *Proc Natl Academy of Sci (USA)*, vol. 36, no. 1, Jan. 1950, pp. 48–49. doi:10.1073/pnas.36.1.48 ▪ www.pnas.org/content/pnas/36/1/48.full.pdf

- ³⁰ Axelrod, Robert M. *The Evolution of Cooperation*. Rev. ed, Basic Books, 2006.
<http://www.eleutera.org/wp-content/uploads/2015/07/The-Evolution-of-Cooperation.pdf>
- ³¹ Kreps, David M., et al. “Rational Cooperation in the Finitely Repeated Prisoners’ Dilemma.” *Journal of Economic Theory*, vol. 27, no. 2, Aug. 1982, pp. 245–52. [https://doi.org/10.1016/0022-0531\(82\)90029-1](https://doi.org/10.1016/0022-0531(82)90029-1)
- ³² https://en.wikipedia.org/wiki/Graph_database#/media/File:GraphDatabase_PropertyGraph.png
- ³³ Little, John D. C., et al. “An Algorithm for the Traveling Salesman Problem.” *Operations Research*, vol. 11, no. 6, Dec. 1963, pp. 972–89. doi:10.1287/opre.11.6.972.
<https://dspace.mit.edu/bitstream/handle/1721.1/46828/algorithmfortrav00litt.pdf>
- ³⁴ Schrader, Charles R. (1997) United States Army Logistics, 1775-1992: An Anthology, Volume 1
https://history.army.mil/html/books/068/68-1/cmhPub_68-1.pdf
- ³⁵ Datta, Shoumen, et al. “Adaptive Value Networks.” *Evolution of Supply Chain Management: Symbiosis of Adaptive Value Networks and ICT*, edited by Yoon S. Chang et al., Springer US, 2004, pp. 3–67. doi:10.1007/0-306-48696-2_1. https://link.springer.com/chapter/10.1007/0-306-48696-2_1
- ³⁶ www.cs.cmu.edu/afs/cs/academic/class/15251/Site/current/Materials/Lectures/Lecture13/lecture13.pdf
- ³⁷ <https://kluge.in-chemnitz.de/documents/fractal/node2.html>
- ³⁸ <https://trove.nla.gov.au/work/21161891?q&versionId=25229969>
- ³⁹ Sterling, Mary Jane (2015) Mathematics and Art. <https://www.bradley.edu/dotAsset/d62c7fce-87ed-4b61-9ce7-23a78b70144d.pdf>
- ⁴⁰ Carmody, Kevin. “Circular and Hyperbolic Quaternions, Octonions, and Sedenions.” *Applied Mathematics and Computation*, vol. 28, no. 1, Oct. 1988, pp. 47–72. doi:10.1016/0096-3003(88)90133-6.
[https://doi.org/10.1016/0096-3003\(88\)90133-6](https://doi.org/10.1016/0096-3003(88)90133-6)
- ⁴¹ Pennisi, Elizabeth, et al. “The Momentous Transition to Multicellular Life May Not Have Been so Hard after All.” *Science*, 28 June 2018. <https://www.sciencemag.org/news/2018/06/momentous-transition-multicellular-life-may-not-have-been-so-hard-after-all>
- ⁴² “How Many Bacteria Live on Earth?” *Sciencing*. <https://sciencing.com/how-many-bacteria-live-earth-4674401.html>
- ⁴³ Prusiner, S. B. “Novel Proteinaceous Infectious Particles Cause Scrapie.” *Science*, vol. 216, no. 4542, Apr. 1982, pp. 136–44. doi:10.1126/science.6801762.
<https://science.sciencemag.org/content/216/4542/136.long>
- ⁴⁴ Pattison, I. H., and K. M. Jones. “The Possible Nature of the Transmissible Agent of Scrapie.” *Veterinary Record*, vol. 80, no. 1, Jan. 1967, pp. 2–9. doi:10.1136/vr.80.1.2.
<https://veterinaryrecord.bmj.com/content/80/1/2>
- ⁴⁵ “1.4 Universality.” *New England Complex Systems Institute*. <https://necsi.edu/14-universality>
- ⁴⁶ Denton, Peter B., et al. “Eigenvectors from Eigenvalues.” *ArXiv:1908.03795* (August 2019)
<https://arxiv.org/pdf/1908.03795.pdf>
- ⁴⁷ Tao, Terence, and Van Vu. “Random Matrices: Universality of Local Eigenvalue Statistics.” *ArXiv:0906.0510* (June 2010) <https://arxiv.org/pdf/0906.0510.pdf>

⁴⁸ Wu, Leting, et al. "A Spectral Approach to Detecting Subtle Anomalies in Graphs." *Journal of Intelligent Information Systems*, vol. 41, no. 2, Oct. 2013, pp. 313–37. doi:10.1007/s10844-013-0246-7 <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.499.3228&rep=rep1&type=pdf>

⁴⁹ Denton, Peter B., et al. "Eigenvalues: The Rosetta Stone for Neutrino Oscillations in Matter." *ArXiv:1907.02534* (July 2019) <https://arxiv.org/pdf/1907.02534.pdf>

⁵⁰ Committee on Information Technology, Automation, and the U.S. Workforce, et al. *Information Technology and the U.S. Workforce: Where Are We and Where Do We Go from Here?* National Academies Press, 2017. doi:10.17226/24649. National Academies of Sciences, Engineering, and Medicine 2017. <https://doi.org/10.17226/24649> and <https://www.nap.edu/download/24649>

⁵¹ Wassén, Olivia. "Big Data Facts - How Much Data Is out There?" *NodeGraph*, 2 Sept. 2019. <https://www.nodegraph.se/big-data-facts/>

⁵² <https://www.seagate.com/files/www-content/our-story/trends/files/idc-seagate-dataage-whitepaper.pdf>

⁵³ David, Paul A. "The Dynamo and the Computer: An Historical Perspective on the Modern Productivity Paradox." *The American Economic Review* 80, no. 2 (1990): 355-61. www.jstor.org/stable/2006600.

(https://pdfs.semanticscholar.org/dff7/9b2f28cbb79da91becaab803667f30394233.pdf?_ga=2.215911511.1520557695.1570682035-1238830782.1562127126)

⁵⁴ Syverson, C. (2013) Will History Repeat Itself? Comments on "Is the Information Technology Revolution Over?" *Intl Productivity Monitor* 25 37-40 www.csls.ca/ipm/25/IPM-25-Syverson.pdf

⁵⁵ Syverson, Chad. *Challenges to Mismeasurement Explanations for the U.S. Productivity Slowdown*. Working Paper, 21974, National Bureau of Economic Research, Feb. 2016. *National Bureau of Economic Research*, doi:10.3386/w21974. <https://www.nber.org/papers/w21974.pdf>

⁵⁶ Gordon, R (2016) *The Rise and Fall of American Growth: U.S. Standard of Living since the Civil War* <https://press.princeton.edu/books/hardcover/9780691147727/the-rise-and-fall-of-american-growth>

⁵⁷ Solow, Robert M. "A Contribution to the Theory of Economic Growth." *The Quarterly Journal of Economics*, vol. 70, no. 1, Feb. 1956, p. 65. doi:10.2307/1884513

⁵⁸ "Information Technology and the U.S. Workforce: Where Are We and Where Do We Go from Here?" doi:10.17226/24649 <https://www.nap.edu/read/24649/chapter/5#55>

⁵⁹ Bivens, Josh and Mishel, Lawrence (2015) Understanding the Historic Divergence Between Productivity and a Typical Worker's Pay: Why It Matters and Why It's Real. Economic Policy Institute. <https://www.epi.org/files/2015/understanding-productivity-pay-divergence-final.pdf>

⁶⁰ "Why Hasn't Technology Sped up Productivity?" *Chicago Booth Review*. <https://review.chicagobooth.edu/economics/2018/article/why-hasn-t-technology-sped-productivity>

⁶¹ OECD. *OECD Compendium of Productivity Indicators 2019*. OECD, 2019. doi:10.1787/b2774f97-en

⁶² Huff, Darrell (1954) *How to Lie with Statistics*. Norton, 1954. <http://faculty.neu.edu.cn/cc/zhangyf/papers/How-to-Lie-with-Statistics.pdf>

⁶³ Blum, Avrim, et al. *Foundations of Data Science*. First edition, Cambridge University Press, 2020.

<https://www.cs.cornell.edu/jeh/book.pdf>

⁶⁴ David, Javier. “Study: Nearly 70 Percent of Tech Spending Is Wasted.” *Vox*, 31 Oct. 2015,

<https://www.vox.com/2015/10/31/11620222/study-nearly-70-percent-of-tech-spending-is-wasted>

⁶⁵ Zobell, Steven. “Why Digital Transformations Fail: Closing The \$900 Billion Hole In Enterprise Strategy.” *Forbes*. <https://www.forbes.com/sites/forbestechcouncil/2018/03/13/why-digital-transformations-fail-closing-the-900-billion-hole-in-enterprise-strategy/>

<https://www.forbes.com/sites/forbestechcouncil/2018/03/13/why-digital-transformations-fail-closing-the-900-billion-hole-in-enterprise-strategy/>

⁶⁶ Giller, Graham L. “A Generalized Error Distribution.” *SSRN Electronic Journal*, 2005.

doi:10.2139/ssrn.2265027.

<http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.542.879&rep=rep1&type=pdf>

⁶⁷ McDonald, James B., and Yexiao J. Xu. “A Generalization of the Beta Distribution with Applications.” *Journal of Econometrics*, vol. 66, no. 1–2, Mar. 1995, pp. 133–52. doi:10.1016/0304-4076(94)01612-4. <https://www.sciencedirect.com/science/article/abs/pii/0304407694016124>

<https://www.sciencedirect.com/science/article/abs/pii/0304407694016124>

⁶⁸ Granger, Clive W.J. (1983) Co-integrated variables and error-correcting models. UCSD Discussion Paper 83-13.

⁶⁹ Engle, Robert F. “Interpreting Spectral Analyses in Terms of Time-Domain Models.” *Annals of Economic & Social Measurement*. Vol 5, no 1, Jan. 1976, pp. 89–109. www.nber.org/chapters/c10429.pdf

www.nber.org/chapters/c10429.pdf

⁷⁰ Engle, Robert F. “Autoregressive Conditional Heteroscedasticity with Estimates of the Variance of United Kingdom Inflation.” *Econometrica*, vol. 50, no. 4, July 1982, p. 987. doi:10.2307/1912773.

<http://www.econ.uiuc.edu/~econ508/Papers/engle82.pdf>

⁷¹ Granger, Clive W. J., et al. *Essays in Econometrics: Collected Papers of Clive W.J. Granger*. Cambridge University Press, 2001. <https://dl.acm.org/citation.cfm?id=781849>

<https://dl.acm.org/citation.cfm?id=781849>

⁷² Granger, Clive W. J. *Time Series Analysis, Cointegration, and Applications*. 2004.

<https://escholarship.org/uc/item/2nb9f668>

⁷³ Engle, Robert. “GARCH 101: The Use of ARCH/GARCH Models in Applied Econometrics.” *Journal of Economic Perspectives*, vol. 15, no. 4, Nov. 2001, pp. 157–68. doi:10.1257/jep.15.4.157.

<http://www.cmat.edu.uy/~mordecki/hk/engle.pdf>

⁷⁴ <https://www.nobelprize.org/prizes/economic-sciences/2003/summary/>

⁷⁵ Baldassare Fronte, Greta Galliano and Carlo Bibbiani (2016) From freshwater to marine aquaponic: new opportunities for marine fish species production. Conference VIVUS, 20th and 21st April 2016, Biotechnical Centre Naklo, Strahinj 99, Naklo, Slovenia.

<https://pdfs.semanticscholar.org/f8b2/fad3fe3f6f92a7b1c8276ad57876d8fd0a70.pdf>

⁷⁶ Matthias, Dipika M., et al. “Freezing Temperatures in the Vaccine Cold Chain: A Systematic Literature Review.” *Vaccine*, vol. 25, no. 20, May 2007, pp. 3980–86. doi:10.1016/j.vaccine.2007.02.052.

<https://www.nist.gov/sites/default/files/documents/2017/05/09/FreezingReviewArticle-Vaccine.pdf>

⁷⁷ D. Ruppert (2011) *Statistics and Data Analysis for Financial Engineering*. Pages 477-504. Springer Texts in Statistics. DOI 10.1007/978-1-4419-7787-8_18

<https://faculty.washington.edu/ezivot/econ589/ch18-garch.pdf>

⁷⁸ Duan, Jin-Chuan (2001) GARCH Model and Its Application.

<http://jupiter.math.nctu.edu.tw/~weng/seminar/GarchApplication.pdf>

⁷⁹ Diebold, F.X. (2019) Econometric Data Science: A Predictive Modeling Approach

<http://www.ssc.upenn.edu/~fdiebold/Textbooks.html>

<https://www.sas.upenn.edu/~fdiebold/Teaching104/Econometrics.pdf>

⁸⁰ Datta, Shoumen and Granger Clive (2006) Potential to Improve Forecasting Accuracy: Advances in Supply Chain Management. <https://dspace.mit.edu/handle/1721.1/41905>

⁸¹ Datta, S., et al. "Management of Supply Chain: An Alternative Modelling Technique for Forecasting." *Journal of the Operational Research Society*, vol. 58, no. 11, Nov. 2007, pp. 1459–69.

doi:10.1057/palgrave.jors.2602419. <https://dspace.mit.edu/handle/1721.1/41906>

⁸² Narayanan, Arvind (2019) *How to recognize AI snake oil*

<https://www.cs.princeton.edu/~arvindn/talks/MIT-STS-AI-snakeoil.pdf>

⁸³ Li, Lingli, et al. "A Survey of Uncertain Data Management." *Frontiers of Computer Science*, vol. 14, no. 1, Feb. 2020, pp. 162–90. doi:10.1007/s11704-017-7063-z.

<https://link.springer.com/article/10.1007/s11704-017-7063-z>

⁸⁴ Agrawal, R., Imielinski, T., Swami, A. (1993) "Mining Association Rules between Sets of Items in Large Databases." *Proceedings of the 1993 ACM SIGMOD International Conference on Management of Data - SIGMOD '93*, ACM Press, 1993, pp. 207–16. doi:10.1145/170035.170072.

⁸⁵ Coenen, Frans. "Data Mining: Past, Present and Future." *The Knowledge Engineering Review*, vol. 26, no. 1, Feb. 2011, pp. 25–29. doi:10.1017/S0269888910000378.

https://www.researchgate.net/publication/220254364_Data_mining_Past_present_and_future

⁸⁶ Kahneman, Daniel. *Thinking, Fast and Slow*. Penguin Books, 2012.

<http://sysengr.engr.arizona.edu/OLLI/lousyDecisionMaking/KahnemanThinkingFast&Slow.pdf>

⁸⁷ Akerlof, George, and Janet Yellen. "Rational Models of Irrational Behavior." *American Economic Review*, vol. 77, no. 2, 1987, pp. 137–42. https://notendur.hi.is/ajonsson/kennsla2003/Akerlof_Yellen.pdf

⁸⁸ <https://spectrum.ieee.org/biomedical/diagnostics/how-ibm-watson-overpromised-and-underdelivered-on-ai-health-care>

⁸⁹ *Minds and Machines Postponed / Canceled - Post Regarding GE Digital Layoffs.*

<https://www.thelayoff.com/t/VtbKYAf>

⁹⁰ <http://bit.ly/MRC-BERT-HAN>

⁹¹ Rumelhart, David E., et al. "Learning Representations by Back-Propagating Errors." *Nature*, vol. 323, no. 6088, Oct. 1986, pp. 533–36. doi:10.1038/323533a0.

https://www.iro.umontreal.ca/~vincentp/ift3395/lectures/backprop_old.pdf

⁹² McCarthy, John, Minsky, Marvin L., Rochester, Nathaniel and Shannon, Claude E. (1955) A Proposal for the Dartmouth Summer Research Project on Artificial Intelligence (31 August 1955)

<http://www-formal.stanford.edu/jmc/history/dartmouth.pdf>

⁹³ Datta, Shoumen and Granger Clive (2006) Potential to Improve Forecasting Accuracy: Advances in Supply Chain Management. <https://dspace.mit.edu/handle/1721.1/41905>

- ⁹⁴ Levy, Frank. "Computers and Populism: Artificial Intelligence, Jobs, and Politics in the near Term." *Oxford Review of Economic Policy*, vol. 34, no. 3, July 2018, pp. 393–417. doi:10.1093/oxrep/gry004. <https://www.russellsage.org/sites/default/files/gry004.pdf>
- ⁹⁵ GE Minds + Machines (November 15, 2016) www.youtube.com/watch?v=OYN9ZtpWCUw
- ⁹⁶ *Why Robots Won't Take over the World*. <https://phys.org/news/2018-04-robots-wont-world.html>
- ⁹⁷ Freedman, David H. "What Will It Take for IBM's Watson Technology to Stop Being a Dud in Health Care?" *MIT Tech Review* www.technologyreview.com/s/607965/a-reality-check-for-ibms-ai-ambitions/
- ⁹⁸ *Minds and Machines Postponed / Canceled - Post Regarding GE Digital Layoffs*. <https://www.thelayoff.com/t/VtbKYAf>
- ⁹⁹ Salmon, Felix. "IBM's Watson Was Supposed to Change the Way We Treat Cancer. Here's What Happened Instead." *Slate Magazine*, 18 Aug 2018. <https://slate.com/business/2018/08/ibms-watson-how-the-ai-project-to-improve-cancer-treatment-went-wrong.html>
- ¹⁰⁰ Perez, Carlos E. "Why We Should Be Deeply Suspicious of BackPropagation." *Medium*, 13 Oct 2017. <https://medium.com/intuitionmachine/the-deeply-suspicious-nature-of-backpropagation-9bed5e2b085e>
- ¹⁰¹ Datta, Shoumen. *Intelligence in Artificial Intelligence*. Oct 2016. <https://arxiv.org/abs/1610.07862>
- ¹⁰² "There's No Good Reason to Trust Blockchain Technology." *Wired*. <https://www.wired.com/story/theres-no-good-reason-to-trust-blockchain-technology/>
- ¹⁰³ Stinchcombe, Kai. "Blockchain Is Not Only Crappy Technology but a Bad Vision for the Future." *Medium*. 9 April 2018. <https://medium.com/@kaistinchcombe/decentralized-and-trustless-crypto-paradise-is-actually-a-medieval-hellhole-c1ca122efdec>
- ¹⁰⁴ "RuuviLab - IOTA Masked Authentication Messaging." *RuuviLab*. <https://lab.ruuvi.com/iota>
- ¹⁰⁵ Andreas Kamilaris, Agusti Fonts and Francesc X. Prenafeta-Boldú (2019) The Rise of Blockchain Tech in Agriculture and Food Supply Chains. <https://arxiv.org/ftp/arxiv/papers/1908/1908.07391.pdf>
- ¹⁰⁶ Press, Gil. "Big Data Is Dead. Long Live Big Data AI." *Forbes*. www.forbes.com/sites/gilpress/2019/07/01/big-data-is-dead-long-live-big-data-ai/#5a262cf71b05
- ¹⁰⁷ Walsh, Mary Williams, and Emily Flitter. "McKinsey Faces Criminal Inquiry Over Bankruptcy Case Conduct." *The New York Times*, 8 Nov 2019. <https://www.nytimes.com/2019/11/08/business/mckinsey-criminal-investigation-bankruptcy.html>
- ¹⁰⁸ Black, Edwin. *IBM and the Holocaust: The Strategic Alliance between Nazi Germany and America's Most Powerful Corporation*. 1st ed, Crown Publishers, 2001. <http://posoh.ru/book/htm/ibm.pdf>
- ¹⁰⁹ Allison, Simon. "Huawei's Pitch to African Mayors: 'Our Cameras Will Make You Safe.'" *The M&G Online*. <https://mg.co.za/article/2019-11-15-00-our-cameras-will-make-you-safe>
- ¹¹⁰ 2007 Joint Workshop on High Confidence Medical Devices, Software, and Systems and Medical Device Plug-and-Play Interoperability: HCMDSS//MD PnP 2007: *Improving Patient Safety through Medical Device Interoperability and High Confidence Software*: Proceedings: 25-27 June 2007, Cambridge, MA. <https://nam.edu/wp-content/uploads/2018/02/3.1-Goldman-Jan-2018-002.pdf>

¹¹¹ Hatcliff, John et al (2011) Medical Application Platforms – Rationale, Architectural Principles, and Certification Challenges. www.nitrd.gov/nitrdgroups/images/8/8b/MedicalDeviceInnovationCPS.pdf

¹¹² Makary, Martin A., and Michael Daniel. “Medical Error—the Third Leading Cause of Death in the US.” *BMJ*, vol. 353, May 2016. doi:10.1136/bmj.i2139 <https://www.bmj.com/content/353/bmj.i2139>

¹¹³ Slight, Sarah Patricia, et al. “Meaningful Use of Electronic Health Records: Experiences From the Field and Future Opportunities.” *JMIR Medical Informatics*, vol. 3, no. 3, 2015, p. e30. doi:10.2196/medinform.4457 <https://medinform.jmir.org/2015/3/e30/>

¹¹⁴ *Meaningful Use*. CDC. 10 Sept. 2019 <https://www.cdc.gov/ehrmeaningfuluse/introduction.html>

¹¹⁵ MIT AUTO-ID LABORATORY <https://autoid.mit.edu/about-lab>

¹¹⁶ Shabandri, Bilal, and Piyush Maheshwari. “Enhancing IoT Security and Privacy Using Distributed Ledgers with IOTA and the Tangle.” *2019 6th International Conference on Signal Processing and Integrated Networks (SPIN)*, IEEE, 2019, pp. 1069–75. doi:10.1109/SPIN.2019.8711591 https://assets.ctfassets.net/r1dr6vzfxhev/2t4uxvsIqk0EUau6g2sw0g/45eae33637ca92f85dd9f4a3a218e1e/c/iota1_4_3.pdf

¹¹⁷ The Coordicide https://files.iota.org/papers/Coordicide_WP.pdf

¹¹⁸ <https://www.iota.org/>

¹¹⁹ *Send IoT Data to the IOTA Tangle with SAP HANA XSA and Analytics Cloud*.

<https://blogs.sap.com/2019/10/08/send-iot-data-to-the-iota-tangle-with-sap-hana-xsa-and-analytics-cloud/>

¹²⁰ <https://www.dds-foundation.org/>

¹²¹ Mark Shepard, Katherine Baicker and Jonathan S. Skinner (2019). *Does One Medicare Fit All? The Economics of Uniform Health Insurance Benefits in Tax Policy and the Economy*, Volume 34, Moffitt. DOI 10.3386/w26472 <https://www.nber.org/papers/w26472.pdf>

¹²² <http://bit.ly/Economics-of-Technology>

¹²³ <http://bit.ly/COASE5PAPERS>

¹²⁴ Merelli, Annalisa. “The Inventor of Microfinance Has an Idea for Fixing Capitalism.” *Quartz*. <https://qz.com/1089266/the-inventor-of-microfinance-has-an-idea-for-fixing-capitalism/>

¹²⁵ Georgescu, Cristian. “Simulating Micropayments in Local Area Networks.” *Procedia - Social and Behavioral Sciences*, vol. 62, Oct. 2012, pp. 30–34. <https://doi.org/10.1016/j.sbspro.2012.09.007>

¹²⁶ Spence, Michael (2011) *The Next Convergence: The Future of Economic Growth in a Multispeed World*. Farrar, Straus and Giroux, 2011. <http://pubdocs.worldbank.org/en/515861447787792966/DEC-Lecture-Series-Michael-Spence-Presentation.pdf>

¹²⁷ Tabassi, Elham, et al. *A Taxonomy and Terminology of Adversarial Machine Learning*. NIST IR 8269-draft. National Institute of Standards and Technology, October 2019. doi:10.6028/NIST.IR.8269-draft <https://nvlpubs.nist.gov/nistpubs/ir/2019/NIST.IR.8269-draft.pdf>

¹²⁸ Duddu, Vasisht. “A Survey of Adversarial Machine Learning in Cyber Warfare.” *Defence Science Journal*, vol. 68, no. 4, June 2018, p. 356. doi:10.14429/dsj.68.12371

¹²⁹ Victoria Morgan, Lisseth Casso-Hartman, David Bahamon-Pinzon, Kelli McCourt, Robert G. Hjort, Sahar Bahramzadeh, Irene Velez-Torres, Eric McLamore, Carmen Gomes, Evangelyn C. Alocilja, Nirajan Bhusal, Sunaina Shrestha, Nisha Pote, Ruben Kenny Briceno, Shoumen Palit Austin Datta, and Diana C. Vanegas (2020) *Sensor-as-a-Service: Convergence of Sensor Analytic Point Solutions (SNAPS) and Pay-A-Penny-Per-Use (PAPPU) Paradigm as a Catalyst for Democratization of Healthcare in Underserved Communities*. *Diagnostics* 2020, 10, 22; doi:10.3390/diagnostics10010022 ▪ MIT Library SNAPS - <https://dspace.mit.edu/handle/1721.1/123983> ▪ <https://dspace.mit.edu/handle/1721.1/111021>

¹³⁰ Datta, Shoumen et al (2004) *ADAPTIVE VALUE NETWORKS: Convergence of Emerging Tools, Technologies and Standards as Catalytic Drivers* in Chang, Yoon Seok, et al., editors. *Evolution of Supply Chain Management: Symbiosis of Adaptive Value Networks and ICT*. Kluwer Academic Publishers, 2004. <https://dspace.mit.edu/handle/1721.1/41908>

¹³¹ Silvestro, Rhian, and Paola Lustrato. “Integrating Financial and Physical Supply Chains: The Role of Banks in Enabling Supply Chain Integration.” *International Journal of Operations & Production Management*, vol. 34, no. 3, Jan. 2014, pp. 298–324. doi:10.1108/IJOPM-04-2012-0131. <https://www.emerald.com/insight/content/doi/10.1108/IJOPM-04-2012-0131/full/html>

¹³² Banerjee, Abhijit V., and Esther Duflo. *Poor Economics: A Radical Rethinking of the Way to Fight Global Poverty*. 1st ed, PublicAffairs, 2011. https://warwick.ac.uk/about/london/study/warwick-summer-school/courses/macroeconomics/poor_economics.pdf

¹³³ Kamenetz, Anya. “Esther Duflo Bribes India’s Poor To Health.” *Fast Company*, 8 August 2011. <https://www.fastcompany.com/1768537/esther-duflo-bribes-indias-poor-health>

¹³⁴ Lie, Robert. *Robertlie/Dht11-Raspi3*. 2018. 2019. *GitHub* <https://github.com/robertlie/dht11-raspi3>

¹³⁵ Handy, Paul. “Introducing Masked Authenticated Messaging.” *Medium*, 9 April 2018. <https://blog.iota.org/introducing-masked-authenticated-messaging-e55c1822d50e>

¹³⁶ Ekaterina D. Kazimirova (2017) *Human-Centric Internet of Things. Problems and Challenges* https://www.researchgate.net/publication/319059870_Human-Centric_Internet_of_Things_Problems_and_Challenges

¹³⁷ Calderon, Marco A., et al. “A More Human-Centric Internet of Things with Temporal and Spatial Context.” *Procedia Computer Science*, vol. 83, 2016, pp. 553–559 doi:10.1016/j.procs.2016.04.263 <https://www.sciencedirect.com/science/article/pii/S1877050916302964>

¹³⁸ McLamore, E.S., S.P.A. Datta, V. Morgan, N. Cavallaro, G. Kiker, D.M. Jenkins, Y. Rong, C. Gomes, J. Claussen, D. Vanegas, E.C. Alocilja (2019) *SNAPS: Sensor Analytics Point Solutions for Detection and Decision Support*. *Sensors*, vol. 19, no. 22, p. 4935 ▪ <https://www.mdpi.com/1424-8220/19/22/4935/pdf>

¹³⁹ *Artificial Intelligence - Intelligent Agents* (2017) https://courses.edx.org/asset-v1:ColumbiaX+CSMM.101x+1T2017+type@asset+block@AI_edx_intelligent_agents_new__1_.pdf

¹⁴⁰ Sutton, Richard S., and Andrew G. Barto. *Reinforcement Learning: An Introduction*. Second edition, MIT Press, 2018. <https://web.stanford.edu/class/psych209/Readings/SuttonBartoIPRLBook2ndEd.pdf>

¹⁴¹ “The Sensor-Based Economy.” *Wired*, January 2017. <https://www.wired.com/brandlab/2017/01/sensor-based-economy/>

¹⁴² Pont, Simon, editor. *Digital State: How the Internet Is Changing Everything*. Kogan Page, 2013.

¹⁴³ Leading the IoT: Gartner Insights on How to Lead in a Connected World

https://www.gartner.com/imagesrv/books/iot/iotEbook_digital.pdf

¹⁴⁴ Dave Evans (2011) The Internet of Things: How the Next Evolution of the Internet Is Changing Everything. https://www.cisco.com/c/dam/en_us/about/ac79/docs/innov/IoT_IBSG_0411FINAL.pdf

¹⁴⁵ David Puglia. “Are Enterprises Ready for Billions of Devices to Join the Internet?” *Wired*, December 2014. <https://www.wired.com/insights/2014/12/enterprises-billions-of-devices-internet/>

¹⁴⁶ “Gartner Says 5.8 Billion Enterprise and Automotive IoT Endpoints Will Be in Use in 2020.” <https://www.gartner.com/en/newsroom/press-releases/2019-08-29-gartner-says-5-8-billion-enterprise-and-automotive-iot>

¹⁴⁷ www.cisco.com/c/dam/en/us/products/collateral/se/internet-of-things/at-a-glance-c45-731471.pdf

¹⁴⁸ *The Internet of Things: Sizing up the Opportunity*. McKinsey.

<https://www.mckinsey.com/industries/semiconductors/our-insights/the-internet-of-things-sizing-up-the-opportunity>

¹⁴⁹ “IoT Overview Handbook: 2019 Background Primer on The Topics & Technologies Driving the Internet of Things.” *Postscapes*. <https://www.postscapes.com/iot/>

¹⁵⁰ Martin Fleming, Wyatt Clarke, Subhro Das, Phai Phongthientham, and Prabhat Reddy (2019) The Future of Work: How New Technologies Are Transforming Tasks (October 31, 2019)

<https://mitibmwatsonailab.mit.edu/research/publications/paper/download/The-Future-of-Work-How-New-Technologies-Are-Transforming-Tasks.pdf>

¹⁵¹ Andrew Ng “Why AI Is the New Electricity” <https://www.gsb.stanford.edu/insights/andrew-ng-why-ai-new-electricity>

¹⁵² Cheekiralla, Sivaram, and Daniel W. Engels. “An IPv6-Based Identification Scheme.” *2006 IEEE International Conference on Communications*, vol. 1, 2006, pp. 281–86. doi:10.1109/ICC.2006.254741 <https://ieeexplore.ieee.org/document/4024131>

¹⁵³ Stallings, W. “IPv6: The New Internet Protocol.” *IEEE Communications Magazine*, vol. 34, no. 7, July 1996, pp. 96–108. doi:10.1109/35.526895. <https://ieeexplore.ieee.org/document/526895>

¹⁵⁴ “Difference Between IPv4 and IPv6” *Tech Differences*, 4 August 2017.

<https://techdifferences.com/difference-between-ipv4-and-ipv6.html>

¹⁵⁵ Datta, Shoumen Palit Austin “An Unified Theory of Relativistic Identification of Information in the Systems Age: Proposed Convergence of Unique Identification with Syntax and Semantics through Internet Protocol Version 6 (IPv6).” *International Journal of Advanced Logistics*, vol. 1, no. 1, July 2012, pp. 66–82. doi:10.1080/2287108X.2012.11006070. <https://dspace.mit.edu/handle/1721.1/41902>

¹⁵⁶ Datta, Shoumen. “Mobile eVote as an IPv6 App.” 23 May 2011.

<https://shoumendatta.wordpress.com/2011/05/23/mobile-e-vote-ipv6-app/>.

<https://dspace.mit.edu/bitstream/handle/1721.1/41902/IPv6%20Apps%20and%20SaaS.pdf?sequence=11&isAllowed=y>

¹⁵⁷ <https://bentley.umich.edu/elecrc/d/duderstadt/Speeches/JJDS6/jjd1341.pdf>

- ¹⁵⁸ Figueroa, Anthony. “Data Demystified — DIKW Model.” *Medium*, 24 May 2019. <https://towardsdatascience.com/rootstrap-dikw-model-32cef9ae6dfb>
- ¹⁵⁹ William S. Angerman (2004) Coming Full Circle With Boyd’s OODA Loop Ideas: An Analysis Of Innovation Diffusion And Evolution (Thesis). <https://apps.dtic.mil/dtic/tr/fulltext/u2/a425228.pdf>
- ¹⁶⁰ Castanedo, Federico. “A Review of Data Fusion Techniques.” *The Scientific World Journal*, 2013, doi:10.1155/2013/704504. <http://downloads.hindawi.com/journals/tswj/2013/704504.pdf>
- ¹⁶¹ <https://www.wur.nl/en/Education-Programmes/wageningen-academy-1/What-we-offer-you/Courses/show-1/Course-Towards-Data-driven-Agri-Food-Business-1.htm>
- ¹⁶² CS 540 Lecture Notes: Intelligent Agents. <http://pages.cs.wisc.edu/~dyer/cs540/notes/agents.html>
- ¹⁶³ Maes, Pattie. “Intelligent Software.” *Proceedings of the 2nd International Conference on Intelligent User Interfaces - IUI '97*, ACM Press, 1997, pp. 41–43 ▪ doi:10.1145/238218.238283
- ¹⁶⁴ Paolucci, Massimo, and Roberto Sacile. *Agent-Based Manufacturing and Control Systems: New Agile Manufacturing Solutions for Achieving Peak Performance*. CRC Press, 2005. <http://jmvidal.cse.sc.edu/library/paolucci05a.pdf>
- ¹⁶⁵ Datta, S (2017) Cybersecurity: Agents based Approach? <https://dspace.mit.edu/handle/1721.1/107988>
- ¹⁶⁶ White, Franklin E. (1997) Data Fusion Group. <https://apps.dtic.mil/dtic/tr/fulltext/u2/a394662.pdf>
- ¹⁶⁷ Rafferty, Ellen R. S., et al. “Seeking the Optimal Schedule for Chickenpox Vaccination in Canada: Using an Agent-Based Model to Explore the Impact of Dose Timing, Coverage and Waning of Immunity on Disease Outcomes.” *Vaccine*, November 2019. doi:10.1016/j.vaccine.2019.10.065.
- ¹⁶⁸ O. Lassila and R.R. Swick. Resource Description Framework (RDF) Model and Syntax Specification. W3C working draft, February 1999. www.w3.org/TR/REC-rdf-syntax/
- ¹⁶⁹ T. Berners-Lee, J. Hendler, and O. Lassila. The Semantic Web. *Scientific American*, March 2001.
- ¹⁷⁰ Shi, Longxiang, et al. “Semantic Health Knowledge Graph: Semantic Integration of Heterogeneous Medical Knowledge and Services.” *BioMed Research International*, vol. 2017, 2017, pp. 1–12 doi:10.1155/2017/2858423 <http://downloads.hindawi.com/journals/bmri/2017/2858423.pdf>
- ¹⁷¹ Ayan Chakraborty, Shiladitya Munshi and Debajyoti Mukhopadhyay (2013) *Searching and Establishment of S-P-O Relationships for Linked RDF Graphs : An Adaptive Approach*. 2013 Int Conf on Cloud & Ubiquitous Comp & Emerging Tech <https://arxiv.org/ftp/arxiv/papers/1311/1311.7200.pdf>
- ¹⁷² Ayan Chakraborty, Shiladitya Munshi and Debajyoti Mukhopadhyay (2013) *A Proposal for the Characterization of MultiDimensional Inter-relationships of RDF Graphs Based on Set Theoretic Approach*. <https://arxiv.org/ftp/arxiv/papers/1312/1312.0001.pdf>
- ¹⁷³ Buneman, Peter. “A Characterisation of Rigid Circuit Graphs.” *Discrete Mathematics*, vol. 9, no. 3, Sept. 1974, pp. 205–212 doi:10.1016/0012-365X(74)90002-8. <http://homepages.inf.ed.ac.uk/opb/homepagefiles/phylogeny-scans/rigidcircuitgraphs.pdf>
- ¹⁷⁴ Sharma, Chandan, and Roopak Sinha. (2019) “A Schema-First Formalism for Labeled Property Graph Databases: Enabling Structured Data Loading and Analytics.” *Proceedings of the 6th IEEE/ACM International Conference on Big Data Computing, Applications and Technologies - BDCAT '19*, ACM Press, 2019, pp. 71–80 doi:10.1145/3365109.3368782

- ¹⁷⁵ Wang, Da-Wei, et al. (2019) “CK-Modes Clustering Algorithm Based on Node Cohesion in Labeled Property Graph.” *J of Computer Science and Technology*, vol. 34, no. 5, September 2019, pp. 1152-1166 doi:10.1007/s11390-019-1966-0
- ¹⁷⁶ <https://aibusiness.com/ending-the-rdf-vs-property-graph-debate-with-rdf/>
- ¹⁷⁷ Tarjan, Robert. “Depth-First Search and Linear Graph Algorithms.” *SIAM Journal on Computing*, vol. 1, no. 2, June 1972, pp. 146–160 doi:10.1137/0201010.
- ¹⁷⁸ Fleischer, Rudolf, and Gerhard Trippen. (2003) “Experimental Studies of Graph Traversal Algorithms.” *Experimental and Efficient Algorithms*, edited by Klaus Jansen et al., vol. 2647, Springer Berlin Heidelberg, 2003, pp. 120–133 doi:10.1007/3-540-44867-5_10
- ¹⁷⁹ Noy, Natasha, et al. “Industry-Scale Knowledge Graphs: Lessons and Challenges.” *Com of the ACM*, vol. 62, no. 8, July 2019, pp. 36–43 doi:10.1145/3331166 <https://queue.acm.org/detail.cfm?id=3332266>
- ¹⁸⁰ <https://tech.ebayinc.com/engineering/akutan-a-distributed-knowledge-graph-store/>
- ¹⁸¹ <https://www.w3.org/TR/owl-guide/>
- ¹⁸² Sengupta K., Hitzler P. (2014) Web Ontology Language (OWL). In: Alhaji, Reda, and Jon Rokne, eds. *Encyclopedia of Social Network Analysis & Mining*. Springer, NY. doi:10.1007/978-1-4614-6170-8
- ¹⁸³ <http://vowl.visualdataweb.org/v2/>
- ¹⁸⁴ <https://tools.ietf.org/html/rfc3987>
- ¹⁸⁵ www.eads-iw.net/web/nfigay
- ¹⁸⁶ Carbone, Lorenzo, et al. *State of Play of Interoperability: Report 2016*. 2017. *Open WorldCat*. <http://dx.publications.europa.eu/10.2799/969314>
https://ec.europa.eu/isa2/sites/isa/files/docs/publications/report_2016_rev9_single_pages.pdf
- ¹⁸⁷ “Blind Men and the Elephant.” www.allaboutphilosophy.org/blind-men-and-the-elephant.htm
- ¹⁸⁸ Bohr, N. (1950) “On the Notions of Causality and Complementarity.” *Science*, vol. 111, no. 2873, January 1950, pages 51–54 doi:10.1126/science.111.2873.51
- ¹⁸⁹ Morrison, Alan (2019) *Is data science/machine learning/AI overhyped right now?* www.quora.com/Is-data-science-machine-learning-AI-overhyped-right-now/answer/Alan-Morrison
- ¹⁹⁰ Fuller, Aidan, et al. “Digital Twin: Enabling Technology, Challenges and Open Research.” Oct. 2019. <http://arxiv.org/abs/1911.01276> ▪ <https://arxiv.org/ftp/arxiv/papers/1911/1911.01276.pdf>
- ¹⁹¹ <https://newsstand.joomag.com/en/iic-journal-of-innovation-12th-edition/0994713001573661267>
- ¹⁹² <https://www.forbes.com/sites/bernardmarr/2017/03/06/what-is-digital-twin-technology-and-why-is-it-so-important>
- ¹⁹³ Pareto, Vilfredo. *Manual of political economy*. Translated by A. M. Kelley, 1971. MIT Press.
- ¹⁹⁴ Eric S. McLamore, R. Huffaker, Matthew Shupler, Katelyn Ward, Shoumen Palit Austin Datta, M. Katherine Banks, Giorgio Casaburi, Joany Babilonia, Jamie S. Foster (2019) “Digital Proxy of a Bio-Reactor (DIYBOT) Combines Sensor Data and Data Analytics for Wastewater Treatment and Wastewater Management Systems.” (*Nature Scientific Reports*, in press) Draft copy of “DIYBOT” available from MIT Libraries <https://dspace.mit.edu/handle/1721.1/123983>

- ¹⁹⁵ Hernlund, E., et al. “Osteoporosis in the European Union: Medical Management, Epidemiology and Economic Burden: A Report Prepared in Collaboration with the International Osteoporosis Foundation (IOF) and the European Federation of Pharmaceutical Industry Associations (EFPIA).” *Archives of Osteoporosis*, vol. 8, no. 1–2, December 2013, p. 136. doi:10.1007/s11657-013-0136-1
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3880487/pdf/11657_2013_Article_136.pdf
- ¹⁹⁶ Mithal, Ambrish, Dhingra, Vibha and Lau, Edith (2009) .The Asian Audit Epidemiology, costs and burden of osteoporosis in Asia 2009. <http://www.iofbonehealth.org/>
www.iofbonehealth.org/sites/default/files/PDFs/Audit%20Eastern%20Europe_Central%20Asia/Russian_Audit-Bulgaria.pdf
- ¹⁹⁸ www.iofbonehealth.org/sites/default/files/PDFs/Audit%20Asia/Asian_regional_audit_Indonesia.pdf
- ¹⁹⁹ www.iofbonehealth.org/sites/default/files/PDFs/Audit%20Asia/Asian_regional_audit_India.pdf
- ²⁰⁰ <https://www.iofbonehealth.org/facts-statistics>
- ²⁰¹ Global Bone Density Test Market Grows Substantially by 2023, Asserts MRRF Unleashing the Forecast for 2017-2023. *Reuters*. www.reuters.com/brandfeatures/venture-capital/article?id=57229
- ²⁰² El Maghraoui, A., et al. “Bone Mineral Density of the Spine and Femur in a Group of Healthy Moroccan Men.” *Bone*, vol. 44, no. 5, May 2009, pp. 965–969 doi:10.1016/j.bone.2008.12.025
- ²⁰³ Angell, Marcia. (2005) *The Truth about the Drug Companies: How They Deceive Us and What to Do about It*. Random House Trade Paperbacks, 2005.
<https://cyber.harvard.edu/cyberlaw2005/sites/cyberlaw2005/images/NYReviewBooksAngell.pdf>
- ²⁰⁴ <https://www.keele.ac.uk/pharmacy-bioengineering/ourpeople/jamesnolan/>
- ²⁰⁵ <https://people.eecs.berkeley.edu/~pabbeel/>
- ²⁰⁶ <http://bit.ly/Farm-IoT-Ranveer>
- ²⁰⁷ <https://www.theaaih.org/>
- ²⁰⁸ Gutterman, D.J. (2009) Silent Myocardial Ischemia. May 2009. *Circulation Journal* 2009 73 785–797.
https://www.jstage.jst.go.jp/article/circj/73/5/73_CJ-08-1209/_pdf
- ²⁰⁹ <https://github.com/alirezadir/Production-Level-Deep-Learning>
- ²¹⁰ Hannah Ritchie (2018) *What do people die from?* <https://ourworldindata.org/what-does-the-world-die-from>
- ²¹¹ https://www.who.int/nmh/publications/ncd_report_chapter1.pdf
- ²¹² Institute for Health Metrics and Evaluation, Human Development Network, The World Bank. *The Global Burden of Disease: Generating Evidence, Guiding Policy — Sub-Saharan Africa Regional Edition*. Seattle, WA: IHME, 2013.
<http://documents.worldbank.org/curated/en/831161468191672519/pdf/808520PUB0ENGL0Box0379820B00PUBLIC0.pdf>
- ²¹³ *Global health risks: mortality and burden of disease attributable to selected major risks*. World Health Organization (2009). ISBN 978 92 4 156387 1
https://www.who.int/healthinfo/global_burden_disease/GlobalHealthRisks_report_full.pdf
- ²¹⁴ https://www.who.int/pmnch/media/press_materials/fs/fs_mdg4_childmortality/en/

²¹⁵ <https://economictimes.indiatimes.com/magazines/panache/jack-dorsey-has-fallen-in-love-with-africa-plans-to-shift-there-for-3-6-months-next-year/articleshow/72275949.cms>

²¹⁶ The concept of “bit dribbling” may not be new but may be attributed to Neil Gershenfeld (MIT) circa 1999 (*personal communication*). The notion is that very small amounts of data and information (bits) transmitted (dribbled) at the right time, are often enough to serve 80% of cases, in several circumstances.

²¹⁷ Parker, Martin (2018) Shut Down the Business School.

<https://www.theguardian.com/news/2018/apr/27/bulldoze-the-business-school>

²¹⁸ Eid, Mohamad A., et al. “A Novel Eye-Gaze-Controlled Wheelchair System for Navigating Unknown Environments: Case Study With a Person With ALS.” *IEEE Access*, vol. 4, 2016, pages 558 - 573. doi:10.1109/ACCESS.2016.2520093.

²¹⁹ *Robots for Lonely Hearts – Asian Robotics Review*. <https://asianroboticsreview.com/home29-html>

²²⁰ Oppenheimer, Andres, and Ezra E. Fitz. *The Robots Are Coming! The Future of Jobs in the Age of Automation*. Vintage Books, a division of Penguin Random House, 2019. ISBN-13 978-0525565000

²²¹ Deming, David. “The Robots Are Coming. Prepare for Trouble.” *The New York Times*, 30 January 2020. <https://www.nytimes.com/2020/01/30/business/artificial-intelligence-robots-retail.html>

²²² http://www.philipkdickfans.com/mirror/websites/pkdweb/short_stories/Autofac.htm

²²³ <https://www.bloomberg.com/news/features/2017-10-18/this-company-s-robots-are-making-everything-and-reshaping-the-world>

²²⁴ Ford, Martin. *Rise of the Robots: Technology and the Threat of a Jobless Future*. Basic Books, 2016.

²²⁵ Pugliano, John. *The Robots Are Coming: A Human’s Survival Guide to Profiting in the Age of Automation*. Ulysses Press, 2017.

²²⁶ The Dutch Safety Board (2009) *Crashed during approach, Boeing 737-800, near Amsterdam Schiphol Airport, 25 February 2009*. https://catsr.vse.gmu.edu/SYST460/TA1951_AccidentReport.pdf

²²⁷ Pacaux-Lemoine, Marie-Pierre, and Frank Flemisch. “Layers of Shared and Cooperative Control, Assistance and Automation.” *IFAC-PapersOnLine*, vol. 49, no. 19, 2016, pp. 159 - 164 doi:10.1016/j.ifacol.2016.10.479

²²⁸ Wickens, Christopher D., et al. “Stages and Levels of Automation: An Integrated Meta-Analysis.” *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, vol. 54, no. 4, Sept. 2010, pp. 389 - 393 doi:10.1177/154193121005400425

²²⁹ Hamby, Chris. “How Boeing’s Responsibility in a Deadly Crash ‘Got Buried.’” *The New York Times*, 20 January 2020. <https://www.nytimes.com/2020/01/20/business/boeing-737-accidents.html>

²³⁰ Hamby, C. and Moses, C. “Boeing Refuses to Cooperate With New Inquiry Into Deadly Crash.” *The New York Times*, 6 February 2020. www.nytimes.com/2020/02/06/business/boeing-737-inquiry.html

²³¹ Solow, Robert M. (1957) “Technical Change and the Aggregate Production Function.” *The Review of Economics and Statistics*, vol. 39, no. 3, Aug. 1957, p. 312. doi:10.2307/1926047

<http://www.piketty.pse.ens.fr/files/Solow1957.pdf>

²³² <http://ghdx.healthdata.org/>

²³³ <https://www.oxfordeconomics.com/recent-releases/how-robots-change-the-world>

²³⁴ <https://apm.byu.edu/prism/index.php/Members/JohnHedengren>

²³⁵ <https://apmonitor.com/do/index.php/Main/ShortCourse>

²³⁶ Osgood, Nathaniel. (2019) Systems Data Science.

<https://www.youtube.com/watch?v=CPUOyqs9G3Q&feature=youtu.be>

²³⁷ Bayes, Thomas. (1763) *An essay towards solving a problem in the doctrine of chances*. Philosophical Transactions of the Royal Society of London 53(0):370-418, 1763 <http://www.rssb.be/bsn57/bsn57-6.pdf>

²³⁸ Exceptions prove the rule. Not all Indians espouse the “body shop” mantra. Global business and tech leaders (2020) of Indian origin include Mrs Jayashree Ullal (CEO, Arista Networks), Mr Arvind Krishna (CEO, IBM, incoming), Mr Sundar Pichai (CEO, Alphabet/Google), Mr Satya Nadella (CEO, Microsoft), Mr Shantanu Narayen (CEO, Adobe), Mr Rajeev Suri (CEO, Nokia, outgoing), Mr V K Narasimhan (CEO, Novartis) and Mr Ajaypal Singh Banga (CEO, MasterCard). The market cap of these 8 companies (~\$3T) may be 20% of the total market cap of the top 50 US companies (~\$15T). www.iweblists.com/us

²³⁹ Sabrie, Gilles (2019) *Behind the Rise of China’s Facial-Recognition Giants* (09.03.2019)

<https://www.wired.com/story/behind-rise-chinas-facial-recognition-giants/>

²⁴⁰ <https://www.purdue.edu/rosehub/>

²⁴¹ Navi Radjou & Jaideep Prabhu (2016) *Frugal Innovation: How to do More With Less*.

<http://naviradjou.com/book/frugal-innovation-how-to-do-more-with-less/>

²⁴² Creighton, Jean (2019) 5 Moon-landing innovations that changed life on Earth

<https://theconversation.com/5-moon-landing-innovations-that-changed-life-on-earth-102700>

²⁴³ <https://www.inc.com/bill-murphy-jr/27-innovations-we-use-constantly-but-that-you-probably-didnt-know-were-from-nasa-space-program.html>

²⁴⁴ <https://spinoff.nasa.gov/>

²⁴⁵ Marcus, Gary (2019) *An Epidemic of AI Misinformation*.

<https://thegradient.pub/an-epidemic-of-ai-misinformation/>

²⁴⁶ Vanegas, D. C., L. Patiño, C. Mendez, D. A. Oliveira, A. M. Torres, C. L. Gomes, and E. S. McLamore. “Laser Scribed Graphene Biosensor for Detection of Biogenic Amines in Food Samples Using Locally Sourced Materials.” *Biosensors*, vol. 8, no. 2, Apr. 2018, p. 42. doi:10.3390/bios8020042

<https://www.mdpi.com/2079-6374/8/2/42>

²⁴⁷ Holmes, E. A., et al. “Applications of Time-Series Analysis to Mood Fluctuations in Bipolar Disorder to Promote Treatment Innovation: A Case Series.” *Translational Psychiatry*, vol. 6, no. 1, Jan. 2016, pp. e720–e720. doi:10.1038/tp.2015.207

<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5068881/pdf/tp2015207a.pdf>

²⁴⁸ Trautmann, Sebastian, et al. “The Economic Costs of Mental Disorders: Do Our Societies React Appropriately to the Burden of Mental Disorders?” *EMBO Reports*, vol. 17, no. 9, Sept. 2016, pp. 1245–1249. doi:10.15252/embr.201642951

www.ncbi.nlm.nih.gov/pmc/articles/PMC5007565/pdf/EMBR-17-1245.pdf

²⁴⁹ Drevets, Wayne C., et al. “Subgenual Prefrontal Cortex Abnormalities in Mood Disorders.” *Nature*, vol. 386, no. 6627, Apr. 1997, pp. 824–827 doi:10.1038/386824a0

²⁵⁰ P. Llamocca, A. Junestrand, M. Cukic, D. Urgelés, V. López. (2018) *Data source analysis in mood disorder research*. XVIII Proceedings of the XVIII Conference of the Spanish Association for Artificial Intelligence, CAEPIA, ISBN: 978-84-09-05643-9 F. Herrera et al. (Eds.), pp. 893-900, Granada, Spain.

²⁵¹ P. Llamocca, D. Urgelés, M. Cukic, V. Lopez. (2019) *Bip4Cast: Some advances in mood disorders data analysis*. Proceedings of the 1st International Alan Turing Conference on Decision Support and Recommender Systems, London 2019.

²⁵² Raymond Perrault, Yoav Shoham, Erik Brynjolfsson, Jack Clark, John Etchemendy, Barbara Grosz, Terah Lyons, James Manyika, Saurabh Mishra, and Juan Carlos Niebles, “The AI Index 2019 Annual Report”, AI Index Steering Committee, Human-Centered AI Institute, Stanford University, Stanford, CA, December 2019. https://hai.stanford.edu/sites/g/files/sbiybj10986/f/ai_index_2019_report.pdf

²⁵³ Chen, Yu-Hsin, et al. “Eyeriss v2: A Flexible Accelerator for Emerging Deep Neural Networks on Mobile Devices.” May 2019. <http://arxiv.org/abs/1807.07928> ▪ <https://arxiv.org/pdf/1807.07928.pdf> https://www.rle.mit.edu/eems/wp-content/uploads/2019/04/2019_jetcas_eyerissv2.pdf

²⁵⁴ Jo, Eun Seo, and Timnit Gebru. “Lessons from Archives: Strategies for Collecting Sociocultural Data in Machine Learning.” Dec. 2019 doi:10.1145/3351095.3372829 <https://arxiv.org/pdf/1912.10389.pdf>

²⁵⁵ Tembon, Mercy Miyang, and Lucia Fort, editors. *Girl’s Education in the 21st Century: Gender Equality, Empowerment and Growth*. The World Bank, 2008. doi:10.1596/978-0-8213-7474-0

²⁵⁶ <https://www.nytimes.com/2006/10/14/world/asia/14nobel.html>

²⁵⁷ Cohn, Alain, et al. “Civic Honesty around the Globe.” *Science*, vol. 365, no. 6448, July 2019, pp. 70–73. doi:10.1126/science.aau8712

²⁵⁸ Grosch, Kerstin; Rau, Holger (2017) : Gender differences in honesty: The role of social value orientation. Discussion Papers, No. 308, University of Göttingen, Center for European, Governance and Economic Development Research (CEGE), Göttingen, Germany.

<https://www.econstor.eu/bitstream/10419/156226/1/882555200.pdf>

²⁵⁹ Sen, Amartya. *The Idea of Justice*. Harvard University Press, 2009.

<https://dutraeconomicus.files.wordpress.com/2014/02/amartya-sen-the-idea-of-justice-2009.pdf>

²⁶⁰ “Artificial Intelligence Makes Bad Medicine Even Worse.” *Wired*. www.wired.com,

<https://www.wired.com/story/artificial-intelligence-makes-bad-medicine-even-worse/>

²⁶¹ Datta, Shoumen (2008) Arm Chair Essays in Energy. <https://dspace.mit.edu/handle/1721.1/45512>

²⁶² Donald Mackenzie (1877) *The Flooding of the Sahara: An Account of the Proposed Plan for Opening Central Africa to Commerce and Civilization*. 1877. S. Low, Marston, Searle, & Rivington, Publishers.

<https://ia902205.us.archive.org/23/items/floodingsaharaa01mackgoog/floodingsaharaa01mackgoog.pdf>

²⁶³ https://www.jstor.org/stable/1761255?seq=1#metadata_info_tab_contents

²⁶⁴ <https://www.nature.com/articles/019509a0.pdf>

²⁶⁵ Rothman, Joshua. *The Equality Conundrum* 13 January 2020. www.newyorker.com/magazine/annals-of-inquiry ♦ <https://www.newyorker.com/magazine/2020/01/13/the-equality-conundrum>

²⁶⁶ <https://www.mikespastry.com/>

²⁶⁷ <https://www.modernpastry.com/>

- ²⁶⁸ Ilić, Suzana, et al. (2018) “Deep Contextualized Word Representations for Detecting Sarcasm and Irony.” *Proceedings of the 9th Workshop on Computational Approaches to Subjectivity, Sentiment and Social Media Analysis*, Association for Computational Linguistics, 2018, pp. 2–7
doi:10.18653/v1/W18-6202 <https://arxiv.org/pdf/1809.09795.pdf>
- ²⁶⁹ Datta, Shoumen (2008) Convergence of Bio, Info, Nano, Eco: Global Public Goods and Economic Growth. <https://dspace.mit.edu/handle/1721.1/41909>
- ²⁷⁰ Steinmueller, W. Edward, 2010. "Economics of Technology Policy" Handbook of the Economics of Innovation, in: Bronwyn H. Hall & Nathan Rosenberg (ed.), Handbook of the Economics of Innovation, edition 1, volume 2, pages 1181-1218, Elsevier ▪ [https://doi.org/10.1016/S0169-7218\(10\)02012-5](https://doi.org/10.1016/S0169-7218(10)02012-5)
- ²⁷¹ Singh, Lakhveer, et al. “Bioelectrofuel Synthesis by Nanoenzymes: Novel Alternatives to Conventional Enzymes.” *Trends in Biotechnology*, Jan. 2020, p. S0167779919303129 doi:10.1016/j.tibtech.2019.12.017
- ²⁷² L. Wang, Y. Chen, F. Long, L. Singh, S. Trujillo, X. Xiao, H. Liu (2020) *Breaking the Loop: Tackling Homoacetogenesis by Chloroform to Halt Hydrogen Production-Consumption Loop in Single Chamber Microbial Electrolysis Cells*. Chemical Engineering Journal. <https://doi.org/10.1016/j.cej.2020.124436>
- ²⁷³ <https://patents.justia.com/inventor/andrew-e-fano>
- ²⁷⁴ <https://patents.justia.com/patent/10095981>
- ²⁷⁵ https://claimparse.com/patent.php?patent_num=10275721
- ²⁷⁶ <https://www.ibm.com/downloads/cas/KMPVGB4W>
- ²⁷⁷ <https://mcgovern.mit.edu/profile/tomaso-poggio/>
- ²⁷⁸ Faro, Scott H., and Feroze B. Mohamed, editors. *Functional MRI: Basic Principles and Clinical Applications*. Springer, 2006. ISBN 978-0-387-23046-7
- ²⁷⁹ <https://towardsdatascience.com/bert-roberta-distilbert-xlnet-which-one-to-use-3d5ab82ba5f8>
- ²⁸⁰ <https://cloud.google.com/tpu/>
- ²⁸¹ <https://blog.floydhub.com/when-the-best-nlp-model-is-not-the-best-choice/>
- ²⁸² Matthew E. Peters, Mark Neumann, Mohit Iyyer, Matt Gardner, Christopher Clark, Kenton Lee, Luke Zettlemoyer (2018) *Deep contextualized word representations*. <https://arxiv.org/pdf/1802.05365.pdf>
- ²⁸³ Devlin, J., Chang, M.-W., Lee, K. and Toutanova, K. (2018) *BERT: pre-training of deep bidirectional transformers for language understanding*. <https://arxiv.org/pdf/1810.04805.pdf>
- ²⁸⁴ Zhenzhong Lan, Mingda Chen, Sebastian Goodman, Kevin Gimpel, Piyush Sharma and Radu Soricut (2020) *Albert: A Lite Bert for Self-Supervised Learning of Language Representations*. 8th International Conference on Learning Representations (2020) <https://openreview.net/pdf?id=H1eA7AEtvS>
- ²⁸⁵ Sun, Cong, et al. “A Deep Learning Approach With Deep Contextualized Word Representations for Chemical–Protein Interaction Extraction From Biomedical Literature.” *IEEE Access*, vol. 7, 2019, pp. 151034–46 doi:10.1109/ACCESS.2019.2948155
- ²⁸⁶ Vahe Tshitoyan, John Dagdelen, Leigh Weston, Alexander Dunn, Ziqin Rong, Olga Kononova, Kristin A. Persson, Gerbrand Ceder and Anubhav Jain (2019) *Unsupervised word embeddings capture latent knowledge from materials science literature*. *Nature* 571, 95–98 (2019)
<https://doi.org/10.1038/s41586-019-1335-8>

²⁸⁷ Babyak, M. A. (2004) “What You See May Not Be What You Get: A Brief, Nontechnical Introduction to Overfitting in Regression-Type Models.” *Psychosomatic Med*, vol. 66, no. 3, May 2004, pp 411-21 DOI 10.1097/01.psy.0000127692.23278.a9 <https://people.duke.edu/~mababyak/papers/babyakregression.pdf>

²⁸⁸ Tarfa Hamed (2017) *Recursive Feature Addition: A Novel Feature Selection Technique, Including a Proof of Concept in Network Security*. PhD thesis submitted to University of Guelph, Ontario, Canada. https://atrium.lib.uoguelph.ca/xmlui/bitstream/handle/10214/10315/Hamed_Tarfa_201704_PhD.pdf?sequence=1&isAllowed=y

²⁸⁹ Aditya Nandy, Chenru Duan, Jon Paul Janet, Stefan Gugler, and Heather J. Kulik (2018) “Strategies and Software for Machine Learning Accelerated Discovery in Transition Metal Chemistry.” *Industrial and Engineering Chemistry Research*, volume 57, number 42, October 2018, pages 13973 - 13986 doi:10.1021/acs.iecr.8b04015

²⁹⁰ Virshup, Aaron M., et al. “Stochastic Voyages into Uncharted Chemical Space Produce a Representative Library of All Possible Drug-Like Compounds.” *Journal of the American Chemical Society*, vol. 135, no. 19, May 2013, pp. 7296 - 7303 doi:10.1021/ja401184g

²⁹¹ Sam Lemonick (2019) As DFT Matures, Will It Become a Push-Button Technology? *Chemical & Engineering News*, volume 97, issue 35 <https://cen.acs.org/physical-chemistry/computational-chemistry/DFT-matures-become-push-button/97/i35>

²⁹² Joan Bruna, Wojciech Zaremba, Arthur Szlam & Yann LeCun (2014) “Spectral Networks and Locally Connected Networks on Graphs.” <http://arxiv.org/abs/1312.6203> ▪ <https://arxiv.org/pdf/1312.6203.pdf>

²⁹³ Justin Gilmer, Samuel S. Schoenholz, Patrick F. Riley, Oriol Vinyals and George E. Dahl (2017) *Neural Message Passing for Quantum Chemistry*. <https://arxiv.org/pdf/1704.01212.pdf>

²⁹⁴ Kyle Swanson (2019) Message Passing Neural Networks for Molecular Property Prediction. Master’s Thesis. EECS, MIT. <https://dspace.mit.edu/bitstream/handle/1721.1/123133/1128814048-MIT.pdf?sequence=1&isAllowed=y>

²⁹⁵ <http://chemprop.csail.mit.edu/>

²⁹⁶ Lars Ruddigkeit, Ruud van Deursen, Lorenz C. Blum and Jean-Louis Reymond (2012) “Enumeration of 166 Billion Organic Small Molecules in the Chemical Universe Database GDB-17.” *J of Chemical Information and Modeling*, vol. 52, no. 11, November 2012, pp. 2864–2875 doi:10.1021/ci300415d

²⁹⁷ Jonathan M. Stokes, Kevin Yang, Kyle Swanson, Wengong Jin, Andres Cubillos-Ruiz, Nina M. Donghia, Craig R. MacNair, Shawn French, Lindsey A. Carfrae, Zohar Bloom-Ackerman, Victoria M. Tran, Anush Chiappino-Pepe, Ahmed H. Badran, Ian W. Andrews, Emma J. Chory, George M. Church, Eric D. Brown, Tommi S. Jaakkola, Regina Barzilay and James J. Collins (2020) “A Deep Learning Approach to Antibiotic Discovery.” *Cell*, vol. 180, no. 4, February 2020, pp. 688-702.e13 doi:10.1016/j.cell.2020.01.021 ♦ [https://www.cell.com/cell/pdf/S0092-8674\(20\)30102-1.pdf](https://www.cell.com/cell/pdf/S0092-8674(20)30102-1.pdf)

²⁹⁸ <http://news.mit.edu/2020/artificial-intelligence-identifies-new-antibiotic-0220>

²⁹⁹ Zhang, Xiang, et al. (2019) “Deep Neural Network Hyperparameter Optimization with Orthogonal Array Tuning.” July 2019. <http://arxiv.org/abs/1907.13359> ♦ <https://arxiv.org/pdf/1907.13359.pdf>

- ³⁰⁰ Lars Kai Hansen and Peter Salamon (1990) *Neural Network Ensembles*. IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 12, No. 10, October 1990.
<https://pdfs.semanticscholar.org/257d/c8ae2a8353bb2e86c1b7186e7d989fb433d3.pdf>
- ³⁰¹ Marcello Pelillo (2014) “Alhazen and the nearest neighbor rule.” *Pattern Recognition Letters* 38 (2014) 34–37 <http://dx.doi.org/10.1016/j.patrec.2013.10.022>
- ³⁰² <https://thenextweb.com/neural/2020/02/19/study-ai-expert-gary-marcus-explains-how-to-take-ai-to-the-next-level/>
- ³⁰³ Russell, Stuart and Norvig, Peter (2010) *Artificial Intelligence: A Modern Approach*. 3rd ed, Prentice Hall. <http://aima.cs.berkeley.edu/>
- ³⁰⁴ Winston, Patrick Henry and Richard Henry Brown, editors. *Artificial Intelligence, an MIT Perspective*. MIT Press, 1979. <https://courses.csail.mit.edu/6.034f/ai3/rest.pdf>
- ³⁰⁵ Buchanan, Bruce G., and Edward Hance Shortliffe, editors. (1984) *Rule-Based Expert Systems: The MYCIN Experiments of the Stanford Heuristic Programming Project*. Addison-Wesley. 1984.
<http://digilib.stmik-banjarbaru.ac.id/data.bc/2.%20AI/2.%20AI/1984%20Rule-Based%20Expert%20Systems.pdf>
- ³⁰⁶ Quinlan, J. R., editor. (1987) *Applications of Expert Systems: Based on the Proceedings of the Second Australian Conference*. Turing Institute Press in association with Addison-Wesley Pub. Co, 1987.
- ³⁰⁷ Giarratano, Joseph C. and Gary Riley. (1989) *Expert Systems: Principles and Programming*. 1st ed. PWS-Kent Publishing Company, Boston. ISBN 0-87835-335-6
- ³⁰⁸ Buchanan, Bruce G. (1989) “Can Machine Learning Offer Anything to Expert Systems?” *Machine Learning*, vol. 4, no. 3–4, December 1989, pages 251–254 doi:10.1007/BF00130712.
<https://link.springer.com/content/pdf/10.1007/BF00130712.pdf>
- ³⁰⁹ Valverde, S. (2016) Major transitions in information technology. *Philosophical Transactions of the Royal Society. B* 371: 20150450 ◆ <http://dx.doi.org/10.1098/rstb.2015.0450>
<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4958943/pdf/rstb20150450.pdf>
- ³¹⁰ Mearian, Lucas. (2017) “CW@50: Data Storage Goes from \$1M to 2 Cents per Gigabyte (+video).” *Computerworld*, 23 March 2017 ◆ <https://www.computerworld.com/article/3182207/cw50-data-storage-goes-from-1m-to-2-cents-per-gigabyte.html>
- ³¹¹ Supernor, Bill (2018) “Why the Cost of Cloud Computing Is Dropping Dramatically.” *App Developer Magazine*, <https://appdevlopermagazine.com/why-the-cost-of-cloud-computing-is-dropping-dramatically/>
- ³¹² Wolpert, H David (2018). “Why Do Computers Use So Much Energy?” *Scientific American Blog Network* ▪ <https://blogs.scientificamerican.com/observations/why-do-computers-use-so-much-energy/>
- ³¹³ David H Wolpert. (2019) “The stochastic thermodynamics of computation.” *Journal of Physics A: Mathematical and Theoretical* 2019 <https://iopscience.iop.org/article/10.1088/1751-8121/ab0850/pdf>
- ³¹⁴ Panesar, S.S., Kliot, M., Parrish, R., Fernandez-Miranda, J., Cagle, Y., Britz, G.W. (2019) Promises and Perils of Artificial Intelligence in Neurosurgery. *Neurosurgery* ▪ <https://doi.org/10.1093/neuros/nyz471>

³¹⁵ Emily Hanhauser, Michael S. Bono, Jr., Chintan Vaishnav, A. John Hart, and Rohit Karnik (2020) Solid-Phase Extraction, Preservation, Storage, Transport, and Analysis of Trace Contaminants for Water Quality Monitoring of Heavy Metals, *Environ Science & Tech* (2020). DOI: 10.1021/acs.est.9b04695

³¹⁶ Rohit Sharma , Sachin S. Kamble , Angappa Gunasekaran , Vikas Kumar , Anil Kumar (2020) A Systematic Literature Review on Machine Learning Applications for Sustainable Agriculture Supply Chain Performance, *Computers and Operations Research*. <https://doi.org/10.1016/j.cor.2020.104926>

³¹⁷ Amelie Gyrard, Manas Gaur, Saeedeh Shekarpour, Krishnaprasad Thirunarayan and Amit Sheth (2018) *Personalized Health Knowledge Graph*. Contextualized Knowledge Graph Workshop, International Semantic Web Conference, 2018.

https://scholarcommons.sc.edu/cgi/viewcontent.cgi?article=1005&context=aii_fac_pub

³¹⁸ “Apple Agrees to Settlement of up to \$500 Million from Lawsuit Alleging It Throttled Older Phones.” *TechCrunch*, <http://social.techcrunch.com/2020/03/02/apple-agrees-to-settlement-of-up-to-500-million-from-lawsuit-alleging-it-throttled-older-phones/>

³¹⁹ Gini, Corrado (1909) “Concentration and dependency ratios” (in Italian). English translation in *Rivista di Politica Economica* (1997) 87: 769–789

³²⁰

www.reddit.com/r/MapPorn/comments/88mw3q/open_defecation_around_the_world_2015_960_684/

³²¹ “Nearly a Billion People Still Defecate Outdoors. Here’s Why.” *Magazine*, 25 July 2017,

<https://www.nationalgeographic.com/magazine/2017/08/toilet-defecate-outdoors-stunting-sanitation/>

³²² Sadhu, Bodhisatwa, et al. “The More (Antennas), the Merrier: A Survey of Silicon-Based Mm-Wave Phased Arrays Using Multi-IC Scaling.” *IEEE Microwave Magazine*, vol. 20, no. 12, Dec 2019, pp 32–50

³²³ Wang, Tengfei and Kang, Jong Woo (2020). *An integrated approach for assessing national e-commerce performance*. Trade, Investment and Innovation Working Paper Series, No. 01/20, ESCAP Trade, Investment and Innovation Division, United Nations (UN). January 2020. Bangkok, Thailand.

https://www.unescap.org/sites/default/files/publications/Working%20Paper%20No.1_2020.pdf

³²⁴ http://www3.weforum.org/docs/WEF_Global_Risk_Report_2020.pdf

³²⁵ Propaganda erudite, credible and respectable scientists, are disturbing, devastating and desacralizing. [This statement and this note must be taken with more than just a pinch of salt because it is the personal opinion of the primary author (SD), who may be best described by others as less than academic dust along the infinite corridors of the esteemed institutions with which he may be affiliated.] Time, events and publications suggest that “giants” who are *good* are occasionally hypnotized by the slippery slope of metamorphosis from *good* to self-anointed “God” particles. Knowledge, which was once regarded as an oak tree, and supposed to usher in self-deprecation, modesty and humility, now, frequently suffers from bloating, sufficient to spill over the *black hole* of hubris. For example, a trio of brilliant (see ref 91) male scientists, in the upper latitudes of North America, are acting as *Nostradamus*, stoked by greed and the quest for immortality, buoyed by corporate largesse, exclusively driven by the desire for wealth creation. A group of complicit organizations and ill-informed media are ever ready to quench the drab voices of reason and restraint, in favour of sensationalizing and amplifying this inane *Nostradamus Effect*.

This harms society (due to derelict reports, for example, see reference number 233) and reduces the credibility of august institutions and organizations which appear as pawns for corporate business development (<https://knowledgegraphsocietypub.org>) often under a camouflage of so-called knowledge for social good. <https://knowledgegraphsocietypub.org/programcommittee>

³²⁶ Boroush, Mark (2020) National Science Board, National Science Foundation. 2020. Research and Development: U.S. Trends and International Comparisons. Science and Engineering Indicators 2020. NSB-2020-3. Alexandria, VA. <https://nces.nsf.gov/pubs/nsb20203/assets/nsb20203.pdf>

³²⁷ Cyranoski, David. "China Awaits Controversial Blacklist of 'Poor Quality' Journals." *Nature*, vol. 562, Oct. 2018, pp. 471–72. www.nature.com, doi:10.1038/d41586-018-07025-5

³²⁸ <https://www.thehindu.com/profile/photographers/Prashant-Waydande/>

³²⁹ "Indian Research Quality Lags Quantity." *Economic Times Blog*, 24 Dec. 2019,

<https://economictimes.indiatimes.com/blogs/et-editorials/indian-research-quality-lags-quantity/>

³³⁰ Jaishankar, Dhruva. "The Huge Cost of India's Discrimination Against Women." *The Atlantic*, 18 Mar. 2013. <https://www.theatlantic.com/international/archive/2013/03/the-huge-cost-of-indias-discrimination-against-women/274115/>

³³¹ Kroll, Barry M. "Writing for Readers: Three Perspectives on Audience." *College Composition and Communication*, vol. 35, no. 2, May 1984, p. 172. doi:10.2307/358094

³³² Soto C., R., Robles-Baldenegro, M.E., López, V. and Camalich, J.A. (2017), MQDM: An Iterative Fuzzy Method for Group Decision Making in Structured Social Networks. *International Journal of Intelligent Systems* 32 pages 17-30 ◆ <https://onlinelibrary.wiley.com/doi/full/10.1002/int.21826>

³³³ Schwartz, M. A (2008) Importance of Stupidity in Scientific Research. *Journal of Cell Science*, vol. 121, no. 11, pp. 1771, doi:10.1242/jcs.033340 ▪ <https://jcs.biologists.org/content/joces/121/11/1771.full.pdf>

³³⁴ <http://shakespeare.mit.edu/macbeth/macbeth.5.5.html>

³³⁵ Jean le Rond d'Alembert (1886) *Oeuvres de D'Alembert*. ISBN-13 9781103953189

³³⁶ Gordin, Michael D. (2015) *Scientific Babel: How Science Was Done before and after Global English*. The University of Chicago Press, 2015.

³³⁷ <https://citations.ouest-france.fr/citation-voltaire/medecins-administrent-medicaments-dont-savent-22351.html>

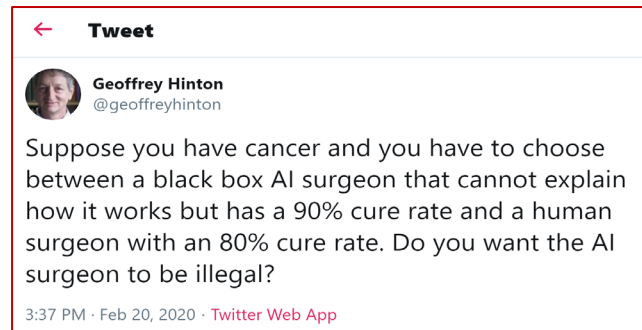
ACKNOWLEDGEMENTS

Critical review by Robert F Curl (<https://www.nobelprize.org/prizes/chemistry/1996/curl/biographical/>) and editorial comments by Alain Louchez (<https://www.itu.int/en/ITU-T/Workshops-and-Seminars/jot/201402/Pages/LOUCHEZAlain.aspx>) may have helped to improve the timbre of this essay.

Market proponents of AI are individuals who blather about neural networks of which they know little, to solve problems using learning tools which they know less, for the society of human beings of whom they know nothing.

(Adapted from “Les médecins administrent des médicaments dont ils savent très peu, à des malades dont ils savent moins, pour guérir des maladies dont ils ne savent rien” – **Voltaire**³³⁷)

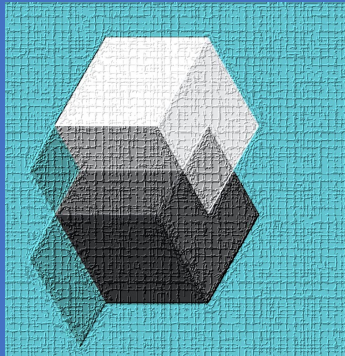
(Doctors are men who prescribe medicines of which they know little, to cure diseases of which they know less, in human beings of whom they know nothing.)



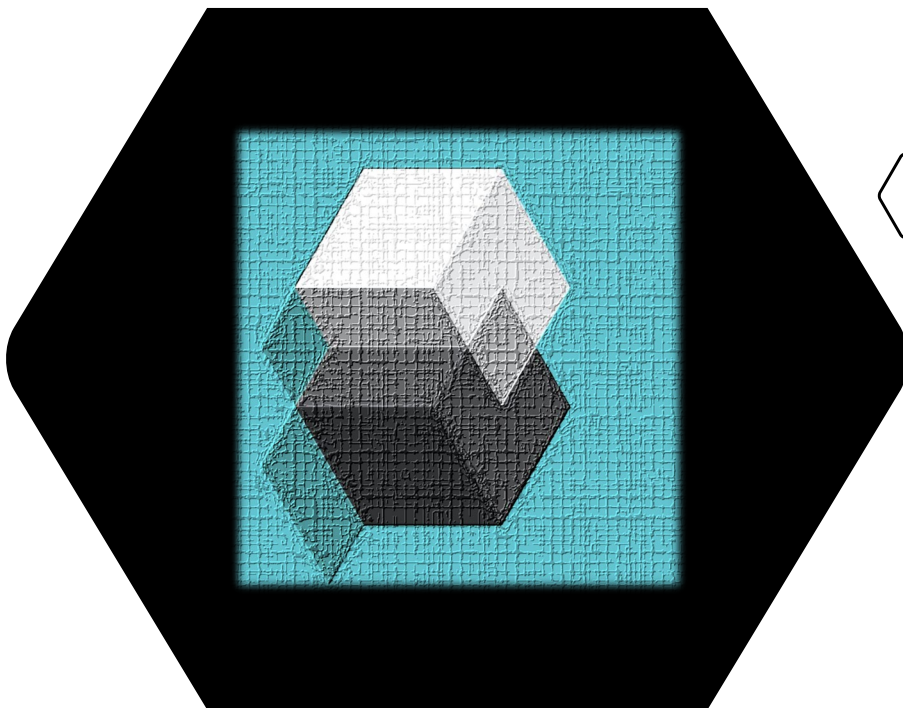
Running Title: Unsustainable and Misaligned Economics of Technology triggers a Porous Pareto Partition Between the Haves and the Have Nots: Can Democratization of Distributed Data act as a Catalyst for the Dissemination of Digital Dividends?

IS THIS A BLANK PAGE? WE SEE AN UNSEEN SENSE OF THE FUTURE IN WHAT APPEARS TO BE A BLANK PAGE.

We are keeping room for disambiguation, discussion, dissent (and imagination, invention, innovation).



Good leadership
requires you to
surround yourself with
people of diverse
perspectives who can
disagree with you



TRANSLATION (ITALIAN)

Shoumen Datta

HAPHAZARD REALITY – IOT IS A METAPHOR

TRANSLATION in ITALIAN

CHAPTER ONE

CONNECTING ATOMS TO BITS

CONNETTERE ATOMI A BIT - E' ABBASTANZA?

IOT E' UNA METAFORA DEL DISEGNO PER UNA TRASFORMAZIONE DIGITALE

Shoumen Palit Austin Datta¹, Marianna Marchesi² and Maddalena Marchesi³

The Italian language version of the original English article “Connecting Atoms to Bits” was edited and translated by co-authors Marchesi & Marchesi. The content was reduced by the publisher, to fit the allotted space, for the Italian publication.

The original article “Connecting Atoms to Bits” is Chapter 1 in the book “*Haphazard Reality – IoT is a Metaphor*” and it may be downloaded from the MIT Library in a PDF format with the title “IoT is a Metaphor” which may be accessed using this URL <https://dspace.mit.edu/handle/1721.1/111021>

¹ Senior Member, Auto-ID Labs, Research Affiliate, Dept of Mechanical Engineering, Massachusetts Institute of Technology, 77 Massachusetts Ave, Cambridge, MA 02139, USA and Senior Scientist, Medical Device Interoperability Program, MDPnP Laboratory, Dept of Anaesthesiology, Massachusetts General Hospital, Harvard Medical School, Partners MGH Research, 65 Landsdowne Street, Cambridge, MA 02139, USA (Email addresses: shoumen@mit.edu and sdatta8@mgh.harvard.edu)

² Marie Skłodowska-Curie Fellow, UK
(Email address: marianna.marchesi@outlook.com)

³ Associate Medical Director, F. Hoffmann-La Roche AG, Grenzacherstrasse 124, CH-4070 Basel, Switzerland (Email address: maddalena.marchesi@roche.com)

The Italian language version of the original English article “Connecting Atoms to Bits” was edited and translated by co-authors Marchesi & Marchesi. The content was reduced by the publisher, to fit the allotted space, for the Italian publication.

The original article “Connecting Atoms to Bits” is Chapter 1 in the book “*Haphazard Reality – IoT is a Metaphor*” and it may be downloaded from the MIT Library in a PDF format with the title “IoT is a Metaphor” which may be accessed using this URL <https://dspace.mit.edu/handle/1721.1/111021>

ABSTRACT

Le idee attinenti l'IoT hanno una lunga storia. Probabilmente il loro fondamento si trova nelle brevi storie di Isaac Asimov. Nel 1953, Sally di Asimov fu concepita come un veicolo automatico¹, in viaggio sulle nostre strade nel 2057. Herbert Simon² nel 1986 e Mark Weiser³ nel 1991 furono dei visionari che contribuirono all'evoluzione delle metafore dell'IoT. Nel 1999, presso il centro MIT Auto ID. Kevin Ashton, un esperto di marketing, dato in prestito a MIT da Procter and Gamble (P&G), propose il termine internet delle cose⁴ o IoT. Il termine esatto (IoT) probabilmente venne usato per la prima volta da Peter Lewis⁵ nel 1985. Osservazioni e scoperte parallele non sono un novita', come riconosciuto in un recente libro⁶ di Sanjay Sarma, co-creatore dell'IoT.

Questo articolo intende informare esperti, università, dirigenti dell'industria, istituzioni, studenti ed il pubblico più in generale su come sfidare la saggezza convenzionale, scomporre i concetti di IoT e catalizzare le richieste di soluzioni nel mondo reale. La trasformazione digitale e l'IoT sono solo un piccolo frammento del grande quadro. Il nostro scopo non è quello di fornire risposte, anche se il contenuto può apparentemente e parzialmente offrire suggerimenti/soluzioni. Le idee contenute nell'articolo, spesso disarticolate, possono indurre invece il lettore ad approfondire i propri pensieri sull'argomento. Il contenuto dovrebbe agire come "gancio" o struttura non finita che il lettore può scegliere di estendere o continuare a costruire o altrimenti demolire.

INTRODUZIONE

Il cruccio in ogni trasformazione è la prospettiva della leadership. Confini mentali prefissati, in alcuni umani, sono impiegati in un erculeo tentativo di ottenere conforto, e quindi, controllare il territorio o il *terreno* metaforico. Si aggrappano disperatamente e cercano molto duramente, di rimanere ignari del cambiamento, preferiscono rimanere chiusi in clausura, rimanere dentro la *scatola* e cercare di ignorare i progressi.

Nell'illustrazione sotto (Fig. 1), sono rappresentate proiezioni in termini di economia digitale per evidenziare la progressione dal mondo fisico degli atomi alla trasformazione in cui le informazioni sugli atomi possono essere rappresentate da bit (**Digital Twins**) o bit, *di per se stessi*. Possono essere informazioni o dati provenienti da decisioni, processi e cose, relativi a IoT e IoT industriale. Alcune proiezioni⁸ non si sono materializzate⁹, ma le eccezioni possono dimostrare la regola, anche se parzialmente. Altri modelli di Poire (vedi Fig. 21) suggeriscono che nel 2020 potremmo assistere a cambiamenti trasformativi.

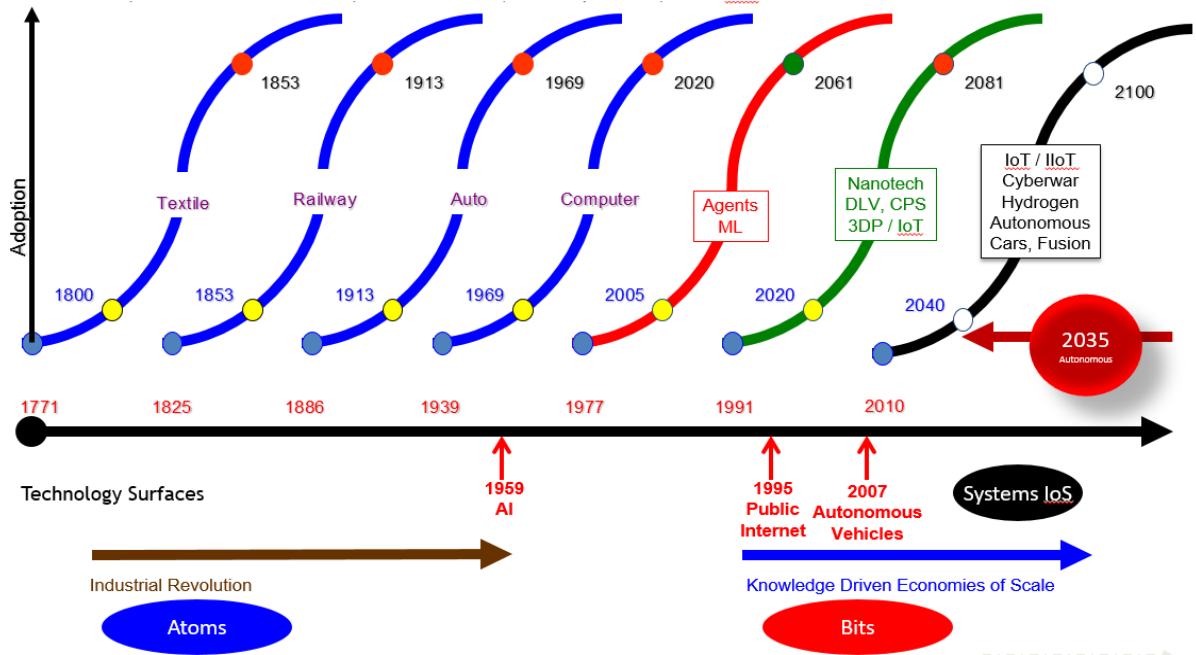


Fig 1: nei modelli di Poire¹⁰ il progresso segue uno schema, scandito da certi intervalli.

LA PROFASE PER LA TRASFORMAZIONE DIGITALE

Prima che le cellule eucariote possano replicarsi (divisione cellulare in piante, animali, inclusi gli umani), la cellula subisce una fase prolungata di cambiamenti interni. La cellula richiede tempo per prepararsi, prima dell'inizio delle fasi attive, che precedono l'effettiva divisione della cellula. Questa fase è indicata come la profase nel ciclo di replicazione o divisione della cellula.

Come analogia, la profase per la trasformazione digitale può essere divisa in due parti, la profase 1 e la profase 2. La profase 1 iniziò con stampe manuali, che sembrano avere circa 35.000 anni. Il culmine della profase 1 potrebbe essere la scrittura cuneiforme, circa 3500 a.C., in Mesopotamia. Era probabilmente la prima volta che pensieri o idee venivano trasferiti dalla mente, tramite stampe e poi sceneggiature o pittogrammi, alle tavolette. La profase 2 iniziò nell'Estremo Oriente, con la stampa di blocchi di legno intorno al 200 d.C., ma si animò con la scoperta della macchina da stampa di Johannes Gutenberg, circa 1440.

Dal copione cuneiforme alla stampa passarono circa 5.000 anni. Questo fu il tempo necessario per creare strumenti per la democratizzazione delle informazioni. Quante persone hanno letto l'Epopèa di Gilgamesh, che è stata scritta in cuneiforme e scolpita sulla tavoletta del Diluvio¹¹ nel 2000 a.C.? Quanti hanno letto "If" di Joseph Rudyard Kipling¹²? Bisognava essere una regina per avere le risorse per poter leggere l'Epopèa di Gilgamesh. Il costo della transazione era troppo alto. Nella società della stampa, "If" era accessibile alle persone durante la vita di Kipling (nato il 30 dicembre 1865 a Bombay e morto il 18 gennaio 1936, a Londra). Nel XXI secolo nella società della post-stampa, "If" può essere scaricato gratuitamente. Il costo della transazione si avvicina a zero, grazie all'economia digitale, per abbassando le barriere della penetrazione nel mercato.

Il costo della transazione, intesa come base economica di cui fu pioniere Ronald Coase (1937), non è l'unico lubrificante per la trasformazione digitale. La trasformazione umana per acquisizione di informazioni e la loro replicazione (tavolette di pietra, papiri, carta, libri, bits) ha avuto un profondo impatto. Il re, così come il cittadino, l'amministratore delegato e l'impiegato, il presidente e il custode possono ora accedere alle stesse informazioni. L'idea promossa da Marshall McLuhan¹² è che chiunque, ovunque, possa consumare le stesse informazioni. Ora siamo in grado di democratizzare i dati, offrire "dati aperti" grazie ai progressi nella nostra evoluzione digitale.

L'ampio spettro della trasformazione digitale, che include un futuro in cui potrebbero esistere i gemelli digitali¹³, potrebbe trasformare la proposta di Marshall McLuhan in realtà in diversi settori verticali, dalla produzione alla robotica, dai sistemi energetici all'assistenza sanitaria.

La preparazione alla trasformazione digitale, la profase, si sta avvicinando al suo conclusivo segmento in pochi paesi, ma ancora con difficoltà nelle nazioni ASEAN e USAN. La discrepanza tra zone economiche è dovuta principalmente alla struttura degli investimenti nelle infrastrutture. Una costruttiva convergenza delle tecnologie è la chiave per la trasformazione digitale per far crescere radici sufficienti, fertilizzare adeguatamente i mercati al fine di aumentare le economie di scala e migliorare i profitti per lo sviluppo economico. Il ritmo globale non è uniforme.

STRUMENTI PER LA TRASFORMAZIONE DIGITALE

Bisogna tenere presente che i riferimenti aneddotici non costituiscono prova. Questa osservazione riguarda Microsoft e il contesto è l'infrastruttura per la trasformazione digitale. In altre parole, gli strumenti di cui abbiamo bisogno devono evolversi ed essere disponibili alle masse, al fine di supportare la trasformazione digitale. La figura 2 mostra la capitalizzazione di mercato delle prime 10 società nel periodo 2001-2011. Durante questo periodo¹⁴, le compagnie statunitensi hanno affrontato un ritorno alla fase economica dell'Inghilterra del XVII secolo, nel quale il NASDAQ ha perso il 78% del suo valore (5046,86 su 1114,11) tra l'11 marzo 2000 e il 9 ottobre 2002. La bolla delle "Dot-com" è stata attribuita, da alcuni osservatori, all'economia del laissez faire. Al contrario, il crollo della Lehman Brothers negli Stati Uniti ha provocato una recessione globale. Il crollo è stato prodotto deliberatamente strutturando strumenti finanziari per seminare l'avidità da parte di alcune istituzioni finanziarie. L'S&P 500 è sceso del 57% dal suo massimo nell'ottobre 2007 di 1576 al suo minimo nel marzo 2009 di 676. Solo Microsoft (e ExxonMobil) è rimasto tra i primi 10 per capitalizzazione di mercato, durante questo decennio (2001-2011) di turbolenza finanziaria mediata da "Dot-com" e "sub-prime".

2001	Name	HQ	Industry	Market Cap USD million	2008 [3]	Name	HQ	Industry	Market Cap USD m	2011 [1]	
1	GE	US	Various	477,406	1	Exxon Mobil	US	Oil and gas	403,366	1	Exxon Mobil
2	Cisco	US	Network	304,699	2	Petrochina	China	Oil and gas	325,320	2	PetroChina
3	Exxon Mobil	US	Oil & Gas	286,367	3	GE	US	Various	253,674	3	Apple Inc.
4	Pfizer	US	Pharma	263,996	4	Microsoft	US	Software	243,687	4	Industrial and Commercial Bank of China
5	Microsoft	US	Software	258,436	5	Wal-Mart	US	Retail	235,605	5	Petrobras
6	Wal-Mart	US	Retail	250,955	6	P&G	US	Retail	211,460	6	BHP Billiton
7	Citigroup	US	Banking	250,143	7	Industrial Commercial Bank of China	China	Banking	208,397	7	China Construction Bank
8	Vodafone	UK	Telco	227,175	8	Berkshire Hathaway	US	Insurance	202,901	8	Royal Dutch Shell
9	Intel	US	Computer	227,048	9	China Mobile	China	Telco	198,558	9	Chevron Corporation
10	Royal Dutch Shell	NL/UK	Oil & Gas	206,340	10	J & J	US	Health care	193,602	10	Microsoft

Fig 2: Lista delle primi dieci società dominanti globalmente per capitalizzazione di mercato: Microsoft sopravvisse alla turbolenza economica.

Un'altra analisi (Fig. 3), che copre circa un decennio (dal 2005 al 2015), mostra che la volatilità economica ha creato un percorso sinusoidale, ma non è riuscita a espellere Microsoft (ed ExxonMobil) dalla lista¹⁵ dei primi dieci fra le società dominanti globalmente.

2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
General Electric	General Electric	Exxon Mobil	Petrochina	Exxon Mobil	Petrochina	Apple Inc	Apple Inc	Apple Inc	Apple Inc	Apple Inc
Exxon Mobil	Exxon Mobil	General Electric	Exxon Mobil	Petrochina	Exxon Mobil	Exxon Mobil	Exxon Mobil	Exxon Mobil	Exxon Mobil	Alphabet Inc
Microsoft	Citigroup Inc	Microsoft	General Electric	Microsoft	Apple Inc	Petrochina	Petrochina	Microsoft	Alphabet Inc	Microsoft
Citigroup Inc	Microsoft	Citigroup Inc	China Mobile	China Mobile	ICBC	BHP Billiton	Microsoft	Petrochina	Microsoft	Berkshire Hathaway
Wal-Mart	BP Plc	Gazprom Pao	ICBC	Wal-Mart	Wal-Mart	ICBC	ICBC	ICBC	Berkshire Hathaway	Exxon Mobil
BP Plc	Wal-Mart	Petrochina	Gazprom Pao	ICBC	CCB	Petrobras	IBM	China Mobile	General Electric	Amazon.com
Pfizer Inc	Bank Of America	ICBC	Microsoft	General Electric	Microsoft	CCB	Chevron	Alphabet Inc	Johnson & Johnson	Facebook
Bank Of America	HSBC	Bank Of America	AT&T	AT&T	HSBC	Microsoft	Alphabet Inc	Wal-Mart	Wal-Mart	General Electric
Johnson & Johnson	Johnson & Johnson	AT&T	Petrobras	Apple Inc	Petrobras	BHP Billiton	Wal-Mart	Berkshire Hathaway	Chevron	Johnson & Johnson
HSBC	Toyota Motor	BP Plc	BP Plc	Johnson & Johnson	Alphabet Inc	China Mobile	China Mobile	General Electric	Wells Fargo	Wells Fargo

Fig 3: Dominio tecnologico globale da parte delle società statunitensi (illustrazione da Goldman Sachs)

Possiamo dare un senso alla trasformazione digitale a partire da questi fatti? Potrebbe essere eretico arrivare a qualsiasi conclusione, ma forse c'è un suggerimento in agguato tra le righe. L'unica altra società statunitense che ha tenuto il passo con Microsoft, è ExxonMobil. È una compagnia di materie prime. Sarà troppo arduo suggerire che anche Microsoft possa essere considerata un'azienda di materie prime "digitali"?

Le aziende tecnologiche stanno producendo e fornendo assistenza alle materie prime digitali per perseguire la trasformazione digitale. Le aziende tecnologiche sono fornitori di strumenti per accelerare l'adozione e la diffusione della trasformazione digitale. Le aziende vendendo le materie prime digitali possono continuare ad amplificare la loro redditività, avviare la crescita economica globale e guidare l'economia digitale. Se l'economia digitale dovesse crescere con radici più profonde, tutte le forme di trasformazione digitale dovrebbero diventare pervasive e formare parte della nostra vita quotidiana. E' anche quest'ultima una materia prima. Se il WiFi non è una merce, allora che cos'è?

Gli strumenti digitali e le loro applicazioni sono materie prime per i cittadini in un mondo connesso, nel mondo fisico di cose o oggetti e società in rete. Da questo punto di vista, il portfolio che mostra la principale fonte di entrate per cinque colossi tecnologici (Fig. 4), suggerisce la ragione per cui Microsoft, in qualità di fornitore di materie prime digitali, possa superare tempeste, sopportare turbolenze e sopravvivere alla volatilità economica. Connettività e materie prime sono essenziali per gli affari di Apple e Amazon, rispettivamente.

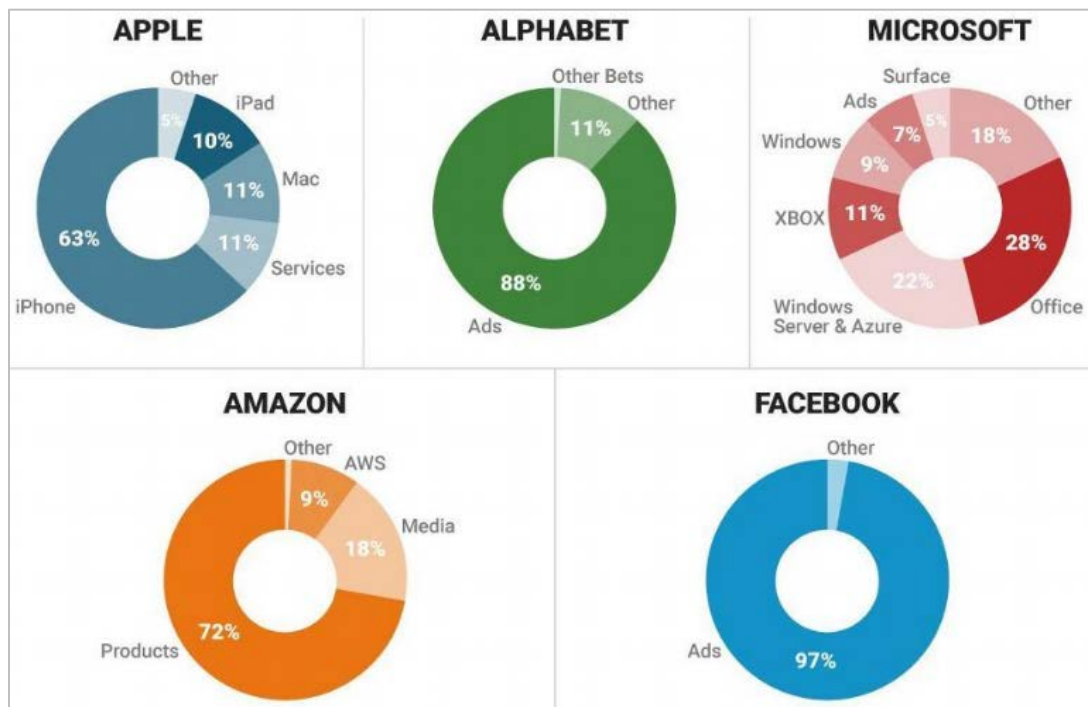


Fig 4: Flussi di entrate¹⁶ dei colossi tecnologici statunitensi e la percentuale di "pubblicità" in ciascuno.

I prodotti possono essere semplificati in due categorie: push e pull. I prodotti nella categoria pull sono "cose" (prodotti, servizi) che vengono consumati (B2B, B2C, C2C). La categoria push è distribuita, quasi indipendentemente dalla domanda. Microsoft (Fig. 4) produce e serve le materie prime digitali, appartenenti la categoria "pull", essendo i consumatori impazienti di consumare.

La pubblicità (annunci), che è presentata ad un largo pubblico, potrebbe avere vita limitata. In altre parole, questo è tanto quanto una pubblicità può aspettarsi di ottenere. Quindi, la dipendenza dagli annunci, prima o poi, può avvicinarsi ad un limite. La fiducia sproporzionata sugli annunci come flusso di entrate, offre spazio a dubbi sulla durata di un simile modello di business. Eppure, a breve termine, entrambi i giganti della tecnologia (Fig. 4) sembrano infallibili nel loro approccio. Forse c'è ancora abbastanza budget pubblicitario per passare dalla stampa e altri supporti audiovisivi al dominio digitale, che hanno il vantaggio di poter adeguare gli annunci a specifici clienti.

Forse un modello potrebbe essere creato (può esistere) dove a un prodotto o un servizio (pubblicizzato) può essere assegnato un punteggio di penetrazione basato su [1] costo del prodotto o del servizio, [2] a parità di potere d'acquisto rispetto al "bisogno" del prodotto / servizio [3], distribuzione demografica del reddito vs reddito disponibile o spesa discrezionale di famiglie / individui e [4] altri fattori, ad esempio riconoscimento del marchio, traiettoria sociale (status), e filantropia. Utilizzando lo strumento "area sotto la curva Receiver Operating Characteristic (ROC)", il modello può mostrare i limiti della capacità d'acquisto. Indipendentemente da quanto si pubblicizzi, il risultato può essere circoscritto alla sua capacità che è limitata entro "area" del potere d'acquisto sotto la curva ROC. L'analisi ROC fa parte della "Teoria della detezione del segnale" sviluppata durante la seconda guerra mondiale per l'analisi delle immagini radar. Il suo attuale utilizzo abbraccia uno spettro di applicazioni, incluse le applicazioni¹⁷ mediche introdotte¹⁸ da Charles Metz¹⁹.

DATI NELLA TRASFORMAZIONE DIGITALE: ARBITRAGGIO DELLE INFORMAZIONI

L'importanza dei dati nel processo decisionale non è un aspetto nuovo del XXI secolo. La contrattazione era il *modus operandi* chiave per negoziare i prezzi dinamici nei bazar di Mohenjo-Daro²⁰ e Harappa²¹, durante la "parte moderna" (3500 aC-1800 a.C.) della civiltà della valle dell'Indo che risale²² al 7000 a.C. La contrattazione è stata la linfa vitale del commercio per i commercianti nelle vie della seta²³ (dal 500 a.C. al 500 d.C.). Dal II secolo a.C. alla fine del XIV secolo d.C., una rotta commerciale proveniva da Chang'an (ora Xian) est e terminava nel Mediterraneo a ovest, oltre Venezia, quindi, collegando la Cina con l'Impero Romano. Il Grande Bazar²⁴ di Istanbul è radicato nella Via della Seta. Kapalıçarşı²⁵ o Büyük Çarşı, iniziò come una piccola stanza di sicurezza, la Bedestan, costruita nel 1461. Crebbe fino a coprire 100 acri, e ora ha 18 porte e circa 4000 negozi, attirando circa 91 milioni di visitatori annuali. Si evolsero tutti i tipi di comportamento contrattuale; trattative complesse fatte semplicemente con gesti delle mani, eseguite sotto la copertura di uno scialle per impedire gli sguardi indiscreti desiderosi di sapere quali accordi venissero raggiunti.

La contrattazione, quindi, era la prima forma di arbitraggio dei dati o di arbitraggio delle informazioni. L'importanza dei dati non è né unica nella trasformazione digitale, né è emersa in un recente passato. I dati e le decisioni sono stati

inestricabilmente collegati, sempre, anche **prima** dell'evoluzione del linguaggio umano. Immagina gli umani che usano i gesti per segnalare o avvisare che un animale si sta avvicinando.

È ironico che la comunicazione del gesto antecedente l'uomo di Neandertal venga reinventata da BMW²⁶ per migliorare l'esperienza di guida finale. Il gesto sembra essere il nuovo giocattolo²⁷ nel mondo connesso, ma ha il potenziale per servire gli umani con impedimenti del linguaggio.

Forse ancora più incredibile, è l'uso da parte degli Stati Uniti, dell'etica dei messaggeri sulla via Reale di Persia. Durante l'impero achemenide (500-330 a.C.), la via Reale di Persia correva da Susa (l'odierna Iran), al Mar Mediterraneo in Asia minore (l'odierna Turchia). Serviva come una delle principali arterie della Via della seta, la rete di rotte commerciali, formalmente istituita durante la dinastia Han della Cina, che collegava le regioni del mondo antico, per il commercio. I persiani mantennero con cura la via Reale e, col tempo, la estesero attraverso strade laterali più piccole. Alla fine, queste strade hanno attraversato l'India e la Mesopotamia verso l'Egitto.

La via Reale di Persia comprendeva le stazioni postali²⁸ lungo il percorso, con giovani cavalli, per assicurare una rapida trasmissione dei messaggi in tutto l'impero. Erodoto, scrivendo della velocità e dell'efficienza dei messaggeri persiani, affermò:

“Non c'è nulla al mondo che viaggi più veloce di questi corrieri persiani. Né la neve, né la pioggia, né il calore, né l'oscurità della notte impediscono a questi corrieri di completare le tappe loro assegnate con la massima velocità.”

Queste linee, dalle Storie di Erodoto, 8.98, sarebbero, secoli dopo, il credo del servizio postale degli Stati Uniti d'America²⁹ (USPS).

I dati e il loro arbitraggio sensibile al fattore tempo, così come lo scambio e la comunicazione, sono fondamentali per l'evoluzione umana. La quantità di dati, la sua rappresentazione visiva e l'estrazione del suo significato contestuale, si sono evoluti nel tempo. La trasformazione digitale è ancora un altro capitolo di questa evoluzione, poiché affina il nostro repertorio di strumenti analitici e continua ad aggiungere nuove tecniche per l'analisi dei dati al fine di visualizzare i dati e darne un senso (Fig. 5).

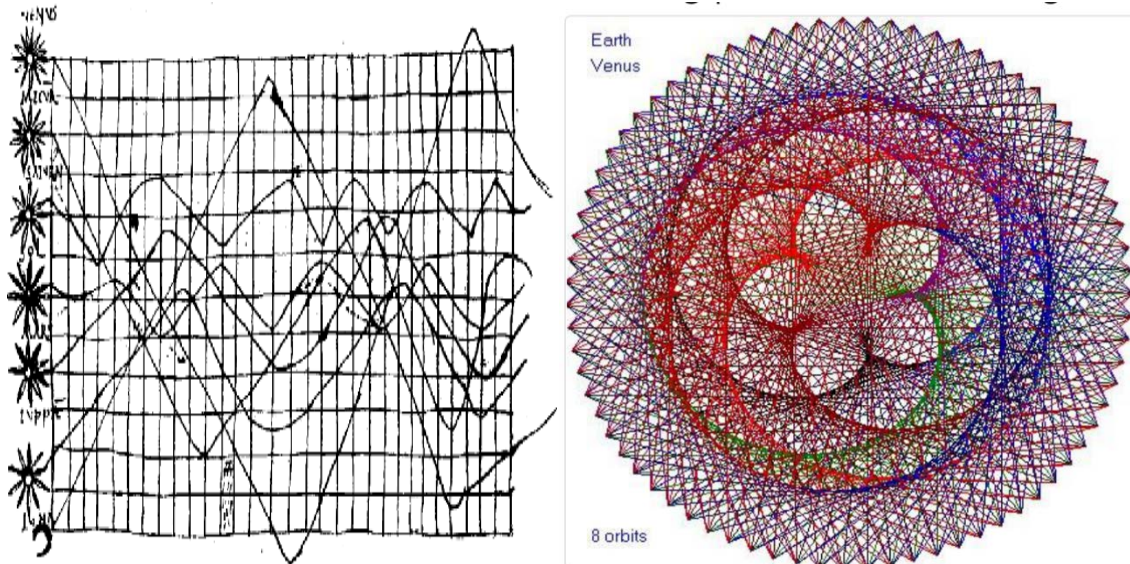


Fig 5: Visualizzazioni – (a sinistra) Posizioni³⁰ del Sole, Luna, Pianeti, dal 950 a.C., Europa; (a destra) Posizione³¹ della Terra e Venus (?) durante 8 anni (scienza³²). Un modello frattale³³?

Nell'evoluzione dell'IoT, l'enfasi principale è sui dati. In altre parole, possiamo pensare di usare l'IoT come metafora del design per DoT o "dati delle cose" implicita nel principio di collegare bit a bit, ossia collegando non solo i dati relativi alle cose (bit relativi atomi) ma anche i dati relativi ai dati o alle informazioni (bit relativi ai bit). Poiché questi archivi di dati e cose devono essere connessi per far parte di un **sistema** o di un ecosistema, la rete di Internet funge da supporto di connessione e dà origine all'acronimo NoT o rete di cose³⁴ sostenuta dal NIST. NoT reinventa un concetto che condivide motivi comuni con la legge di Metcalfe.

La Legge di Metcalfe³⁵ afferma che il valore di una rete di telecomunicazioni è proporzionale al quadrato del numero di utenti connessi del sistema (n^2) (Fig. 6). Tale legge è legata al fatto che il numero di connessioni uniche in una rete di un numero di nodi (n) può essere espresso come il numero triangolare $n(n-1)/2$, che è proporzionale a n^2 asintoticamente³⁵. Attribuita a Robert Metcalfe per quanto riguarda Ethernet, la legge di Metcalfe è stata originariamente presentata, circa nel 1980, non in termini di utenti, ma piuttosto di "dispositivi di comunicazione compatibili" (ad esempio, fax, telefoni, ecc.). In altre parole, sulla base di questa legge il valore apparente della rete aumenta con il numero di connessioni. Quindi, la legge di Metcalfe evidenzia il "valore" dei social network. Quest'ultimo ha creato grandi illusioni e catalizza varie forme di delusioni contribuendo sempre più spesso alla trasmutazione del foraggio dei tabloid dalla mera speculazione alla verità.

Successivamente, con la globalizzazione di Internet e la rapida diffusione del concetto di IoT, l'idea è stata ripresa per includere, forse erroneamente, utenti e reti. Il suo intento originale era descrivere la connettività di Ethernet.

Il significato dell'"effetto rete" in questi concetti si riferisce al valore delle informazioni da un nodo a una rete di nodi. Una moltitudine di nodi può agire come uno *swarm*. I dati di tali *swarm* possono prestarsi all'analisi utilizzando i principi dell'intelligenza dello *swarm*, e per esempio, gli algoritmi delle colonie di formiche,

utilizzati nelle routine³⁶ per l'ottimizzazione della reti di sensori³⁷ oltre alle applicazioni emergenti nei digital twins (vedere Capitolo 3 in *Haphazard Reality - IoT è una metafora*³⁸).

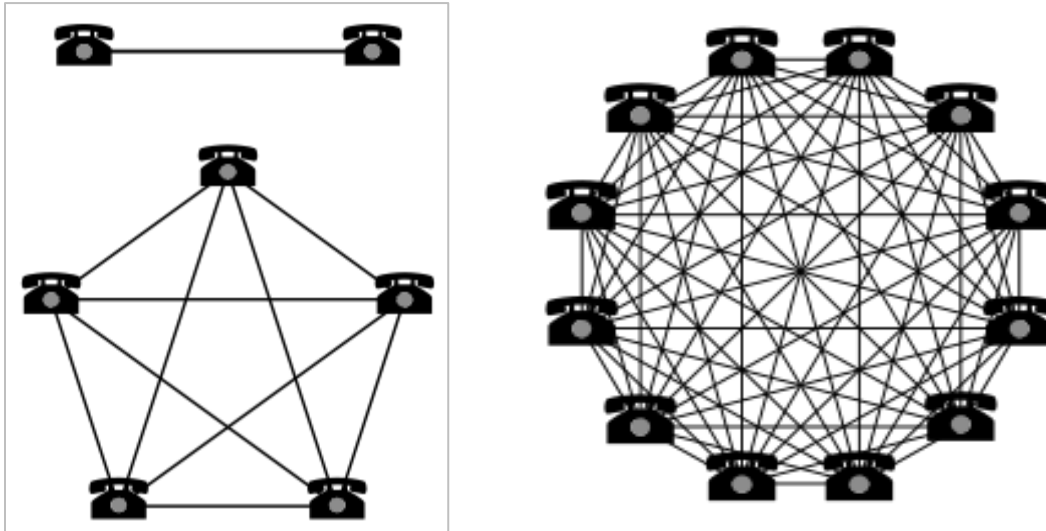


Fig 6: Legge di Metcalfe - due telefoni possono effettuare una connessione, 5 possono effettuare 10 connessioni e 12 possono effettuare 66 connessioni [12 (12-1) / 2].

SENSAZIONALISMO DELL'INTELLIGENZA ARTIFICIALE NELLA TRASFORMAZIONE DIGITALE

L'odierno marketing senza scrupoli sul potere e i benefici derivanti dall'intelligenza artificiale ricorda la campagna di bugie orchestrata dall'industria statunitense dello zucchero. Queste bugie si protrassero per oltre 50 anni³⁹ e il più' egregio atto⁴⁰ da parte dell'industria dello zucchero fu di corrompere i ricercatori di Harvard⁴¹ nel pubblicare risultati falsi, per celare gli effetti negativi di un uso eccessivo di zucchero⁴², rivelati in una pubblicazione apparsa su JAMA⁴³ il 12 Settembre del 2016. Il volume esponenziale di deliberato falso marketing e proclami circa l'intelligenza artificiale di certi colossi aziendali si sta sempre più' amplificando attraverso la mal informata rete sociale con una inclinazione al narcisismo.

Questa disastrosa sparatoria contro l'AI ha quasi soppresso le voci ragionate di scienziati credibili e di veri e propri leader di pensiero, che sono riluttanti ad essere proattivi e agiscono nel rispetto di un codice di decoro; preferiscono una sottovalutazione e si astengono dall'auto-promozione.

L'AI e la sua mancanza di intelligenza non e' una notizia né una novita' (vedere capitolo 4 in *Haphazard Reality - IoT e' una Metafora*⁴⁴). Il termine AI e' una espressione impropria, ma ha catturato l'immaginazione del pubblico. John McCarthy conio' il termine e lo propose il 31 Agosto del 1955⁴⁵ nella conferenza Dartmouth tenutasi nell'estate del 1956. L'utilita' della Machine Learning (ML) e' un dato noto, ma non allo stesso livello in cui AI e' pubblicizzata in questo momento.

Dare un senso ai dati è fondamentale per la redditività nell'economia digitale. I commercianti che contrattavano negli antichi bazar avevano un insieme limitato di dati (ad esempio, il prezzo delle merci). La serie di dati era sufficiente per consentire agli

esseri umani con una buona memoria di sviluppare abilità astute di contrattazione, attraverso l'arbitraggio dei dati, ed eccellere nell'ottimizzazione dei prezzi dinamici. Anche uomini superdotati con memoria fotografica potrebbero non essere in grado di gestire i dati dei prezzi relativi ad un singolo venditore come Amazon⁴⁶ che vende oltre 480 milioni di prodotti negli Stati Uniti. La selezione di prodotti di Amazon è aumentata di 235 milioni dal primo trimestre 2016. Ha aggiunto circa mezzo milione di nuovi prodotti (485.000 SKU) al giorno.

Gestire un immenso volume di dati è una delle principali inabilità per gli esseri umani. Gli strumenti di calcolo e di analisi dei dati (Fig. 7), incluse le applicazioni di tipo ML/AI, sono utili e necessari. Si pensi al problema di ottimizzare la pianificazione della consegna delle merci da parte di Amazon.

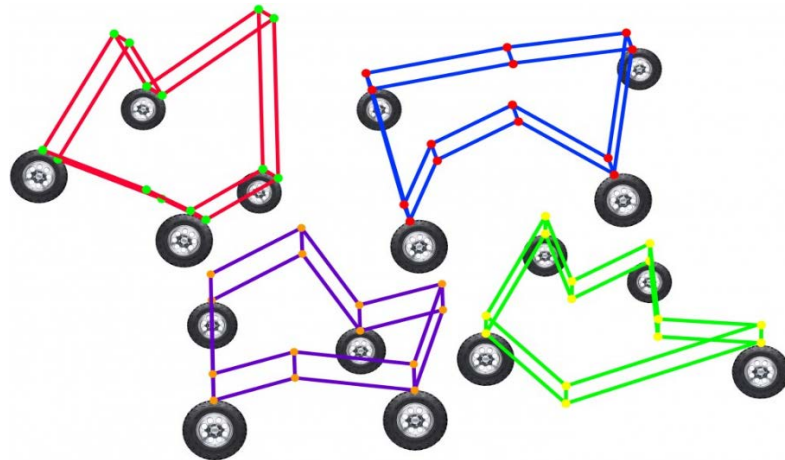
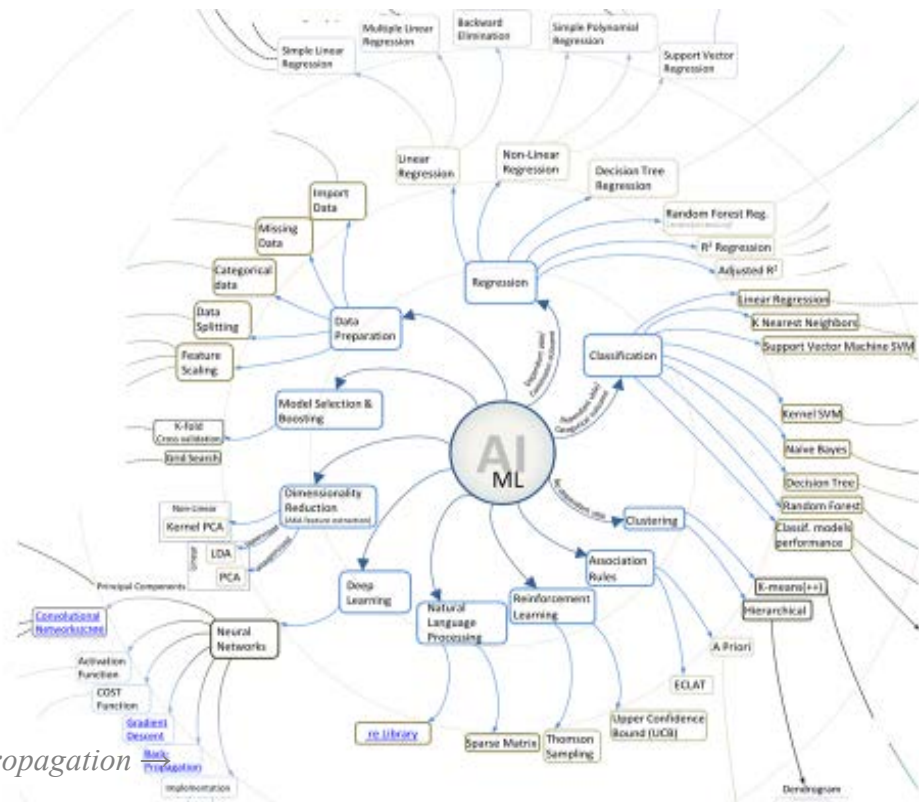
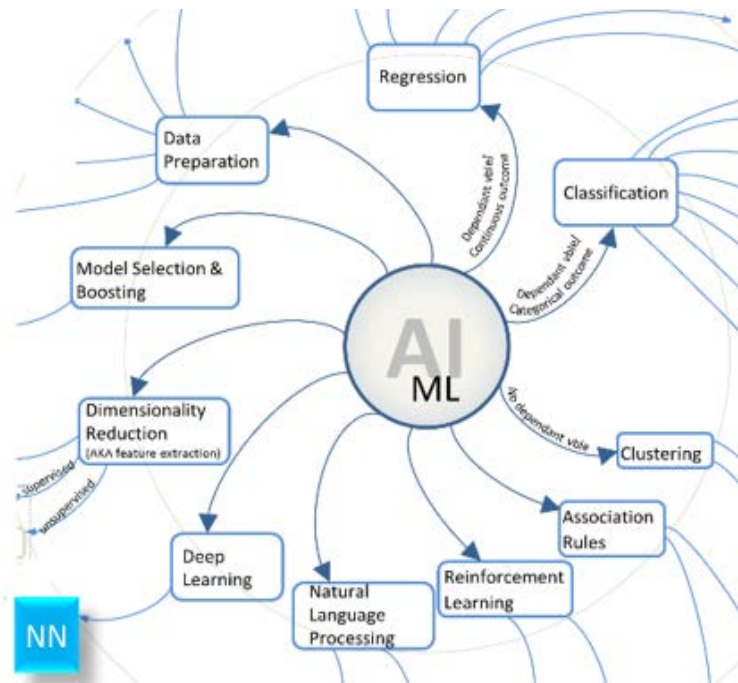


Fig 7: Gli algoritmi sono la chiave per le vie di trasporto e la sequenza per la consegna⁴⁷

AI e ML (Fig. 8) sono un termine generico per molte diverse serie e sottoserie di strumenti. La conoscenza dello spazio del problema, il contesto dei dati, la struttura e la qualità dei dati, la selezione delle caratteristiche, l'ingegneria delle funzioni e la comprensione concettuale profonda della convergenza, detiene la chiave nella selezione del portafoglio appropriato di tecniche⁴⁸ e algoritmi, che, se combinata in sequenza, può fornire un risultato ottimale.



Backpropagation

Fig 8: AI e ML - diverse serie e sottoserie di strumenti.

Nello spazio delle applicazioni del mondo reale, la selezione degli strumenti AI/ML deve essere dipendente dal contesto. In pratica, le persone che hanno una conoscenza del settore, ad esempio nel commercio al dettaglio e nei beni di consumo in rapido movimento, potrebbero non essere esperti nell'ottimizzazione della supply chain. Quest'ultimo è classicamente il dominio degli specialisti nella ricerca operativa (OR). Il settore del commercio al dettaglio può impiegare esperti OR, per cogliere le sfumature del commercio al dettaglio nel contesto dei mercati (comprensione della domanda, dati demografici, distribuzioni etc.). Nell'ambito della catena di fornitura digitale, l'analista al dettaglio dovrebbe utilizzare o applicare strumenti AI/ML per ottimizzare i risultati. Nella Fig. 9 ad esempio, il coordinamento di questi compiti all'interno dell'impresa, nel contesto della trasformazione digitale, può essere, ancora, in gran parte in una fase di "power-point". Connettere strumenti di acquisizione dati (RFID, sensori, dati di mercato) con il dominio di cura dei dati, seguito dagli strumenti di analisi dei dati, nel contesto della selezione delle funzionalità rispetto alla logica di business/mercato, è l'essenza del design nel cuore del concetto di IoT. Connettere dati su cose, processi e decisioni, è una parte dell'ampio spettro del paradigma atomi a bit. La confluenza delle conoscenze, la comprensione dei dati e la selezione degli algoritmi devono convergere per l'armonizzazione dei processi. Gli analisti devono inquadrare le domande corrette, aspettarsi informazioni utili e utilizzarle per migliorare i sistemi decisionali, *prima* che il valore dei dati/informazioni perisca.

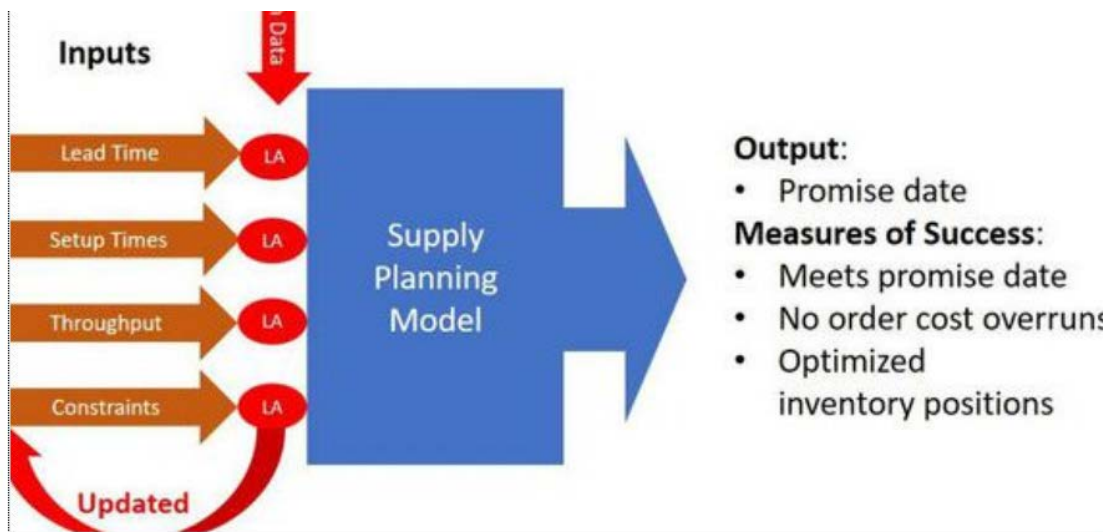


Fig 9: Produzione, pianificazione e ottimizzazione della Supply Chain, utilizzando strumenti AI/ML.

Trasformare le aziende in aziende digitali é una impresa titanica. Potrebbero volerci **decadi** prima che una vera trasformazione prenda piede, sopravviva la fase pilota e sia accettata dall'unita' di business, come parte delle **loro** operazioni. Cambi nelle risorse umane sono necessari per trasformare l'idea in realtà. Ma è anche la sede della maggiore incertezza. La prospettiva della leadership e la capacità del management esecutivo di guidare questi cambiamenti sono spesso dubbi. Anche quando i capi

sembrano capire e difendere il cambiamento, il ritmo del cambiamento é lento, o é contenuto entro specifici domini o unita' di business specifici con la necessaria visione di convergenza e confluenza di idee.

La diffusione del cambiamento in qualsiasi organizzazione è difficile. Un certo fermento si è creato nel "change management" e nell'"open innovation" che sono tuttavia spesso zoppicanti e vaghi. Per aggiungere la beffa al danno, le grandi società di consulenza approfittano di queste "lacune" e aumentano le ore fatturabili. Pubblicisti e magnati del marketing, alla ricerca di buoni morsi e dell'attenzione dei media creano e diffondono fantasie che sono vuote, insulse e ciniche (Fig. 10) per svendere strumenti di AI e alimentare l'immaginario erudito.

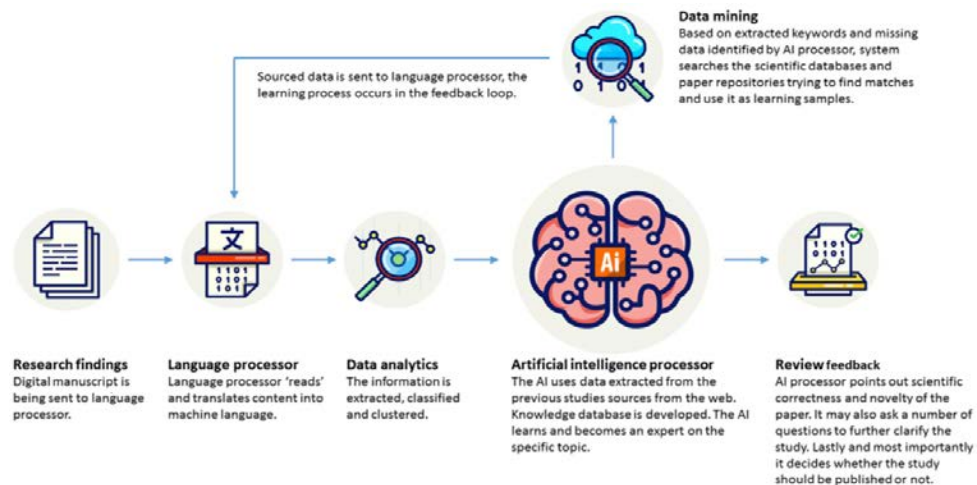


Fig 10: Irrazionale sciocchezza inventata⁴⁹ in merito ad AI, specchio per le allodole proveniente da un'organizzazione⁵⁰ del "mondo dello spettacolo".

La Figura 11 intende illustrare i benefici pragmatici della trasformazione digitale che ci si potrebbe aspettare dall'uso ragionevole degli strumenti (dati i loro limiti) provenienti dal portafoglio di tecniche, generalmente definite AI/ML (intelligenza artificiale / apprendimento automatico) come ad esempio l'utilizzo di RFID, dati dei sensori e agenti software per ridurre le scorte nella gestione dell'inventario. AI manca di intelligenza, naturalmente. Non è questo il problema. La mancanza di capacità di alcuni umani di capire il perché l'intelligenza artificiale manchi di intelligenza perpetua l'enigma. Ma l'enigma vende le notizie, le notizie pseudo-sensazionali, ed accelera la pubblicità, gli incantesimi del profitto, quindi l'inclinazione per l'industria a prolungare il mito dell'intelligenza in AI.

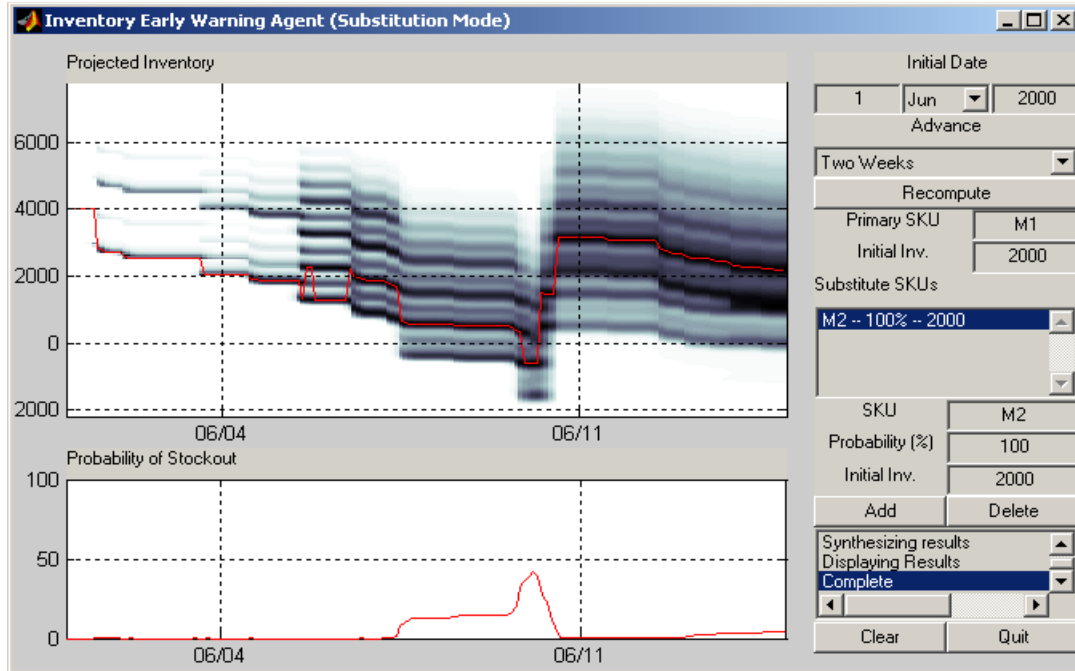


Fig 11: Modello di applicazione che utilizza strumenti di AI (screen shot SAP del 1° giugno 2000).

La Figura 12 creata da una società di consulenza per un gigante commerciale nel 2001 circa, mostra la *trasformazione digitale* attraverso un "power-point" basato sugli sviluppi EPC RFID elaborati dal Centro ID Auto del MIT e l'applicazione del modello. La vignetta ha generato grande clamore, ma non è stata mai resa operativa per motivi di business.

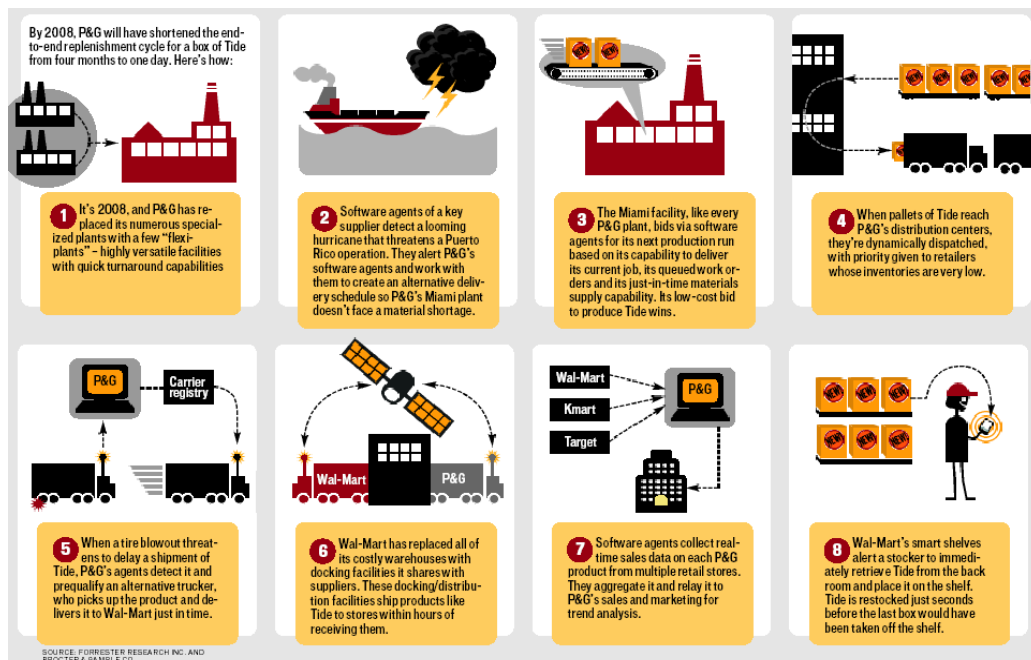


Fig 12: La trasformazione digitale - un esempio del 2001 circa, mai realizzato.

Il modello Open Source Interconnect (OSI) illustrato nella Figura 13, in basso, mostra la struttura dell'infrastruttura che ci consente di accedere ai bit. Ma l'accesso non è lo stesso della connettività, nel **contesto del processo**. Connettere partner commerciali e domini (Figura 12) con processi aziendali (Figura 13, IoT layers) può essere molto più difficile. L'accesso e l'analisi dei bit dai silos di dati intra-aziendali è sterile.

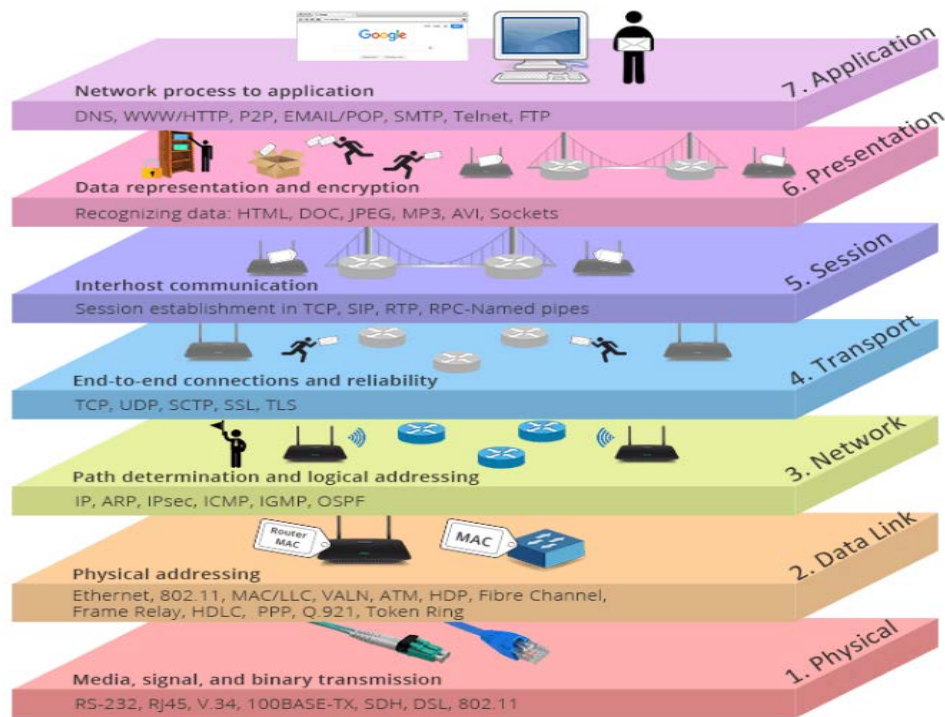
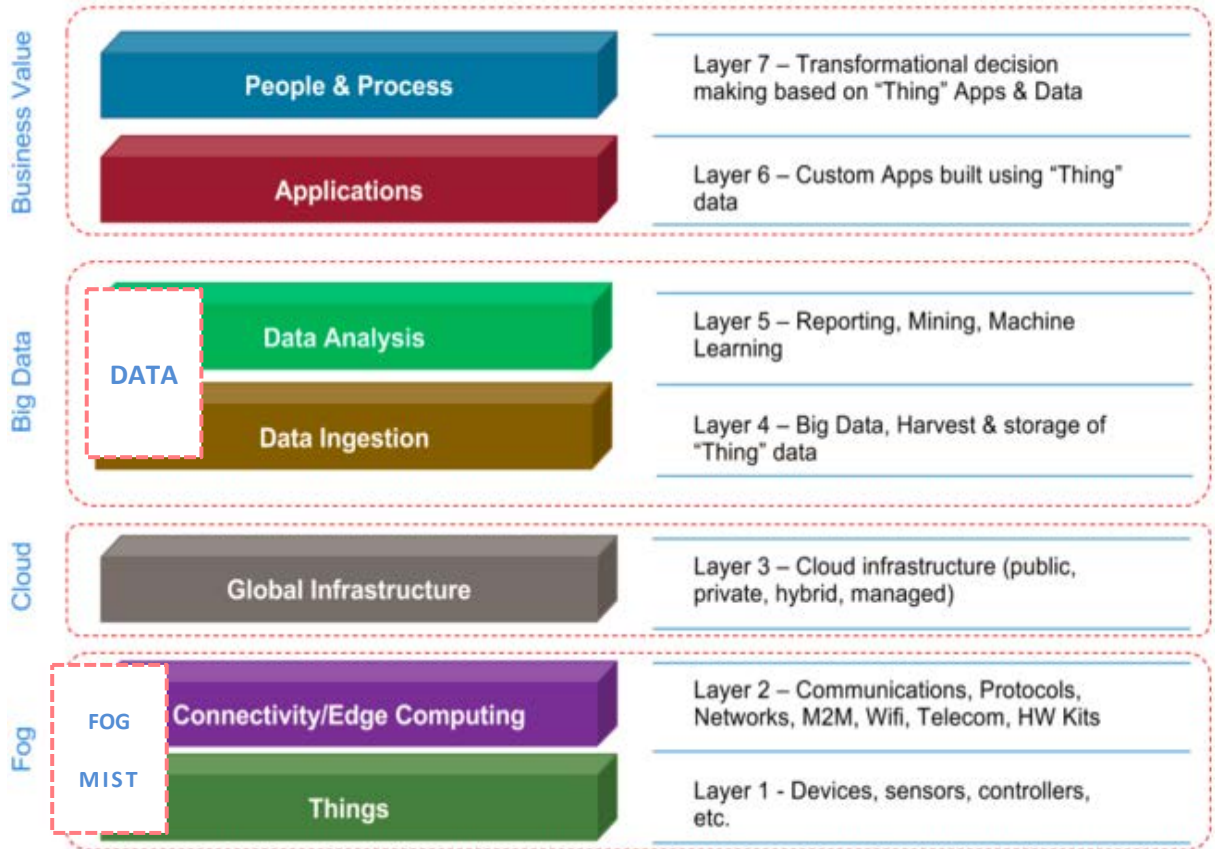


Fig 13: La struttura della connettività (da atomi a bit) – OSI⁵¹ vs IoT. Le dinamiche di cloud and fog computing, e QoS⁵² saranno influenzate⁵³ dalla larghezza di banda, dalla latenza e dallo jitter.

La mancata implementazione dell'applicazione AI (descritta nella Figura 11) o la mancata esecuzione della visione P&G (Figura 12) sono dovute alle immense difficoltà procedurali e alla intrinseca resistenza umana al collegamento tra processo e flusso di dati nel **contesto** dei **rapporti** commerciali, che devono convergere per generare il risultato (illustrato in figura 13, in alto, sette layers di IoT). Collegare i bit (Fig. 13, in basso) agli atomi (Fig. 13, in alto) è una semplice metafora del progetto, in linea di principio, ma difficilmente realizzabile nella pratica. Siamo ancora nella fase del "power-point"?

L'integrazione dei sistemi relativi agli strumenti di AI nei vari nodi analitici di dati (core vs edge, cloud vs fog computing, cloud computing in tempo reale) all'interno di un ecosistema, è lontana dalla realtà. Add-on o motori di analisi dei dati esterni sono, logicamente, il primo punto di ingresso per nuovi strumenti, tra cui AI/ML. L'esito analitico rimanda ai dati nel sistema o nel processo decisionale. L'elaborazione di enormi quantitativi di dati non strutturati è assorbita dal trial-and-error.

L'applicazione degli strumenti AI/ML fa parte di questo processo di "apprendimento". Il processo di apprendimento è in sé privo di problemi. Gli algoritmi sono tormentati da idee sbagliate su come funziona il cervello umano, in particolare le reti neurali (vedi Capitolo 4 in Haphazard Reality - IoT è una metafora⁵⁴) e il modello per reti neurali artificiali.

Un esempio è l'algoritmo di backpropagation⁵⁵ (Fig. 14) che è un punto fermo nel mondo AI. Nel 1986, Geoffrey Hinton fu co-autore della carta seminale, che, a distanza di trent'anni, è centrale nell'esplosione del marketing dell' AI. In YYZ, il 13 settembre 2017, Hinton affermò⁵⁶ che il suo metodo dovrebbe essere soppresso: egli si mostrò "profondamente sospettoso" del metodo di backpropagation⁵⁷, che è alla base del battage mediatico relativo all' AI, inclusa la capacità di ordinare le foto e parlare con Apple Siri. Hinton disse: "dal mio punto di vista si butti via tutto e si ricominci da capo".

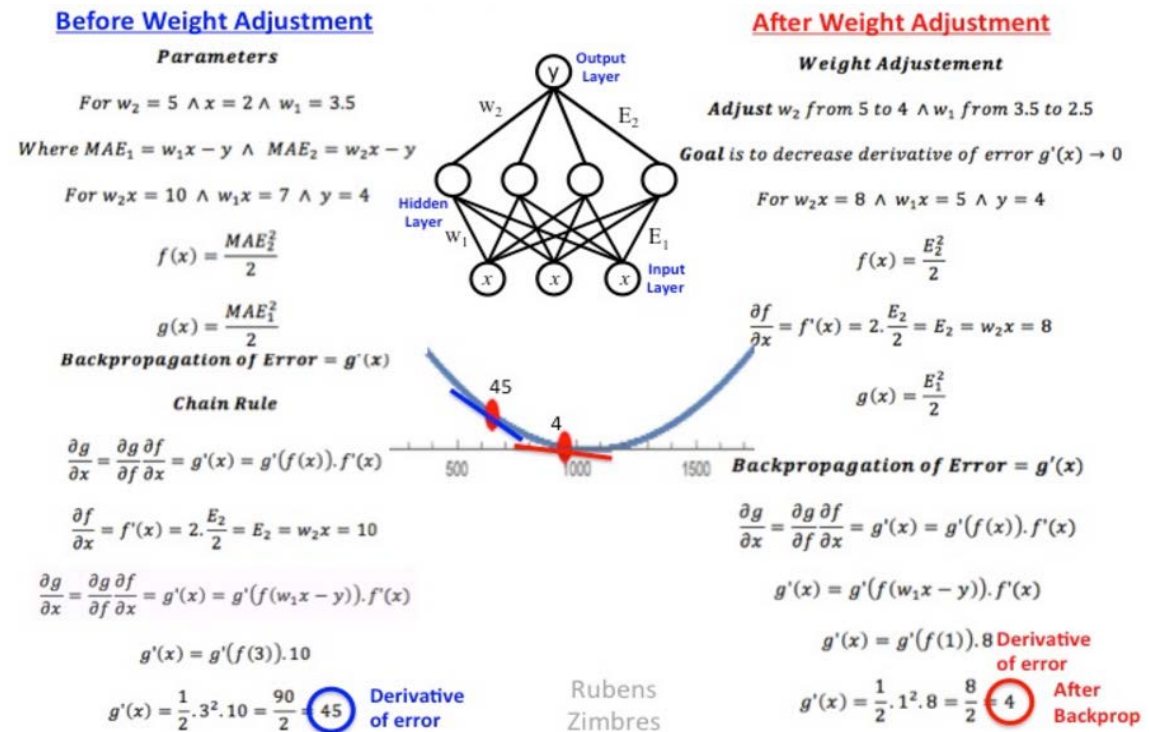


Fig 14: L'algoritmo della backpropagation⁵⁸ (vedere anche Fig. 8)

In linea di principio, si tratta di una routine di correzione degli errori. È una forma di apprendimento⁵⁹ "supervisionato" per addestrare le reti neurali artificiali (ANN). Dopo l'allenamento, l'ANN dovrebbe essere in grado di fare ciò che il formatore si aspetta (l'output), ad esempio, riconoscere un hot dog da una foto di un venditore di hot dog per le strade di New York City. Se ANN non riconosce l'"hot dog" (se l'output è una *mazza da baseball*) allora l'algoritmo di allenamento torna *indietro* e aggiusta i "pesi" associati a ciascun passo, per **guidare** la rete neurale all'output "hot dog", come risultato dell'apprendimento supervisionato. La correzione degli errori è una base e uno strumento matematico inestimabile, nella scienza e nell'ingegneria. È di fondamentale importanza in molti campi. Senza codici di correzione dell'errore, la teoria dell'informazione⁶⁰ potrebbe non funzionare. Le applicazioni nella finanza⁶¹ e nella supply chain⁶² precedono le voci dei "big data" di almeno un quarto di secolo. Quindi, la routine di correzione degli errori nella backpropagation, in linea di principio, è estremamente valida e concettualmente è essenziale.

Il malcontento sulla backpropagation deriva dal **montaggio forzato** di pesi per fornire un *apprendimento anticipato*. La regolazione dei pesi è una miscela quasi "voodoo" di metodi stocastici ed euristici. Non riflette i processi biomimetici negli organismi superiori e non rappresenta probabilmente reti neurali. La chiamata a "*ricominciare*" è sia giudiziosa che giustificata. L'applicazione della correzione degli errori, nel **contesto** della formazione ANN, può essere rivisitata o rivista da "nuovi" occhi per fornire nuovi strumenti e per integrare o addirittura sostituire il metodo della backpropagation. Tuttavia, gli strumenti AI/ML (Fig. 15) verificabili sono **essenziali** nel nostro futuro. La loro importanza nell'analisi dei dati dipenderà dalla domanda e dal suo **contesto**.

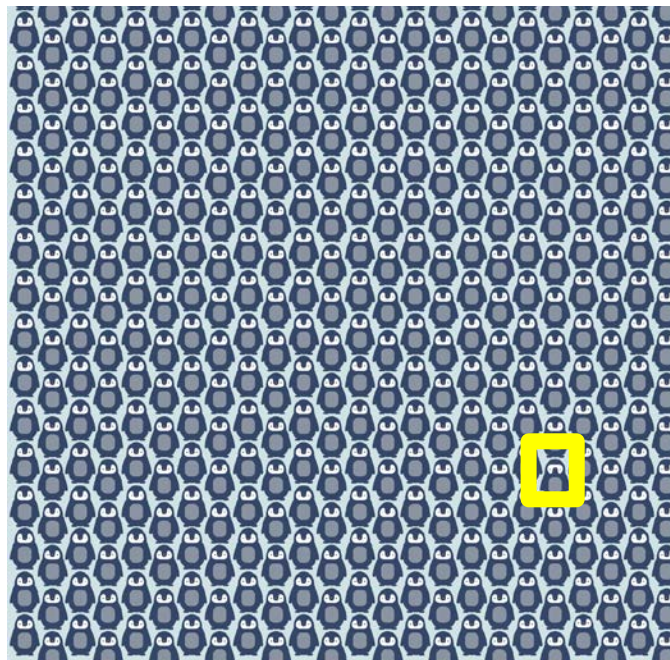


Fig 15: Machine Learning (ML) può essere un modo per rilevare le anomalie⁶³ in grandi serie di dati.

Andando oltre, al di là della backpropagation, Geoffrey E Hinton di Google Brain ha adesso, fortunatamente, reiventato una grande idea che stava brillando nella relativa oscurità da più di mezzo secolo. Le pubblicazioni⁶⁴ "capsule" di Hinton rappresentano "i nuovi vestiti dell'imperatore" derivate dal "cube-on-cube" di Marvin Minsky (le "capsule" di Hinton). L'idea di Minsky risale a diversi decenni fa, ma è stata pubblicata⁶⁵ in un libro solo nel 1985. L'illustrazione di "Society of Mind" è riprodotta in Figura 16. In combinazione con le soluzioni gerarchiche basate su agenti (agente, agenti, agenzia, agenzie), i principi e la pratica dell'uso di ant-based algoritmi in sistemi multi-agente e' esistito sino dal 1960. L'astrazione si basa vagamente su connessioni sinaptiche fatte dai neuroni (nel cervello) e potrebbe aver anche ispirato Charles Babbage, intorno al 1850, a gettare le basi del progetto (ma non a costruire) la macchina differenziale⁶⁶. Ogni unità di dati o di informazioni o ogni parametro o variabile o valore (binario) può essere catturato in cubi nel diagramma di Marvin Minsky. Esso può essere ricondotto al nuovo concetto di "capsula", ideato da Geoffrey E Hinton di Google Brain, e presentato alla XXXI Conferenza sui sistemi di elaborazione delle informazioni neurali (NIPS 2017, Long Beach, California, USA). Il potere del concetto di "cube-on-cube" è evidente grazie a numerose "re-invenzioni" di questo principio e a certe forme di prodotti commerciali che possono aver preso a prestito le sue caratteristiche salienti (ad esempio, il software "containers"⁶⁷). Cube-on-cube riappare in diversi capitoli del libro *Haphazard Reality - IoT è una metafora*⁶⁸ per illustrare varie idee, tra cui il concetto di tabella hash⁶⁹ e blockchain⁷⁰, nonché l'essenza chiave della connettività'.

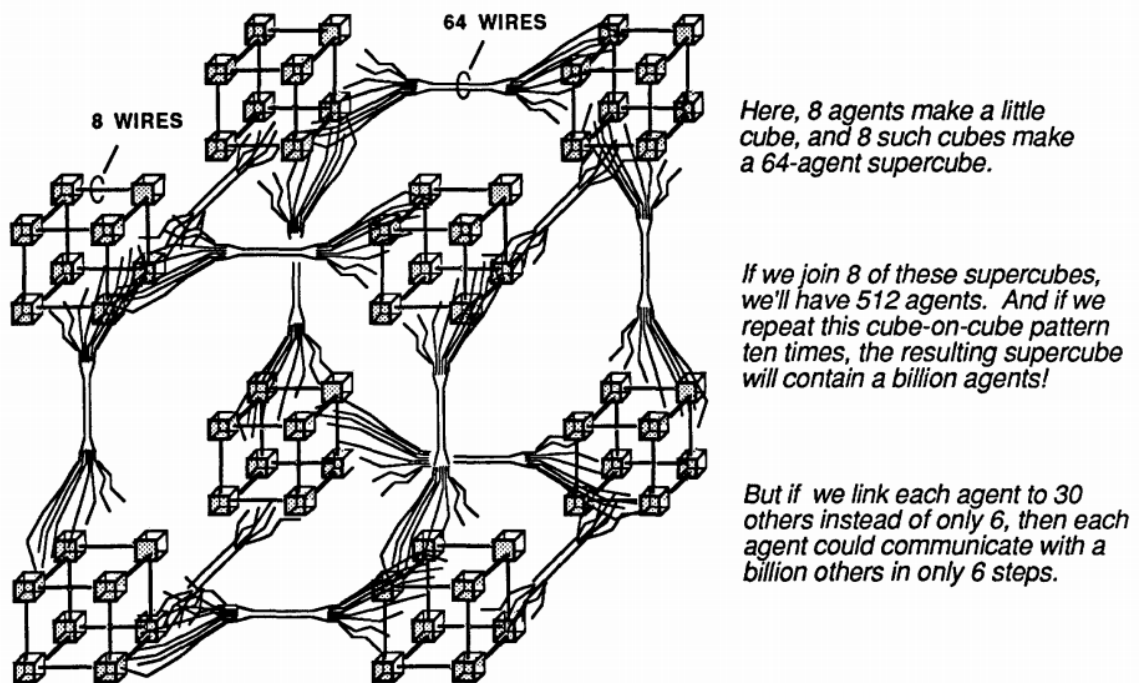


Fig 16: Il concetto di rete è evidente in questa illustrazione di Marvin Minsky⁶⁵.

ELUSIVA RICERCA DELLA BIO-ISPIRAZIONE NELLA TRASFORMAZIONE DIGITALE

Dall'alba del design del computer⁷¹, la gestione della complessità architettonica (livelli inferiori di circuiti logici a livelli superiori, annidati l'uno sopra l'altro) ha attinto dalla biologia⁷² dei neuroni, in generale, e dal ridimensionamento neuronale, in particolare, come modello bio-ispirato. La storia della ricerca dell'AI e dei motori differenziali, proposta da Charles Babbage⁷³, sembra prendere spunti dalle strutture neurali trovate in vermi, animali, mammiferi e umani. Il cervello umano è spesso paragonato a un computer. È un errore grossolano e una distorsione di proporzioni astronomiche. Il cervello **non** è un computer (Fig. 17).

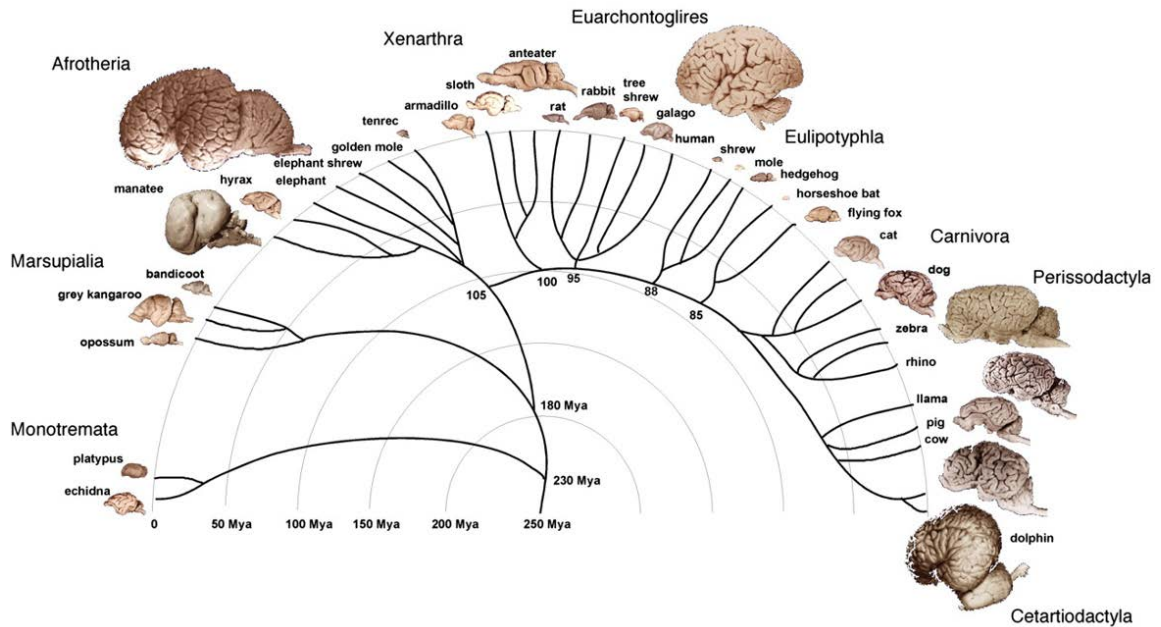


Fig 17: Il mito⁷⁴ del cervello umano "grande". L'Homo sapiens non è speciale. I grandi cervelli compaiono più volte nella radiazione evolutiva dei mammiferi (Mya = milioni di anni fa).

In termini di analogia, l'approssimazione più grossolana, per semplificare, è la nozione che il cervello possa eseguire parzialmente funzioni simili a una piattaforma molto avanzata di integrazione dei sistemi. Il cervello non è un computer, ma il calcolo può essere una parte di analogia della piattaforma. L'inafferrabile ricerca di sistemi d'ispirazione biologica è giustificata dal fatto che "la natura" ha creato strutture e funzioni che sono sopravvissute con successo ai test evolutivi.

Le lezioni dal bio-mimetismo suggeriscono che dovremmo investire molto sui sensori e sul rilevamento. Perché? Perché l'epidermide (ad esempio, la pelle umana) è un sensore tattile di tutto il corpo (pressione). Altri sensori si trovano intorno al cranio (ottica-occhi, udito-orecchie, olfatto-naso, gusto-lingua). La comunicazione biologica tramite segnali elettrochimici (analogia - telecomunicazione) funziona come un sistema hub-spoke. Il cervello è il mozzo mentre i raggi (motoneuroni) sono i muscoli. L'elaborazione del segnale⁷⁵ avviene nel cervello, quindi, per analogia, il cervello può essere inteso come una piattaforma di integrazione dei sistemi, con una componente

"cloudy". Un'altra elaborazione del segnale (arco riflesso⁷⁶) avviene attraverso il midollo spinale (analogia con fog o mist computing), ad esempio il riflesso rotuleo (anch'esso analogo all'*elaborazione in rete*).

La trasformazione digitale sta scoppiando con i suoi sensori, ma dare un senso ai dati, produrre informazioni utilizzabili, è il pantano della " *Haphazard Reality* " ⁷⁷ nell'IoT.

FONDAMENTALE PER LA TRASFORMAZIONE DIGITALE: LA SICUREZZA INFORMATICA

In mancanza della sicurezza informatica, l'annientamento del digitale è inevitabile. Se si desidera uno scambio di dati e di informazioni che non sia un qualcosa di isolato, la sicurezza non può essere secondaria.

Implementare la sicurezza tramite la progettazione, attraverso i principi strutturali dell'ingegneria, non è solo prudente, ma può aumentare il profitto e il riconoscimento del marchio. L'esempio dall'industria automobilistica, illustrato di seguito (Fig. 18), è di interesse storico, nonchè un messaggio per i professionisti al fine di promuovere l'integrazione della sicurezza informatica nella trasformazione digitale. E J Claghorn brevettò la cintura di sicurezza⁷⁸ nel 1885, ma furono necessari gli studi medici⁷⁹ e il lavoro di Griswold⁸⁰ e Volvo Bohlin⁸¹ per una sua adozione diffusa. La Saab GT750 automobile svedese (Gran Turismo 750 prodotta tra il 1958 e il 1960) presentata al Salone Internazionale dell'automobile di New York, nel 1958, includeva le cinture di sicurezza come standard.

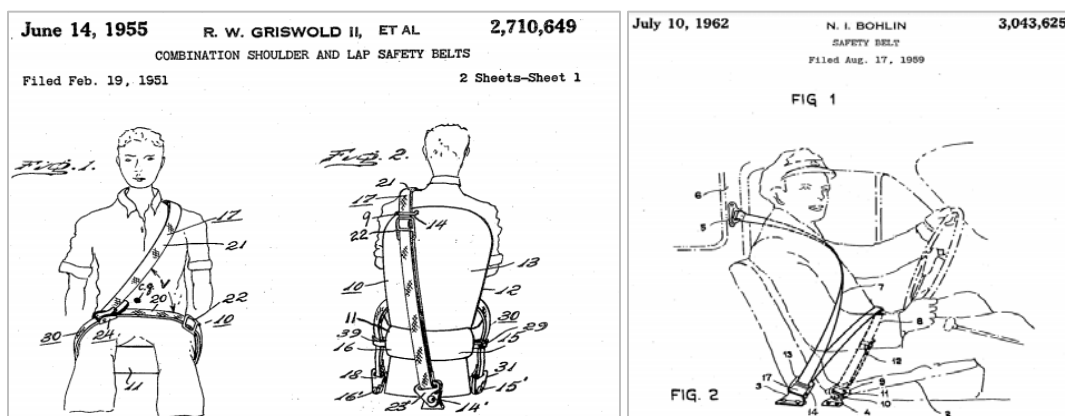


Fig 18: Brevetto della cintura di sicurezza (E J Claghorn, 1885)⁷⁸.

La drammatica storia della sicurezza informatica del 2016 è arrivata ad una conclusione⁸² l'8 dicembre 2017, in un tribunale di Anchorage (Alaska), mentre tre giovani informatici americani si sono dichiarati colpevoli di aver creato Mirai, un botnet senza precedenti, alimentato da dispositivi Internet non-sicuri come telecamere di sicurezza, router wireless, che hanno scatenato l'attacco DDoS il 21 ottobre 2016 utilizzando un dispositivo internet. La strategia "pacchetto" di Mirai (PCAP) mirava agli indirizzi IPv4 e ai relativi registri DNS (Dyn).

Potrebbe IPv6 offrire una migliore protezione per la sicurezza informatica grazie alla progettazione ingegneristica? La resistenza a passare da IPv4 a IPv6 è dovuta ai

colossi del business, fortemente focalizzati su IPv4 che, prima di tutto, devono salvaguardare il profitto.

TRASFORMAZIONE DIGITALE X.0

Hai la tua bussola? Siamo agli albori di una nuova evoluzione. La strada da percorrere è ancora in costruzione, tormentata da ambiguità, buche e passi falsi. La convergenza costruttiva e la sintesi di idee potrebbero non essere così facili. Gli indossabili (Fig. 19) sono una nuova direzione per l'IoT. Sono pubblicizzati per misurare i segni vitali, come strumento per il monitoraggio remoto. Il potenziale esiste, ma la pratica attuale è profondamente imperfetta, in parte dovuto al fatto che i tecnici del software si stanno immischiando in questioni mediche. Il cardiofrequenzimetro sulla fascia da polso mostra una frequenza cardiaca di 40 BPM (battiti al minuto) ma la frequenza cardiaca rilevabile dal medico, registrata da Dr Wayne Whitwam, MD, è di 147 BPM. Questo tipo di errore può significare la differenza tra la vita e la morte?

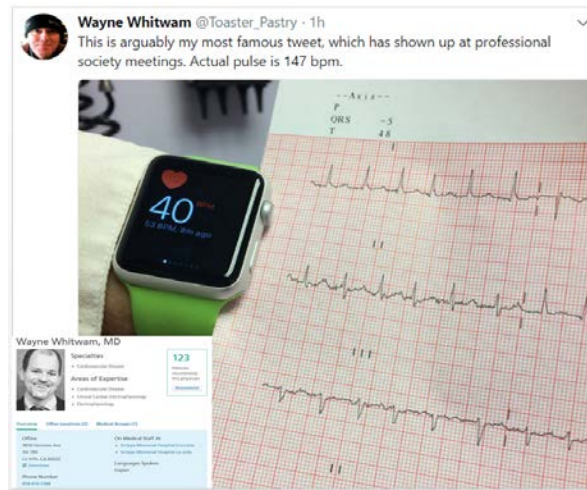


Fig 19: Gli indossabili - una nuova direzione per l'IoT.

In *Darwin's Middle Road*⁸³, Stephen Jay Gould ha scritto: "Se il genio ha un comune denominatore, proporrei l'ampiezza di interesse e la capacità di costruire fruttuose analogie tra gli ambiti". Questo articolo suggerisce molti domini diversi e offre indizi. Abbiamo alluso a diversi domini, che devono convergere, per trasformare la visione e tesserla nel tessuto della trasformazione digitale.

Il principio di connettere gli atomi a bit deve essere pervasivo e sistemico per essere utile e redditizio. Aumentare la potenza di calcolo a un costo decrescente di computazione, così come lo storage, può aiutare la nozione di computing ubiquo. Tuttavia, le idee relative a l'IoT sono solo una piccola parte⁸⁴ del mondo connesso. Lo tsunami dei cambiamenti sarà molto più grande della trasformazione digitale. Abbiamo bisogno di cambiamenti per migliorare la qualità della vita⁸⁵ di miliardi di persone. Alcuni dei suggerimenti sono in "*Haphazard Reality- IoT e'una Metafora*"⁸⁶, scaricabile dall' MIT Library.

SEGNALI STRADALI SULLA VIA DIGITALE DELLA SETA⁸⁷

La trasformazione non è limitata all'economia digitale. Lo scopo stesso dell'economia è soggetto a cambiamenti, basati su altri indicatori di civilizzazione, ad esempio energia, cibo, acqua, salute e diffusione dell'istruzione. Il ciclo dell'evoluzione economica può abbracciare diverse generazioni e coprire secoli, prima che questi cambiamenti appaiano sorprendenti (Fig. 20).

La previsione sul corso di questi cambiamenti non è facile, ma è fornita in abbondanza. Gli studi economici accurati sono pochi e lontani tra loro. È generalmente accettato che nel mondo moderno (inizio del XXI secolo) siamo ugualmente o più interessati all'accesso all'energia sostenibile e rinnovabile, rispettosa delle questioni ecologiche e ambientali.

Quindi l'innovazione nel campo delle scienze energetiche e dell'ingegneria, così come nell'assistenza sanitaria e nell'igiene⁸⁸, possono cambiare il futuro delle nazioni e, di conseguenza, l'economia globale.

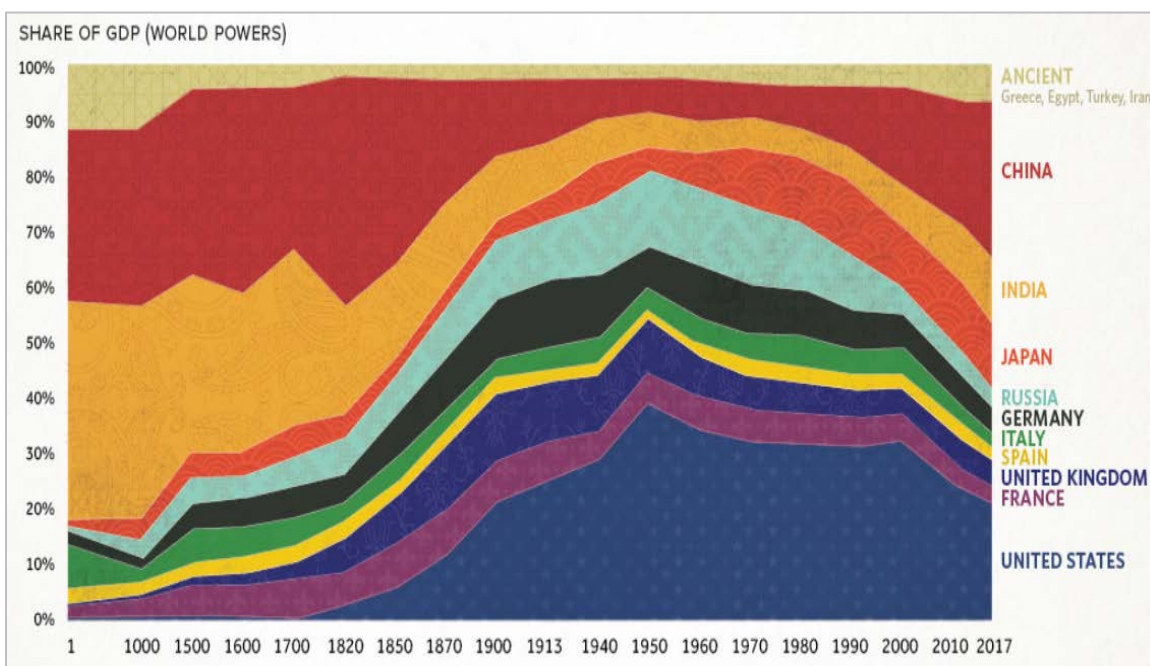


Fig 20: Variazioni⁸⁹ della quota del PIL (prodotto interno lordo) negli ultimi 2000 anni.

Scienza, ingegneria e fattibilità tecnologica stabiliranno se le buone idee provenienti dalla ricerca energetica possano trovare la loro strada verso la realizzazione e la diffusione. Per cambiare gli indicatori economici del mondo, la disponibilità di tale energia deve raggiungere i miliardi. I percorsi di adozione saranno inestricabilmente legati agli investimenti. Potrebbe co-dipendere da altre forme di infrastruttura, ad esempio comunicazioni e strade.

Sulla base del modello sinusoidale (Fig 21), sembra che il prossimo decennio (circa nel 2026), si potrà assistere all'emergere di una nuova direzione globale, seguita da un progresso tecnologico trasformativo, pronto a emergere all'alba del XXII secolo.

Si può supporre che l'innovazione tecnologica (circa 2105) possa coinvolgere l'energia. L'approvvigionamento di energia rivoluzionerà la supply chain globale.

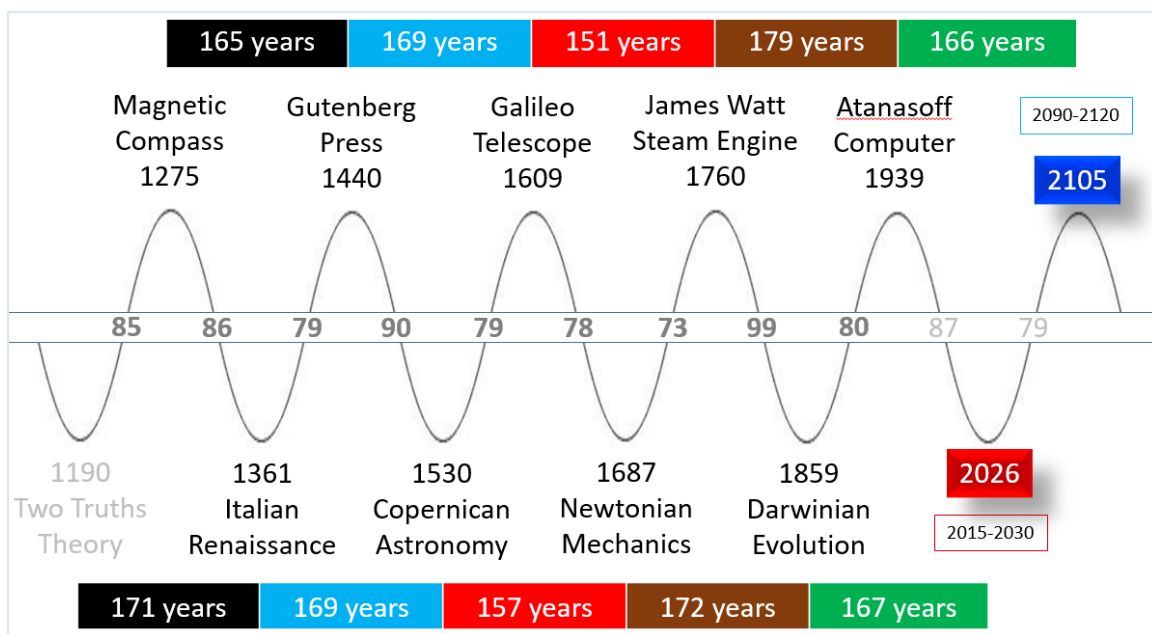


Fig 21: La "marcia della ragione" sinusoidale di Norman Poire, basata sul lavoro di diversi economisti, tra cui Joseph Alois Schumpeter⁹⁰, un economista politico di origine austriaca, all'Università di Harvard (8 febbraio 1883 - 8 gennaio 1950), e sulla teoria delle onde di Kondratieff⁹¹.

Forse lo sviluppo delle celle a combustibile ad idrogeno, concepito come un telefono cellulare di dimensioni medie (fattore di forma), o anche meglio, una *cella a combustibile* delle dimensioni di una carta di credito, *in ogni tasca*, potrebbe essere uno slogan presidenziale⁹². Il futuro potrebbe essere testimone dell'introduzione dell'FCV (veicoli a celle a combustibile) e del declino dell'EV (veicoli elettrici). Il fattore di forma delle celle a combustibile PEM può raggiungere le dimensioni di una carta di credito o di un iPhone sottile. La taglia unica si adatta a tutti? Forse no. Immagina di poter inserire la cella a combustibile a membrana a scambio protonico nota anche come cella a combustibile a membrana elettrolitica polimerica (PEM) (PEMFC) delle dimensioni di una carta di credito (cc) nel tuo laptop o smartphone o tablet per alimentare i dispositivi. Ora *re-immagina* la catena di approvvigionamento energetico.

Lo stesso ccPEMFC può essere inserito nel cruscotto della tua automobile, come fonte di energia. Il "range anxiety" è, giustamente, motivo di preoccupazione. Quanto può viaggiare l'auto per "una dose" di ccPEMFC? Ma, prima di questo, *re-immagina* il concetto di città intelligente.

Supponiamo che un veicolo possa percorrere 10 miglia per unità ccPEMFC. Sei un taxi a New York, dove la distanza media⁹³ per viaggio è di 2,6 miglia. Nel contesto del *massiccio spostamento*, hai perso o guadagnato 15-30 galloni di benzina (per i veicoli ICE) dal trasporto di una batteria da 700 kg (per veicoli elettrici) rispetto ad un cruscotto ccPEMFC del peso di 10-100 grammi?

Scambia il tuo ccPEMFC esaurito di energia con un nuovo ccPEMFC e sei appena entrato nell'era degli "atomi scambiabili" in cui il fattore di forma dell'energia mobile portatile ti consente di *scambiare gli atomi*. Trasporta un 6-pack di ccPEMFC o

scambia ccPEMFC in un negozio di alimentari o in un minimarket. La realtà dello "scambio" potrebbe essere messa in pratica⁹⁴ in India (Fig. 22).

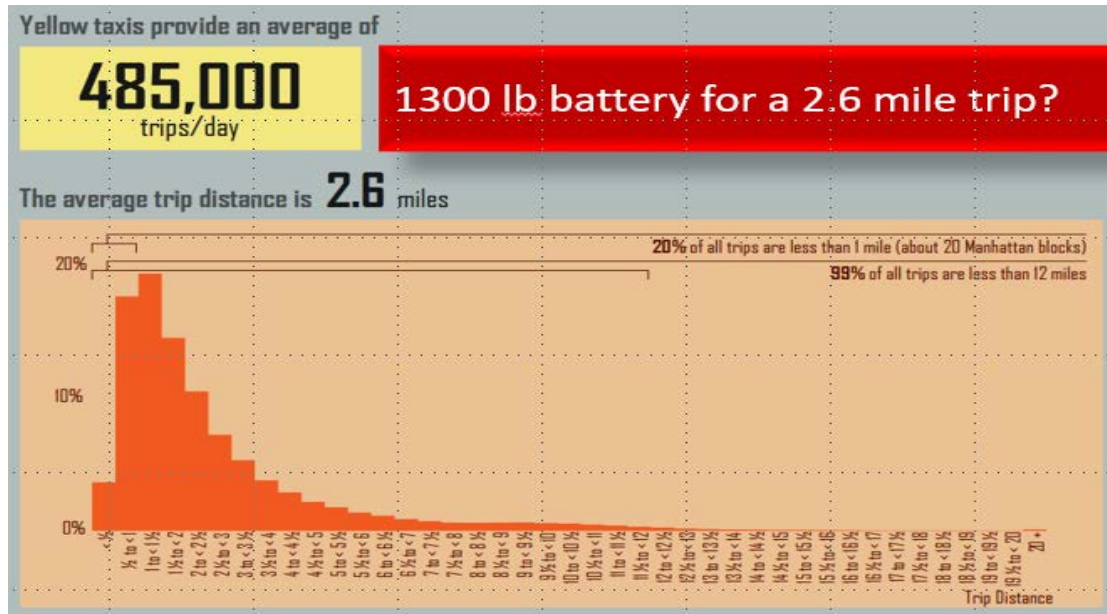


Fig 22: Complementarità tra "atomi e bit" e il paradigma degli "atomi scambiabili"

Le "carte" delle celle a combustibile (ccPEMFC) possono svanire a favore dell'energia sotto forma di microUSB flash drive. *Re-immaginare* il ccPEMFC mobile, senza rete e scambiabile ma in una nuova forma: una sottile unità flash-drive inserita in una porta simile al microUSB.

La fonte di energia può essere l'idrogeno solido. Contrariamente ai libri di testo standard di chimica, J. D. Bernal suggerì che le sostanze gassose, sotto alta pressione, possano essere trasformate in reticoli metallici o di valenza. Nel 1935, Wigner e Huntington⁹⁵ calcolarono teoricamente l'energia di un reticolo di idrogeno centrato sul corpo in funzione della costante del reticolo (che corrisponde ad una densità molte volte superiore a quella del normale reticolo molecolare dell'idrogeno solido). Glenn Seaborg⁹⁶ (elemento Seaborgio⁹⁷ numero atomico 106) illustrò (a SD) la previsione. La nozione di idrogeno solido, in un contenitore di dimensioni ditali, fu la base di una proposta, presentata in una pubblicazione⁹⁸ nel 2005 (pubblicata da TEKES, governo finlandese) (Fig. 23).

L'articolo (2005) non menzionava l'idrogeno solido, né affermava che un'unità del sottile dispositivo microUSB simile a un sottile flash-drive possa essere sufficiente a far funzionare un Boeing 787 o Airbus 380 o la più grande nave container, il CSCL Globe, registrata a Hong Kong, che misura più di 400 m (1,312 piedi) e porta circa 20.000 contenitori standard.

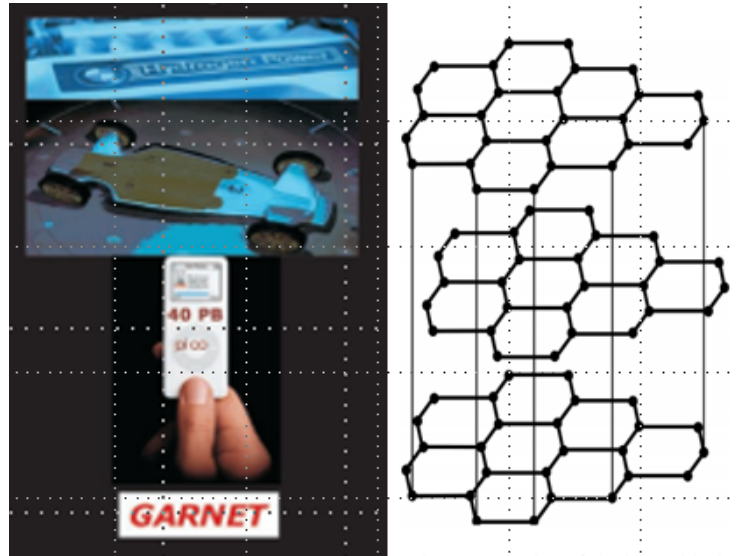


Fig 23: A sinistra, energia per un veicolo che utilizza un mezzo delle dimensioni di una carta di credito sottile, proposta nel 2005. A destra, rappresentazione schematica del reticolo stratificato di grafite. L'idrogeno metallico può assumere questo tipo di struttura reticolare, secondo Wigner & Huntington⁹⁵.

Nel 2017, l'impossibile è stato reso possibile⁹⁹ da Ranga Dias, uno studente laureato presso l'Università di Harvard, che ha sostenuto di aver formato idrogeno¹⁰⁰ metastabile (solido) ad una pressione di 495 GigaPascal. Come in tutte le scoperte seminali, congratulazioni¹⁰¹ e saluti sono arrivati da tutti gli angoli del globo (Fig 24¹⁰¹).

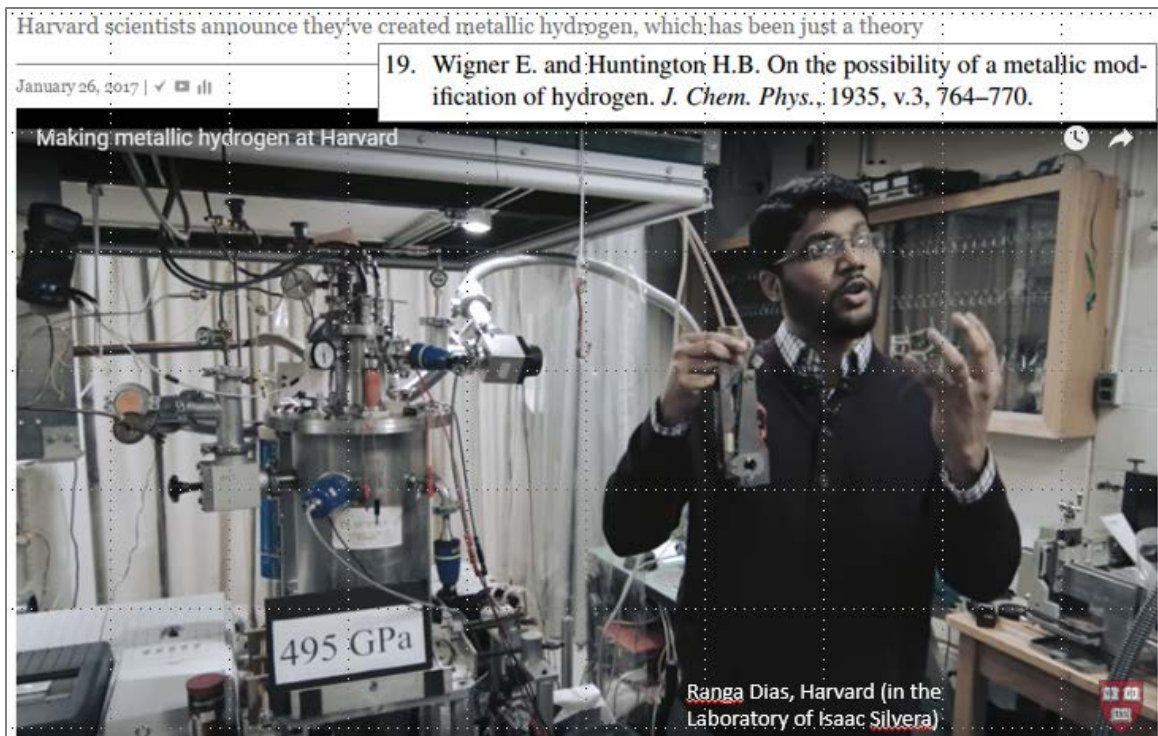


Fig 24: La formazione di idrogeno metallico di uno studente Ranga Dias dell'Università di Harvard.

Tutto ciò che ha bisogno di energia ("elettricità") potrebbe incorporare una porta microUSB standard nel progetto del dispositivo (telefono, laptop, automobile, aereo, edificio, tosaerba e sottomarino) ed essere alimentato da idrogeno metastabile compattato. Oggi possiamo inserire la spina all'EV nelle nostre case per caricare il veicolo. Le economie in crisi, senza rete, senza energia, in difficoltà, possono cambiare in meglio, possono **connettere le loro case** al futuro FCV, per alimentare la loro vita. Il fattore di forma dell'energia portatile, mobile e grid-free può subire un'evoluzione radicale, e raggiungere il suo apice intorno al 2105-2120. La metafora del collegamento degli atomi ai bit (IoT) può abbracciare la complementarità che evolverà dagli atomi scambiabili. Il cambio di paradigma nel costo dell'energia, nell'accesso e nella sua distribuzione, avrà un impatto su quasi tutte le catene di approvvigionamento e potrà catalizzare un'ondata inarrestabile di libertà, sviluppo e crescita economica. Il *potere alle persone* cesserà di essere semplicemente una banalità politica.

Un portafoglio di energia poco costosa aprirà l'ultima frontiera per le imprese e il commercio accelerando ulteriormente la creazione di mercati nel continente africano. I benefici del rimpasto energetico incontreranno la resistenza nelle nazioni occidentali avanzate, a causa del peso morto della vecchia tecnologia, legata alla lobby politica dei pochi ricchi. L'Asia e l'Africa potrebbero scavalcare il futuro grazie al solare, all'idrogeno e alla fusione, come parte del loro portafoglio energetico rinnovabile, a emissioni zero e sostenibile.

La forza della scienza, dietro la chimica dell'idrogeno metastabile, rende possibile suggerire che il futuro dell'energia basata sull'idrogeno possa essere confezionato in un

dispositivo micro-USB, con l'idrogeno metallico¹⁰² come combustibile (Fig. 25). Per gli oggetti immobili e le funzioni tradizionali (edifici), la commercializzazione¹⁰³ dell'energia da fusione¹⁰⁴ potrebbe essere un salto economico altrettanto importante per il XXII secolo. Solare, idrogeno e fusione possono coesistere come soluzioni commerciali pragmatiche, a livello globale, nell'anno 2121.

Ma che dire del previsto cambiamento nella direzione globale, nel prossimo decennio? Si è tentati di ipotizzare che le forze globali per sempre possano iniziare ad affrontare la disuguaglianza di genere¹⁰⁵. L'aumento delle opportunità per le donne, nel mercato del lavoro, potrebbe aggiungere 12 trilioni di dollari al PIL globale annuo nel prossimo decennio. La parità di genere sarà davvero una nuova direzione, una trasformazione che cambierà il tessuto della civiltà.



Fig 25: L'informatica onnipresente incontra energia onnipresente nel XXII secolo.

CONCLUSIONI

Collegare gli atomi ai bit è un passo importante per lo sviluppo globale e i sistemi decisionali. La trasformazione digitale è una delle molte aree chiave che devono marciare a ranghi serrati con altri aspetti. La Digital Silk Road¹⁰⁶ promette qualsiasi cosa per essere liscia¹⁰⁷ come la seta. Le previsioni su energia e supply chain aggiungeranno turbolenze ai cambiamenti previsti. Il viaggio sarà impantanato da false promesse e sensazionalismo fanatico.

Nessuno può sfuggire ai travagli del tempo, in particolare a quelli esagerati di arroganza. L'ascesa e la caduta cicliche di General Electric¹⁰⁸ sono un esempio. Il 28 agosto 2000, GE¹⁰⁹ era al suo apice con un prezzo azionario di \$ 34,55 (Fig 26). Più recentemente¹¹⁰, il 20 dicembre 2016, le azioni di GE erano scese a \$ 32,25 per azione. Entro il 29 dicembre 2017, il prezzo delle azioni di GE era quasi dimezzato a \$ 17,45 per azione. In una recente analisi dei sei regimi CEO a GE (Wilson, Cordiner, Borch, Jones, Welch e Immelt), la megalomania di Jack Welch potrebbe aver in modo sproporzionato sparso i semi del declino di GE¹¹¹, ma anche Jeff Immelt¹¹² non è esente da responsabilità. Trasformare GE in un'azienda energetica o in una società di software, e' un buon proposito per lo sfarzo e il glamour sul palco, per l'esibizione "Minds and Machines".

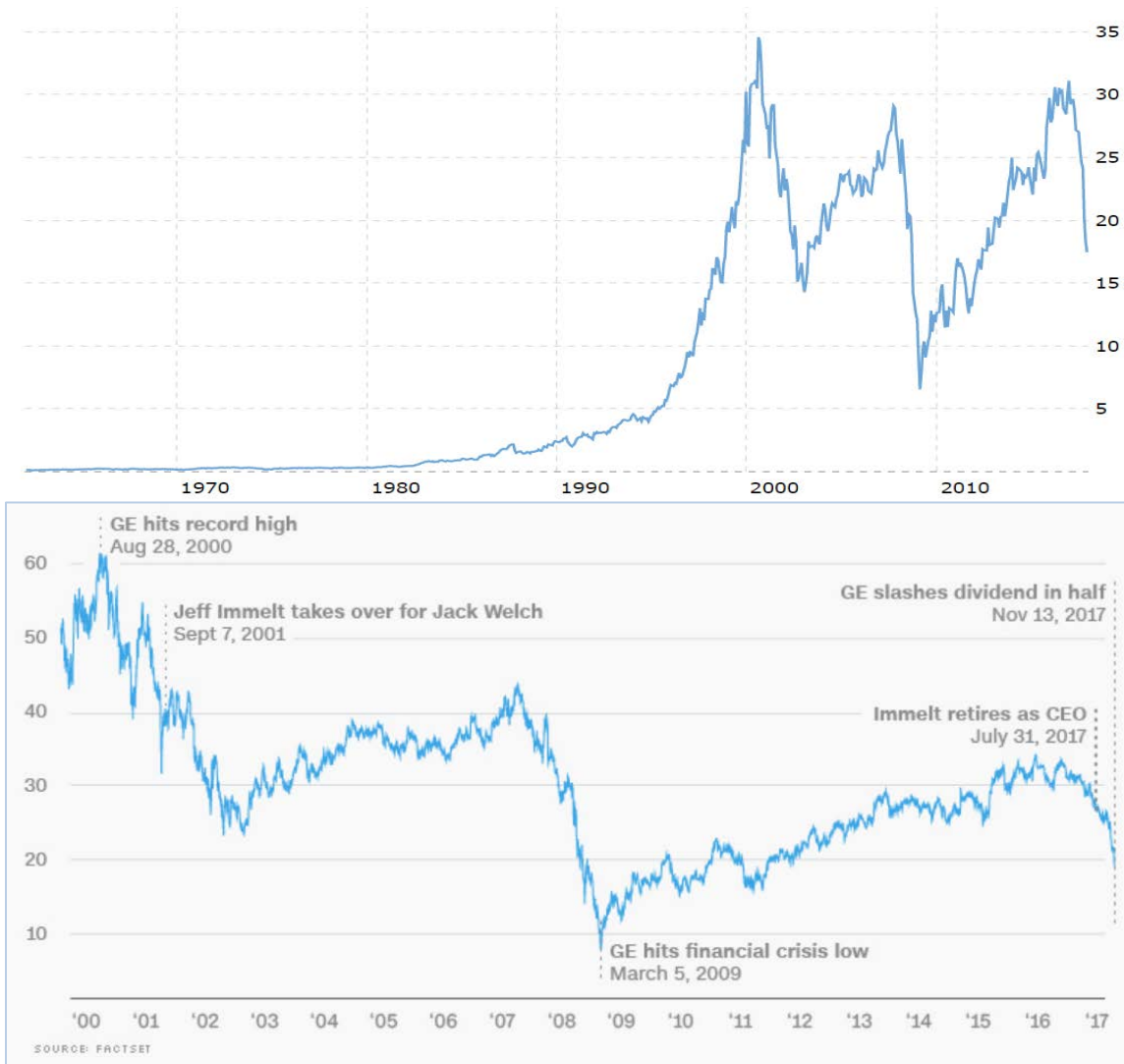


Fig 26: Prezzo delle azioni GE¹¹³ nel 1962-2017 (sopra) in rapporto al cambio della leadership in GE (sotto).

Lo squilibrio economico¹¹⁴ dovuto al baratro tecnologico potrebbe fare a pezzi¹¹⁵ il tessuto sociale, secondo quanto riportato in un rapporto¹¹⁶. L'indebita enfasi sulla trasformazione digitale in questo e in altri articoli è un esempio allarmante di parzialità. GE è un esempio di ciò che accade quando i leader sono guidati da tracotanza o sono invaghiti dalla pubblicità¹¹⁷ e agiscono come agenti di marketing, piuttosto che visionari. Veloce e sporco può vincere, ma, per quanto tempo?

Sulla base delle nostre conoscenze limitate potrebbe essere prematuro suggerire quali domini sono ugualmente (o più) importanti. Tuttavia, prevediamo la crescente domanda di **sistemi come servizi** perché la sintesi di strumenti, tecnologie e dati deve generare soluzioni globali.

Nutrire il mondo è in cima alla lista delle soluzioni necessarie, non solo per il suo bisogno a breve termine (fame quotidiana), ma anche per il suo impatto a lungo termine

sull'evoluzione del cervello¹¹⁸. In parallelo, una ragionevole eliminazione dello zucchero¹¹⁹ nella nostra dieta può migliorare la nutrizione e la salute. Nel corso di uno studio di 15 anni¹²² sullo zucchero aggiunto e le malattie cardiache, i partecipanti che hanno assunto il 25% o più delle loro calorie giornaliere in forma di zucchero avevano più del doppio delle probabilità di morire per malattie cardiache rispetto a quelli la cui dieta includeva meno del 10%. L'aspra politica dello zucchero¹²⁰ e la sua collusione con le grandi aziende potrebbero seminare un'epidemia, chiamata diabete. Quindi, in tale ambito, l'autocontrollo della glicemia¹²¹ rappresenta la quintessenza al fine di prevenire lo zucchero in eccesso nella dieta quotidiana. I componenti necessari per creare la soluzione di monitoraggio glicemico sono un altro esempio di *sistemi come servizio*. L'energia pulita a basso costo può essere un indicatore chiave delle prestazioni economiche che influenzerà l'industria, il commercio, la forza lavoro, l'arbitraggio finanziario e la globalizzazione. Il percorso verso l'energia a basso costo può ancora passare attraverso campi politici minati.

È opinione generale che il trio di servizi d'igiene, acqua e salute, così come l'assistenza sanitaria, sono necessità fondamentali¹²³ per miliardi di persone, per lo più ignorate dal mondo opulento.

Gestione delle emergenze, telecomunicazioni e strade (infrastrutture) sono il pane e il burro del mondo connesso. 5G è la ciliegina sulla torta, non l'elemento base immediato.

Il progresso di qualsiasi dominio per il progresso umano è radicato nella scienza e nell'ingegneria. Gli strumenti per il bene pubblico, ad esempio nanotecnologie e grafene per celle solari fotovoltaiche, nonché desalinizzazione e purificazione dell'acqua, sono i frutti della **ricerca** accademica.

È ironico che la forza di GE sia nell'energia e nella sanità. Sta ancora portando l'azienda su una traiettoria discendente. Una ragione potrebbe essere la sua estrema affinità con l'idea occidentale di redditività aziendale. GE punta a servire i propri azionisti e massimizzare i profitti. Se un'azienda, come GE, dovesse servire la comunità e, quindi, rastrellare i micro-pagamenti da miliardi di utenti, potrebbe generare miliardi di entrate, *nel tempo*.

L'etica della scuola di business occidentale di profitti su profitti è il metro del capitalismo. In parte, alimenta lo stile di vita e il lusso che diamo per scontato in Occidente.

Un dogma del business occidentale è quello di ottimizzare il "valore per gli azionisti" che è stato praticato fino alla nausea dalla scuola di Jack Welch¹²⁴. La richiesta di "educazione dei dirigenti" da parte delle università statunitensi d'élite suggerisce che le economie emergenti sono ancora desiderose di emulare le pratiche occidentali basate più sulla costruzione di pilastri, e meno sulla costruzione di ponti.

Le scuole di business cinesi e indiane stanno predicando la creazione di ricchezza personale nonché come catalizzare il ROI. Ma ciò che ha funzionato per la ricca società occidentale (USA e EU) potrebbe non essere riproducibile in Oriente, con miliardi di persone affamate che non possono permettersi né l'assistenza sanitaria né l'istruzione. L'inclinazione orientale per le pratiche commerciali occidentali è una forma di miopia che né Joshua Silver¹²⁵ né la sua missione¹²⁶ o la sua visione¹²⁷ possono curare.

A livello globale, c'è una mancanza di comprensione. Gli strumenti e le tecnologie da soli sono impotenti nell'ottenere miglioramenti stabili, quindi non sono in

grado di generare redditività a lungo termine e ricchezza delle nazioni. Quando strumenti e tecnologie fanno parte di un *sistema*, nell'approccio *sistemico* ad una soluzione, il risultato, ossia **i sistemi come servizio**, è redditizio.

L'uso di strumenti *ad hoc* è spesso impantanato da errori iniziali. L'uso della tecnologia RFID, come strumento di identificazione per tracciare le merci nella catena di approvvigionamento, è ancora una grande idea. Nel 2000 i rivenditori si aspettavano istantaneamente **quella** produttività semplicemente schiaffando su un tag RFID. E 'stato catalizzato dal clamore e dalla fuga precipitosa per una nuova fonte di *ore fatturabili* da parte di una varietà di consulenti e società di consulenza, ignari dei *sistemi* e dell'integrazione sistemica.

Le lezioni¹²⁸ di *produttività* sono intrise di *complementarità*. Non puoi averne uno senza l'altro. La complementarità riguarda *sistemi* in cui più strumenti e molte tecnologie¹²⁹, sia nuove sia vecchie, possono *convergere* per produrre un impatto, maggiore della somma delle parti. Illustrate con l'eleganza dalla storia dell'elettrificazione¹³⁰, lezioni simili si applicano alla maggior parte degli strumenti (RFID, sensori, AI, ML, blockchain, stampa 3D, e digital foundry).

Cosa significa, per la trasformazione globale, la trasformazione digitale e il suo sottoinsieme presi insieme? Sfortunatamente dovremo assistere a scontri catastrofici, soprattutto per quanto riguarda la sfilata in corso sulle aspettative dell'AI¹³¹ e sui suoi poteri apparentemente super-naturali. Ancora più preoccupante è l'osservazione che le società, le mastodontiche società di consulenza e i cosiddetti "capitani" delle industrie stanno mettendo in vendita falsità.

L'ottimismo richiede di affrettarci ad affrontare la realtà e i fatti (Fig. 27) relativi alle lacune globali che perpetuano la morbosità. Ognuno di noi ha un ruolo da svolgere, non importa quanto piccolo, per contribuire a migliorare la qualità della vita umana a livello globale. Non è sufficiente incolpare le politiche e la politica degli esseri umani non etici, occupati in tradimento, lussuria e dissolutezza, piuttosto che contribuire a catalizzare la scienza per servire la società, fornire valori umani e aiutare lo sviluppo economico attraverso beni pubblici globali.

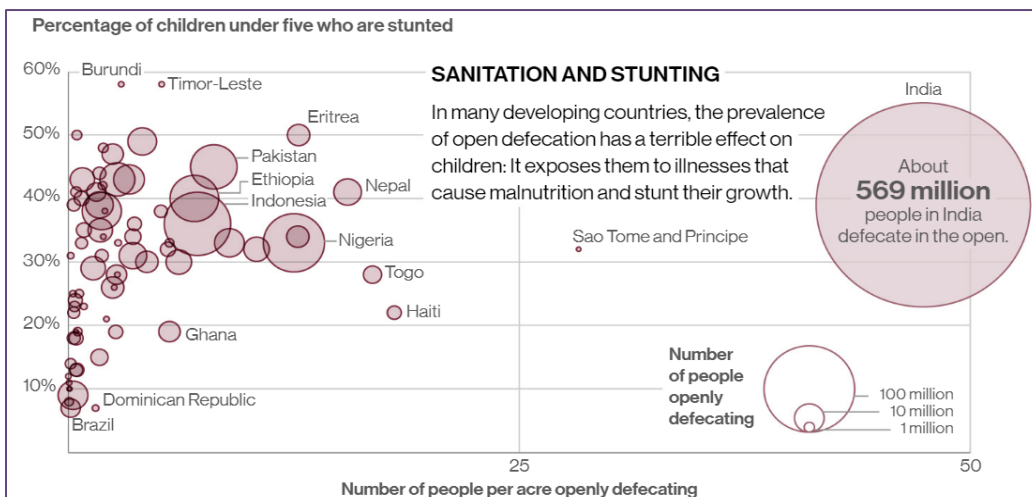


Fig 27: Ingiustizia rimediabile? La mancanza di igiene adeguata potrebbe privare miliardi di bambini nel mondo di un'infanzia sana⁸⁸. La scienza può aiutare la società.

La nostra esistenza è basata sulla compassione e sulla conoscenza. La compassione senza conoscenza è inefficace. La conoscenza senza compassione è inumana¹³². Nella nostra ricerca di idee, dobbiamo sforzarci di pensare alle domande corrette¹³³. Domande sbagliate genereranno risposte sbagliate¹³⁴. L'umanità ha bisogno di sognatori compassionevoli¹³⁵, di un senso etico di scopo superiore e di umiltà. Noi, la gente comune, dobbiamo trovare una via per la dignità.

The Italian language version of the original English article “Connecting Atoms to Bits” was edited and translated by co-authors Marchesi & Marchesi. The content was reduced by the publisher, to fit the allotted space, for the Italian publication.

The original article “Connecting Atoms to Bits” is Chapter 1 in the book “*Haphazard Reality – IoT is a Metaphor*” and it may be downloaded from the MIT Library in a PDF format with the title “IoT is a Metaphor” which may be accessed using this URL <https://dspace.mit.edu/handle/1721.1/111021>

Note

- 1 [https://en.wikipedia.org/wiki/Sally_\(short_story\)](https://en.wikipedia.org/wiki/Sally_(short_story))
- 2 <http://digitalcollections.library.cmu.edu/awweb/awarchive?type=file&item=34057>
- 3 <https://www.ics.uci.edu/~corps/phaseii/Weiser-Computer21stCentury-SciAm.pdf>
- 4 <https://www.postscapes.com/internet-of-things-history/>
- 5 <https://www.linkedin.com/in/petertlewis/>
- 6 <https://mitpress.mit.edu/books/inversion-factor>
- 7 www.smithsonianmag.com/history/the-world-will-be-wonderful-in-the-year-2000-110060404/
- 8 http://intersticia.com.au/wp-content/uploads/2014/12/Semantic_Technologies_White_Paper.pdf
- 9 <http://knowledgeweb.semanticweb.org/o2i/menu/KWTR-whitepaper-43-final.pdf>
- 10 Poire, Norman P. (2011) The Great Transformation of 2021. <http://www.lulu.com/shop/norman-poire/the-great-transformation-of-2021/paperback/product-14729057.html>
- 11 https://en.wikipedia.org/wiki/History_of_poetry
- 12 McLuhan, M. (1964). *Understanding Media: The Extensions of Man*. http://robynbacken.com/text/nw_research.pdf
- 13 <https://dspace.mit.edu/handle/1721.1/107989>
- 14 <http://www.investopedia.com/features/crashes/>
- 15 <http://www.goldmansachs.com/our-thinking/pages/2015-10-favorite-charts.html>
- 16 <http://www.visualcapitalist.com/chart-5-tech-giants-make-billions/>
- 17 <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3523200/pdf/nihms417135.pdf>
- 18 <http://amos3.aapm.org/abstracts/pdf/77-22628-310436-101934.pdf>
- 19 <http://www.iaea.org/inis/collection/NCLCollectionStore/Public/11/541/11541418.pdf>
- 20 www.nationalgeographic.com/archaeology-and-history/archaeology/mohenjo-daro/
- 21 <https://en.wikipedia.org/wiki/Harappa>
- 22 <https://en.wikipedia.org/wiki/Mehrgarh>
- 23 https://www.ancient.eu/Silk_Road/
- 24 https://www.goodreads.com/book/show/251270.Stories_From_The_Silk_Road
- 25 https://en.wikipedia.org/wiki/Grand_Bazaar,_Istanbul
- 26 <http://driving.ca/bmw/7-series/auto-news/news/how-it-works-bmw-gesture-control>
- 27 <https://www.myo.com/>
- 28 www.ancient.eu/Silk_Road/

29 https://en.wikipedia.org/wiki/United_States_Postal_Service_creed
30 http://data-art.net/resources/history_of_vis.php
31 <http://www.itsookaytobesmart.com/post/13691235184/alleluiaaa-these-are-the-patterns-of-planets;>
[https://johncarloshbaez.wordpress.com/2014/01/04/the-pentagram-of-venus/;](https://johncarloshbaez.wordpress.com/2014/01/04/the-pentagram-of-venus/) [http://blog.recursiveprocess.com/2015/05/19/tracking-venus-and-earth-over-8-years/;](http://blog.recursiveprocess.com/2015/05/19/tracking-venus-and-earth-over-8-years/) [https://www.geogebra.org/material/show/id/67741;](https://www.geogebra.org/material/show/id/67741) <http://freemasonry.bcy.ca/anti-masonry/venus.html>
32 [https://ia902708.us.archive.org/11/items/astronomyexplai00ferggoog/astronomyexplai00ferggoog.pdf;](https://ia902708.us.archive.org/11/items/astronomyexplai00ferggoog/astronomyexplai00ferggoog.pdf)
<http://xxx.lanl.gov/pdf/astro-ph/0305536v1>
33 http://users.math.yale.edu/~bbm3/web_pdfs/encyclopediaBritannica.pdf
34 <http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-183.pdf>
35 https://en.wikipedia.org/wiki/Metcalf%27s_law
36 https://ti.arc.nasa.gov/m/pub-archive/archive/ACO_SGD.pdf
37 <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3280839/pdf/sensors-09-00909.pdf>
38 <https://dspace.mit.edu/handle/1721.1/111021>
39 <http://www.motherjones.com/environment/2012/10/sugar-industry-lies-campaign/>
40 www.pbs.org/newshour/health/sugar-industry-artificially-sweetened-harvard-research
41 <http://www.downloads.imune.net/medicalbooks/Jama%20-%20Sugar%20Industry%20and%20Coronary%20Heart%20Disease%20Research.pdf>
42 <http://www.teethforlife.co.za/images/Pure.%20White%20and%20Deadly%20-%20John%20Yudkin.pdf>
43 <https://jamanetwork.com/journals/jamainternalmedicine/article-abstract/2548255?redirect=true>
44 <https://dspace.mit.edu/handle/1721.1/111021>
45 <http://www-formal.stanford.edu/jmc/history/dartmouth.pdf>
46 <https://www.businesswire.com/news/home/20171026006422/en/Amazon.com-Announces-Quarter-Sales-34-43.7-Billion>
47 <https://www.technologyreview.com/s/608640/inside-the-increasingly-complex-algorithms-that-get-packages-to-your-door/>
48 <https://www.slideshare.net/jgorchs/jose-gorchs-machine-learning-az>
49 <https://www.weforum.org/agenda/authors/bart-kolodziejczyk>
50 www.weforum.org/agenda/2017/05/your-next-peer-review-will-be-done-by-a-machine
51 <https://community.fs.com/blog/tcpip-vs-osi-whats-the-difference-between-the-two-models.html>
52 <https://www.rfc-editor.org/rfc/pdf/rfc2598.txt.pdf>
53 <http://ieeexplore.ieee.org/abstract/document/1203740/>
54 <https://dspace.mit.edu/handle/1721.1/111021>
55 https://www.iro.umontreal.ca/~vincentp/ift3395/lectures/backprop_old.pdf
56 <https://www.axios.com/ai-pioneer-advocates-starting-over-2485537027.html>
57 <https://cs.stanford.edu/~quocle/tutorial1.pdf>
58 <https://www.datasciencecentral.com/profiles/blogs/neural-networks-the-backpropagation-algorithm-in-a-picture>
59 <https://en.wikipedia.org/wiki/Backpropagation>
60 <http://affect-reason-utility.com/1301/4/shannon1948.pdf>
61 http://www.ntuzov.com/Nik_Site/Niks_files/Research/papers/stat_arb/EG_1987.pdf
62 <http://www.tandfonline.com/doi/full/10.1057/palgrave.jors.2602419>
63 <https://www.anodot.com/>
64 [https://arxiv.org/pdf/1710.09829.pdf;](https://arxiv.org/pdf/1710.09829.pdf) <https://openreview.net/pdf?id=HJWLfGWRb>
65 <http://www.acad.bg/ebook/ml/Society%20of%20Mind.pdf>
66 <http://ieeexplore.ieee.org/document/1541948/>
67 [https://en.wikipedia.org/wiki/Docker_\(software\)](https://en.wikipedia.org/wiki/Docker_(software))
68 <https://dspace.mit.edu/handle/1721.1/111021>
69 https://en.wikipedia.org/wiki/Hash_table
70 <https://en.wikipedia.org/wiki/Blockchain>
71 <https://mitpress.mit.edu/books/computing>
72 <http://www.suzanaherculanohezeli.com/lab>
73 <http://www.computerhistory.org/babbage/>
74 http://www.pnas.org/content/109/Supplement_1/10661.full
75 <https://neurology.mhmedical.com/book.aspx?bookID=1049>
76 https://www.asu.edu/courses/pgs461/Reflexes%20Arcs_PGS%20461.pdf
77 <http://en.aup.nl/books/9789089642004-haphazard-reality.html>
78 <https://www.google.com/patents/US312085>
79 <http://jamanetwork.com/journals/jama/article-abstract/302856>
80 <https://docs.google.com/viewer?url=patentimages.storage.googleapis.com/pdfs/US2710649.pdf>
81 <https://docs.google.com/viewer?url=patentimages.storage.googleapis.com/pdfs/US3043625.pdf>
82 <https://www.wired.com/story/mirai-botnet-minecraft-scram-brought-down-the-internet/>
83 http://www.sjgouldessays.com/content/nh_essay_summaries_content/02%20The%20Pandas%20Thumb.pdf
84 <https://www.automationworld.com/article/internet-things-search-critical-mass>
85 Daron Acemoglu and Pascual Restrepo (2017) *Artificial Intelligence, Automation and Work* Economic Consequences of AI and Robotics. Annual Meeting of the American Economic Association (Jan 6, 2018) www.aeaweb.org/conference/2018/preliminary/1476
86 <https://dspace.mit.edu/handle/1721.1/111021>
87 <http://www.universityworldnews.com/article.php?story=20150611130705830>
88 <https://www.nationalgeographic.com/magazine/2017/08/toilet-defecate-outdoors-stunting-sanitation/>
89 <https://ourworldindata.org/economic-growth>
90 https://en.wikipedia.org/wiki/Joseph_Schumpeter
91 http://www.researchgate.net/profile/A_Korotayev/publication/294086817_Kondratieff_Waves_Juglar_-_Kuznets_-_Kondratieff/links/56bda73308aefe60e4c572af/Kondratieff-Waves-Juglar-Kuznets-Kondratieff.pdf
92 <https://www.presidentsusa.net/1928slogan.html>

- 93 http://www.nyc.gov/html/tlc/downloads/pdf/2014_taxicab_fact_book.pdf
- 94 <https://qz.com/1001518>
- 95 <https://doi.org/10.1063/1.1749590>
- 96 https://www.nobelprize.org/nobel_prizes/chemistry/laureates/1951/seaborg-bio.html
- 97 <https://en.wikipedia.org/wiki/Seaborgium>
- 98 <https://dspace.mit.edu/handle/1721.1/56251>
- 99 <http://news.harvard.edu/gazette/story/2017/01/a-breakthrough-in-high-pressure-physics/>
- 100 <http://science.sciencemag.org/content/early/2017/01/25/science.aal1579/tab-figures-data>
- 101 <https://www2.ph.ed.ac.uk/~gja/thermo/HydrogenGI.pdf>
- 102 <https://nature.berkeley.edu/garbelotto/wp-content/uploads/hydro2017a.pdf>
- 103 www.sciencealert.com/the-uk-has-just-switch-on-its-tokamak-nuclear-fusion-reactor
- 104 <http://news.mit.edu/2016/alacator-c-mod-tokamak-nuclear-fusion-world-record-1014>
- 105 <https://www.mckinsey.com/global-themes/employment-and-growth/how-advancing-womens-equality-can-add-12-trillion-to-global-growth>
- 106 <http://www.telegraph.co.uk/sponsored/china-watch/technology/11764541/tech-companies-to-build-digital-silk-road.html>
- 107 https://en.wikipedia.org/wiki/One_Belt_One_Road_Initiative
- 108 <http://ieeexplore.ieee.org/document/477434/>
- 109 <https://seekingalpha.com/article/4125284-ge-fall>
- 110 Ocasio, William and Joseph, John. (2008) Rise and Fall or Transformation? The Evolution of Strategic Planning at the General Electric Company, 1940–2006. Long Range Planning. **41** 248–272 DOI: 10.1016/j.lrp.2008.02.010
- 111 https://www.nytimes.com/2017/06/15/business/ge-jack-welch-immelt.html?_r=0
- 112 <https://finance.yahoo.com/news/general-electric-co-ge-fall-143554997.html>
- 113 <http://www.macrotrends.net/stocks/charts/GE/prices/genl-electric-stock-price-history>
- 114 <https://journals.fe.up.pt/index.php/IJMAI/article/view/190/133>
- 115 https://www.nytimes.com/2017/01/16/world/eight-richest-wealth-oxfam.html?_r=2
- 116 <https://www.oxfamamerica.org/static/media/files/2017-Oxfam-America-Annual-Report-web.pdf>
- 117 Edward W. Felten, Manav Raj and Robert Seamans (2017) *Linking Advances in Artificial Intelligence to Skills, Occupations, and Industries*. Economic Consequences of AI and Robotics. Annual Meeting of the American Economic Association (Jan 6, 2018). <https://www.aeaweb.org/conference/2018/preliminary/1476>
- 118 http://www.pnas.org/content/109/Supplement_1/10661.full.pdf
- 119 <http://www.teethforlife.co.za/images/Pure,%20White%20and%20Deadly%20-%20John%20Yudkin.pdf>
- 120 <http://blogs.plos.org/publichealth/2013/03/28/the-not-so-sweet-politics-of-sugar-consumption/>
- 121 <https://www.leeds.ac.uk/news/article/3723/non-invasive-device-could-end-daily-finger-pricking-for-people-with-diabetes>
- 122 <https://jamanetwork.com/journals/jamainternalmedicine/fullarticle/1819573>
- 123 http://www.who.int/water_sanitation_health/monitoring/jmp2012/fast_facts/en/
- 124 https://en.wikipedia.org/wiki/Jack_Welch
- 125 <http://www.stcatz.ox.ac.uk/node/625>
- 126 <http://www.globaleyeshightnow.org/self-adjusting-glasses/>
- 127 <http://www.vdwoxford.org/about/>
- 128 https://eml.berkeley.edu/~bhall/e124/David90_dynamo.pdf
- 129 <https://pdfs.semanticscholar.org/05d5/971cec0ddb43f19f615ef820b873fa216cde.pdf>
- 130 <https://www.nuffield.ox.ac.uk/economics/history/paper31/a4.pdf>
- 131 <http://www.nber.org/papers/w24001>
- 132 <http://web.mit.edu/dikaiser/www/Kaiser.Weisskopf.pdf>
- 133 https://studies2.hec.fr/jahia/webdav/site/hec/shared/sites/czellarv/acces_anonyme/OringJASA_1989.pdf
- 134 <http://www.bmj.com/content/bmj/360/bmj.j5808.full.pdf>

The Italian language version of the original English article “Connecting Atoms to Bits” was edited and translated by co-authors Marchesi & Marchesi. The content was reduced by the publisher, to fit the allotted space, for the Italian publication.

The original article “Connecting Atoms to Bits” is Chapter 1 in the book “*Haphazard Reality – IoT is a Metaphor*” and it may be downloaded from the MIT Library in a PDF format with the title “IoT is a Metaphor” which may be accessed using this URL <https://dspace.mit.edu/handle/1721.1/111021>

Over the past couple decades, Jeff Wilke (JAW), current CEO of Amazon, found time to comment on a few ideas which I shared with him. Here are three of his emails from 2004, 2011 and 2019. Thank you.

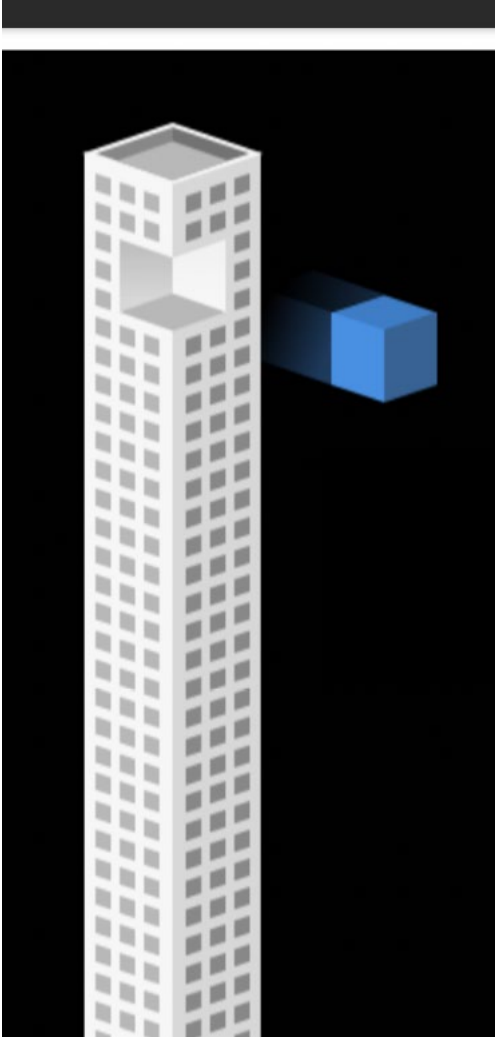
Observations by Jeff Wilke

Look beyond the horizon



L'humanité a besoin de rêveurs

L'humanité a besoin de rêveurs



Shoumen - I finally had some time to complete a thorough reading of your recent paper, "Adapting Decisions, Optimizing Facts and Predicting Figures." It was certainly thought-provoking. As you know, we have been thinking about some of these ideas, but it is nice to see them woven together more completely than I have before. I think the trick for industry will be to fearlessly use these ideas instead of rejecting them out of ignorance, cynicism, or short-sightedness.

JAW

17 June 2004

Jeffrey A. Wilke

Jeffrey A. Wilke
CEO
AMAZON

Jeff Wilke (JAW) has served as CEO Worldwide Consumer since April 2016. From February 2012 to April 2016, Jeff served as Senior Vice President, Consumer Business, from January 2007 until February 2012, he served as Senior Vice President, North American Retail, and from January 2002 until December 2006, he was Senior Vice President, Worldwide Operations. Jeff joined Amazon.com as Vice President and General Manager, Operations in September 1999. He left AlliedSignal (Honeywell) where he was Vice-President and General Manager, Pharmaceutical Fine Chemicals. Jeff spent the preceding six years in a variety of operations and general management assignments in the chemical, polymer, and electronics industries. Jeff did his graduate work (MBA and MS in Chemical Engineering) at MIT's Leaders for Global Operations (formerly Leaders for Manufacturing) program where he focused on Total Quality and Process Improvement techniques. He began his working career writing software and leading software development at Andersen Consulting (now Accenture). Jeff also holds a BSE degree in Chemical Engineering (*summa cum laude*) from Princeton University, NJ.

From: **Wilke, Jeff**
Date: Thu, Jun 2, 2011 at 7:24 PM
Subject: RE: Gibberish for the Soul <?/?>
To: Shoumen Datta <shoumendatta@gmail.com>

Interesting, as always. Certainly much of what you anticipate will happen. Some key questions include: which technologies will become the dominant design and are they already invented? How quickly will consumers' on-hand devices change? (skin vs. six sided mobile device for example) Interesting plug for micro-philanthropy. Always good to think through this as large businesses are important and visible "citizens."

I don't have much criticism; just questions about which technologies on which to bet.

Best,
JAW

Jeff Wilke, CEO, Amazon



RE: Foot traffic, bone density, Whole Foods and your online pharmacy

wilke@amazon.com

To: Shoumen Palit Austin Datta

Monday, January 21, 2019 4:44 PM

Certainly lots of possibilities here. It was my step-father. I've been noodling on the impact of CS on healthcare for, oh, 36 years 😊 Hope all is well.

JAW

From: Shoumen Palit Austin Datta <shoumen@mit.edu>
Sent: Sunday, January 20, 2019 10:13 AM
To: Wilke, Jeff <wilke@amazon.com>
Subject: Foot traffic, bone density, Whole Foods and your online pharmacy

Hi Jeff -

If my memory serves me correctly, I think you told me that your father-in-law was a doctor?

The convergence of your online pharmacy (Taha K-H) and foot traffic at Whole Foods is the future of wellness IoT, which I think you are planning. Think DEXA scanners for bone density of shoppers and recommend adding milk (wellness IoT) with Calcium and Vitamin D to their grocery shopping list. Also, mammograms for \$1.99 anytime and remote sensing for vitals for Amazon GO ??

I wonder if you may be interested ?

Regards and thanks,

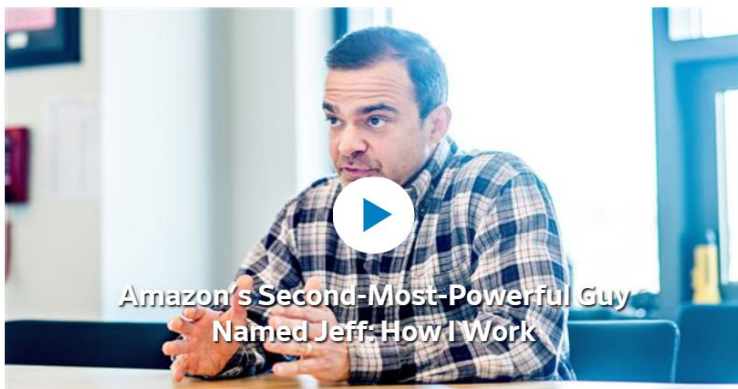
Shoumen

THE WALL STREET JOURNAL.

Subscribe | Sign In

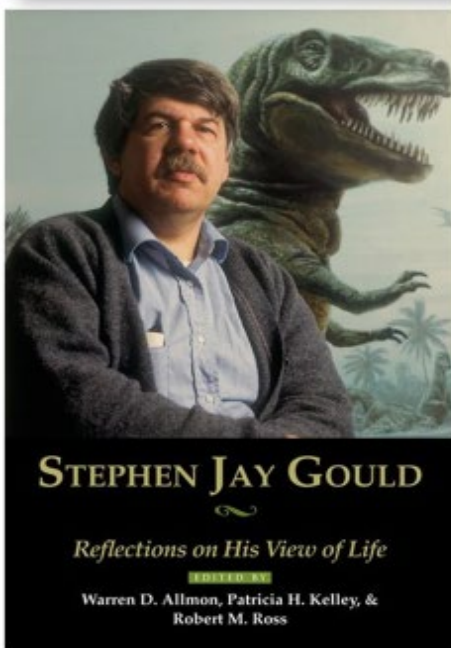
Home World U.S. Politics Economy **Business** Tech Markets Opinion Life & Arts Real Estate WSJ Magazine 🔍

Amazon's head of world-wide consumer talks about integrating Whole Foods—and what it is like to disagree with CEO Jeff Bezos

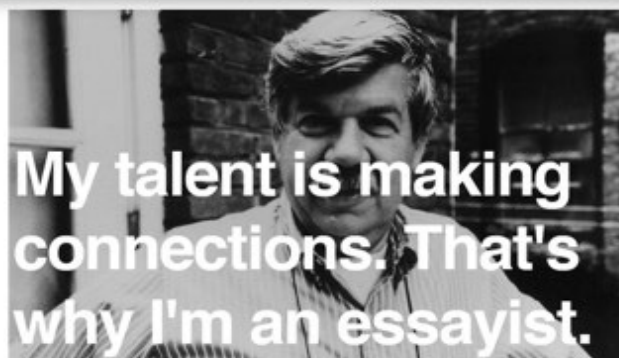


Jeff Wilke, Amazon CEO Worldwide Consumer, talks to The Wall Street Journal about how much sleep he gets each night, the one trait he looks for in a new hire, and what it's like being the second-most-powerful person at Amazon named Jeff. Photo: Wigan Ang for The Wall Street Journal

CONNECT THE DOTS ...



September 10, 1941 – May 20, 2002



If genius has any common denominator, I would propose breadth of interest and the ability to construct fruitful analogies between fields.

in Darwin's Middle Road