

Brief History of the Internet of Things and the Elusive Quest to Measure Performance

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ABSTRACT

Performance is a purveyor for the progress of civilization. Progress is synonymous with improvement, efficiency and a general sense of being or building *better* than before. Quantification of states *before* and *after* are indicators of the *value* of performance, which, if positive, may constitute tangible (physical, procedural) or intangible (moral sentiments, security) contribution toward progress. Social and scientific tools to measure performance are a part of our historical progress. In the past few centuries frameworks and tools have been developed. In the 20th century electrification, automobiles, computation and connectivity accelerated our pace of progress. In the 21st century even more tools and technologies are attempting to measure many different aspects of performance. This brief essay is an attempt to selectively discuss a few of these concepts and how they relate to performance measurements. Here we consider the underlying concept of connectivity and how it has germinated the ideas we refer to as the internet of things (IoT), context awareness and the interaction between percepts, environment, actuators and sensors (PEAS). The complexity of these related domains and their convergence shapes performance. Measurement of isolated parts may offer an incomplete glimpse of performance but that is all which is possible, at present. Measurement of performance is only as good as the granularity of data, the ability to sense the critical nodes of data, the quality of the acquired data and curation of data. We have conjured a tool in this process (measurement of performance) based on connectivity and context awareness between PEAS. This context awareness tool (CAT) is expected to be replete with problems both in principle and in practice. Nevertheless, we address a narrow cross-section of CAT in the context of the agro-ecosystem (AES). We discuss digital architecture for mapping sensors (DAMS) as a tool to explore performance at the nexus of AES, which includes critical domains (food, energy, water, soil) where it is important for civilization to monitor and measure performance, locally and globally.

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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 Gomara¹ suggested (in his book, published in 1552) Panama, Nicaragua, Darien and Tehuantepec as choices for a canal. Not until the 19th century, would the canal building commence under the leadership of Ferdinand Marie Vicomte de Lesseps, a French diplomat credited with “parting the seas” to construct (1859-1869) the first² Suez Canal³. In 1877, buoyed by the engineering feat in Egypt, Ferdinand de Lesseps floated an “old” idea to create an inland sea in Algeria. Flooding the Sahara⁴ garnered attention⁵ which continued⁶ to stir debate⁷ and fueled a fiction⁸ which could be transformed to reality⁹ in the future. Ferdinand de Lesseps commenced the construction of the Panama Canal (circa 1881-1882) but did not live to see the completion of the Panama Canal which had to stop due to deaths from malaria and yellow fever¹⁰. Lesseps died in France (1805-1894) before the US Army Corps of Engineers could resume construction in 1904. The Panama Canal was completed in 1914, more than 400 years after the discovery of the isthmus at Panama.

Grand ideas¹¹ take time to germinate. More importantly, the context for the emergence of the vision may take millennia to evolve. The event of the discovery of the isthmus at Panama by Vasco Núñez de Balboa was not a point of time but a grand culmination of a tapestry of progress of maritime exploration. Such events may have started with human evolution but milestones with scientific evidence points to events which occurred 65,000¹² years ago, 11,000¹³ years ago and 8,000¹⁴ years before the fateful discovery of 1513 which connected seas, lands and people.

Automation captured the human psyche as far back as the 10th century BC. Apocryphal (?) anecdotes suggest¹⁵ that life-size, human-shaped figure created by mechanical engineer Yan Shi was supposedly presented to King Mu of Zhou (1023-957 BC). A programmable automatic flute¹⁶ from the 8th century BC may have inspired the 18th century AD automaton flute player by Jacques de Vaucanson (1709-1782) and first exhibited on February 11, 1738 in Paris (Vaucanson claimed that the idea came to him in a dream). He also created the *Canard Digérateur* or Digesting Duck unveiled on 30 May 1739¹⁷. A century later, Charles Babbage designed (1833) the Difference Engine. In 1840¹⁸, his wife, Ada Lovelace “sketches” an account of the Difference Engine¹⁹ noting that the “Analytical Engine weaves algebraic patterns just as the Jacquard loom weaves flowers and leaves.” In another century automation arrives through Asimov’s²⁰ fictional automobile *Sally*²¹ in 1953. A journey that began in the 10th century BC and accelerated in the 20th century AD from fiction (*Sally*) to fact (autonomous vehicles on roads).

Exploration and automation stretching to computing represents an agile fabric of innumerable systems, events and instances whose movement gained momentum²² in the USA in the post-Sputnik era. Norbert Wiener²³, Claude Shannon²⁴ and Joseph Licklider²⁵ represent pillars of thought²⁶ who paved the path for the *industrial revolution* to enter the *systems age* via the Internet²⁷ and its veritable tsunami of data and information. The concept of the internet of things (IoT) is a part of this fabric of connectivity.

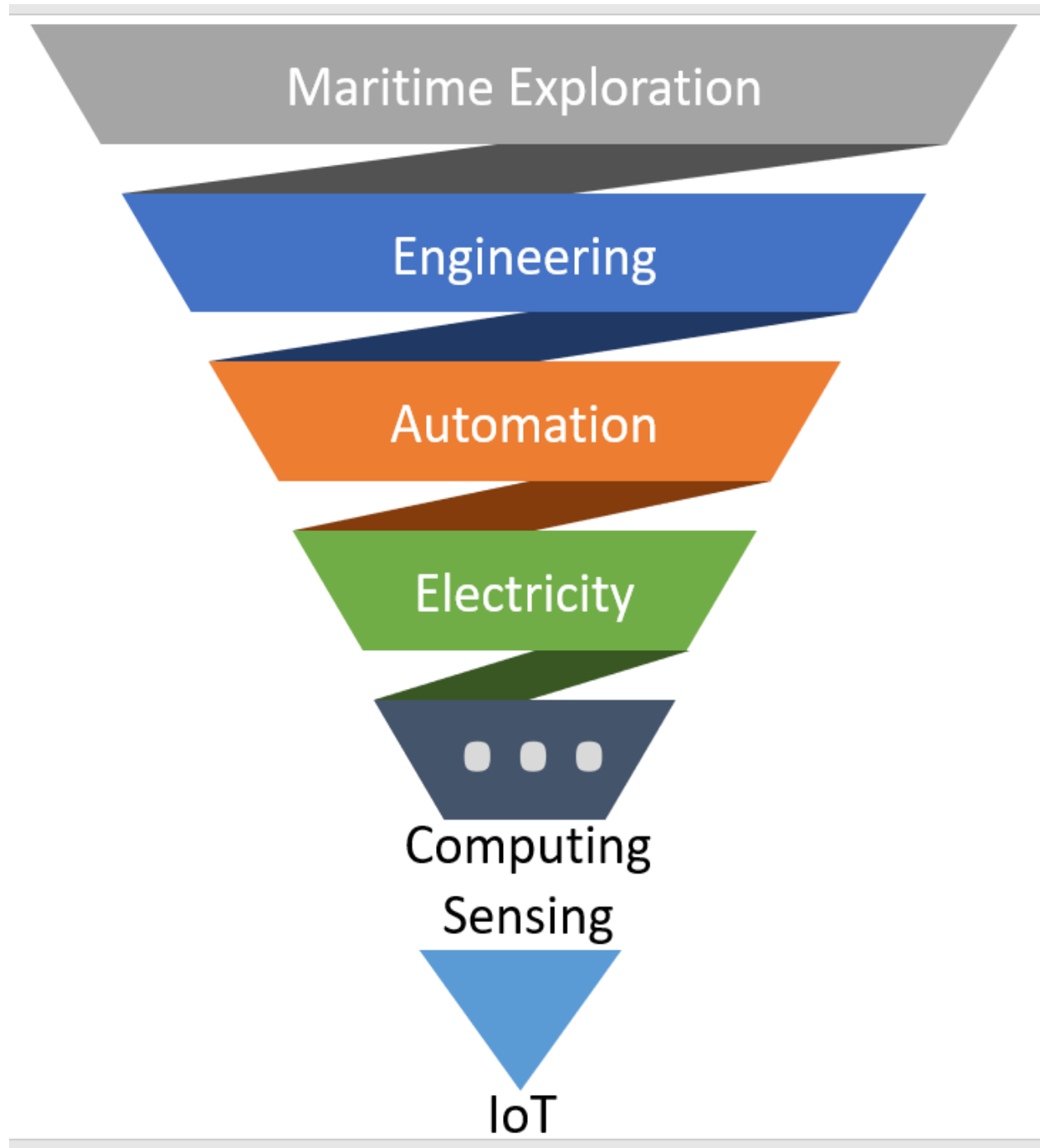


Figure 1: The fragment of the tsunami that we refer to as the concept of the internet of things²⁸ (IoT) is a design metaphor where objects, processes and decisions may be connected between domains, people and networks through the medium of the internet. IoT is neither a technology nor a tool. IoT is a blanket of ideas suggesting how to connect with entities²⁹ that generate data (perhaps acquired from sensors) and use the data to inform (linear) systems or humans who may use the information to actuate systems, change parameters or supply knowledge stores to enrich logic, rules and reasoning tools.

Connectivity is a natural law because every atom is connected to every other atom through the forces of gravity (graviton³⁰). It is difficult to decide whether physics mimicked biology or if biology mimicked physics with respect to connectivity. Ramón y Cajal's drawing of neurons³¹ (see Figure 2) connected in layers is a striking example of connectivity validating Charles Babbage's design (artifact) of *The Difference Engine* and Ada Lovelace's description of the same (*Analytical Engine*) as "patterns" analogous to "flowers and leaves" woven by Jacquard looms. In the 20th century artifacts of connectivity may include the network of highways³² and the information superhighway³³ which evolved from NII³⁴ (National Information Infrastructure) which was a term coined by Robert Kahn³⁵ in the mid 1980's. Information Superhighway has grown due to the internet. Dining table discussions about the internet occasionally may include the parallel that the 7-layers of the OSI model and 5-layers of the TC/IP³⁶ protocol may have been inspired by Ramón y Cajal's sketch of the neural organization of the human retina (Figure 3). The "impression" is connected to Vinton Cerf's undergraduate years at Stanford³⁷.

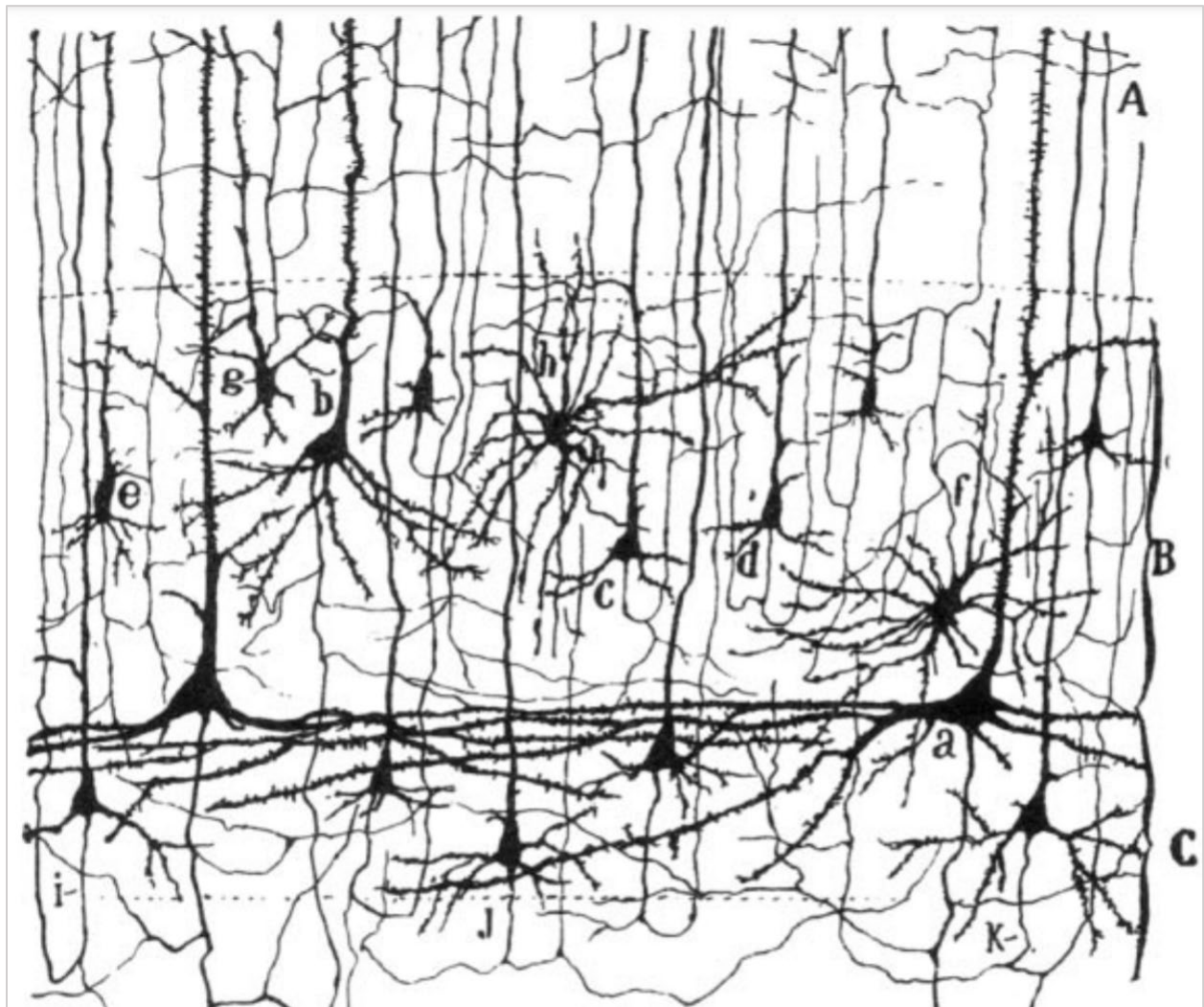


Figure 2: Ramón y Cajal's drawing³⁸ of neurons in layers 5–7 of the 15-day-old human infant visual cortex, using the Golgi method.

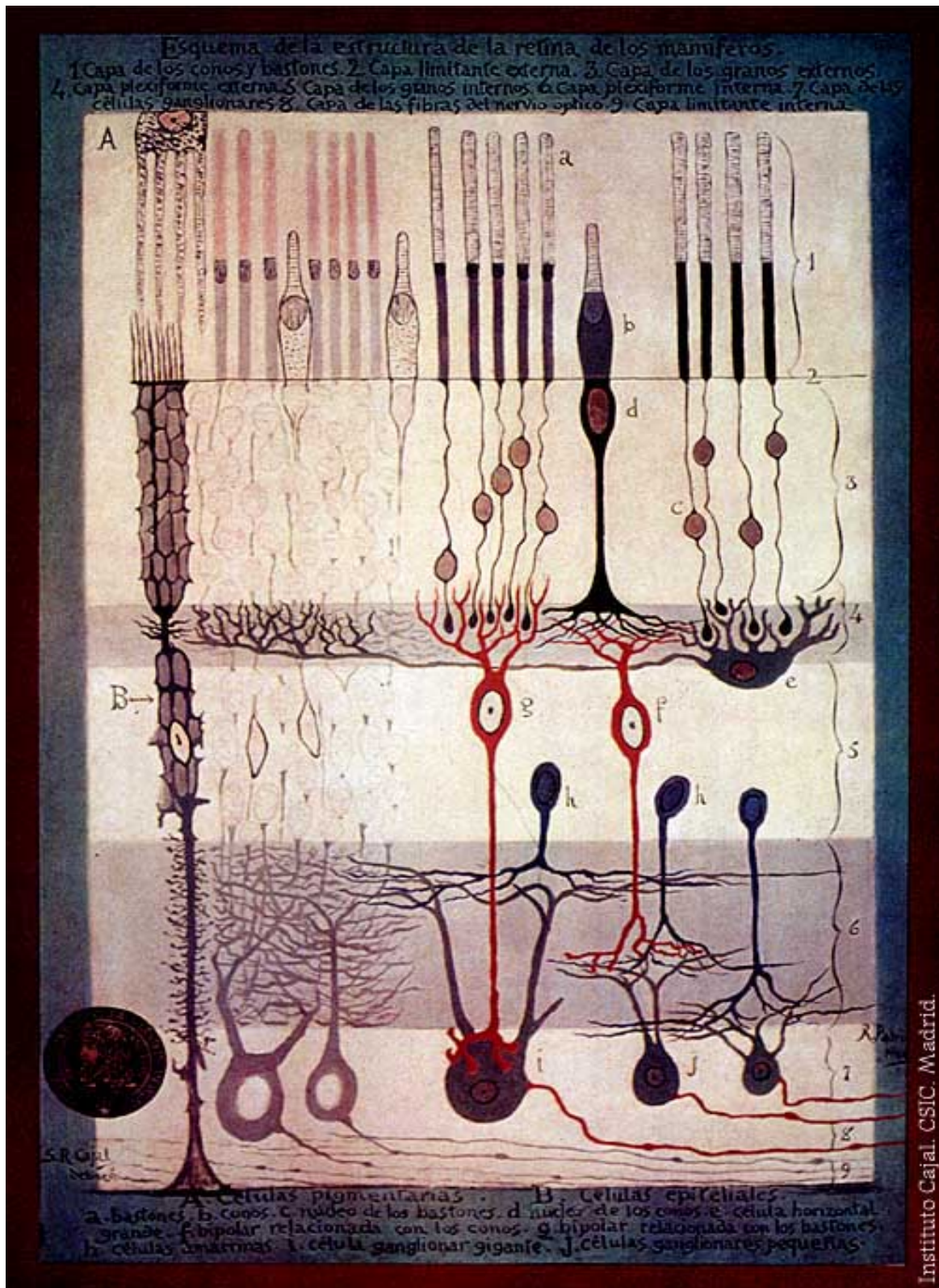


Figure 3: Neurons in the mammalian retina³⁹ by Ramón y Cajal (1900) may have inspired graph theory and knowledge graphs⁴⁰, as examples of biomimicry in computation and bio-inspired technologies⁴¹.

Another artifact of connectivity is the subset of digital connectivity which evolved from the advent of telecommunications⁴² and exploded with the implementation of the internet where data was conceived as packets⁴³ with *delivery addresses*. Instantly, access to data was *as easy as a packet which can be delivered to any digital address, anytime, anywhere via the internet*. Suddenly data from sensors⁴⁴ and remote sensing and imaging tools (oil and gas pipelines⁴⁵, leaves⁴⁶, tree⁴⁷ canopy^{48,49}, radiation⁵⁰) made it virtually possible to SEE or *sense everything everywhere* (paint-based computation⁵¹, sensors in fabrics⁵²) through the medium of information technologies using packets to transmit data (*data delivery as a service, data as a service*).

Hence, evolved the principle of ubiquitous⁵³ computing⁵⁴ which in principle may be in real time. However, it stumbled in practice due to the cost⁵⁵ of computation⁵⁶. Vinton Cerf's "I P on Everything"⁵⁷ (*I pee on everything*) was the witty clarion call for embedding the IPv6⁵⁸ standard⁵⁹ in all things⁶⁰ to enable "bit dribbling" between "digital" objects. These ideas were flanked by "tangible bits"⁶¹ from Hiroshi Ishi⁶² and the "atoms to bits" paradigm⁶³ of "*Internet 0*" from Raffi Krikorian⁶⁴ and Neil Gershenfeld⁶⁵ followed by the origins⁶⁶ of internet of things⁶⁷ by Sanjay Sarma^{68, 69} and others⁷⁰. The borborygmi of radio frequency identification (RFID) and standardization of the electronic product code (EPC⁷¹) shifted the thinking from stationary goods and products with static bar codes to dynamic digital objects which can be uniquely identified in any process or supply chain and tracked and traced digitally between any number of transactions and globally routed to any recipient or system as *data packets*.

Project Oxygen⁷² offered extraordinary insight into the art of the possible⁷³ and represented a consilience and confluence⁷⁴ of ideas but it was cost-prohibitive for real world applications, circa 2000. With decreasing cost of computation⁷⁵, memory⁷⁶, data storage⁷⁷ and transmission⁷⁸, these streams, turned into raging rivers. The convergence of these tools with initial thoughts about the networked physical world⁷⁹ were far more than the sum of the parts. It ignited the concept IoT⁸⁰ to transform connectivity as a foundation germane for all things, systems, enterprises, domains to be "*always-on*" in an "*asleep but aware*" interactive mode with each other to optimize outcome and promote performance.

The anastomosis⁸¹ of IoT with cyberphysical systems⁸² (CPS⁸³) has penetrated almost every field from asteroids to zeolites and engulfed them within the new⁸⁴ laissez-faire world of DIKW⁸⁵ hierarchy. The mobile smartphone represents the grand conduit for the aggregated dissemination of distributed facets emanating from the DIKW pyramid. The mobile platform appears to be the global choice to access and implement all and any service which is possible, via the smartphone, where this ubiquitous mobile device serves as the platform for information⁸⁶ arbitrage. With ease of access to mobile connectivity, the quantum leap of expectation from connectivity has catalyzed a paradigm shift. Users desire that their *experience*⁸⁷ must be oblivious of the underlying technology. Customers demand user-friendly platforms to access *actionable* information in real time at the point of use, faster and faster, cheaper⁸⁸ and better.

The paradox of connecting our kitchens, cars and bodies⁸⁹ to a smartphone and the cloud⁹⁰ is the new paradigm for ubiquitous connectivity. The service is of value only if the outcome delivers improved performance.

PERFORMANCE - PEAS

The shift of focus from data quality to quality of *actionable* information is one metric to measure improvement in performance. Plethora of systems and vast number of tools are available to address performance. The framework referred to as PEAS⁹¹ is a mnemonic borrowed from Agent-based systems and addresses performance through convergence of percepts (P), environment (E), actuators (A), and sensors (S). PEAS is a platform for a systems-level, collective, broad spectrum analysis of data from multiple nodes in operational domains, sensors and cyber-physical systems (CPS⁹²). Dissection and synthesis of (curated) data using application/domain specific logic, rules and reasoning tools (for example, machine⁹³ learning) may generate information to inform decisions and/or decision support systems (DSS). The latter viewed as “actuation” may be partially or fully automated or trigger humans to act on data and information, if the data generated actionable information and if information was present in the data (raw data).

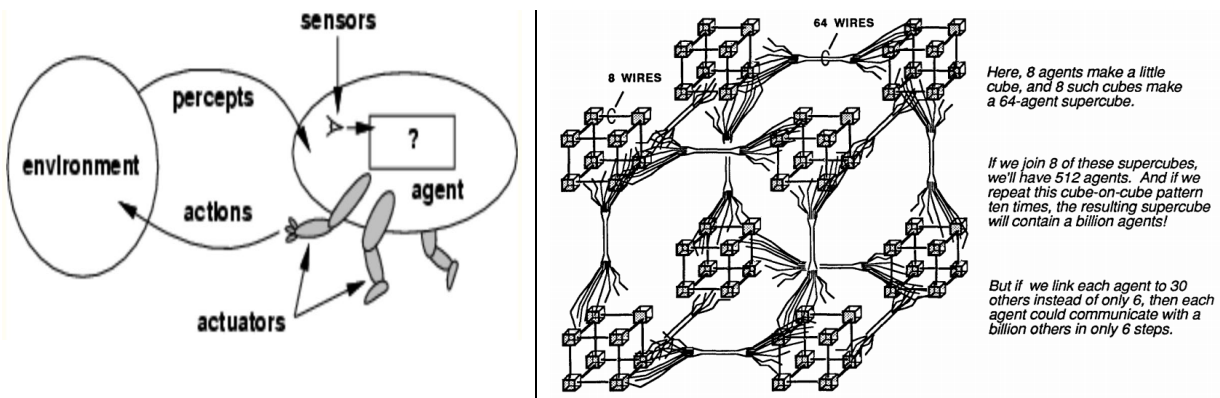


Figure 4: Illustration (right) from *Society of Mind* by Minsky⁹⁴ (page 315) shows the *cube-on-cube* concept where each cube is a software Agent. In application specific performance optimization, data and contribution from each sub-component of PEAS may be viewed as individual cubes. It may represent a digital proxy⁹⁵ of the physical entity or serve as a container or receptacle to acquire data from specific nodes (comprised of different data sources, for example sensors, RFID, PLC systems). Connectivity between cubes are central to optimize performance by prioritizing factors which influences the outcome. In one regard, *cube-on-cube* may be a traditional linear optimization problem common in operations research. But, *cube-on-cube* Agents are not a series of static, rigid and inflexible PDE or ODE. The Agent system is dynamic, flexible and non-linear with respect to feedback and configuration of data cubes (which could be left “empty” if the data is not relevant to that instance of optimization). In an equation based model (EBM) optimization may become error prone if variables lack data or are asynchronously eliminated with changes in configuration, for example, UAV (drone) collecting soil sensor data from a field to estimate soil nitrogen, phosphorous and pH to inform users or fertilizer distribution systems. The *cube-on-cube* system is scalable (10 to 10,000 acre field). Each Agent (cube) may be linked to 30 or 300 cubes rather than six cubes (shown in cartoon). Composability enables agile systems to adjust, adapt and secure⁹⁶ diverse applications to improve performance for linear and non-linear systems.

The complexity of fine-tuning performance⁹⁷ improvements using parameters relevant⁹⁸ to “global goals” in a dynamic environment⁹⁹ must consider a range of activation/inhibition¹⁰⁰ actions between parameters. Linear push-pull systems may use one or more combinations of numeric values, weights, rates, flows and/or ranges. The situation may become unwieldy. State space¹⁰¹ expansion may paralyze traditional optimization routines. Adaptive autonomous¹⁰² agents (for example, agents in the *cube-on-cube* system) may better serve non-linear optimizations and propose *good enough* outcomes (for that scenario) using composable elements to adapt to applications and/or domains. PEAS evolved from these ideas as a “fluid” tool in a portfolio of systemic solutions. However, in many routine instances, point¹⁰³ solutions with a limited set of variables may provide sufficient information to be valuable.

Improving performance by capitalizing on connectivity is the essence of integration of the principles of IoT with the practice of PEAS. But one must hasten to add that it is not a general solution. Perhaps 80% of scenarios may be better served with point solutions or point solutions plus a mild dose of machine learning (ML) to optimize data-informed decision as a service¹⁰⁴ (DIDAS). In higher order DIDAS we move to the next layer of linear logic, rules and reasoning tools (LRRT or artificial reasoning tools, ART) to go beyond sense, analyze, respond to trigger SARA¹⁰⁵ (Sense, Analyze, Respond, Actuate).

In complex optimization scenarios the combination of IoT plus PEAS may reveal its promise by its ability to address non-linear systems. The potential vastness¹⁰⁶ of the IoT connectivity fabric may feed data from a wide selection of percepts, signals from the environment and sensors (remote monitoring). By combining and analyzing data using a PEAS model, the data-informed decision (DIDAS) may not only auto-actuate a few instances but could deploy swarm¹⁰⁷ actuation (SARA activation of wastewater systems in a county or a million acre farm). Insufficient trust in DIDAS may limit auto-actuation but it may inform humans in the loop who may decide when (if) to deliver the actuation command.

The challenges of cybersecurity¹⁰⁸ must be considered for PEAS knowledge stores, knowledge networks and knowledge graph¹⁰⁹ databases. The risk in swarm complexity¹¹⁰ (applying¹¹¹ the concept¹¹² of swarm intelligence) is the trust in the task of building dynamic and composable application-specific and/or domain-specific PEAS models which are replete with logic, rules and reasoning tools (LRRT) which are essentially linear systems. Unleashing swarm actuation of water irrigation on a million acre farmland by activating sprinklers may be unnecessary if the PEAS model was updated with data and information about forthcoming rainfall.

Is the PEAS system capable of discovery? Discovered data and information must be relevant, current and updated. PEAS is expected to discover and connect, often in an *ad hoc*¹¹³ manner, to a spectrum of percepts [P], environmental [E] signals and sensors [S] which feeds data to help PEAS, as a system, to perform its function. PEAS may not be “hard” wired to these data sources. Security and discovery is pivotal to “reasoning¹¹⁴, searching and finding” the correct percepts, the environment and the sensors which the PEAS system needs for case specific¹¹⁵ instances, queries, applications, domains.

Connectivity to *deliver discovered data* to data fusion or LRRT engines (for example, data from sensor search engines) will depend on systems interoperability, systems integration and systems synergy. Therein lies a greater challenge for standards based operations in a world with highly unstructured data. One solution proposed¹¹⁶ circa 1972, is the concept of knowledge graphs (KG) which took 40 years¹¹⁷ to enter the technical parlance with respect to connectivity of data and relationships. Importance of KG appears to be over-shadowed by the irrational exuberance due to the hype of artificial intelligence (AI).

Analytical frameworks in PEAS must address the marketing bluster about AI. In one example, non-scientists and publicity people define artificial intelligence erroneously¹¹⁸ as simulation of human intelligence by computers. It may remind the scientific community of another misadventure in naming, the fact that statistical mechanics¹¹⁹ is a field in physics that is incorrectly named.

Today, intelligent machines are catch-all sound-bites without teeth because it is based on unfounded optimism which ignores problems even within the narrow confines of IoT and PEAS systems. Just underneath the IoT umbrella lies CPS where time-synchronized hardware-software integration is a hallmark¹²⁰ yet to be achieved. CPS, in turn, is the foundation of embedded¹²¹ systems. Time guarantee (concurrency) in embedded systems plays a critical role but we are far from its practice¹²² even though it is recognized as essential in the CPS framework¹²³.

The future¹²⁴ of the IoT roadmap¹²⁵ is littered with problems from many sources which may influence¹²⁶ the paradigm of ubiquitous connectivity. Leaps in computation and telecommunications catapulted the notion of ubiquitous connectivity to the cacophony of digital transformation which incorporates innovation from wireless systems¹²⁷ and broadband communication¹²⁸ to better enable time critical¹²⁹ operations using 5G. The latter, if combined with 8K¹³⁰ visualization, may catalyze robotic surgery. It is true real benefits from remote surgical procedures such as laparoscopic cholecystectomy, appendicitis and phacoemulsification (cataracts) far outweigh the risks on the path to progress. CPS, IoT, PEAS and other systems will continue to pose hard and harder problems, which we view as opportunities.

Discovery tools for auto-detection of attributes and characteristics between entities, Agents, models are components of the digital-by-design metaphor. Research in connectivity must develop digital semantic sensors to sense *what needs sensing*. The notion of “sensing the need to sense” moves beyond semantic detection and introduces cognition where cognitive supervisors¹³¹ monitor the semantics and epistemology¹³² of processes which calls for convergence of knowledge graphs and semantic¹³³ tools.

Hence, many PEAS must connect as an ecosystem (PEAS in a pod). The rate limiting steps are cryptic within the functional orchestration of these alliances and systems which are inextricably linked and must be guided by the practice of connectivity. In order to deliver value, connectivity must span a broad spectrum of dynamic ecosystems yet must be *domain*¹³⁴ *specific*. Implementation of connectivity must be protocol-agnostic, location agnostic and time sensitive (maximize transmission, minimize steps), with respect to sense and response, between the core system and the edge user. At the dawn of the 21st Century, connectivity came of age through the Internet.

The internet was viewed as a storage platform¹³⁵, copying machine¹³⁶ and economists¹³⁷ explored its ability to reduce transaction cost (for example, education¹³⁸, communication, replication, transportation, tracking, verification). Democratization of information was thought of as a driver for global economic growth, development and intangible benefits due to digital dark matter¹³⁹. These advances may be traced to a single seminal work in the 19th century¹⁴⁰ (and its follow up¹⁴¹) and a single seminal work in the 20th century¹⁴² (and its follow up¹⁴³) which revolutionized computing, search, discovery and helped not only in creating software, robotics, IoT, CPS, and PEAS but opened up new vistas, such as networking¹⁴⁴ nano-things¹⁴⁵ by building on the molecular connectivity between atoms and bits¹⁴⁶ which espouses the idea that any “thing” (atom) can be connected to its data, that is, the data of things, in terms of bits.

BITS of DATA

In an oversimplified view, models that facilitate data cross-pollination are at the heart of performance. One conceptual model is given by PEAS. Modeling PEAS versus implementing PEAS are two different worlds where interdisciplinary actions are necessary to meaningfully translate science, engineering and data to real life solutions and decisions. The rationale of data cross-pollination salient to appreciating the significance of the cleavage between data, meaningful data and contextual value of information, suggests that we avoid the use of the phrase “data driven” and adopt “data informed” to trigger a reasonable change of perspective acknowledging that all data is not meaningful. Data in different contexts and semantic scenarios may assume different meanings. Data in a linear system have a different value than in a non-linear system where the feedback loop could alter the significance of data.

Can data guide our decision-making process if it is devoid of experience, intuition and lacks prior knowledge? Data may not *drive* decisions because we do not know how to meaningfully embed experience or encapsulate knowledge¹⁴⁷ from graphical models. Upgrading from DIDAS (data informed decision as a service) to KIDS (knowledge informed decision as a service) may remain aspirational. Data *informs* the process but other data (data fusion, feedback) and humans-in-the-loop may re-structure, re-curate, re-configure and modify the data in order to use it in a manner that fits the purpose to deliver an anticipated outcome. This iterative approach has left room for bias which could color the outcome. By acknowledging the imperfection of the system, where data may be only one input, the collective outcome may be best described simply as *data informed*.

Thus, any attempt to discuss data will lack veracity. Comments may be made about the tools with which data may be analyzed. Depending on the application, data tool kits may include feature selection and feature engineering in data preparation and presentation to analytical processes. With increasing data volume, automated feature extraction and automated knowledge graph discovery may reveal novel or new dimensions in data analytics, if the quality of data and curation of data assures that anomalies¹⁴⁸ are removed and data represents more meaningful signals¹⁴⁹, less noise.

Machine learning (ML) may become routine for analyses in domains where probabilistic induction is applicable. If the process is iterative (Markov chain) then probabilistic analyses (Bayesian tools) may be uninformative¹⁵⁰. Hence, ML may be valuable if based on rigor, reason and humility rather than hype and hubris. Point solutions and simple PEAS cases are linear instances where ML, if judiciously applied, may be beneficial. In non-linear instances Bayesian inferences relating past and current probabilities with future predictions may be worthless¹⁵¹.

The inability of machine learning algorithms to be useful in non-linear instances reinforces that AI is a misnomer. ML is often viewed *under the bonnet* of AI. There is no canonical ‘intelligence’ in ‘artificial intelligence’ or any possibility that intelligence can be distilled in the form of knowledge representation¹⁵² using conceptual graphs¹⁵³, discrete symbols and logic in computational modules, which are all linear, for practical purposes. That does not make graphs useless but useful when relevant.

Intelligence builds on non-linear feedback (loops which affirm learning, behavior, experiences) with cyclic dependencies which can neither be replicated by graphical models nor fixed¹⁵⁴ with statistics or rescued by statistical dependencies to generate Bayesian intuition, which is the mainstay in ML and DL (deep learning using neural networks). Deep neural networks (DNN) relying on Bayesian inferences are clogged with artifacts of linearities and entrenched in bias so much so that it may not offer trustworthy or reliable¹⁵⁵ answers of value (numbers are not answers). These linear connections are devoid of memory that separates biological intelligence from machines or prediction engines. The latter lacks memory and hence unsuitable and incapable of predicting complex behavior.

The example of the usefulness of ant-based¹⁵⁶ algorithms are not about “intelligence” but rather “swarm” activity representing a *cross-section* of animal behavior in a specific circumstance. Capturing the essence of the latter proved to be useful in routing protocols but it does not warrant the conclusion that we have captured intelligence. We transformed biomimicry¹⁵⁷ to our advantage in decision systems.

AI was erroneously named due to historical accidents and may continue to conjure images in the social conscience as a marketing blitz in historical context. A fitting analogy may be the impressions carried over from movies, for example, *A.I. - The Movie*¹⁵⁸ or *The Boston Strangler*¹⁵⁹, a movie¹⁶⁰.

At best, rehabilitated AI may be referred to as artificial reasoning tools (ART) but there is nothing “artificial” because logic and rules in *any analytics* approach or analytical technique are programmed by humans. To be mathematically correct, *analysis* is a term applied to calculus and all higher mathematics that uses calculus. Logic, rules and reasoning tools (LRRT) devoid of calculus may be hand-waving. Machine “learning” also takes “artistic” license by creating the illusion that machines are *learning*, when in reality machines are likely to be linear systems, applying stored logic and rules, programmed by humans, to data and information from infrastructures created by humans.

Neither ML nor AI creates anything new or novel but applies programmed logic and rules in all possible and “allowed” permutations and combinations to data. There aren’t any “magic inside the black box” but “machinery” which *supplies correlations using correspondence rules that govern the function*. The “machinery” is the **relation** between variables determined by functions. By definition, function is a relation between two variables which maps to values given by domain, range, Cartesian coordinates (x,y) or polar coordinates (r,θ). Values or sets of values and limits are deduced, derived, formulated and programmed by humans (algorithms) at the heart of the engine in any *learning machinery*.

Pedantically speaking “LRRT” are *machinery applications* of mostly linear logic (LO), rules and reasoning (RE) tools (TO) and techniques. LRRT or LORETO are not glib and smug acronyms or labels but conveys the unvarnished concept in an effort to reduce bias and increase credibility with respect to what is deliverable. R2T2 (Rules, Reasoning, Tools, Techniques) may be a nostalgic¹⁶¹ option but is it sufficient for a society besotted with the term AI irrespective of the insanity of artificial intelligence?

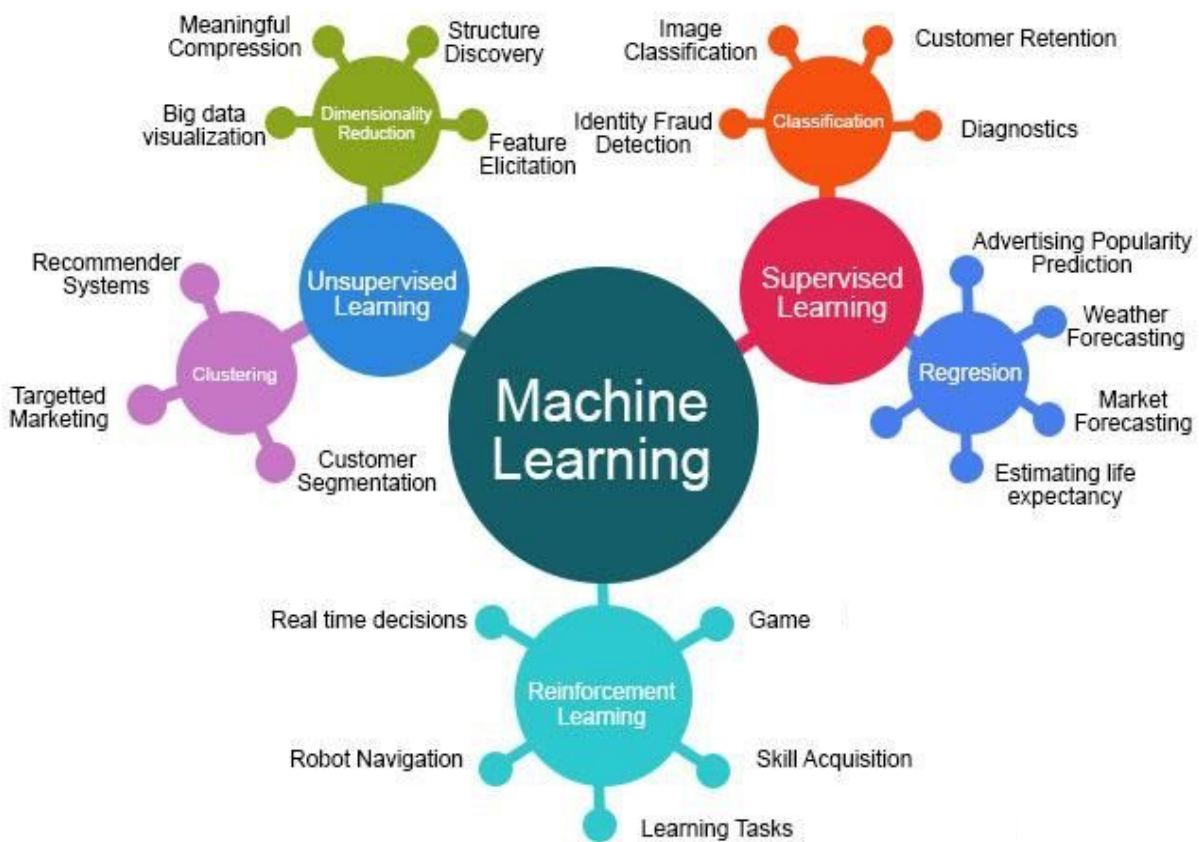


Figure 5: Machine learning algorithms may convey illusions of analytical grandeur but *learning* simply refers to a mathematically astute ensemble of logic, rules and reasoning tools (LRRT). There are no magic outcomes from feeding or applying data to any ML tool without significant *a priori* preparation.

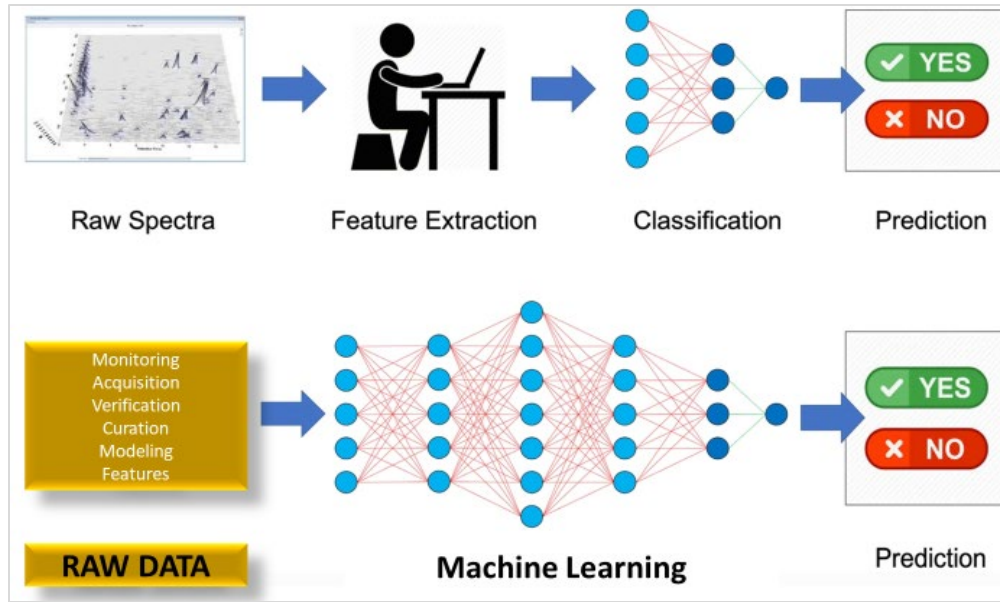


Figure 6: Using data to predict¹⁶² or inform a decision does not abide by standard operating procedures.

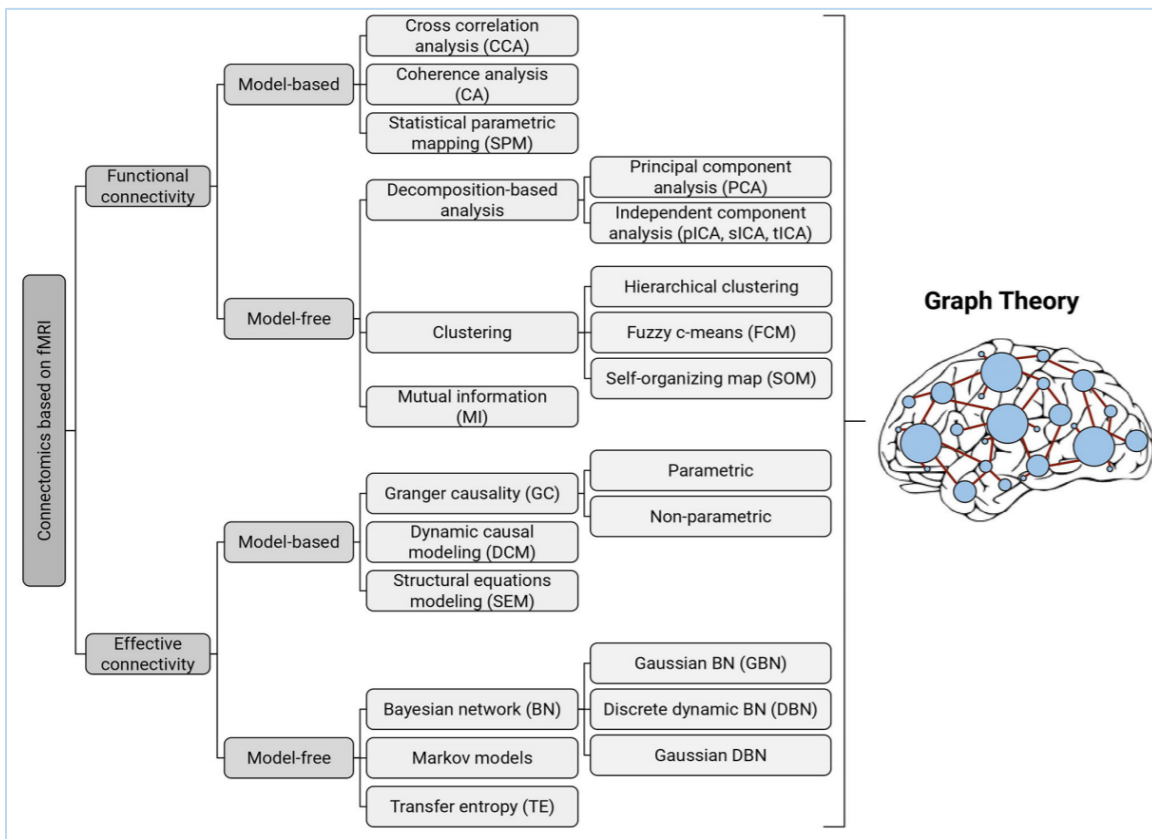


Figure 7: Encapsulating correspondences and connectivity between data using graph theory is useful but non-linearity remains unresolved even if the methods (left) can be represented by graphs. Extrapolating nodes as regions in the brain and edges as connections is just a sketch. Drawing inferences about brain function from fMRI data may be comparable to using Lomekwi stone tools¹⁶³ to build MOSE¹⁶⁴.

FROM BITS of DATA TO INFORMATION (LINEAR) AND KNOWLEDGE (NON-LINEAR)

One of the attributes of software Agent-based systems is the ability to share information without exposing data. Inference about sender's data may be deduced by the recipient from the information but the raw data remains unexposed (hence, its applications in cybersecurity, Datta, 2016). A very simplified example which is often provided to undergraduate students when introducing hidden Markov models¹⁶⁵ (HMM) in steganography¹⁶⁶ or steganalysis¹⁶⁷ or other applications of Markov chains¹⁶⁸ often involves a dynamic duo¹⁶⁹ (Alice¹⁷⁰ and Bob¹⁷¹, Bonnie and Clyde¹⁷²) featured extensively¹⁷³ in game¹⁷⁴ theory¹⁷⁵ and decision¹⁷⁶ science¹⁷⁷.

In this example, Bob (who lives in Boston, Massachusetts) engages in activities based on whether it is “sunny” or “rainy” but refuses to share with Alice (in Alice Springs, Australia's geographic center) the actual weather. From their conversation, Alice gets to know whether Bob was gardening or cleaning. Alice deduces the weather in Boston when Bob states that he is gardening (deduction: “sunny”) or he is cleaning (deduction: “rainy”). Albeit oversimplified, this is an example of hidden Markov model where the weather data is “hidden” but the shared information contain sufficient clues to reconstruct the data.

These linear connections abstracted from information and/or behavior are amenable to linear (acyclic) techniques generally used in artificial neural networks (ANN) devoid of any “intelligence” in this context. Abstraction of the behavior of an ant foraging for food versus its behavior after acquisition of food offers the opportunity to track pheromone¹⁷⁸ deposits. Summation of the pheromone deposits over a *swarm* of ants reveal patterns: the shortest distance. Over the past couple decades, tools based on ant¹⁷⁹ algorithms¹⁸⁰ are staple in network¹⁸¹ routing¹⁸², load balancing in software systems¹⁸³, graph¹⁸⁴ networks and optimization applications including directed acyclic graphs¹⁸⁵ (DAG) and beyond¹⁸⁶.

Non-linearity in DAG is emphasized by the fact that a directed acyclic graph (DAG) is a directed graph that has no cycles but sequences, organized in a topological order. This is the core of computation. Human programming makes computation adept in handling information where sequence and linearity rules. Information technologies are bereft of cyclic dependencies but knowledge and intelligence depend on cyclic dependencies. Humans are still incapable of encapsulating knowledge. Information-informed decision as a service is the best possible higher level outcome following data-informed decision as a service (DIDAS). If methods are expressed in terms of graphs (Figure 7) and if graphs with edges and vertices are linear, then knowledge graphs and artifacts claiming *knowledge* as a tool are *misnomers*.

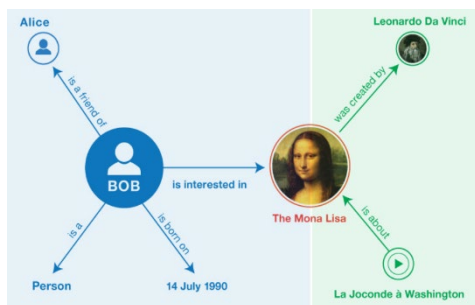


Figure 8: Traditional knowledge graphs (KG) are encoded as *<subject, predicate, object>* RDF¹⁸⁷ triples (cartoon, left). RDF Graphs¹⁸⁸ and Labelled Property Graphs¹⁸⁹ (LPG) are directed graphs (linear) but allows instantiating each fact by attaching auxiliary key-value (relation-entity) pairs to edges. Edges representing relationships can have properties (useful to provide metadata & semantics to relationships of nodes).

Abstraction in the *cube-on-cube* model fits linear and sequential data flow. The PEAS paradigm offers room for cyclic dependencies (see Figure 4) as an embedded natural concept where percepts and environments are expected to interact. Actuation changes “state” of things which will modify percepts and environments. Transforming information from PEAS to PEAS-derived knowledge may be difficult to accomplish using tools built with and biased toward linear systems. Non-linear cyclic dependencies in PEAS may be modeled using Agents, where each Agent is a specific node or sub-node which re-informs itself and updates its parameters with each relevant event/cycle that occurs and re-occurs (Figure 10) in its environment and ecosystem. Non-linearity of PEAS and cyclic dependencies fit Agent-based systems.

There is room for doubt whether even advanced software Agent-based systems can represent knowledge but it may be possible to accomplish a rudimentary state of knowledge possessed by the lowest members of the animal kingdom (for example, ants). The speed of travel on the information superhighway bears little, if any, on the dimensions of knowledge. Solving Newton’s equations of motion for 3 bodies under their own gravitational force, 100 million times faster¹⁹⁰ than a state-of-the-art solver versus deep artificial neural network (DANN) is a remarkable display of brilliant engineering but perhaps not an intelligent operation. It has the computational brawn but doesn’t it lack the brain?

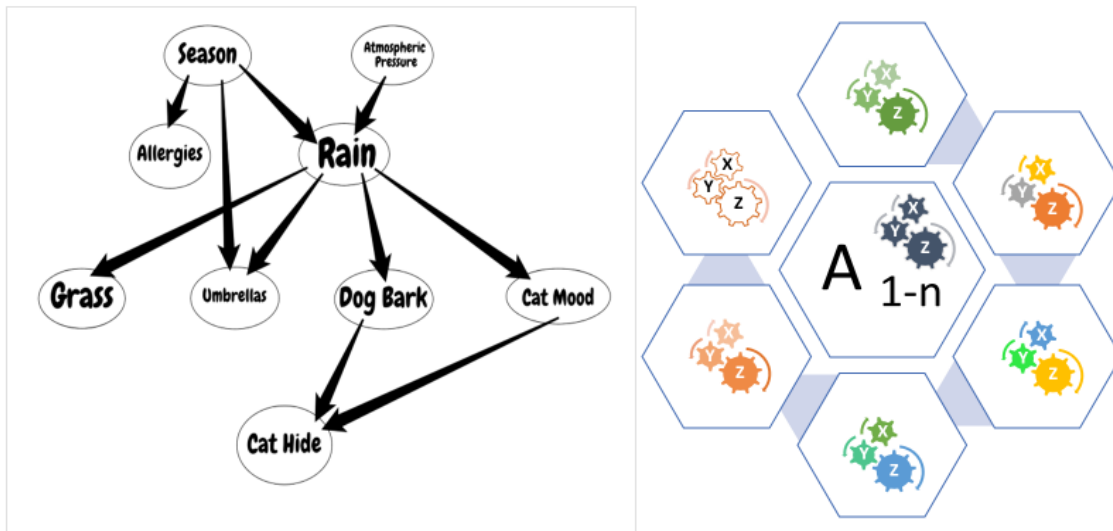


Figure 9: Linearity (acyclic) of Information (left) vs Non-linearity (cyclic) of Knowledge (right). At the heart of graphs are models, for example probabilistic graphical models (Bayesian Belief Networks¹⁹¹) representing conditional dependencies between random variables through directed acyclic graph (left). Information as sequence of events is the ground zero theme irrespective of the sophistication of tools or techniques. The outcome may be immensely beneficial and really valuable as a service for society even if it is devoid of true knowledge or what may be justified as intelligence. In the non-linear (right) world of knowledge, as a *prelude* to intelligence, information is acted on by other pieces of information, either continuously or asynchronously, in a cyclic manner (x, y, z gears and connected hexagons) over several different layers (A_1 through A_n in cartoon) but all parameters (hexagons) may not be always relevant.

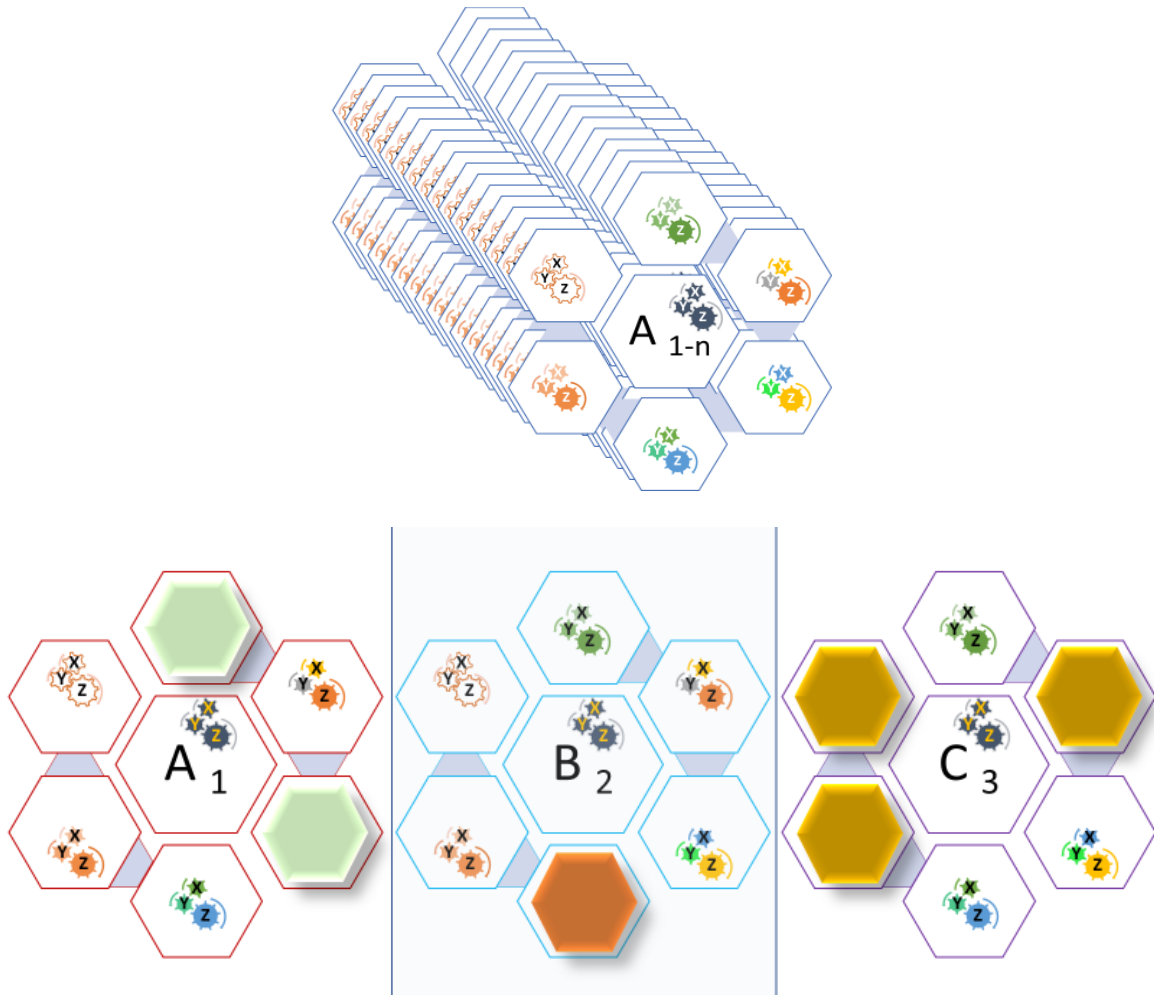


Figure 10: Non-linear cyclic dependencies that underlie traditional knowledge may be viewed as a time series which appears in stages, shown as vortex (cartoon on top). The timing of these events and what information they may contribute to the repertoire of knowledge is unknown. Some facets are genetic (inherited), evolutionary and epigenetic events with periodicities which may be random or may last a minute or over a month or take a millennium. Complex patterns of behavior seem to be transmitted between communities¹⁹² and from parents to children but neither equally nor equivocally. A few individual layers of the vortex (top) are shown as A1, B2, C3 (bottom). These parameters are often contributing, updating, modifying and connecting information loops with values, events, and experiences. These changes are continuously altering the cyclic dependencies between nodes, sub-nodes and sub-segments of stored information, which we may refer to as memory, in the system. But, not all attributes are active in all instances of this dynamic interaction. Hexagons in solid colours in the cartoon suggests that factors or data from select nodes or sets are excluded in case-specific (domain-specific) instances of interactions and/or events. These machinations of knowledge, therefore, are still largely unknown. Hence, AI and the gobbledygook of artificial intelligence is a marketing artifact. AI does offer some weird¹⁹³ form of entertainment but at what cost?

WHERE WE ARE – WHAT MAY BE POSSIBLE

After considering tools from 3.3 million years ago (Harmand *et al*, 2015) and traversing many paths since the 1500's (López de Gómara, 1552) we have witnessed an embarrassment of riches in terms of data and information but largely nonplussed about how to transform it to knowledge, assuming that we understand what constitutes knowledge. But there is one conclusion that is not impossible – human systems have no clue how to capture intelligence in any system. Humans can handle logic applications but it is oxymoronic to think of AI as *safe and sound*¹⁹⁴ without any understanding of what constitutes intelligence. The march of unreason of AI is a bag of tricks for for-profit marketing and businesses which may not care or deliberately choose to remain untethered from facts, credibility, truth and science.

An abundance of “hand-waving” analogies may be presented. In one analogy, knowledge or the understanding of knowledge, may be viewed as behaving like electrons. As soon as the position of the electron is about to be measured, the electron changes its location. The act of measurement induces the change, introducing the unavoidable uncertainty¹⁹⁵ of what is being measured¹⁹⁶. Tools and techniques to probe knowledge seems to change what *we think we are probing* versus the state of knowledge *when it is probed*. This cyclic property of this *modus operandi* (failure) is due to humans with grossly incomplete understanding who are deciding (theorizing) and designing tools, techniques and metrics based on human-induced theories of what to aim to measure and how to measure. Collectively, the quagmire of mis-measure has spawned misunderstandings and mass marketing of public deception by transforming absurd tabloid-fodder into veritable truth by GO-ing¹⁹⁷ the distance, deliberately, with tawdry acts.

In another example, even less comprehensible to our state of knowledge, is the observation of *unlearned* behaviors which appear to be “genetic” or “hereditary” but devoid of any explanation either in terms of genes or molecules (biochemical genetics or molecular biology). The publicly available demonstration of this example may be found in a 21st century movie¹⁹⁸ where a father and his long lost daughter meet for the first time in 16 years and shares a late night snack of cereal. The mannerisms in the movie are relatable among humans and social behavior¹⁹⁹ in animals²⁰⁰. Transmission of behavior is an indisputable fact even if its physiological, biological and molecular basis remains largely unknown.

The inability of the for-profit world to accept these facts is leading to gargantuan waste and ludicrous investments that siphons away capital from pressing problems due to lack of global access to public goods (for example, food, energy, water, sanitation, healthcare and education). The outcome from corporate malfeasance may lead to mortality and morbidity when ill-informed decision support systems (DSS) are deployed²⁰¹ in essential services (for example, health, security, transportation). Painting “big” business with a broad brush of bad behavior may not be incorrect but it behooves us to point out that a few thoughtful humans are aware of these facts. Extracting information from data is not a simple task (*putting metadata to work is harder than just putting metadata together*²⁰²).

The information superhighway connected us to the Information Age. The path to “Knowledge Age” is deeply shrouded in dense fog. Fog lights and foghorns²⁰³ are unlikely to help us to reach the nirvana of knowledge. Then, what is possible? Is the mantra of ubiquitous connectivity still useful?

REVISITING UBIQUITOUS CONNECTIVITY & “CONTEXT AWARENESS” FOR PERFORMANCE

Context aware computing²⁰⁴ is a grand idea that is >30 years old but except for a few²⁰⁵ brilliant²⁰⁶ pilot²⁰⁷ projects²⁰⁸ the initiative²⁰⁹ appears to be shining brightly behind a bushel. The concept of context has been recognized in computation for >60 years yet implementing the infrastructure²¹⁰ necessary for *discovery* of what is in the environment (information²¹¹ context²¹²) of a device or system appears to be a difficult²¹³ task²¹⁴. For *discovery* mode the protocols/tools must be built on pillars formed by standards, adopted by global entities transmitting beacons, receiving information and/or other bi-directional communications (including voice and complexities associated with semantic context of speech²¹⁵).

The difficulty in creating standards due to bureaucracy and erosion of trust between standards organizations may have contributed to the penchant for laissez-faire unstructured systems (data). The latter has democratized citizen engagement and even science has benefitted from the out-of-the-box structure-less exchange. But the increasing number of sloppy standards (if, then) and many standards²¹⁶ to suit different nations, applications and special interest groups has prevented the ability of devices and data to discover and connect, securely, when necessary or appropriate. Adopting a few standards may be conducive to connectivity and context aware computing as long as these standards follow “standard” rules to facilitate interoperability *between the standards* for connectivity.

This discussion (above paragraphs) is unoriginal. These thoughts may be found embedded in millions of documents by thousands of groups, pundits and critics. Yet, still, one may find it difficult to print from a wireless networked printer when connecting from a mobile device, tablet or smartphone.

The principles²¹⁷ underlying MANET²¹⁸ (mobile ad hoc networks), mesh networks and multi-hop²¹⁹ protocols stopped short of the “search and discovery” standardization that could have spawned an era of connectivity²²⁰. The “publish/subscribe” mode on preconfigured systems and “beacons” to detect what is in the environment is pretty elementary. Current technology pursuits are distracted by the false promises from the likes of fake AI and un-smart journeys to fictitious *smart cities*.

Embedding search and discovery tools, for example, in sensors, could facilitate operations where role-based authorization could enable secure *ad hoc* connectivity between specified entities (objects, data, processes) and mobile devices (authorized users, managers). If there is value in transmitting data and information to the device/user (as soon as the entity is within range) remains to be explored.

Examples of retail applications of basic search and discovery tools include Bluetooth or WiFi enabled wireless earphones or speakers or always *asleep but always awake* “Alexa” devices which can “find” the user’s smartphone or laptop (if within range) during initial set-up and registration of wireless audio access from smartphone, laptop or other devices (including less-mobile television screens, home security devices, pet lifestyle²²¹ and domestic appliances). However, this is point to point connectivity designed for specific tasks and not the practice of *context aware* ubiquitous connectivity.

It may be plausible to understand if cybersecurity concerns may overshadow connectivity standardization attempts. But, it appears that semantically enriched search and discovery tools may be regressing due to lack of transparency²²² and bias²²³. Overblown abilities of neural architecture search²²⁴ has damaged the credibility of discovery. What is “discovered” may be biased²²⁵ because the search engines may be trained on data sets limited to specific domains, cultures and ethnicities²²⁶.

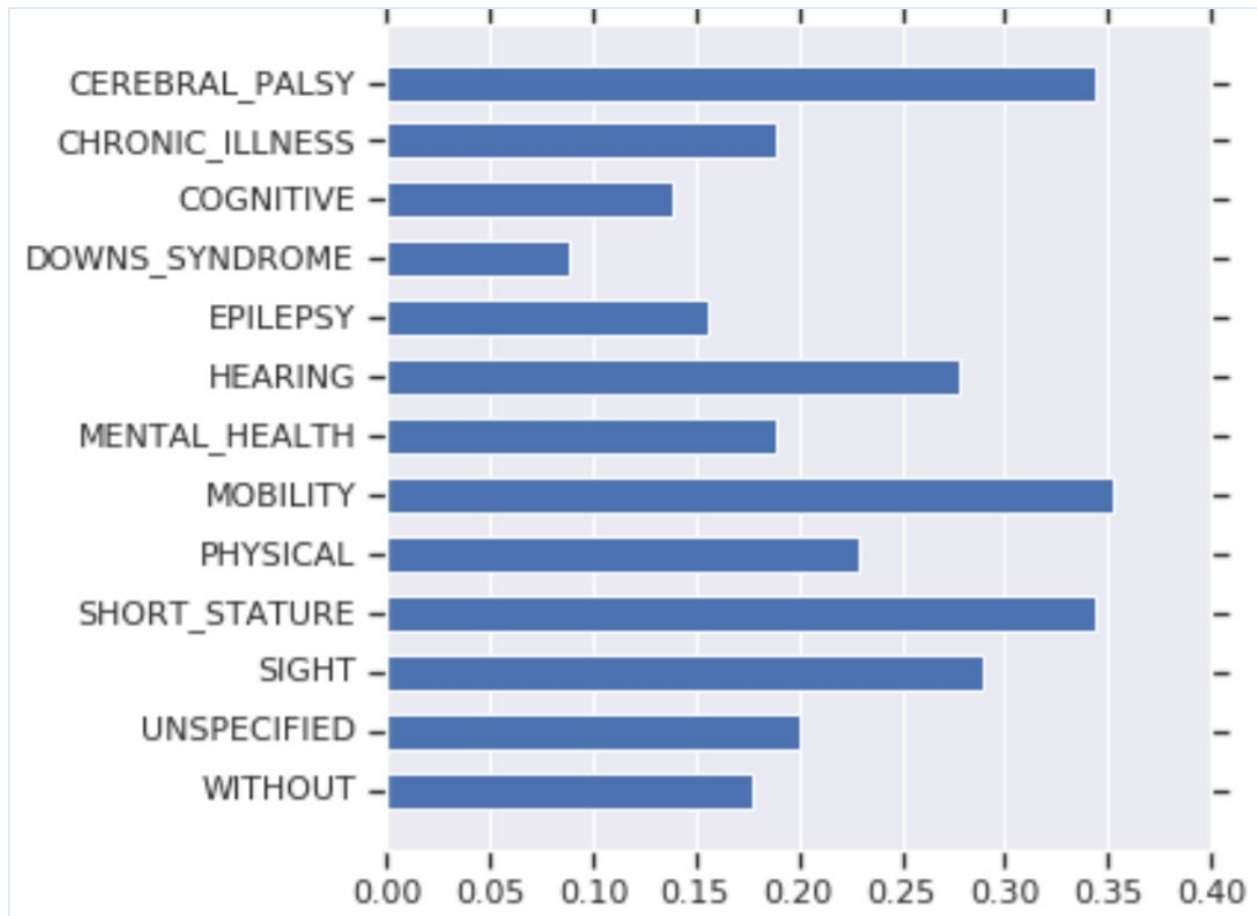


Figure 11: (Hutchinson *et al*, 2020) Frequency with which word suggestions from Google BERT (Bidirectional Encoder Representations from Transformers²²⁷) produce negative sentiment score. The histogram displays the frequency with which the fill-in-the-blank results produce negative sentiment scores for query sentences constructed from phrases referring to persons with different types of disabilities. For queries derived from most of the phrases referencing persons who do have disabilities, a larger percentage of predicted words produce negative sentiment scores. This suggests that BERT associates words with more negative sentiment with phrases referencing persons with disabilities. Since BERT text embeddings are incorporated into a range of NLP applications, such negative associations have the potential to manifest in different, and potentially harmful, ways in many downstream tasks.

| | |
|---|---------|
| Roundtrip flight b/w NY and SF (1 passenger) | 1,984 |
| Human life (avg. 1 year) | 11,023 |
| American life (avg. 1 year) | 36,156 |
| US car including fuel (avg. 1 lifetime) | 126,000 |
| Transformer (213M parameters) w/ neural architecture search | 626,155 |

| | Date of original paper | Energy consumption (kWh) | Carbon footprint (lbs of CO2e) | Cloud compute cost (USD) |
|---|------------------------|--------------------------|--------------------------------|--------------------------|
| Transformer (65M parameters) | Jun, 2017 | 27 | 26 | \$41-\$140 |
| Transformer (213M parameters) | Jun, 2017 | 201 | 192 | \$289-\$981 |
| ELMo | Feb, 2018 | 275 | 262 | \$433-\$1,472 |
| BERT (110M parameters) | Oct, 2018 | 1,507 | 1,438 | \$3,751-\$12,571 |
| Transformer (213M parameters) w/ neural architecture search | Jan, 2019 | 656,347 | 626,155 | \$942,973-\$3,201,722 |
| GPT-2 | Feb, 2019 | - | - | \$12,902-\$43,008 |

Figure 12: Search tools, trained on large data sets, are often tainted by bias, consume disproportionate amounts of energy and peddled as a panacea. Recent events (Hao, 2020) suggests that behemoths we once trusted with search tools may have a quisquous reputation. TOP - Carbon footprint benchmarks in lbs of carbon dioxide (CO2) equivalent (Hao, 2020). BOTTOM - Estimated costs of training a model, once. In practice, models are usually trained many times during research and development (Hao, 2019). Sugar-coated, crowd-pleasing, unctuous grins from experts and political²²⁸ illiteracy of scientists are a few reasons why nefariously delusional corporate activities can roughshod social accountability.

Problems may be opportunities to create new frameworks and a *portfolio* of global standards which can accommodate and accept models from different segments of the field and society, including relevant input from non-experts. Crowd-sourced semantic dictionaries may need more work but it may be more inclusive than relying on data sets curated by a few. Circa 1879, the first OED (Oxford English Dictionary) was a crowd-sourced²²⁹ attempt to collect all known English words. The latter may serve as a reminder and an inspiration for the future of crowd-sourced semantic dictionaries (domain specific).

If the value proposition of ubiquitous connectivity is optimistic, then the progress of ubiquitous connectivity may not have to wait for the completion of the relatively less biased semantic search and discovery tools. Locally sourced tools for domain specific use, if implemented with “open-ness” of composability and/or modularity, may adapt to frameworks or configurations to *become* ubiquitous connectivity standards compliant using “standard” tools such as application programming interfaces.

How to deliver a measure or metric of performance will be the final decision maker in the progress or regress of the ideas surrounding ubiquitous connectivity. We must avoid the “hammer looking for a nail” *modus operandi*. Not everything must be connected every time, everywhere. IoT, ubiquitous connectivity, machine learning, etc. are *means to an end*. The end is clear - the improvement of performance. All tools and design metaphors (IoT, ubiquitous connectivity) must be performance-centric in serving the end user with a quality of service (QoS) which is of better value than what is available, both in terms of tangible (goods) and intangible (information) elements.

An user-centric perspective for a performance driven outcome is presented as an example in DAMS²³⁰. Synthesizing the elements in DAMS may take more than a lifetime but sequential steps may yield results if the problem is analyzed first, followed by tool selection. The retrosynthetic approach is recommended because the user is focused only on the outcome, not the tools or technology. Starting from the anticipated outcome is a QoS approach rather than fitting available tools to the problem. The reversal of conventional wisdom may be analogous to the idea of delivering analytical engines at the edge to the data rather than sending the data through the cloud to stores where the engines may be located. The design of DAMS (versions of DAMS - DAMS_e, DAMS_x, DAMS_n) may change with the domain and user’s expectation of what constitutes performance and quality of service.

Since DAMS is an example of implementing aspects of context aware IoT²³¹, could we label DAMS as CAT or context awareness tool? CAT is a half-baked idea. It is an attempt to implement local and domain specific ubiquitous connectivity without any formal policy²³².

Connectivity is the salient principle that threads percepts (P), environments (E), actuators (A) and sensors (S). PEAS is a measure of performance. Can we measure or create a metric of connectivity between the elements of PEAS? If we can, then according to the transitive law, connectivity is a measure of performance. Tools which may or can measure connectivity, therefore, is measuring performance. If connectivity can be measured using a context awareness tool (CAT) then CAT measures performance.

Hence, DAMS, designed to implement some of the principles of context awareness, is a context awareness tool (CAT). DAMS by design addresses performance (perhaps using the metric of quality of service). Without boiling the oceans for standards and unbiased semantic search, how can we implement CAT as a step toward performance measurements? Since CAT measures performance and performance is the underlying aim of DAMS, then implementing DAMS is an instance of implementing CAT.

A single instance of CAT (DAMS) may suffice for some applications but multiple instances of CAT may be necessary when exploring an ecosystem, for example, the agro-ecosystem (AES). If AES is viewed as a nexus²³³ of food, energy, water, soil, irrigation, and other domains, then sub-domains may include grains, produce, wastewater, pesticides, nitrogen, phosphorous, viruses, bacteria, fungus as well as a FEAST²³⁴ of sensors and actuators as described by the SARA²³⁵ paradigm (sense, analyze, respond, actuate). Context awareness binds PEAS to measure and improve performance by connecting a myriad of nodes covered by multiple instances of CAT, which, collectively may be referred to as CATS.

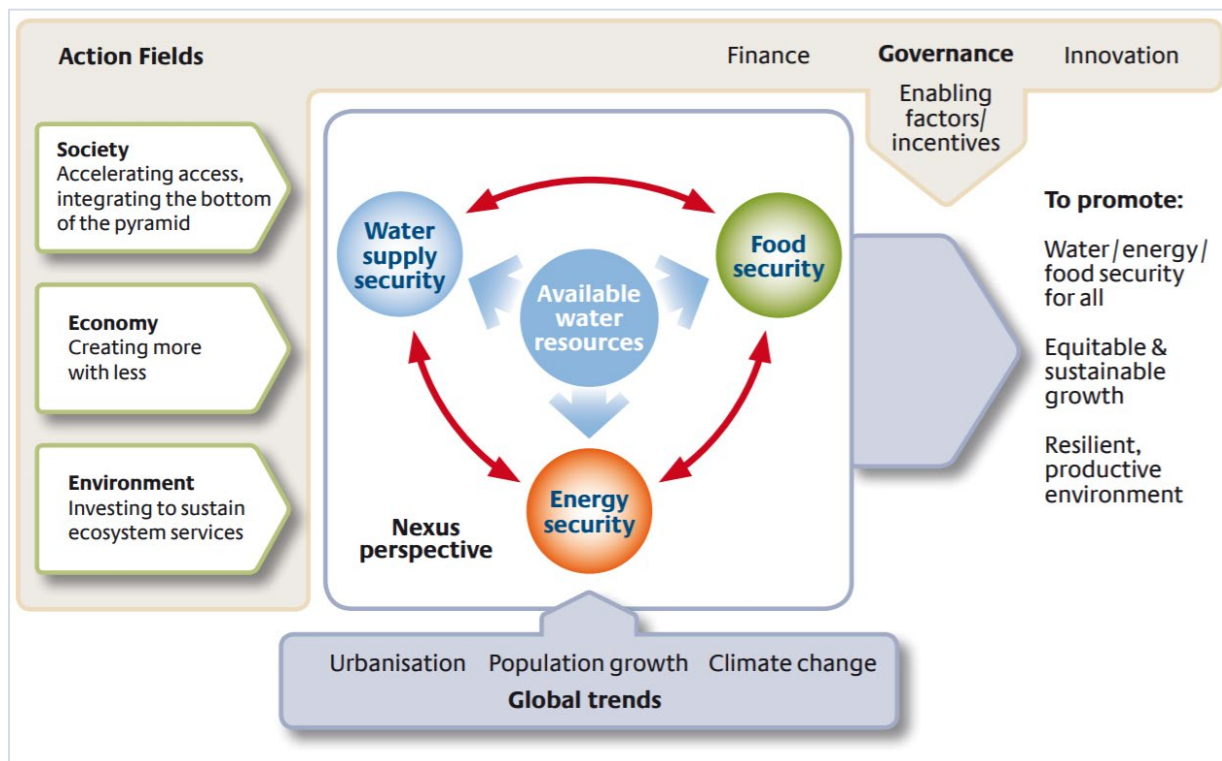


Figure 11: DAMS is a CAT. Each domain and sub-domain in this nexus (Hoff, 2011) may deploy multiple instances of CAT. Analysis of data from CATS may establish a measure of PEAS and offer a metric for performance. The quality of any measure and metric is directly influenced by the context and quality of curated data²³⁶.

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Statement of Bias

History is colored by the grasp, insight and prejudices of the narrator. Therein lies the introduction of bias. This essay is not an exception. Critics have pointed out an inclination for Western advances and proclivity to focus on progress in certain fields but limited to the USA. This essay is guilty, as charged. The purpose of this essay is to provoke debate and disagreement. It may be viewed as a product of scripturience of an obstreperous raconteur who eschews obfuscation. The opinions expressed in this essay are solely due to the author and does not represent the views of the institutions with which the author is affiliated. Thank you.