http://bit.ly/DATA-AA

DATA

Mini Course: Review and Outline of "Data Acquisition and Applications"

DATAAA

Dr Shoumen Palit Austin Datta, Auto-ID Labs, Massachusetts Institute of Technology and Massachusetts General Hospital, Harvard Medical School

http://bit.ly/DATA-AA

- STUDENTS -

YES, YOU CAN SHARE THIS FOLDER WITH ANYBODY.

http://bit.ly/DATA-AA

Zipped folder contains this discussion and additional material

Think

Thinking and Thought

Substance - https://plato.stanford.edu/entries/santayana/
Stupidity - https://www.jaacap.org/article/S0890-8567(09)61480-5/pdf

5MB (1956) versus 4TB (2016)

Seagate Backup Plus Slim 4TB Portable External Hard Drive (STDR4000300)

4TB = 4,000,000 MB (4 million MB)

5MB hard drive being shipped from IBM (1956)

5MB weighed 1,000,000g (grams) / 1,000 kg

4TB (4 million MB) weighs 500g

Without science and engineering, weight of 4TB may be 800 million kg or 800,000 tonne

Seagate Backup Plus Slim 4TB Portable External Hard Drive (STDR4000300)

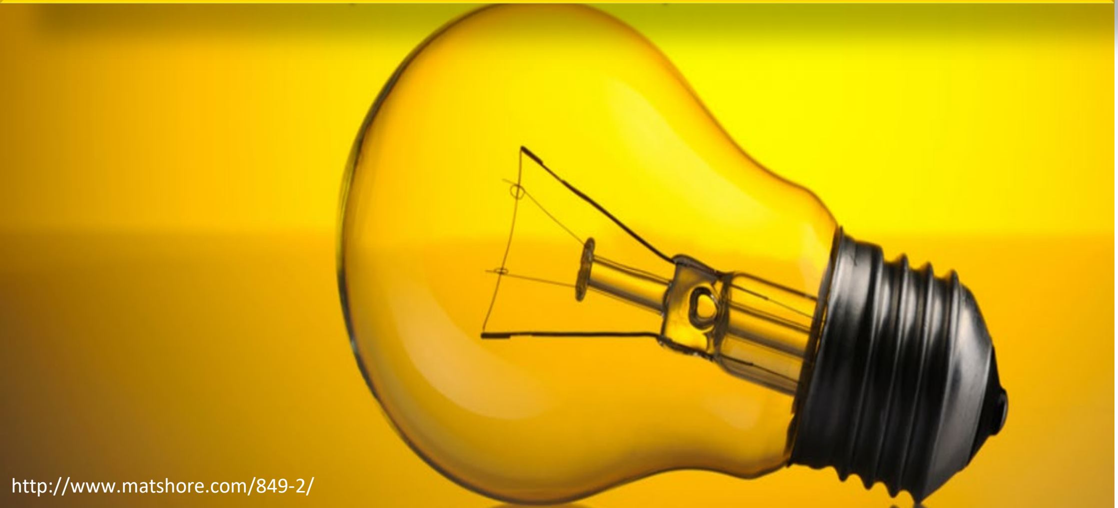
What is the question?

Without science and engineering, weight of one 4TB HD may be 800 million kg or 800,000 tonne

> "If I had asked people what they wanted, they would have said faster horses."
>
> **Henry Ford**

www.cnbc.com/2019/02/08/how-apple-iphone-gorilla-glass-is-made-corning-factory.html ▪ https://www.youtube.com/watch?v=jzLYh3j6xn8&t=6s

Electric bulb did not result from incremental improvement of candles.



http://www.matshore.com/849-2/

NBC 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.

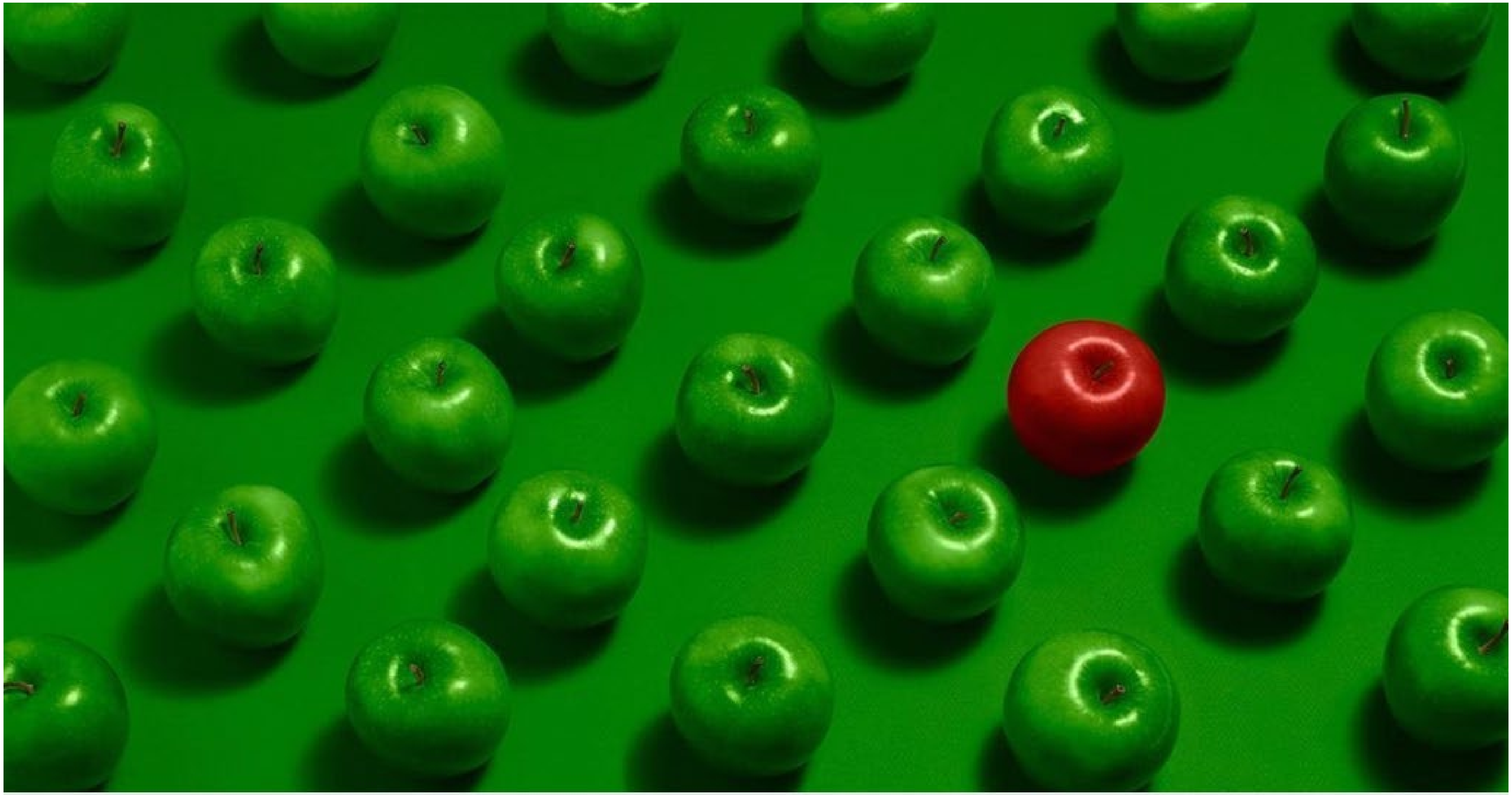
https://yourstory.com/2013/09/silcon-valley-legend-vinod-khosla-plans-slowdown-next-25-years/

Think different.

May be agnostic of topic, domain or context

Are you asking the correct question?

Think different.



Are you asking the correct question?

Think different.

https://www.nytimes.com/2019/02/09/opinion/sunday/child-care-daycare-democrats-progressive.html

Opinion

Day Care for All

The progressive to-do list is missing a very important idea.

Are you asking the correct question?

Think different.

Are you asking the correct question?

Confluence of Ideas

CONVERGENCE, CROSS-POLLINATION, COMBINATION

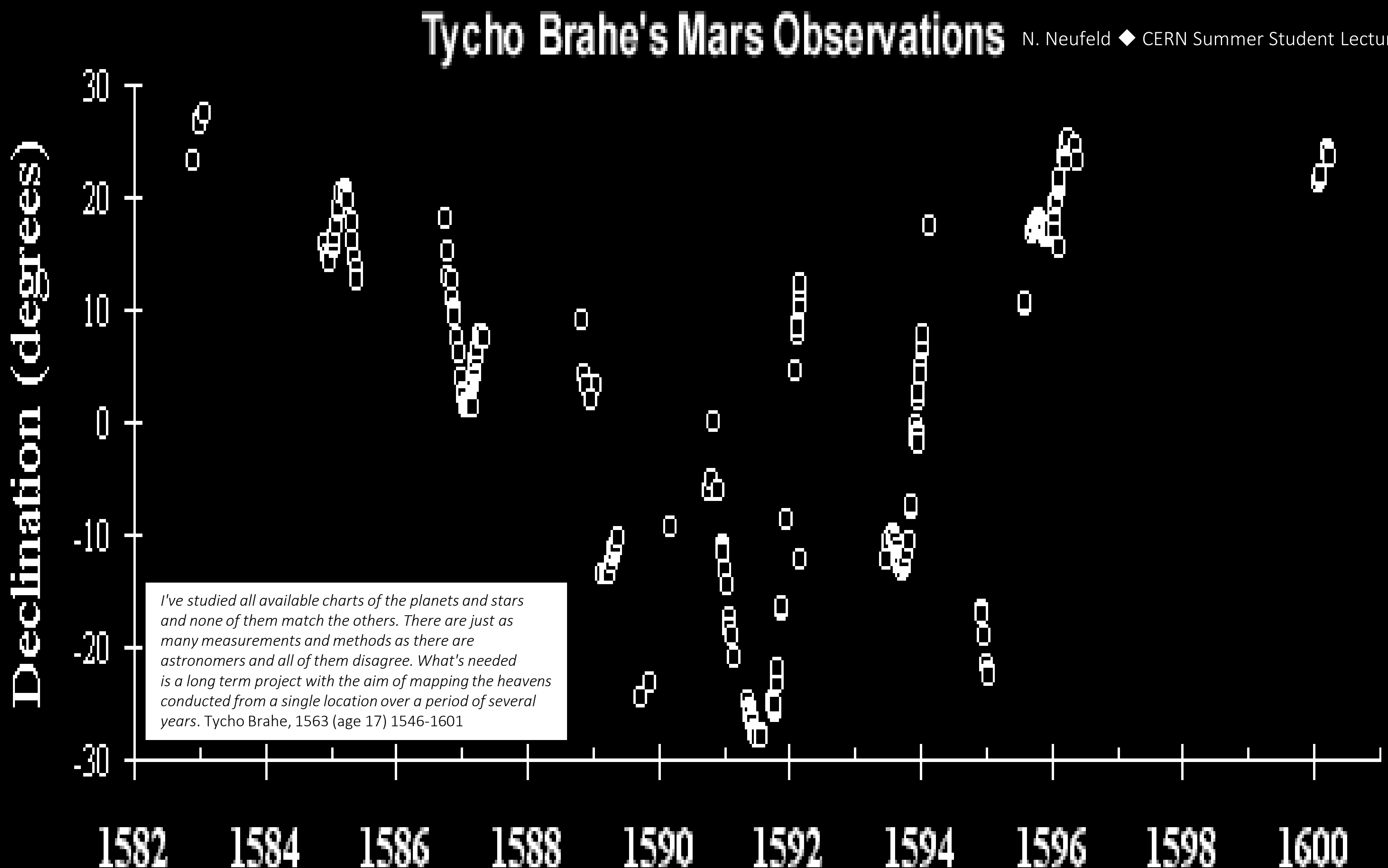
MULTI-DISCIPLINARY, TRANS-DISCIPLINARY

DATA

Because the plural of anecdote is not evidence.

The first ‘systematic’ data acquisition?

N. Neufeld ◆ CERN Summer Student Lectures, 2009

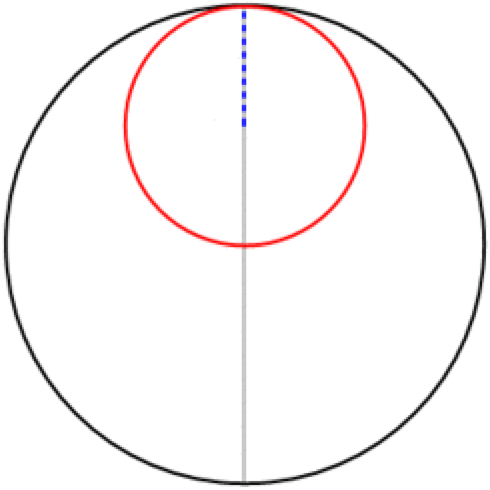


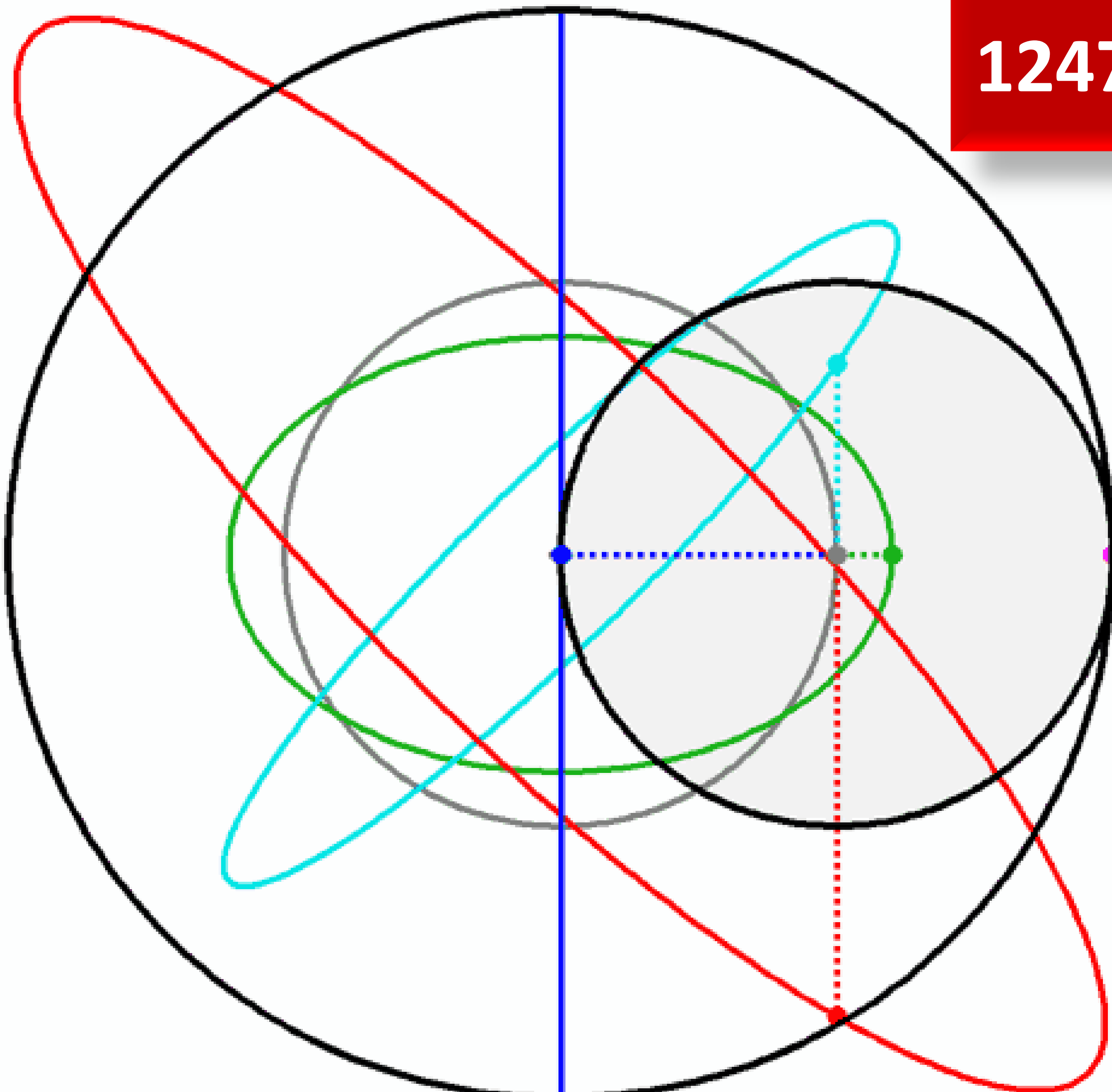
I've studied all available charts of the planets and stars and none of them match the others. There are just as many measurements and methods as there are astronomers and all of them disagree. What's needed is a long term project with the aim of mapping the heavens conducted from a single location over a period of several years. Tycho Brahe, 1563 (age 17) 1546-1601

Monthly data over 18 yrs. Measurements lasted ~1 hour (naked eye)

https://en.wikipedia.org/wiki/Tycho_Brahe

1247



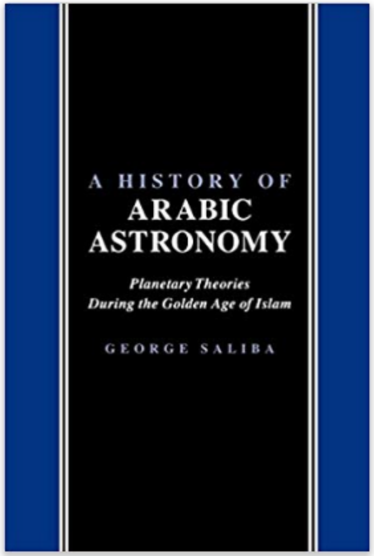


Tusi couple is a mathematical device in which a small circle rotates inside a larger circle twice the diameter of the smaller circle. Rotations of the circles cause a point on the circumference of the smaller circle to oscillate back and forth in linear motion along a diameter of larger circle. Tusi couple is a 2 cusped hypocycloid. The ellipses (green, cyan, red) are hypotrochoids of the Tusi couple. A property of the Tusi couple is that points on the inner circle that are not on the circumference trace ellipses. These elipses, and the straight line traced by the classic Tusi couple, are special cases of hypotrochoids. Proposed by the 13th century Persian astronomer and mathematician Nasir al-Din al-Tusi in his 1247 Tahrir al-Majisti (Commentary on Almagest) as a solution for the latitudinal motion of the inferior planets, and later used as a substitute for the equant introduced over a thousand years earlier in the 2nd century by the Greek Claudius Ptolemy in his influential treatise Almagest.

Circa 1200 AD - http://bit.ly/TUSI-COUPLE
https://en.wikipedia.org/wiki/Tusi_couple

Tycho Brahe was born 300 hundred years later https://www.amazon.com/History-Arabic-Astronomy-University-Civilization/dp/0814780237

Look inside



A History of Arabic Astronomy: Planetary Theories During the Golden Age of Islam (New York University Studies in Near Eastern Civilization) Paperback – July 1, 1995

by George Saliba (Author)

A History of Arabic Astronomy is a comprehensive survey of Arabic planetary theories from the eleventh century to the fifteenth century based on recent manuscript discoveries. George Saliba argues that the medieval period, often called a period of decline in Islamic intellectual history, was scientifically speaking, a very productive period in which astronomical theories of the highest order were produced.

Based on the most recent manuscript discoveries, this book broadly surveys developments in Arabic planetary theories from the eleventh century to the fifteenth. Taken together, the primary texts and essays assembled in this book reverse traditional beliefs about the rise and fall of Arabic science, demonstrating how the traditional "age of decline" in Arabic science was indeed a "Golden Age" as far as astronomy was concerned.

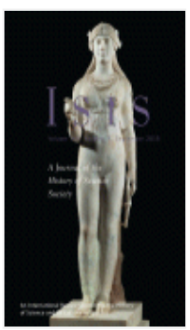
Some of the techniques and mathematical theorems developed during this period were identical to those which were employed by Copernicus in developing his own non-Ptolemaic astronomy. Significantly, this volume will shed much-needed light on the conditions under which such theories were developed in medieval Islam. It clearly demonstrates the distinction that was drawn between astronomical activities and astrological ones, and reveals, contrary to common perceptions about medieval Islam, the accommodation that was obviously reached between religion and astronomy, and the degree to which astronomical planetary theories were supported, and at times even financed, by the religious community itself. This in stark contrast to the systematic attacks leveled by the same religious community against astrology.

To students of European intellectual history, the book reveals the technical relationship between the astronomy of the Arabs and that of Copernicus. Saliba's definitive work will be of particular interest to historians of Arabic science as well as to historians of medieval and Renaissance European science.

JOURNAL ARTICLE

Late Medieval Planetary Theory

E. S. Kennedy

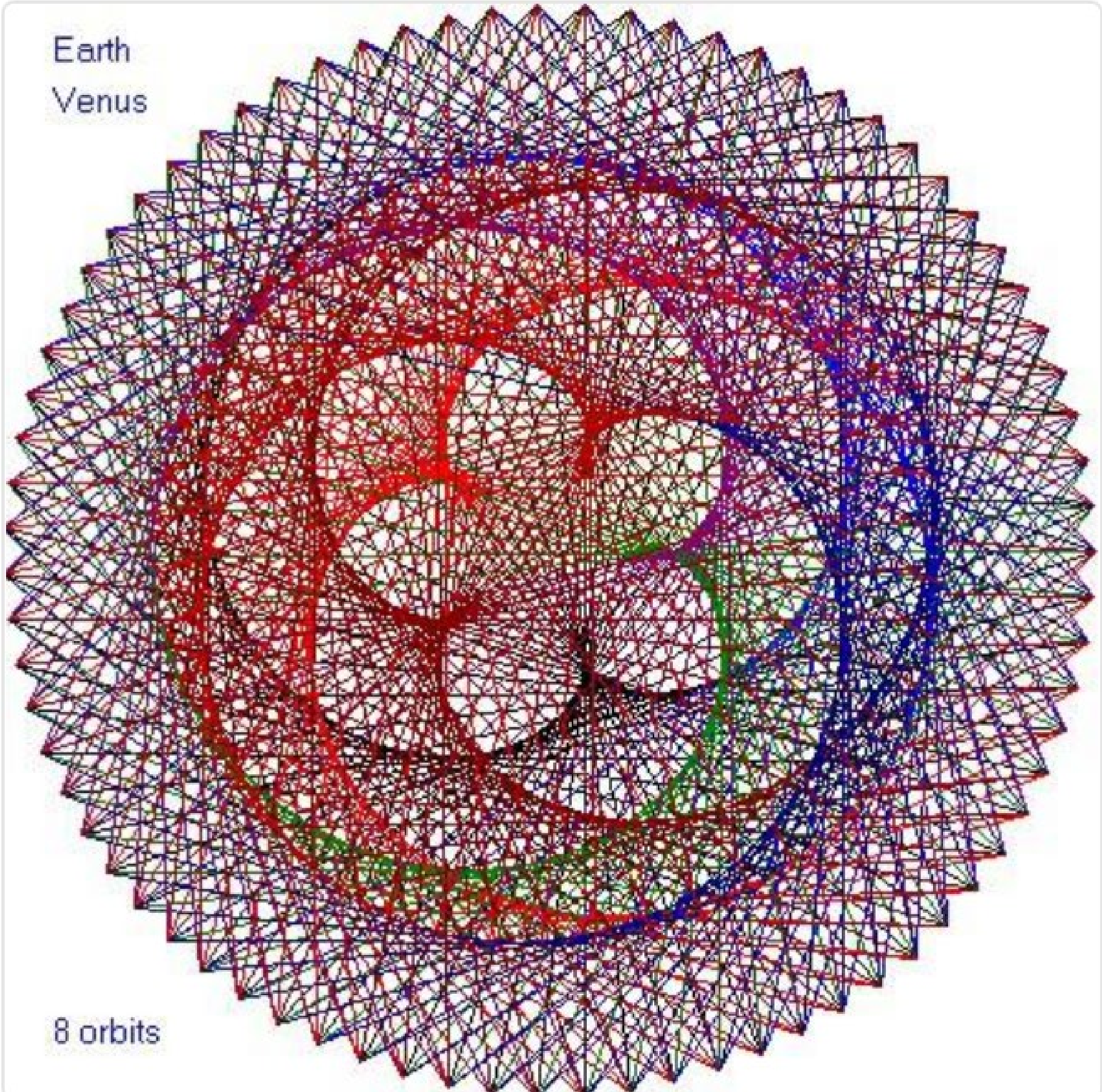


Isis
Vol. 57, No. 3 (Autumn, 1966), pp. 365-378 (14 pages)

Published by: The University of Chicago Press on behalf of The History of Science Society

Circa 1200 AD - http://bit.ly/TUSI-COUPLE
https://en.wikipedia.org/wiki/Tusi_couple

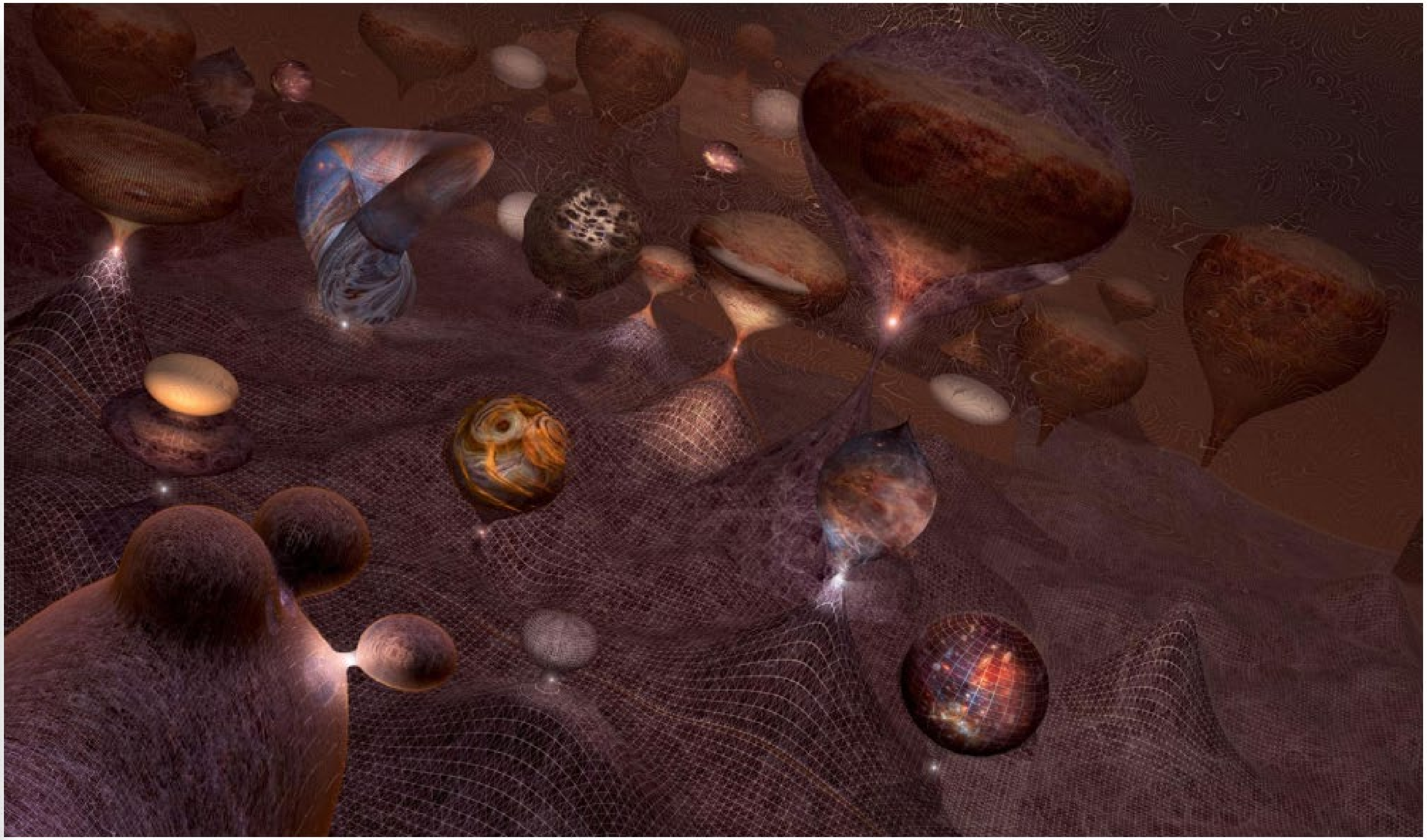
If you track the relative positions of Earth Venus over an 8 year period, this is the resulting pattern. Credits: Ensign



8 Earth Orbits equal 13 Venus Orbits with 5 Earth Venus 'Kisses'

www.youtube.com/watch?time_continue=4&v=4cgQNUhtmHM

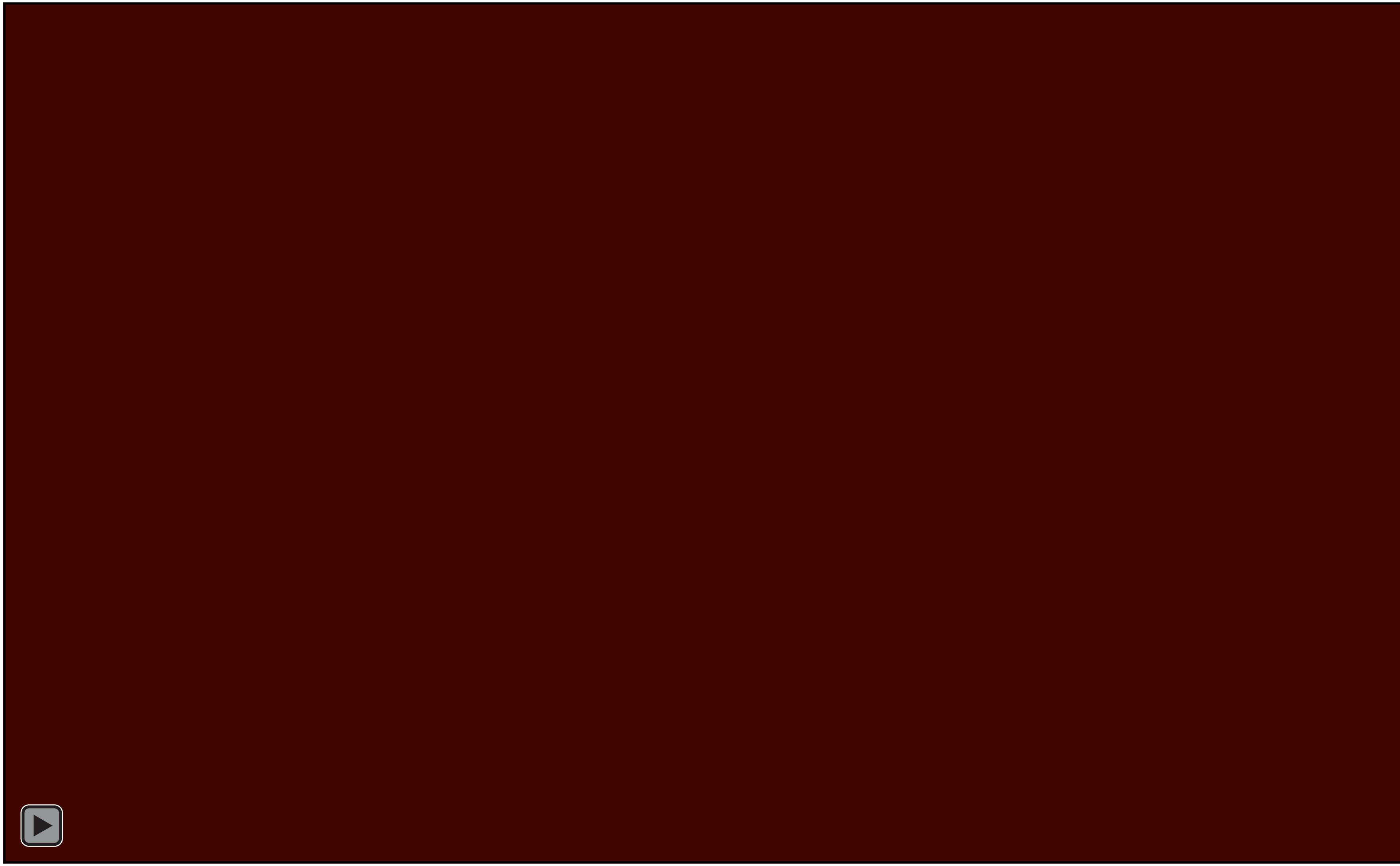
IMAGINE



INFINITE BEGINNINGS

Pushing the limits of theory and imagination in true Einsteinian fashion, cosmologists are daring to speculate that ours is not the only universe. The big bang that created everything we know of space and time could be just one of an infinite number of beginnings, yielding a never ending sequence of universes. The scenario, shown in this artist's concept, emerges from inflation theory, a descendent of Einstein's general theory of relativity. Relativity implies that space and time can stretch to vast dimensions from a tiny starting point; inflation describes how our universe ballooned in its first moments and suggests that the same thing can happen anywhere, at any time. The result: an eternal expanse of space erupting with bubbles of energy, or big bangs, each the seed of a universe. Not all universes will be alike. While a cosmos like our own glows with galaxies (at lower right) others may contain more dimensions or different forms of matter. In some, even the laws of physics work differently (twisted universe at upper left). https://www.nationalgeographic.com/magazine/2005/05/einstein-relativity-cosmology-space-time-big-bang/

You can't see the past or the future if your imagination is out of focus



http://hermes.ffn.ub.es/luisnavarro/nuevo_maletin/Einstein_GRelativity_1916.pdf

Idea, Prediction, Theory

DATA

https://www.ligo.caltech.edu/mit/news/ligo20160211

Gravitational Waves Detected 100 Years After Einstein's Prediction

News Release • February 11, 2016

Gravitational Waves

Gravitational waves are ripples in space-time (the fabled "fabric" of the Universe) caused by massive objects moving with extreme accelerations (in outer space that means objects like neutron stars or black holes orbiting around each other at ever increasing rates, or stars that blow themselves up). Explore the links below to learn more about these ephemeral phenomena.

- **What are Gravitational Waves?**
- **Why Detect Them?**
- **Sources and Types of Gravitational Waves**

Contact LIGO MIT

LIGO Project MIT
MIT NW22-295
185 Albany Street
Cambridge, MA 02139

Information: **(617) 253-4824**

Caltech MIT NSF

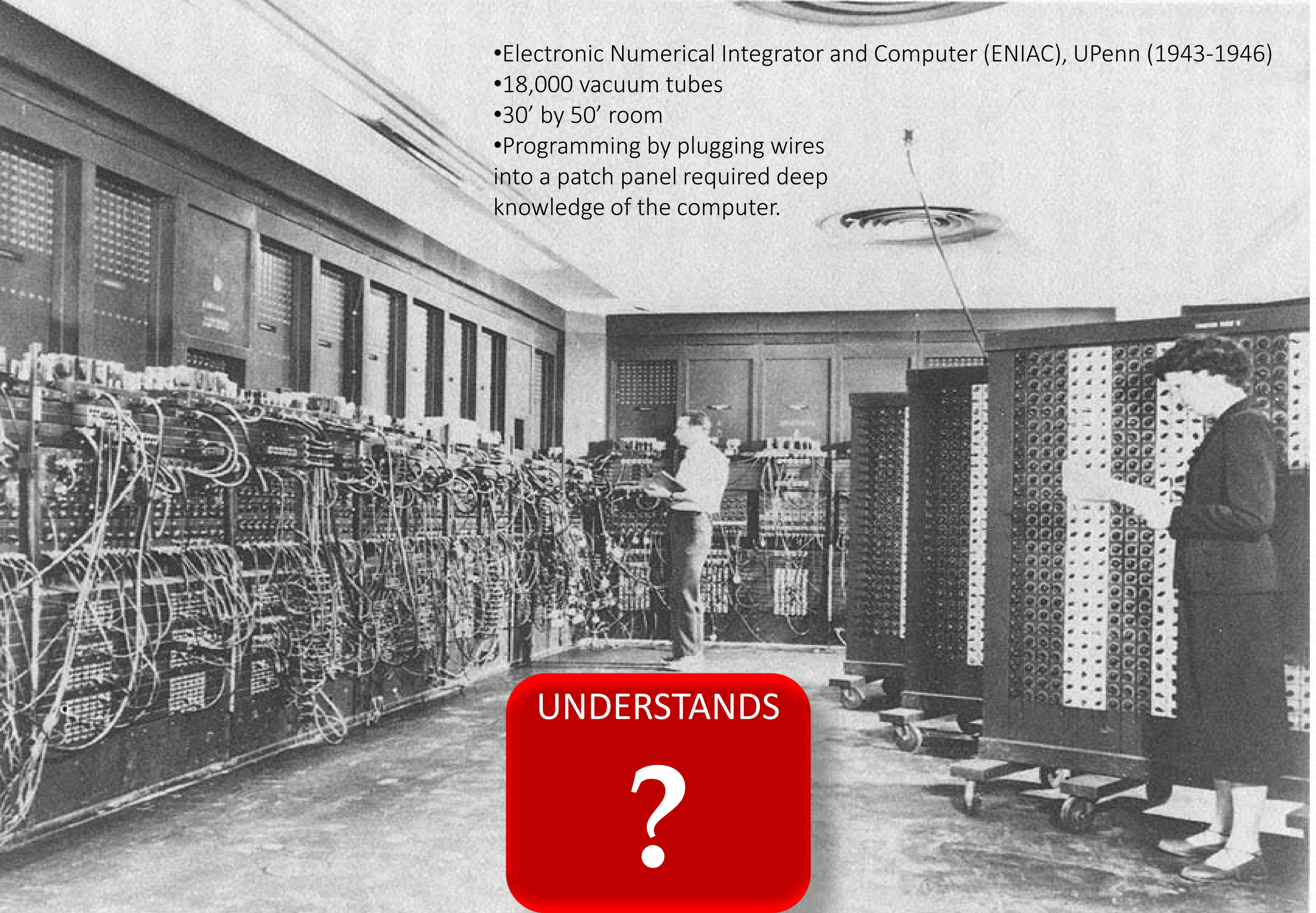
LIGO is jointly operated by Caltech and MIT
LIGO is supported by the U.S. National Science Foundation

For the first time, scientists have observed ripples in the fabric of spacetime called gravitational waves, arriving at the earth from a cataclysmic event in the distant universe. This confirms a major prediction of Albert Einstein's 1915 general theory of relativity and opens an unprecedented new window onto the cosmos.

Gravitational waves carry information about their dramatic origins and about the nature of gravity that cannot otherwise be obtained. Physicists have concluded that the detected gravitational waves were produced during the final fraction of a second of the merger of two black holes to produce a single, more massive spinning black hole. This collision of two black holes had been predicted but never observed.

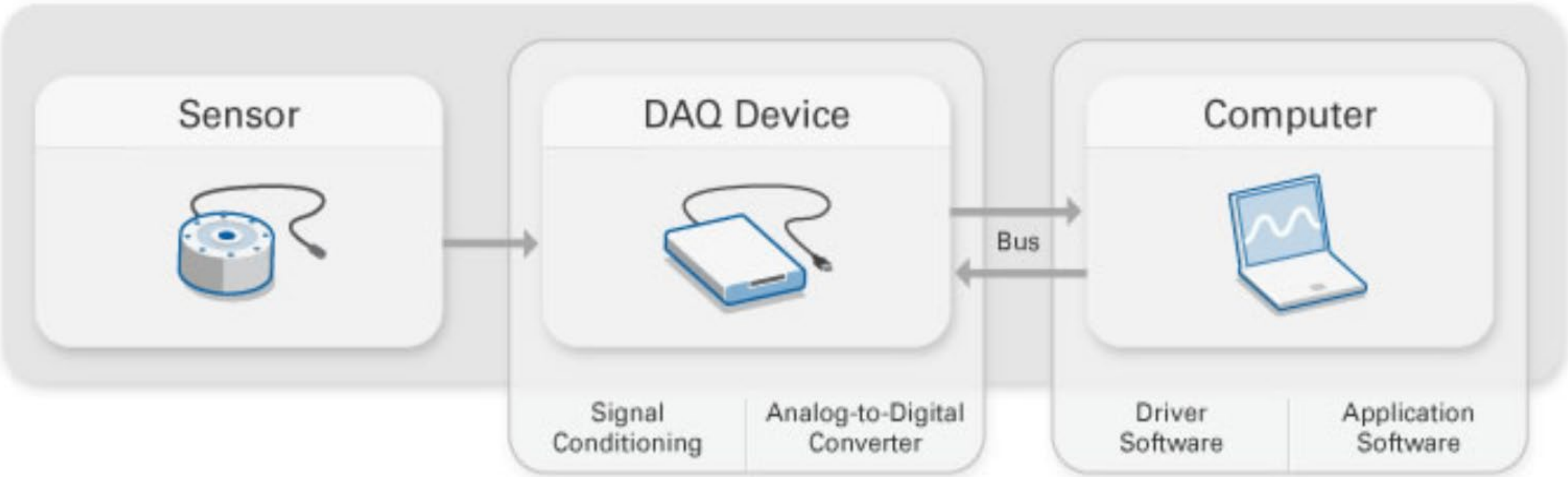
The gravitational waves were detected on September 14, 2015 at 5:51 a.m. Eastern Daylight Time (09:51 UTC) by both of the twin Laser Interferometer Gravitational-wave Observatory (LIGO) detectors, located in Livingston, Louisiana, and Hanford, Washington, USA. The LIGO Observatories are funded by the National Science Foundation (NSF), and were conceived, built, and are operated by Caltech and MIT. The discovery, accepted for publication in the journal Physical Review Letters, was made by the LIGO Scientific Collaboration (which includes the GEO Collaboration and the Australian Consortium for Interferometric Gravitational Astronomy) and the Virgo Collaboration using data from the two LIGO detectors.

- Electronic Numerical Integrator and Computer (ENIAC), UPenn (1943-1946)
- 18,000 vacuum tubes
- 30’ by 50’ room
- Programming by plugging wires into a patch panel required deep knowledge of the computer.

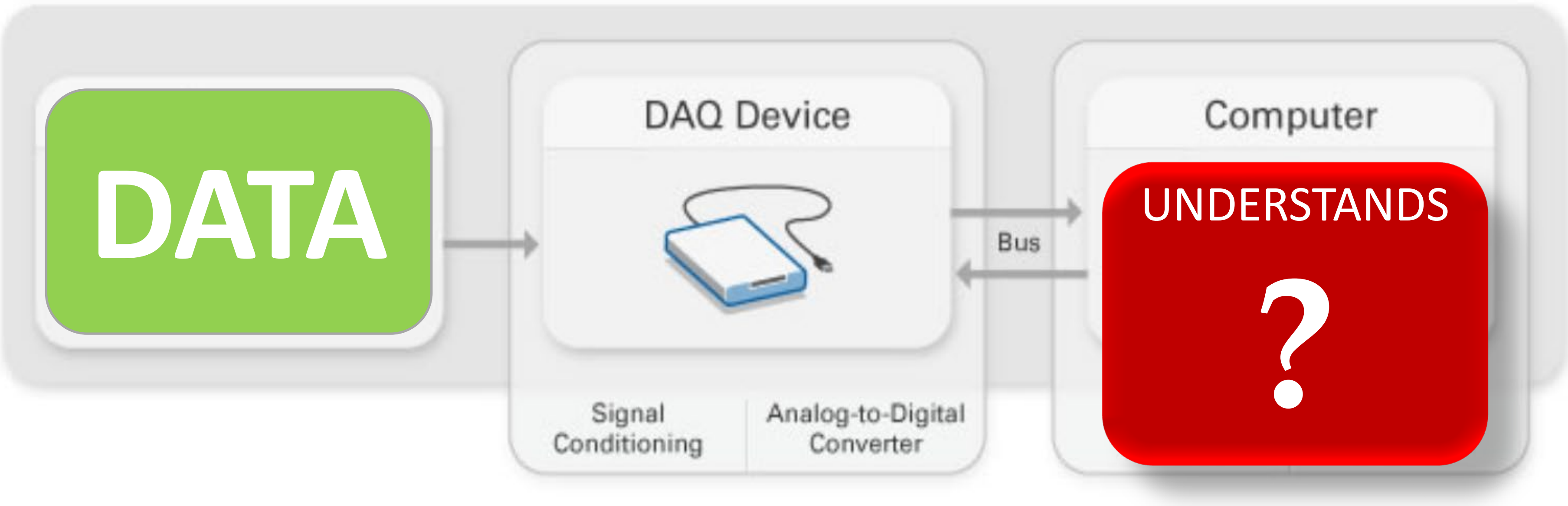


The ENIAC.
Smithsonian Institution Photo No. 53192. http://americanhistory.si.edu/collections/search/object/nmah_334742

Parts of a DAQ System



Parts of a DAQ System



What is the value of

Data Acquisition

WITHOUT UNDERSTANDING ?

# -	Data and Understanding Data - CURATE

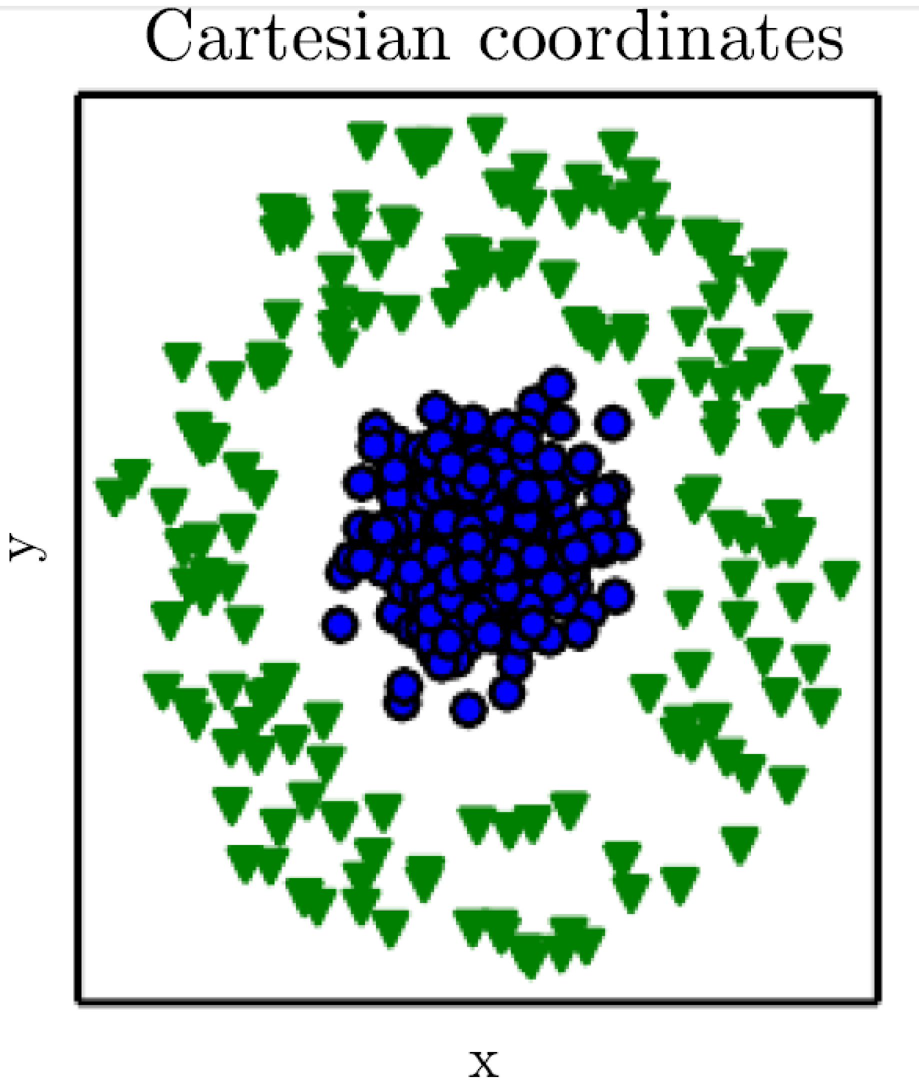


Figure 1.1: Example of different representations: suppose we want to separate two categories of data by drawing a line between them in a scatterplot. In the plot on the left, we represent some data using Cartesian coordinates, and the task is impossible.

From Ian Goodfellow in *Deep Learning*, MIT Press

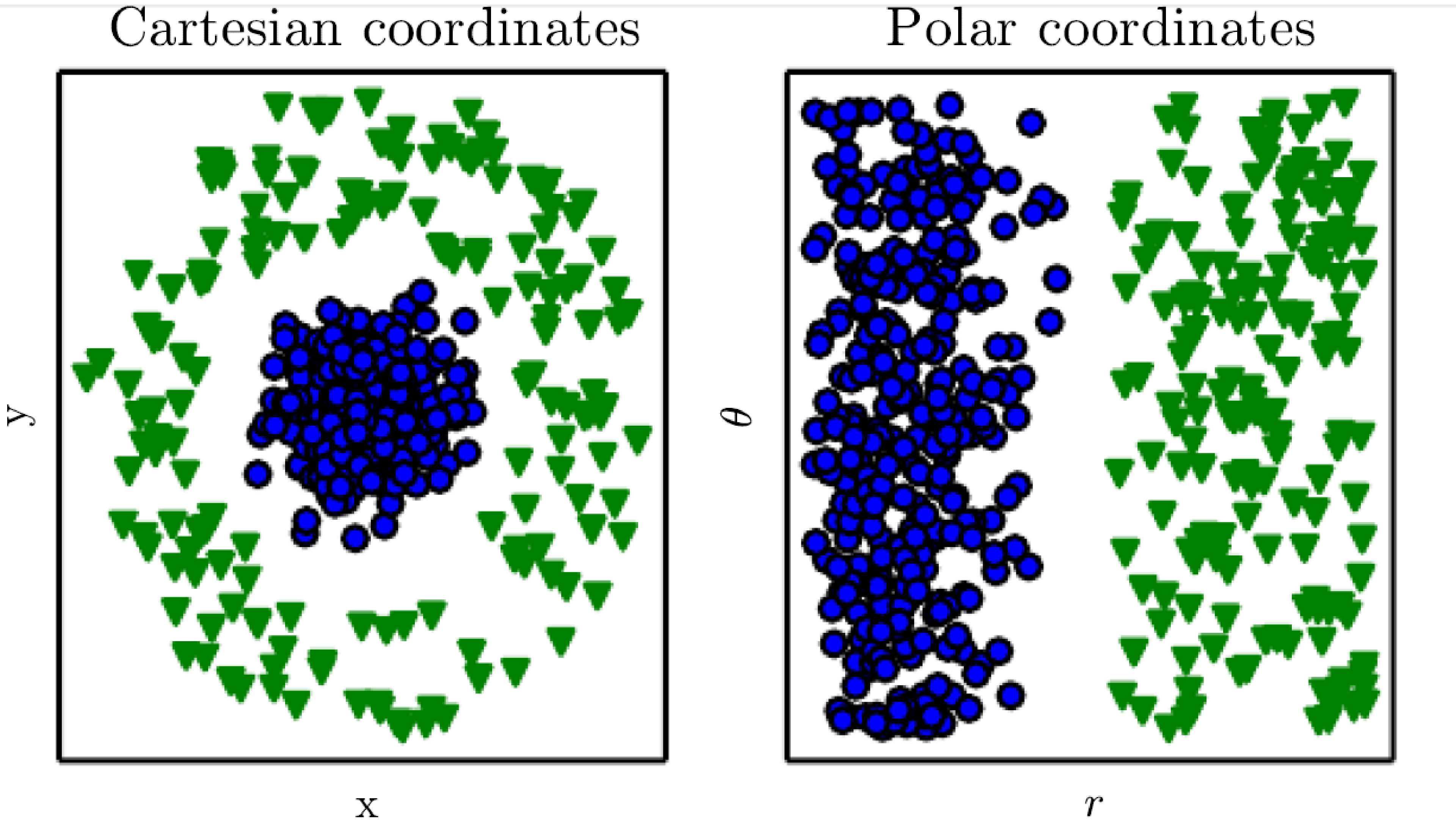


Figure 1.1: Example of different representations: suppose we want to separate two categories of data by drawing a line between them in a scatterplot. In the plot on the left, we represent some data using Cartesian coordinates, and the task is impossible. In the plot on the right, we represent the data with polar coordinates and the task becomes simple to solve with a vertical line. Figure from Ian Goodfellow in *Deep Learning*, MIT Press (2017)

- Data and Understanding Data - CONTEXT

Data curation may be rendered useless unless selected for context

The latest US influenza season is more severe and has caused more deaths than usual.

EPIDEMIOLOGY

When Google got flu wrong

US outbreak foxes a leading web-based method for tracking seasonal flu.

BY DECLAN BUTLER

When influenza hit early and hard in the United States this year, it quietly claimed an unacknowledged victim: one of the cutting-edge techniques being used to monitor the outbreak. A comparison with traditional surveillance data showed that Google Flu Trends, which estimates prevalence from flu-related Internet searches, had drastically overestimated peak flu levels. The glitch is no more than a temporary setback for a promising strategy, experts say, and Google is sure to refine its algorithms. But as flu-tracking techniques based on mining of web data and on social media proliferate, the episode is a reminder that they will complement, but not substitute for, traditional epidemiological surveillance networks.

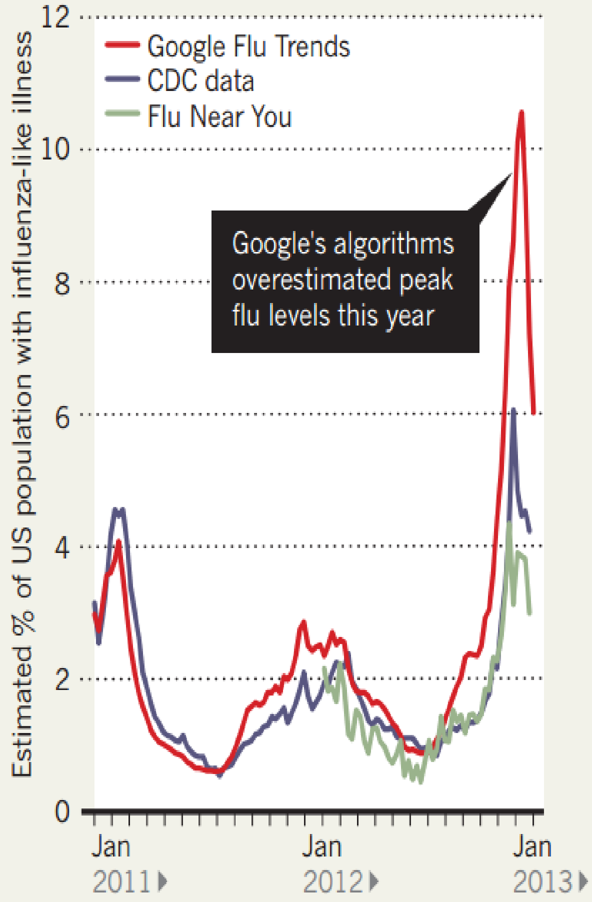
"It is hard to think today that one can provide disease surveillance without existing systems," says Alain-Jacques Valleron, an epidemiologist at the Pierre and Marie Curie University in Paris, and founder of France's Sentinelles monitoring network. "The new systems depend too much on old existing ones to be able to live without them," he adds.

This year's US flu season started around November and seems to have peaked just after Christmas, making it the earliest flu season since 2003. It is also causing more serious illness and deaths than usual, particularly among the elderly, because, just as in 2003, the predominant strain this year is H3N2 — the most

nologies could open the way to easier, faster estimates of ILI, spanning larger populations.

FEVER PEAKS

A comparison of three different methods of measuring the proportion of the US population with an influenza-like illness.



Without context, syntax is oblivious of semantics

Project Oxygen, CSAIL, MIT

1997

- Data and Understanding Data - SEMANTICS & ONTOLOGY

Value of Data - Understanding Data - semantic twins related by ontology

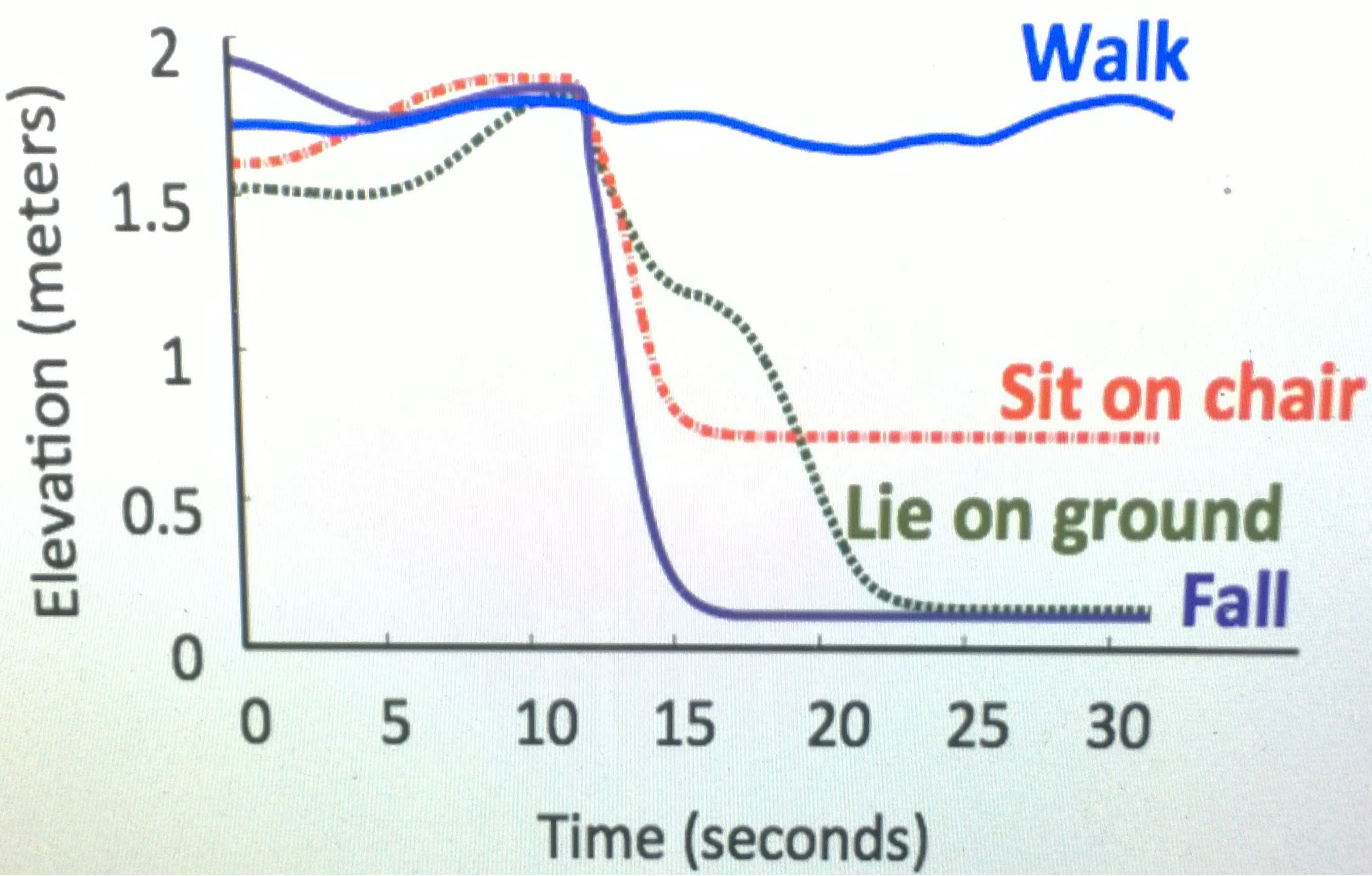
1997

- Data vs Understanding Data -

as important as life and death

PROFESSOR DINA KATABI ◆ http://people.csail.mit.edu/dina/

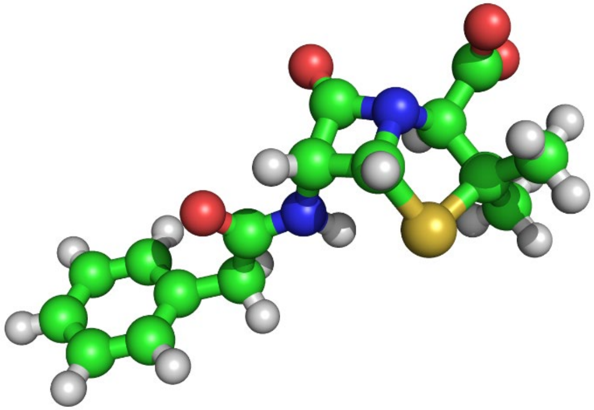
Fall Detection – Wire less, Sensor less, Without Wearables



RF Reflection Data - Professor Dina Katabi, Wireless Center, CSAIL, MIT ● IIC Member

SENSE

CONVERGE

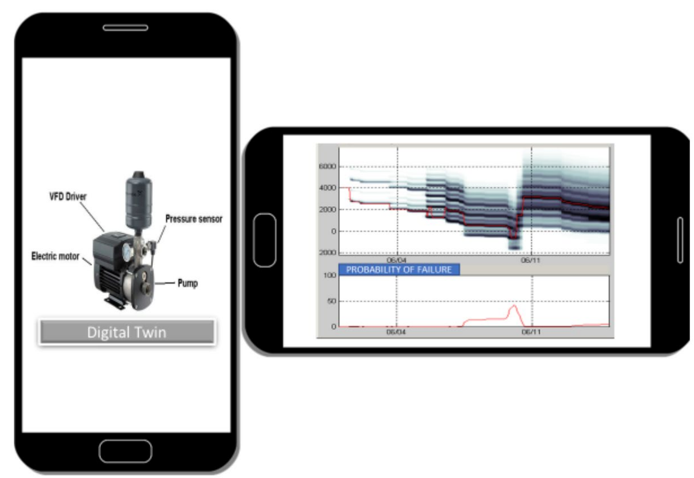


SENSE

BINDING OF ANALYTE

ANALYZE

TRANSMIT



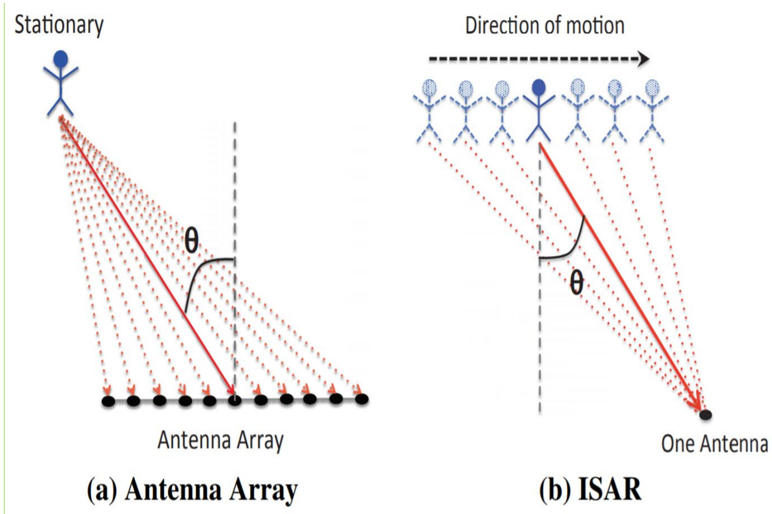
DECISION SUPPORT

SYNERGIZE

S E N S E

Reflection

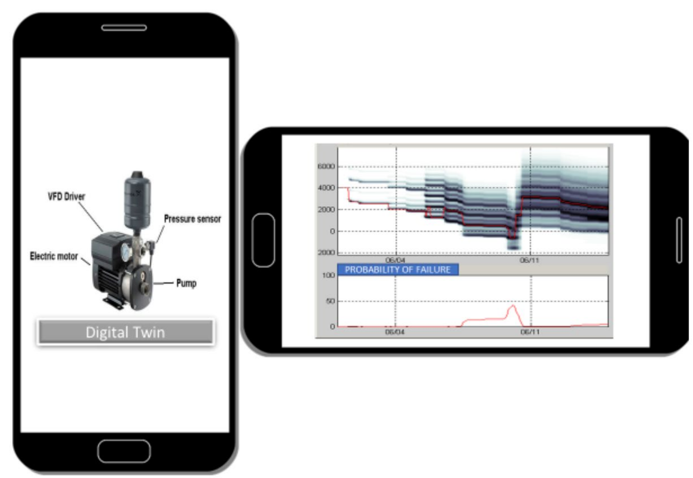
CONVERGE



SENSE RF REFLECTION

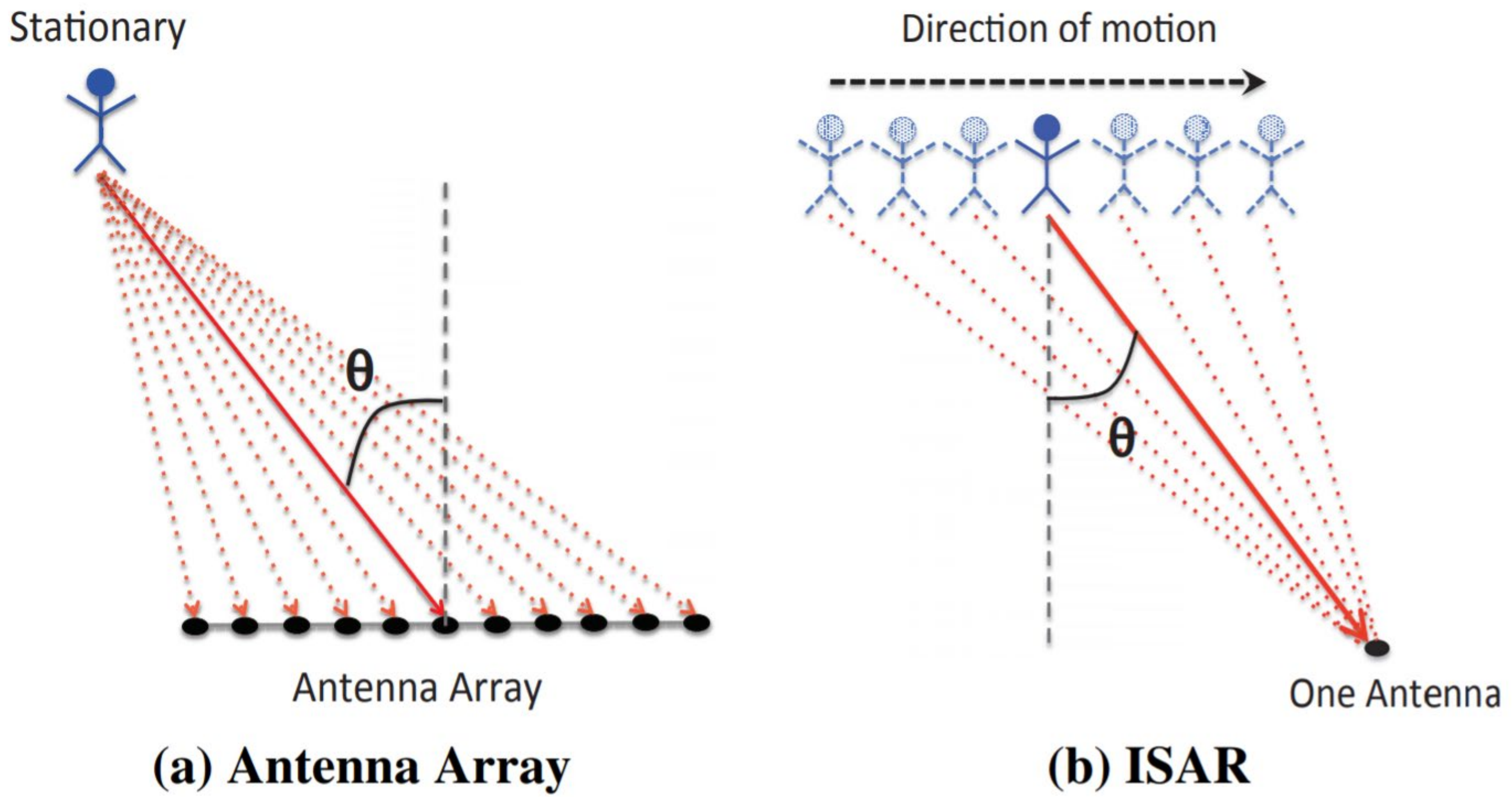
ANALYZE

TRANSMIT



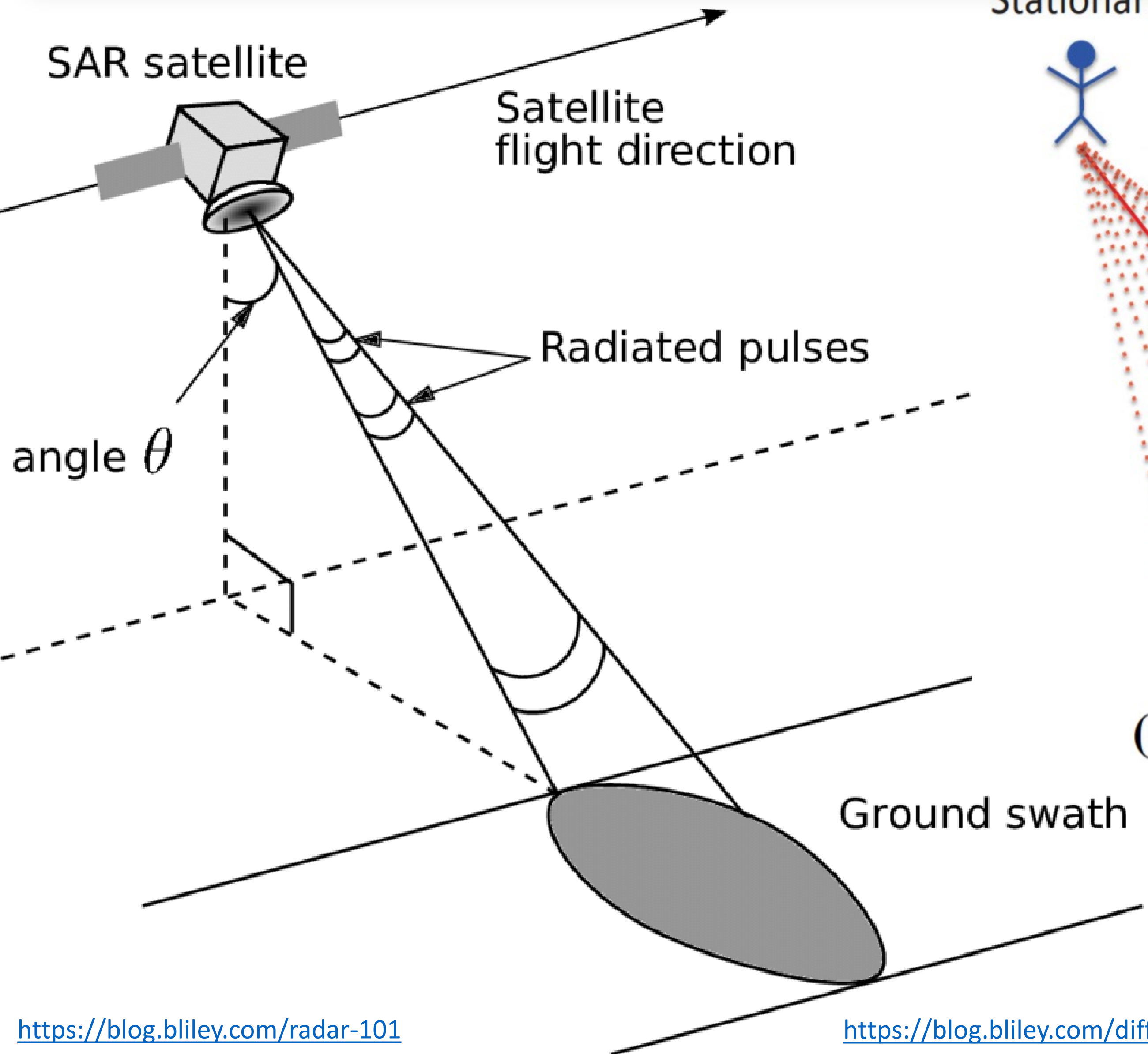
DECISION SUPPORT

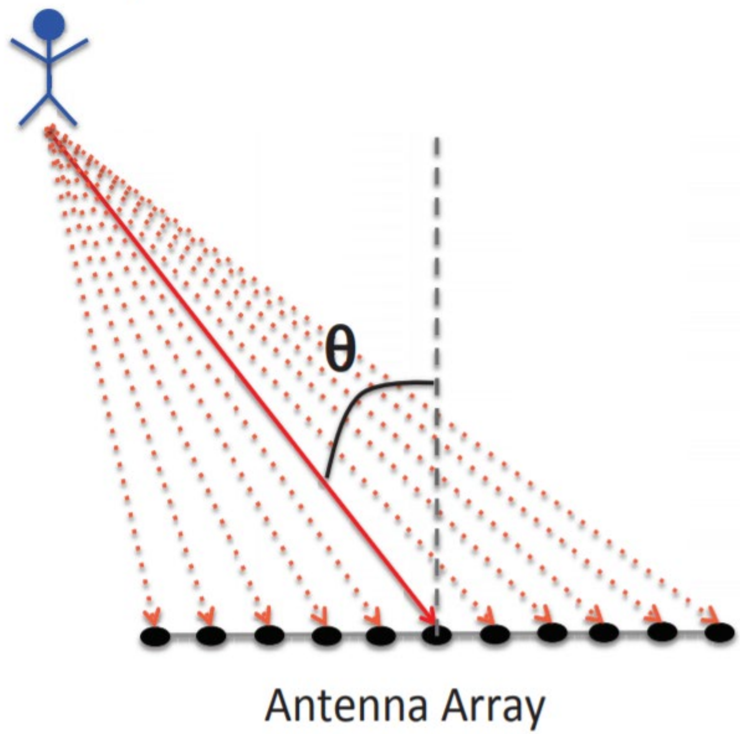
SYNERGIZE



https://people.csail.mit.edu/fadel/papers/wivi-paper.pdf

Synthetic Aperture Radar (SAR)



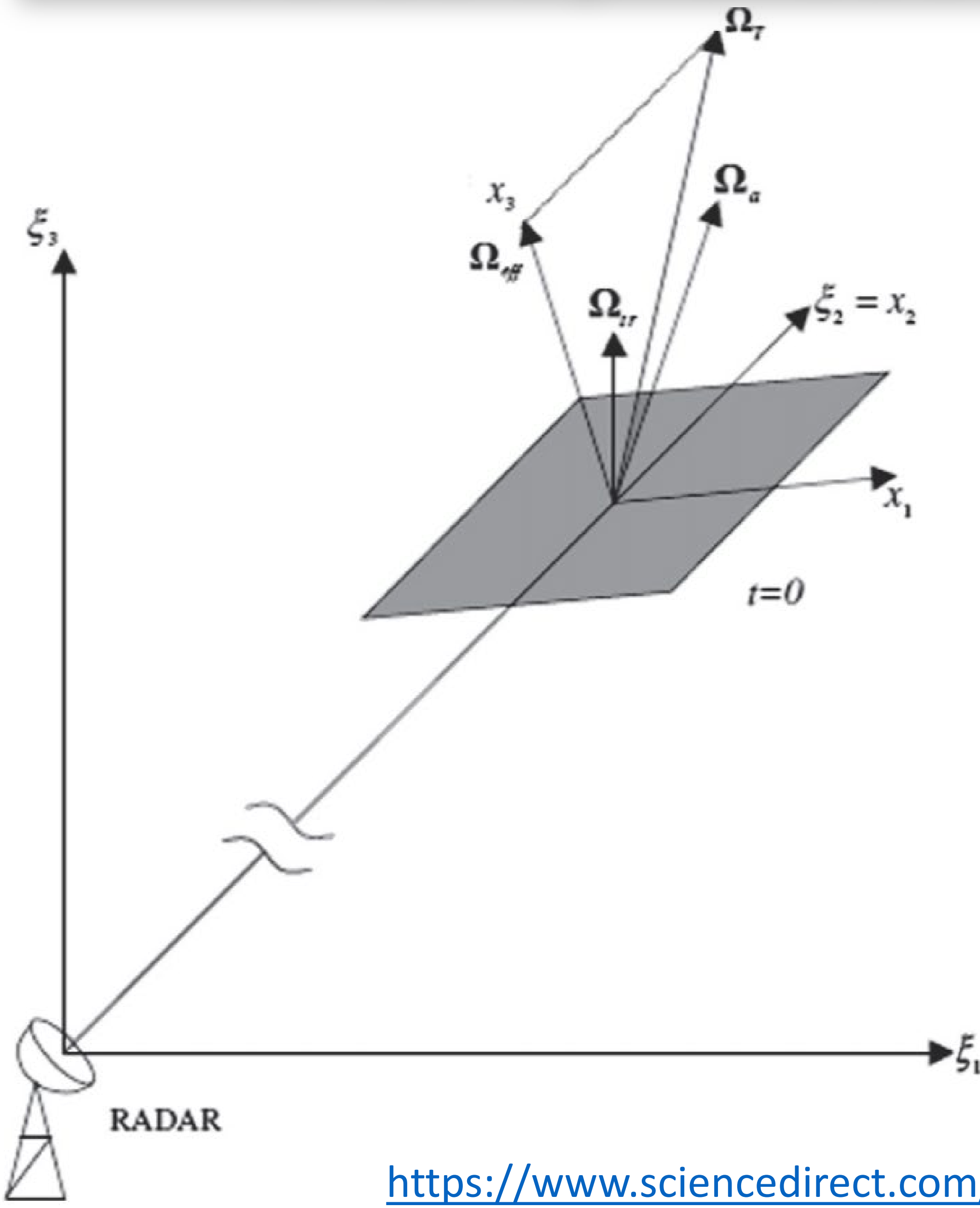


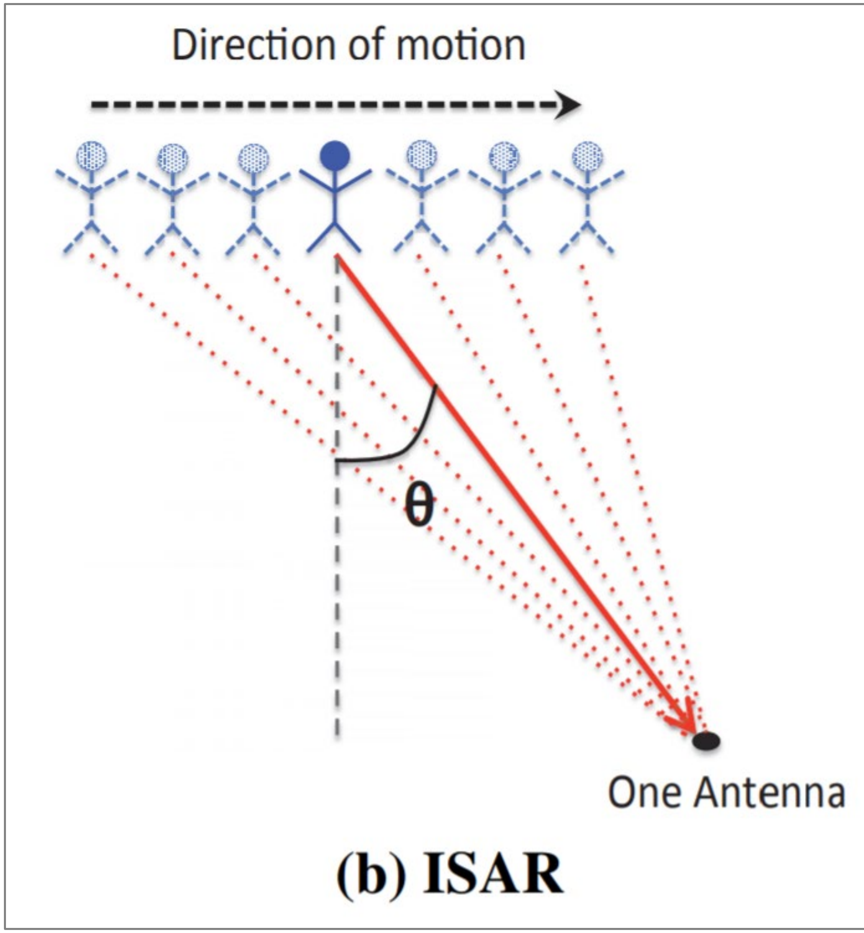
(a) Antenna Array

https://blog.bliley.com/radar-101

https://blog.bliley.com/difference-between-synthetic-aperture-radar-isar

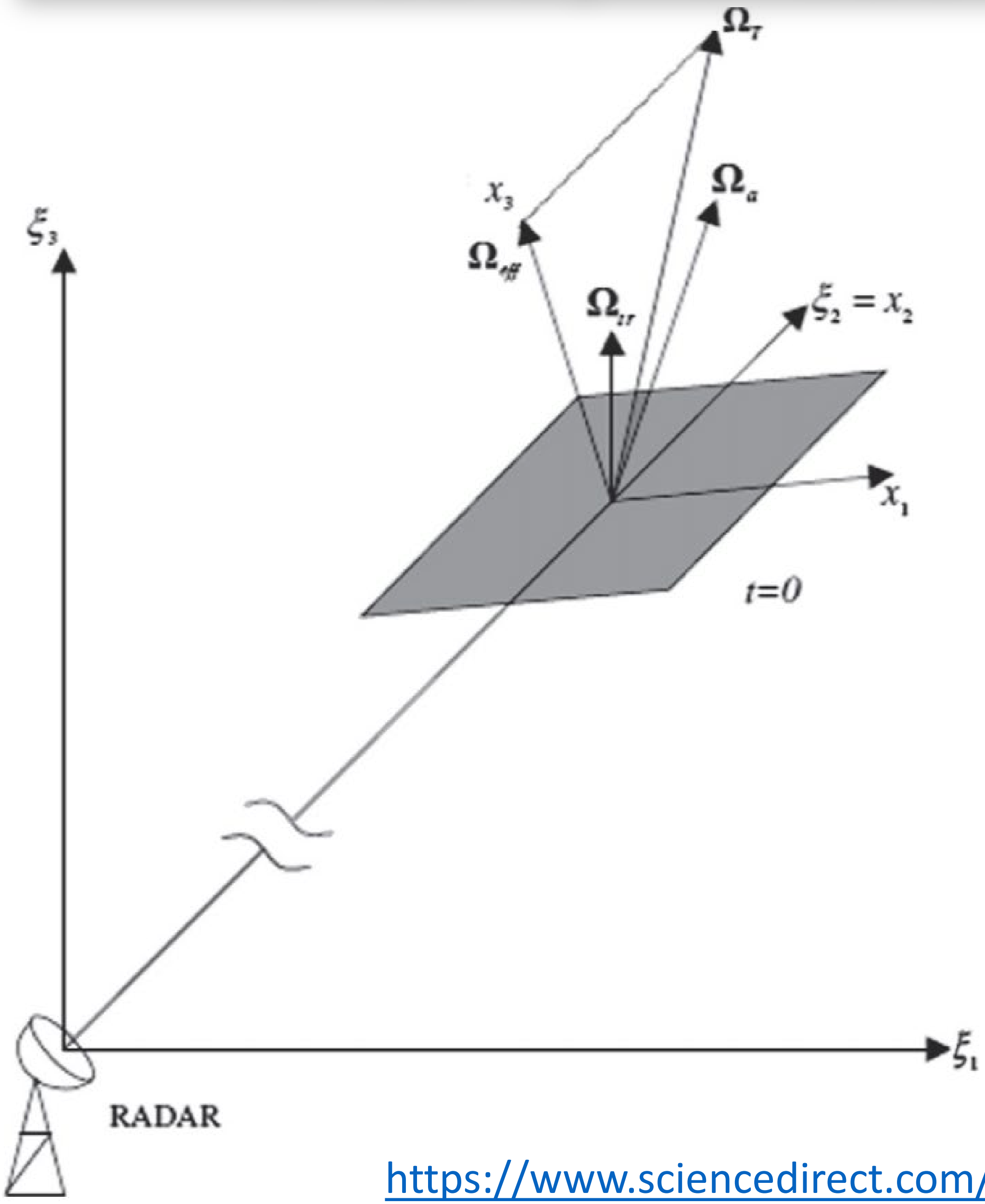
Inverse Synthetic Aperture Radar

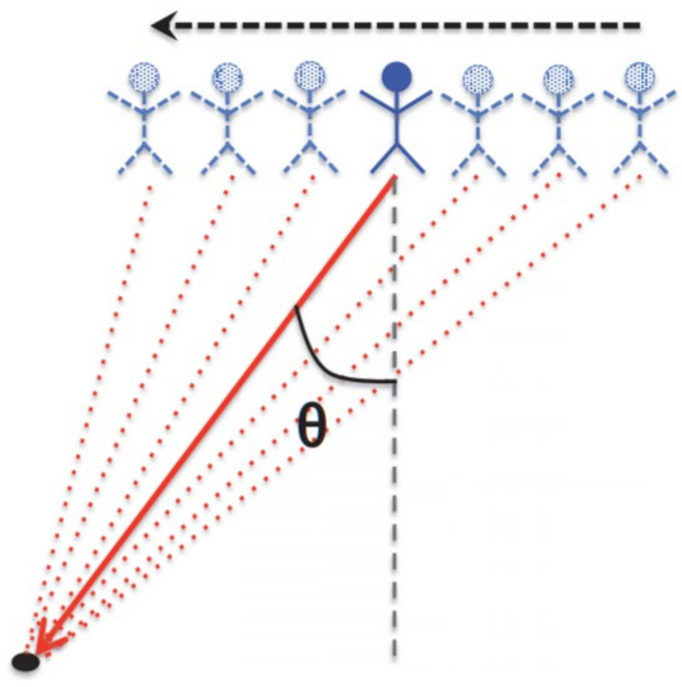




https://www.sciencedirect.com/science/article/pii/B9780123965004000193

Inverse Synthetic Aperture Radar





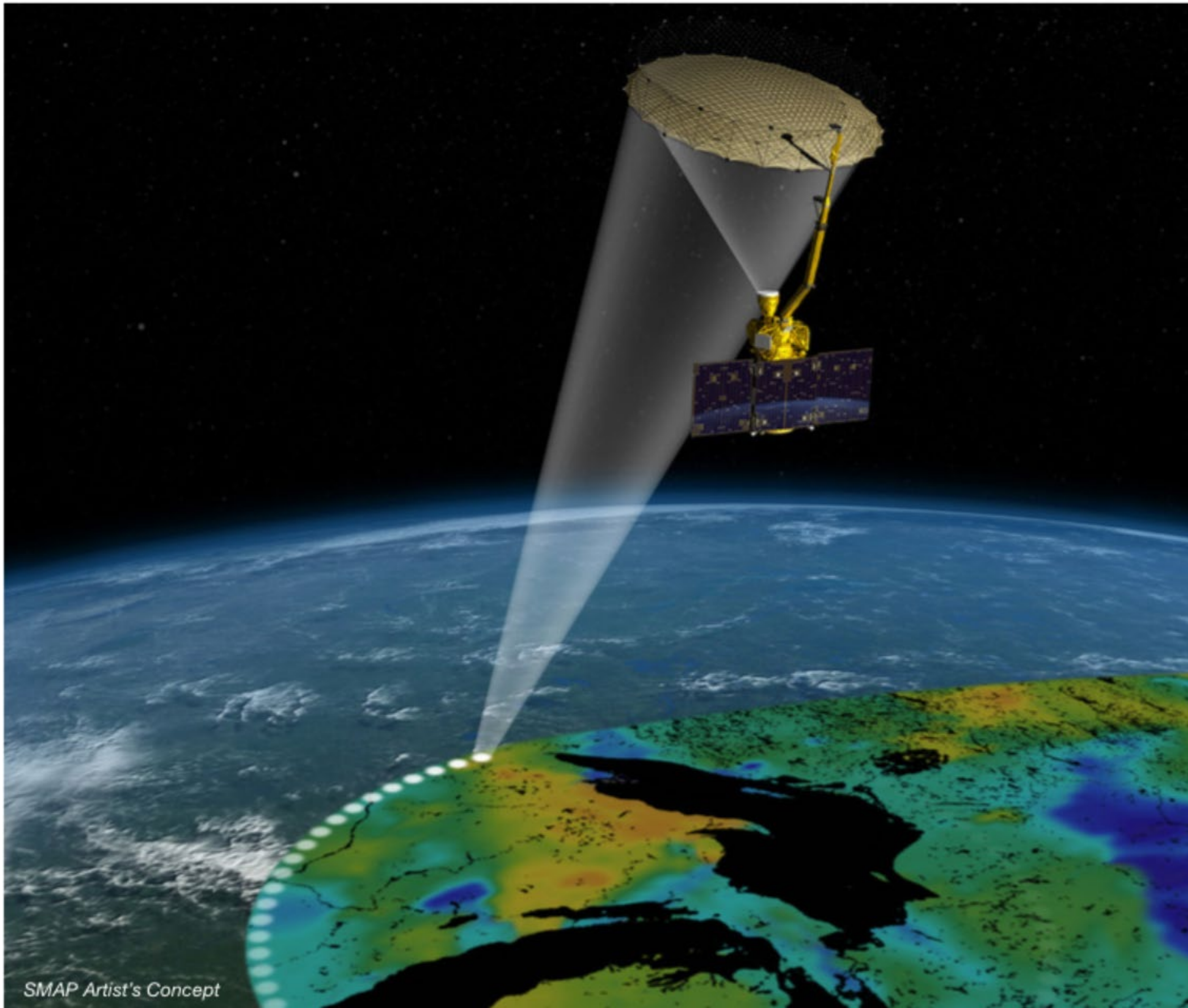
https://www.sciencedirect.com/science/article/pii/B9780123965004000193

Soil Moisture Active Passive Launch

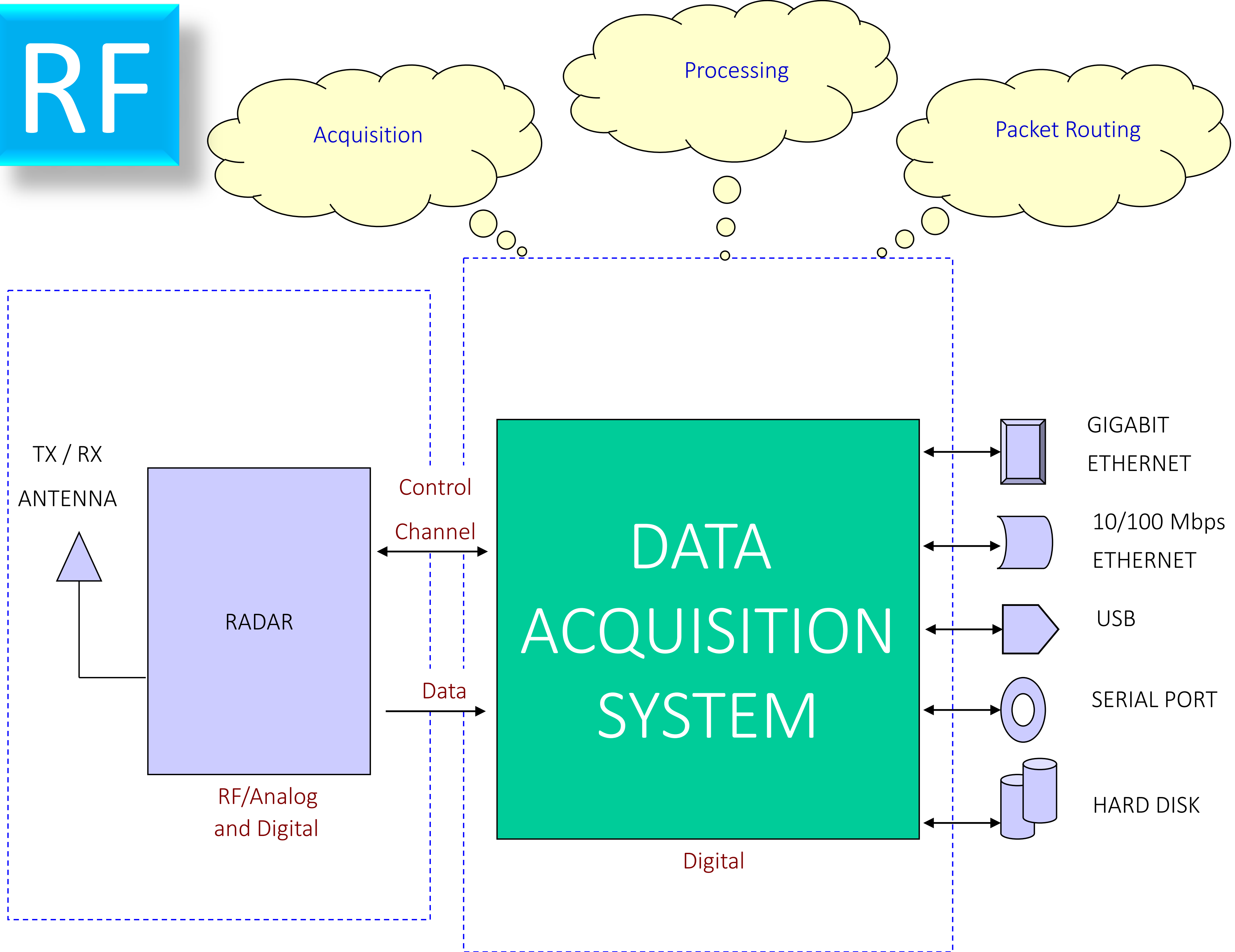
https://smap.jpl.nasa.gov/files/smap2/SMAP_Handbook_FINAL_1_JULY_2014_Web.pdf

NASA On Air: NASA Launches Soil Moisture Satellite to Aid Weather Forecasts (1/31/2015)

Released on January 30, 2015



RF



Acquisition
Processing
Packet Routing
TX / RX
ANTENNA
RADAR
Control
Channel
Data
RF/Analog
and Digital
DATA
ACQUISITION
SYSTEM
Digital
GIGABIT
ETHERNET
10/100 Mbps
ETHERNET
USB
SERIAL PORT
HARD DISK

Data Acquisition Milestone ?

ALEXANDER GRAHAM BELL

UNITED STATES PATENT OFFICE.

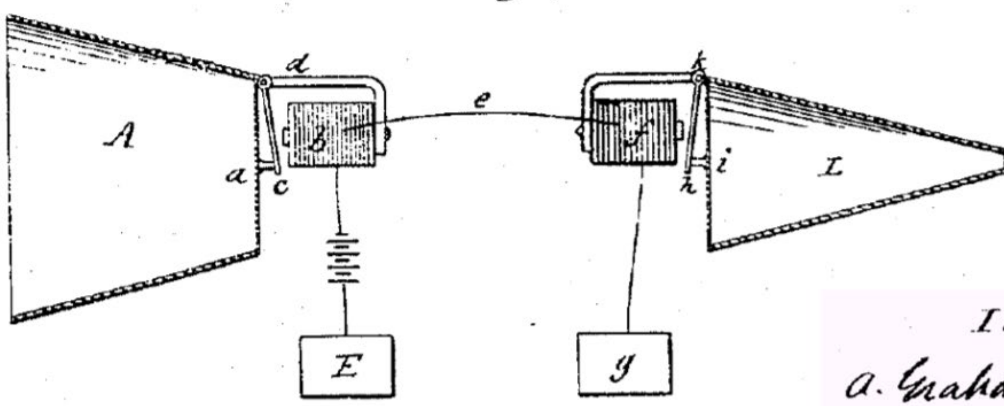
ALEXANDER GRAHAM BELL, OF SALEM, MASSACHUSETTS.

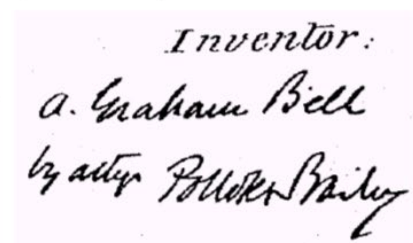
IMPROVEMENT IN TELEGRAPHY.

Specification forming part of Letters Patent No. **174,465**, dated March 7, 1876; application filed February 14, 1876.

⋮

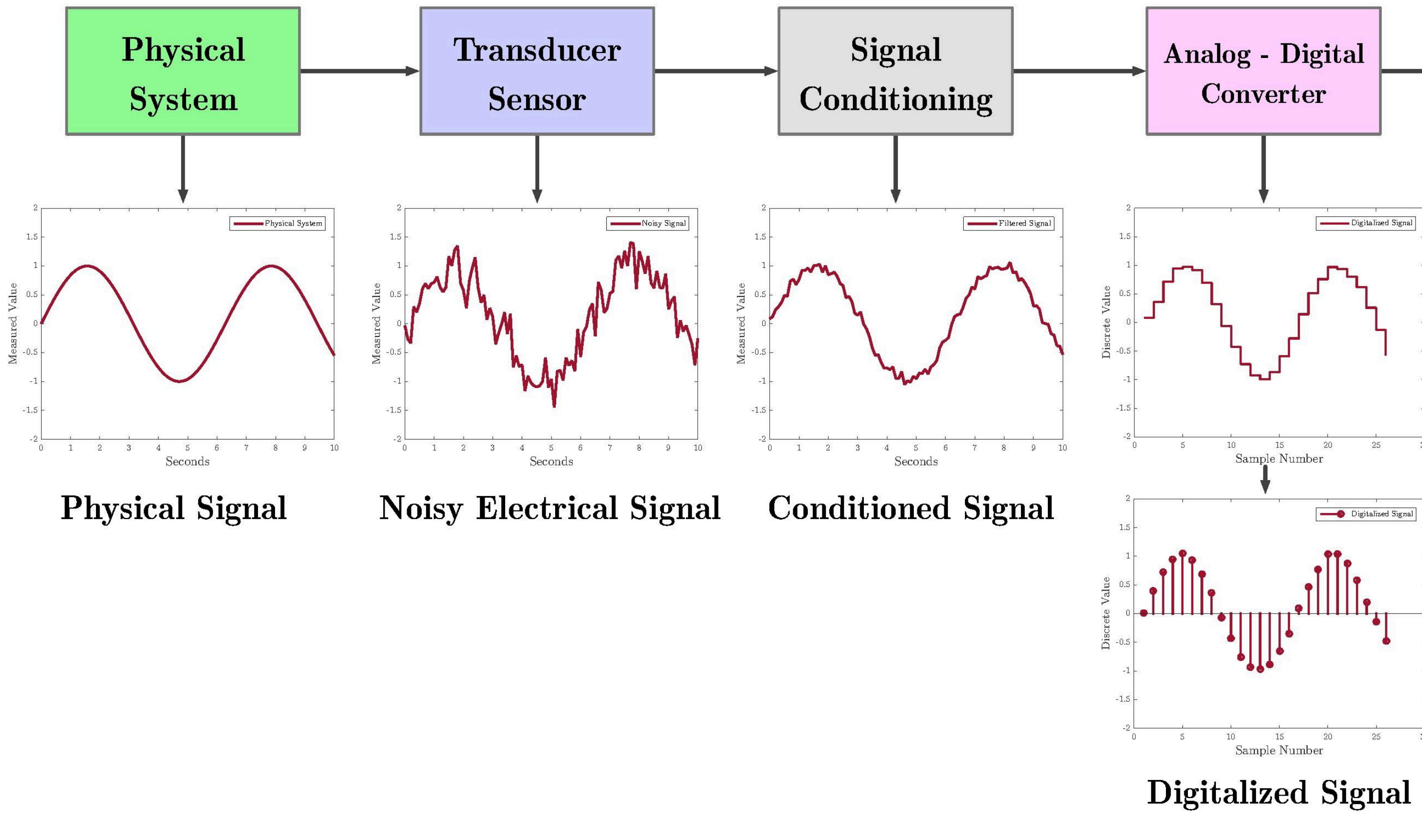
Fig. 7





Extracted from *U.S. Patent 174,465*,
Filed February 14, 1876, Issued March 7, 1876

Digital Data Acquisition System



8 Bit Code

0	1	1	1
0	0	0	1
0	1	1	1
1	0	1	1
1	1	0	0
1	1	1	1
0	1	1	0
1	0	1	0
1	1	1	0
1	1	1	1
0	1	1	1
1	1	1	0
1	1	1	1
0	0	1	1
1	1	0	0
0	1	1	1
0	1	1	1
0	1	1	0
0	1	1	0
1	0	1	1
1	1	1	0
0	0	0	1
1	1	1	1
1	0	1	1
0	0	1	0
0	0	1	1
1	1	1	1
1	0	0	1
1	1	0	1
1	1	1	0

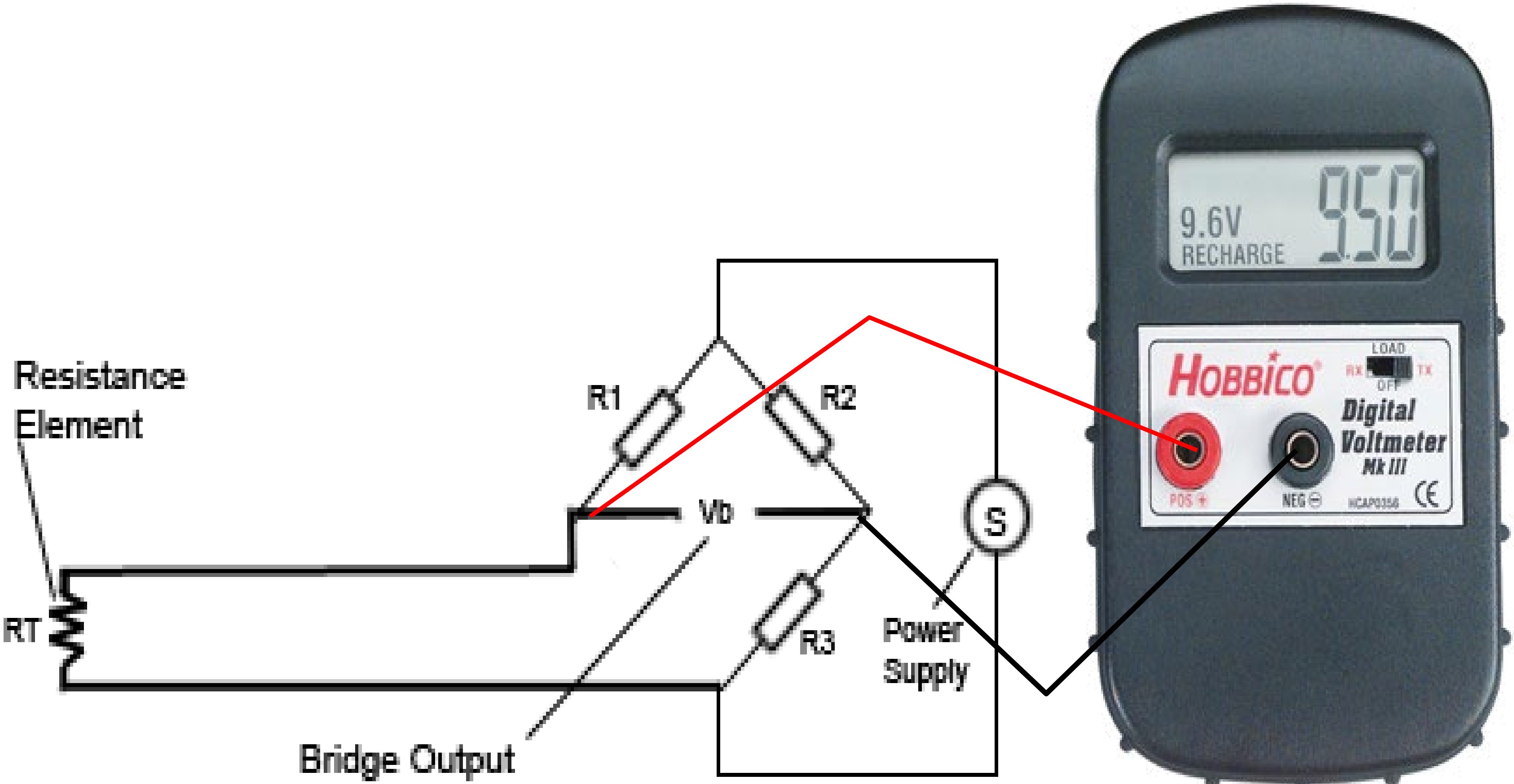
Analog signals are continuous.
Digital signals are discrete.

https://upload.wikimedia.org/wikipedia/commons/thumb/9/97/DigitalDAQv2.pdf/page1-3129px-DigitalDAQv2.pdf.jpg

Historic example of a Data Acquisition System

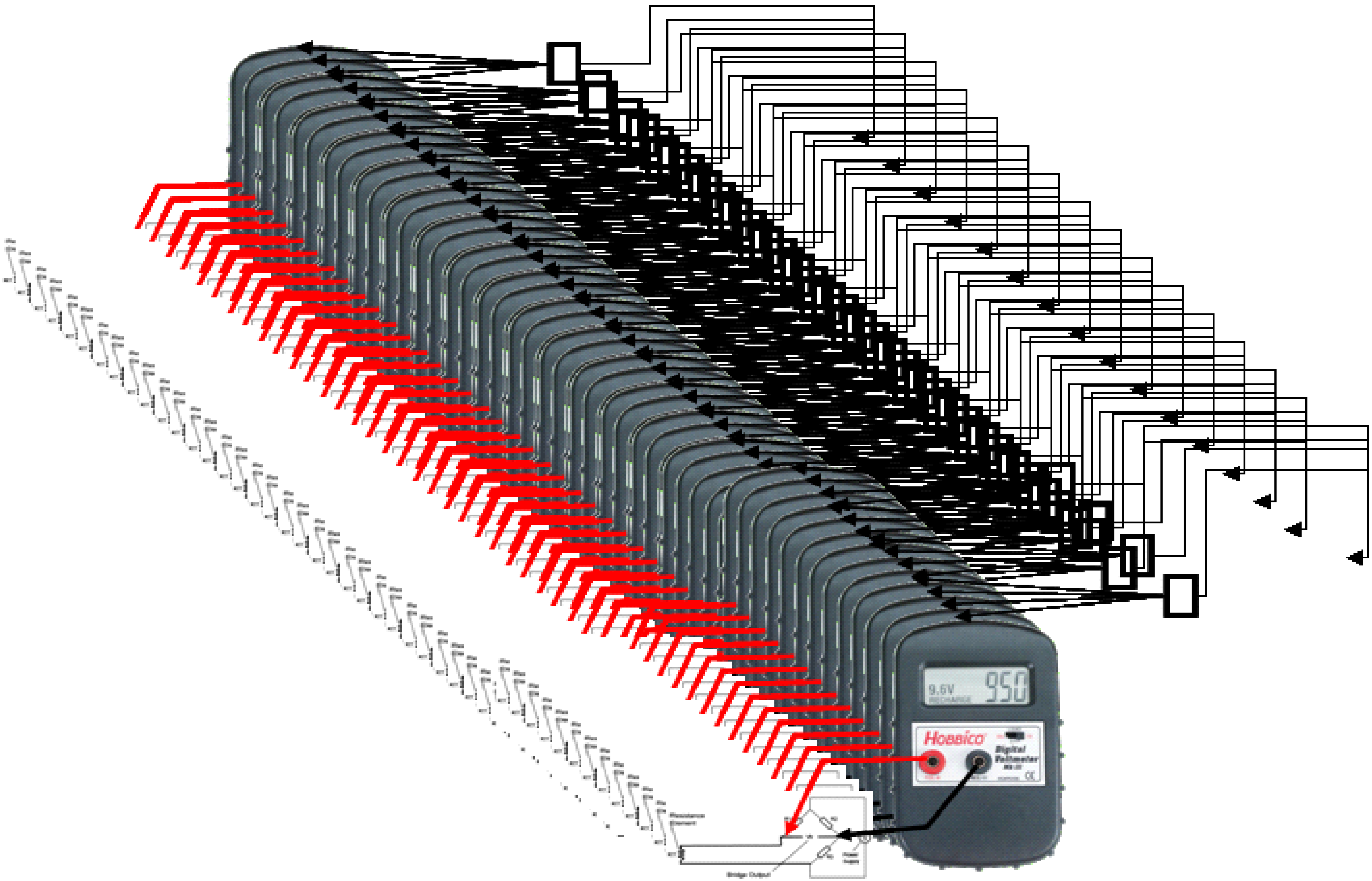
Measuring Temperature ➔ 1 Sensor

- Pt100 thermo-resistor
- Read temperature as a voltage with a digital voltmeter

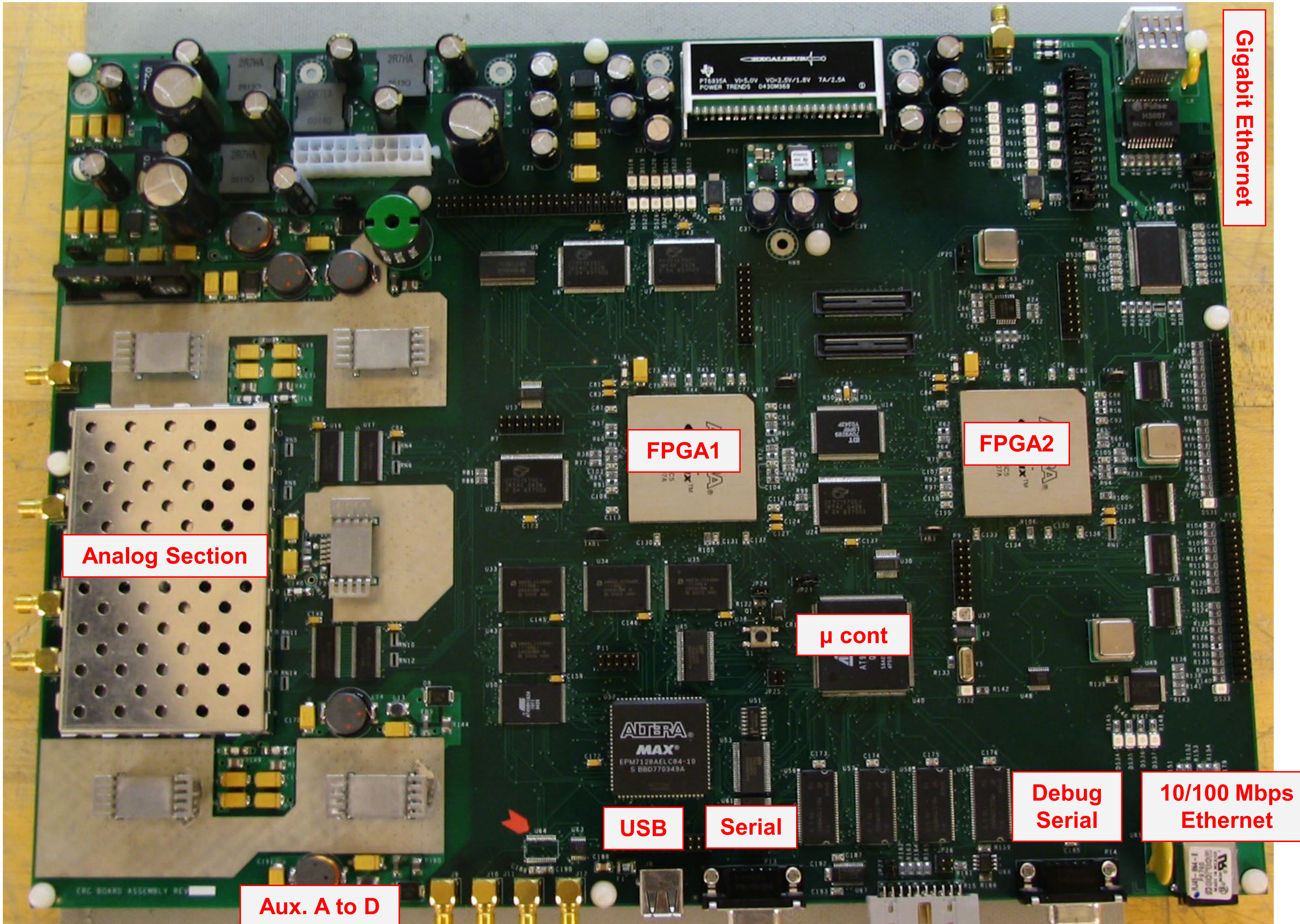


Measuring Temperature ➔ 16 Sensors

Measuring Temperature ➔ 160 Sensors

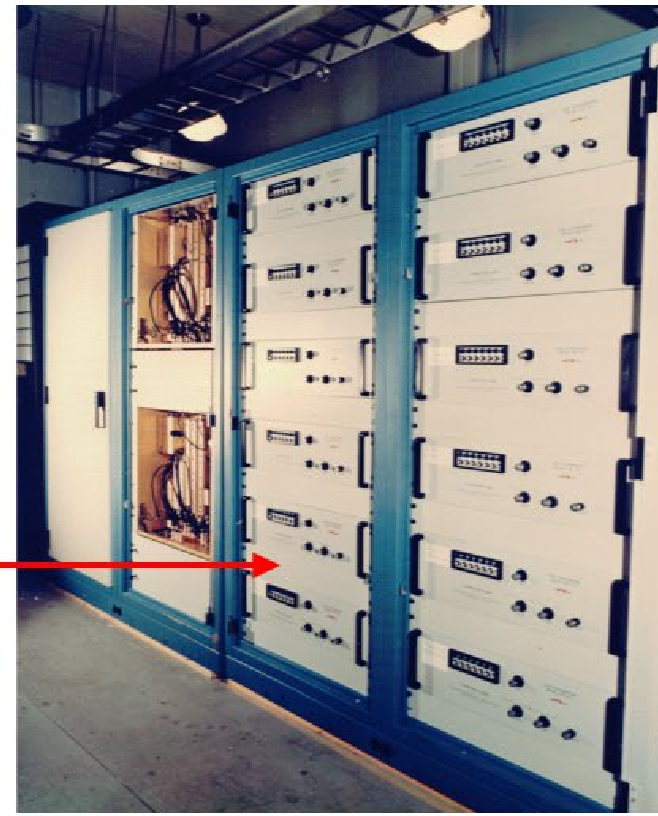


Museum Sample of Data Acquisition System



Corporation, Beckman Instruments, Reeves Instruments, Texas Instruments, Raytheon Computer, Preston Scientific, and Zeltex, Inc. Many of the data converters of the 1960s were in the form of digital voltmeters which used integrating architectures, although Adage introduced an 8-bit, 1-MSPS sampling ADC, the Voldicon VF7, in the early 1960s (Reference 5).

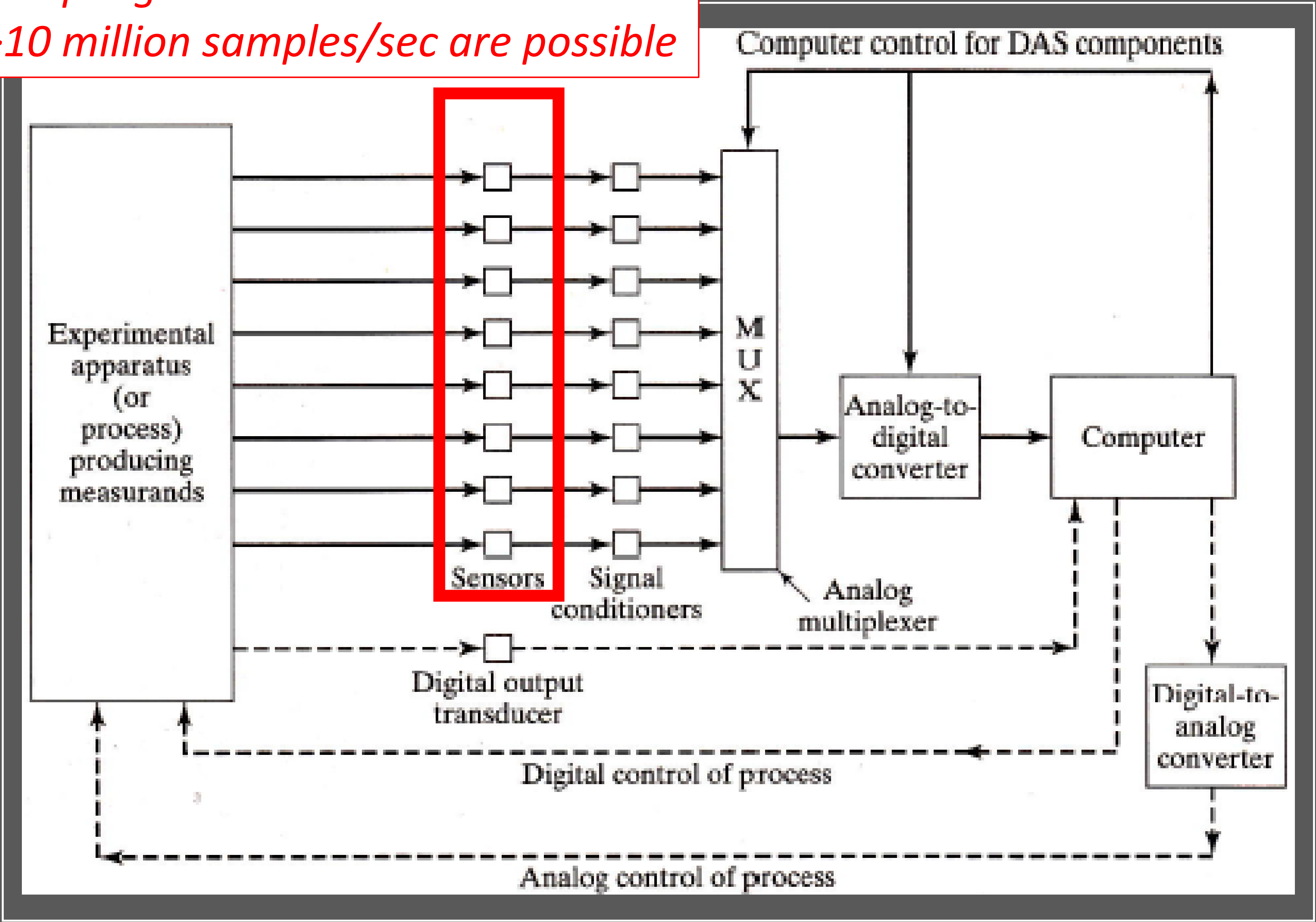
19" RACK-MOUNTED, 150W, $10,000.00



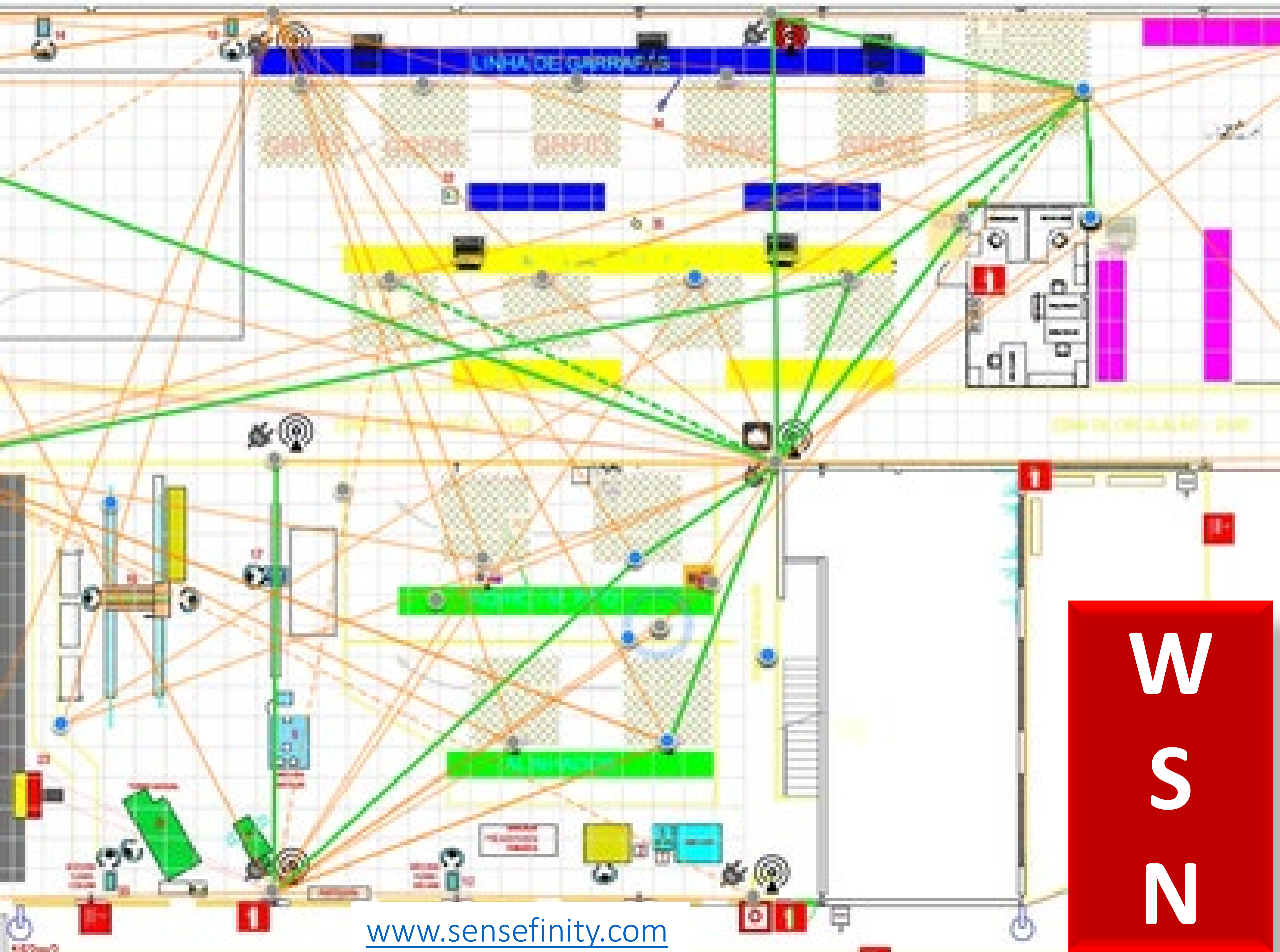
INSTALLATION OF 12 ADCs IN EXPERIMENTAL DIGITAL RADAR RECEIVER

Figure 1.18: *HS-810, 8-bit, 10-MSPS ADC Released* ***1966***

Sampling rates
>10 million samples/sec are possible



For monitoring & controlling systems, embedded computers are used (eg fuel control in automobiles, medical devices and imaging equipment, assembly-line robots).



www.sensefinity.com

W
S
N

σ

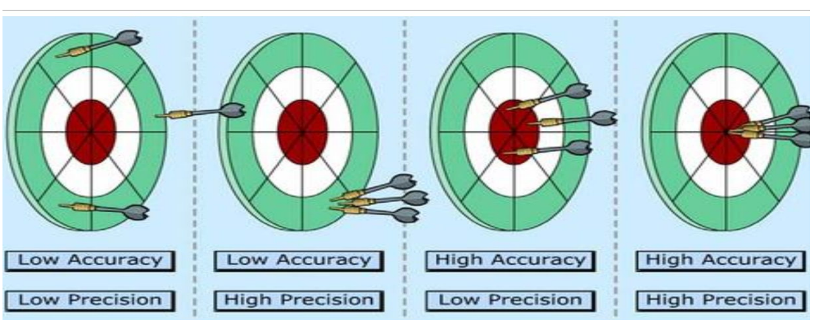
Standard Deviation ~ a measure of precision for repetitive measurements

Sensors are characterized by 2 different yet important attributes: precision and accuracy.

Precision refers to how close values are to each other. For the same test you will get very similar results.

Accuracy means how close you are of a measured value to a standard value like NIST.

Sensor precision often remains high. Drifting will affect the sensor's accuracy and causing it to be off target.



Drift is a natural phenomenon for sensors. It affects all sensors regardless of the vendor. It is caused by physical changes in the sensor.

Sensors breathe air. In order to work they need to be in contact with the air surrounding them. This means that sensors are exposed to conditions that will affect their accuracy.

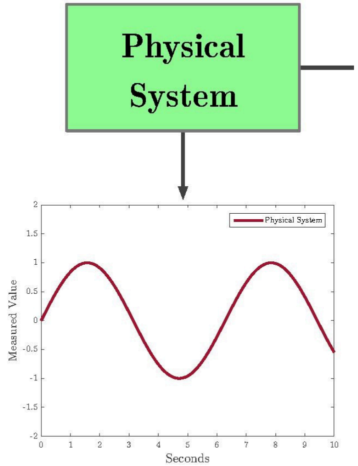
Main impact comes from contamination from airborne pollutants such a dust, chemicals, vapor and other contaminants. Installation may also impact drift.

The only way to know if your sensor has drifted is through calibration. List of static characteristics:

- Drift
- Error
- Noise
- Calibration
- Selectivity
- Sensitivity
- Detection Limit
- Reproducibility
- Stability

- Range
- Precision
- Resolution
- Accuracy
- Offset
- Linearity
- Hysteresis
- Response Time
- Dynamic Linearity

Digital Data Acquisition System



Physical Signal

Deterministic

If predictable for the time span of interest and can be described by mathematical models (eg sinusoidal signal, sine wave)

Stochastic

Cannot be predicted exactly if value has some element of chance associated. Consequently, statistical properties and probabilities used to describe stochastic (random) signals.

Representation of a signal as a plot of amplitude vs time constitutes the

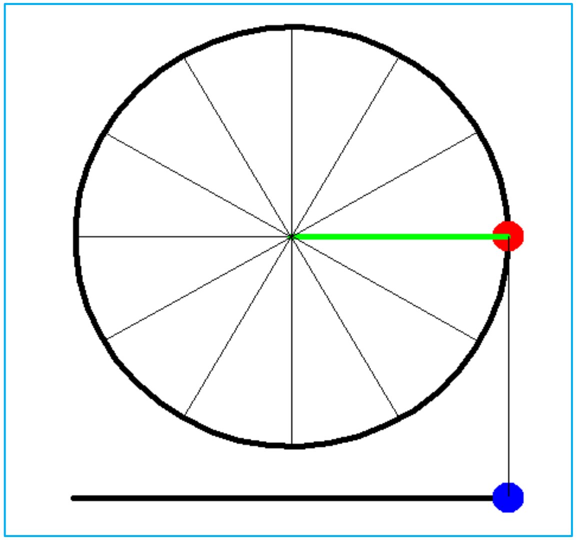
waveform

Pattern of variations in waveforms is data which may contain information
For example, speech is created due to fluctuations in acoustic pressure.

WAVEFORM

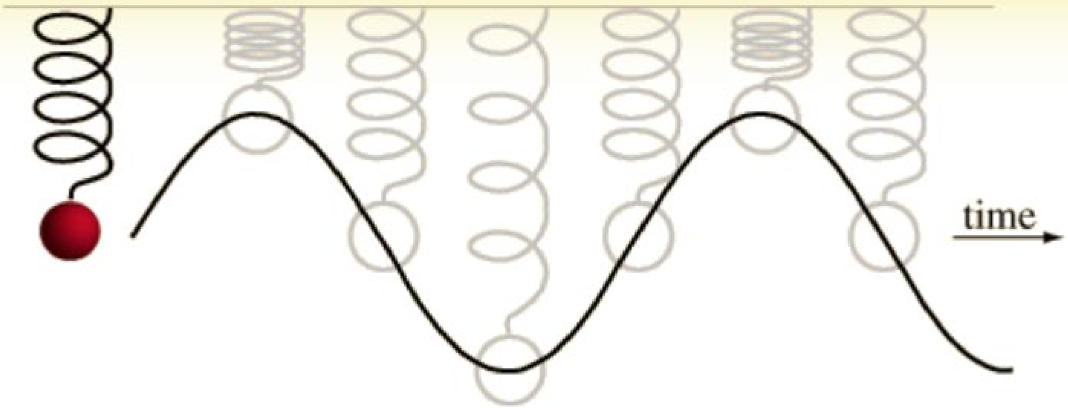
Uniform Circular Motion
(radius A, angular velocity ω)

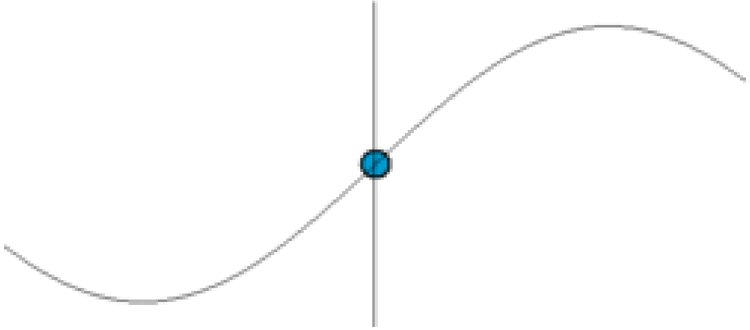
Simple Harmonic Motion
(amplitude A, angular frequency ω)



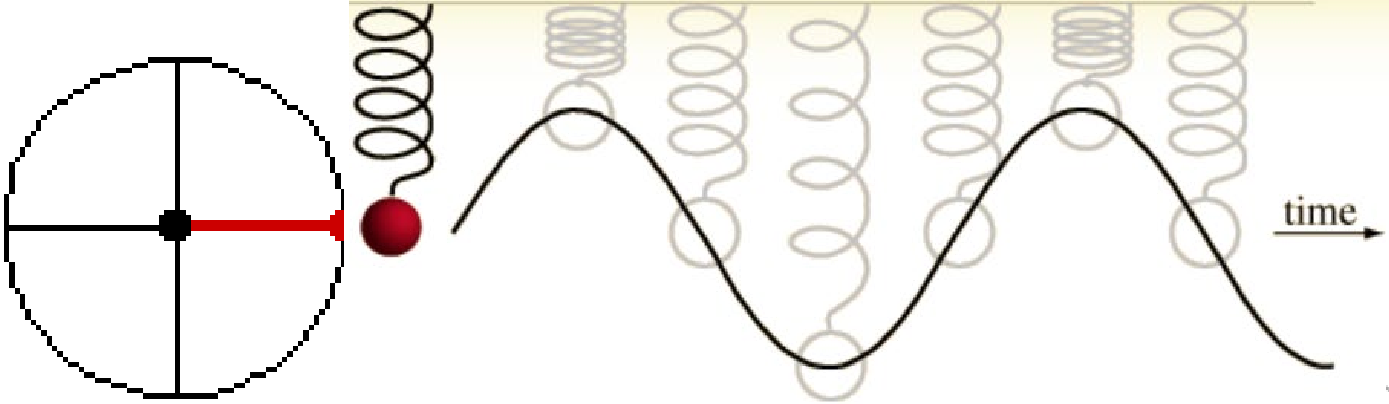
labman.phys.utk.edu/phys221core/modules/m11/harmonic_motion.html

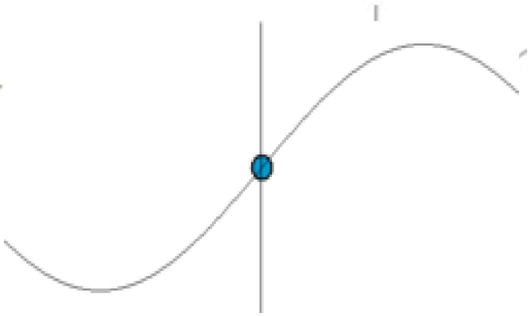
Harmonic motion

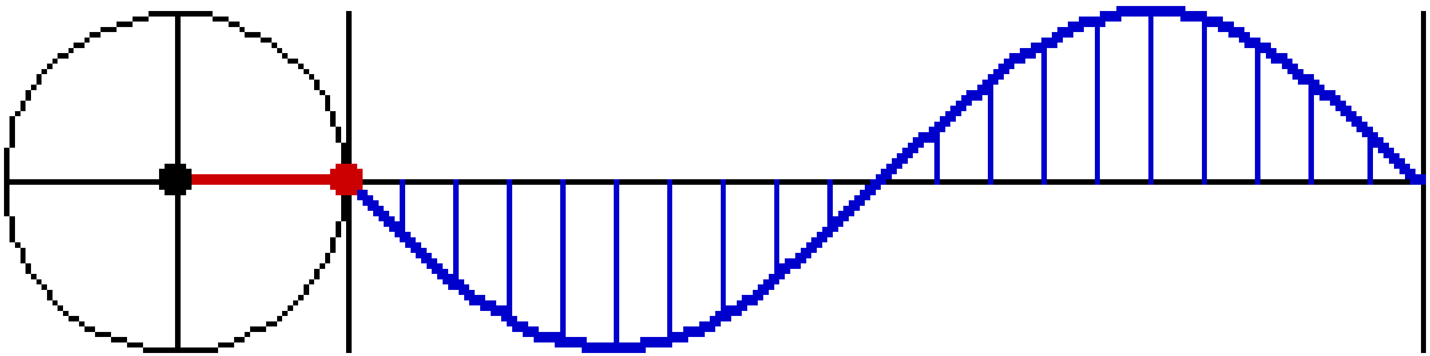




Harmonic motion







https://www.youtube.com/watch?v=BkAnmKI_4Io
https://www.youtube.com/watch?v=eeYRkW8V7Vg

Simple harmonic motion (SHM) is repetitive.

A = **amplitude** of oscillation i.e. max displacement of object from equilibrium (positive or negative x-direction).

Period T is the time it takes the object to complete one oscillation and return to the starting position.

Angular frequency ω (omega) is given by $\omega = 2\pi/T$. Angular frequency is measured in radians per second.

Inverse of period is **frequency** ($f = 1/T$). $f = 1/T = \omega/2\pi$ gives the number of complete oscillations per unit time, unit Hertz (1 Hz = 1/s).

Velocity of object, as a function of time, is givne by $v(t) = -\omega A \sin(\omega t + \phi)$

Acceleration is given by $a(t) = -\omega^2 A \cos(\omega t + \phi) = -\omega^2 x$.

The quantity ϕ is called the **phase constant.** If object has max displacement at $t = 0$ in the positive x-direction, then $\phi = 0$ (if negative x-direction, then $\phi = \pi$). At $t = 0$ particle is moving through its equilibrium position with max velocity in negative x-direction then $\phi = \pi/2$. The quantity $\omega t + \phi$ is the **phase** (omega times t + phi)

Wavelength (lambda, λ) is the shortest distance between two successive points on a wave that are in the same phase.

Sine wave - Fundamental Waveform of Periodic Analog Signal

$$s(t) = A \cdot \sin(2\pi f t + \varphi)$$

(1.1) **peak amplitude (A) – absolute value of signal's highest intensity – unit: volts [V]**

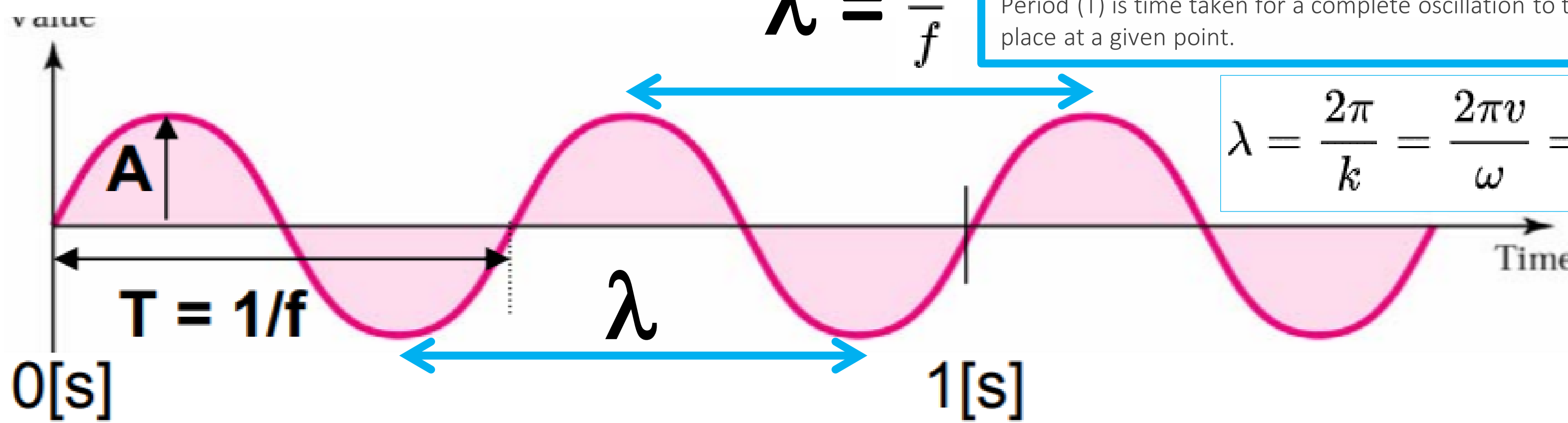
(1.2) **frequency (f) – number of periods in one second – unit: hertz [Hz] = [1/s] – inverse of period (T)!**

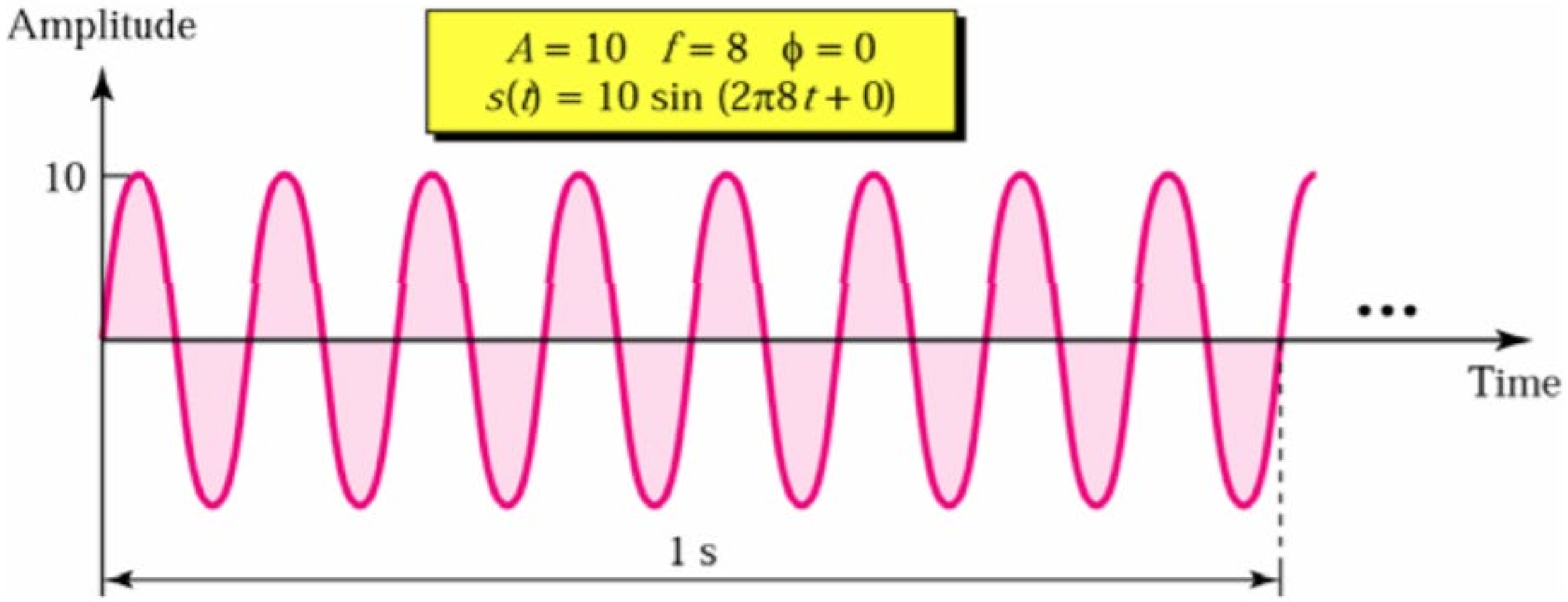
(1.3) **phase (φ) – absolute position of the waveform relative to an arbitrary origin – unit: degrees [º] or radians [rad]**

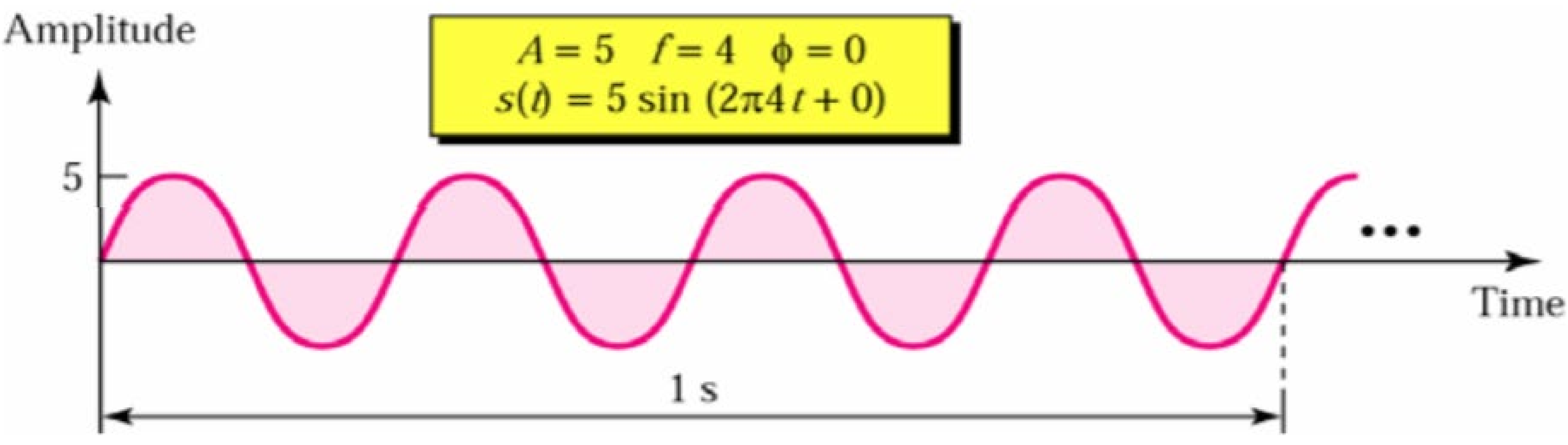
$$\lambda = \frac{v}{f}$$

Wavelength (λ) is the shortest distance between two successive points on a wave that are in the SAME phase. Period (T) is time taken for a complete oscillation to take place at a given point.

$$\lambda = \frac{2\pi}{k} = \frac{2\pi v}{\omega} = \frac{v}{f}$$




Amplitude
A = 10 f = 8 ϕ = 0
s(t) = 10 sin (2π8t + 0)
10
Time
1 s

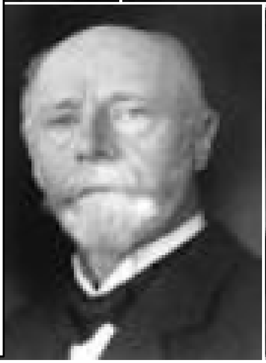

Amplitude
A = 5 f = 4 ϕ = 0
s(t) = 5 sin (2π4t + 0)
5
Time
1 s

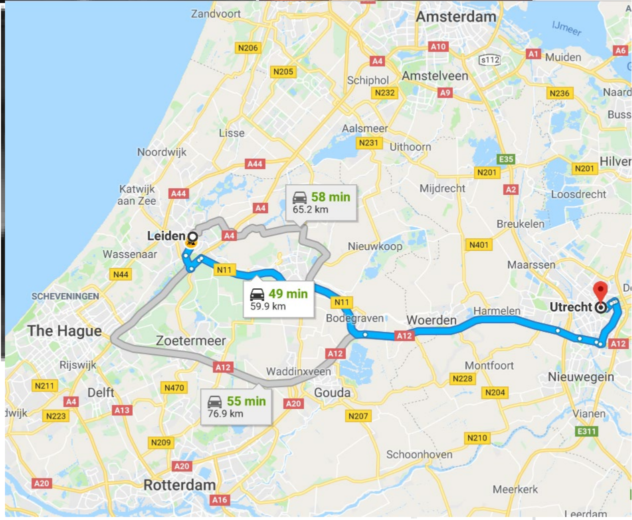
Waveform data acquisition and understanding the information in data

can make a difference between life and death

Why do we need rib cages?

Hearts are wild creatures.





Willem Einthoven

Dutch doctor

Willem Einthoven was a Dutch doctor and physiologist. He invented the first practical electrocardiogram in 1903 and received the Nobel Prize in Medicine in 1924 for it. Wikipedia

Born: May 21, 1860, Semarang, Indonesia

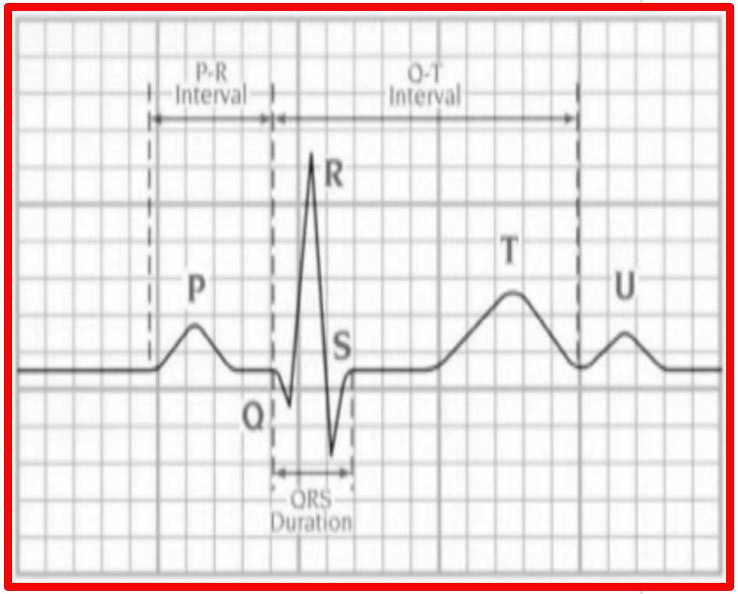
Died: September 29, 1927, Leiden, Netherlands

Known for: Electrocardiography

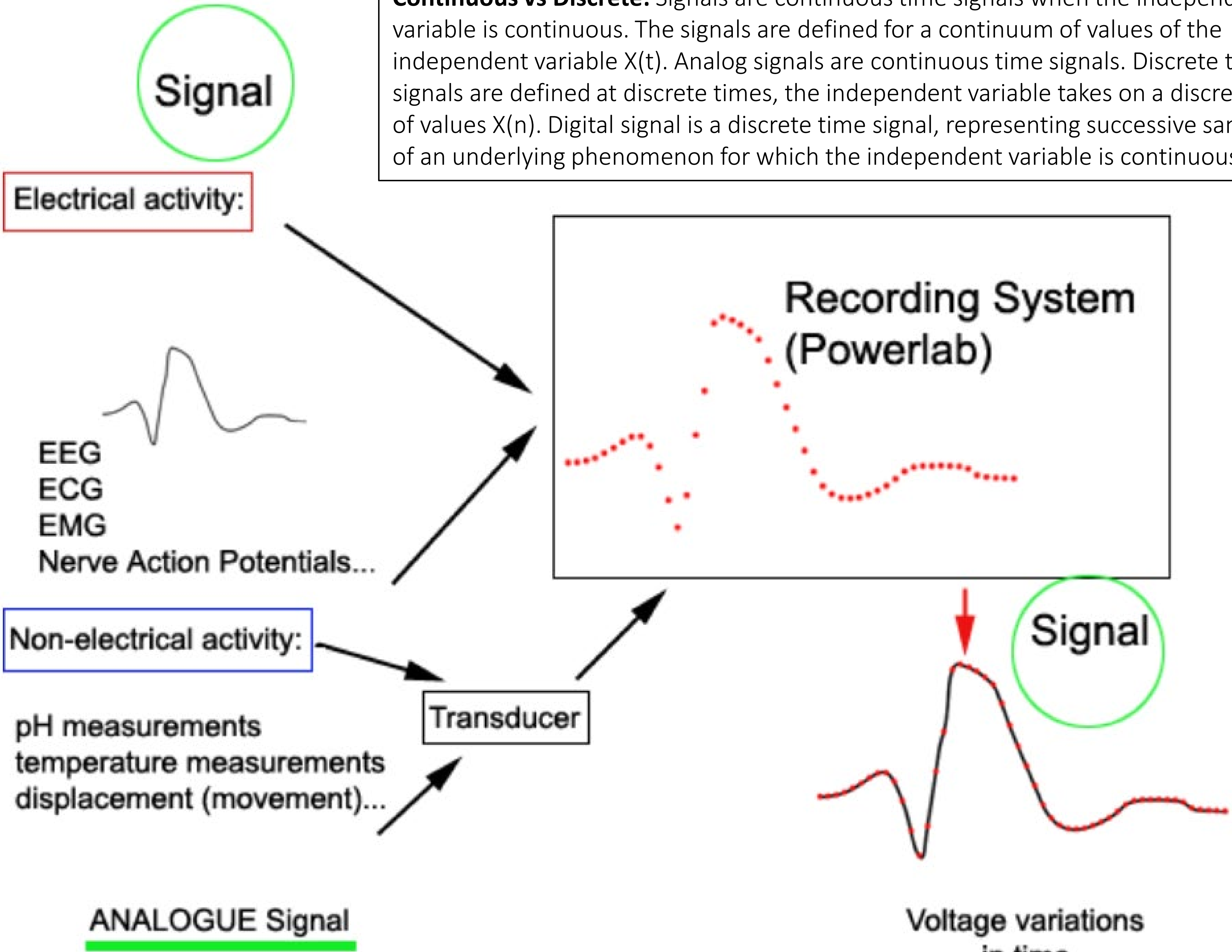
Education: Utrecht University

Parents: Jacob Einthoven, Louise Marie Mathilde

Awards: Nobel Prize in Physiology or Medicine



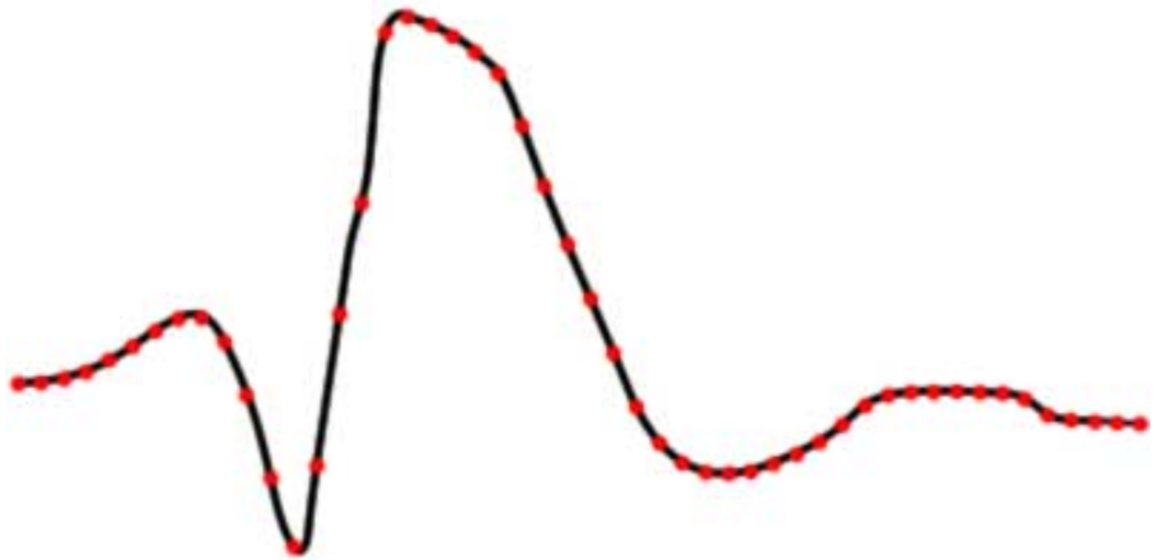
Continuous vs Discrete: Signals are continuous time signals when the independent variable is continuous. The signals are defined for a continuum of values of the independent variable X(t). Analog signals are continuous time signals. Discrete time signals are defined at discrete times, the independent variable takes on a discrete set of values X(n). Digital signal is a discrete time signal, representing successive samples of an underlying phenomenon for which the independent variable is continuous.



Consider the signal shown in the figure which is part of an electroencephalogram. It is an analogue signal, since it is continuously changing in time. Any arbitrarily given value that is within the range of the signal can be obtained simply by measuring electrical activity at the right point in time. The object of A/D conversion is to convert this signal into a digital representation, and this is done by **sampling** the signal. A digital signal is a *sampled* signal, obtained by sampling the analogue signal at discrete points in time. These points are usually evenly spaced in time, with the time between being referred to as the **sampling interval**.

Discrete signal represents successive **samples** of an underlying phenomenon for which the independent variable is continuous.

In the figure, the sampling interval is 2.5 milliseconds, with samples being taken at the times indicated by the red dots on the waveform.

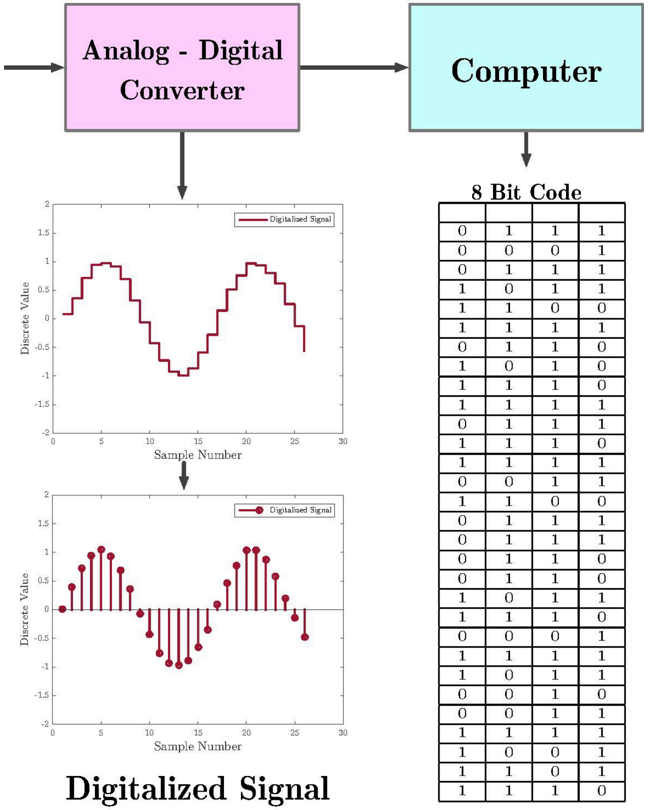


The electronic circuit that carries out the process of sampling the signal and A/D conversion is called an analogue-to-digital converter (ADC). Being an electronic device, it requires an electrical signal at its input. Thus the first step in the process of A/D conversion is to convert the analogue (non-voltage) signal into an analogue voltage signal. The device that carries out this function is called a **transducer**. For signals which are inherently voltages such as the electrocardiogram from the heart, the electrooculogram from the eyes, or the electromyogram from muscle, transduction is of course not necessary.

DATA SAMPLING

errors could turn day into night

Digital Data Acquisition System



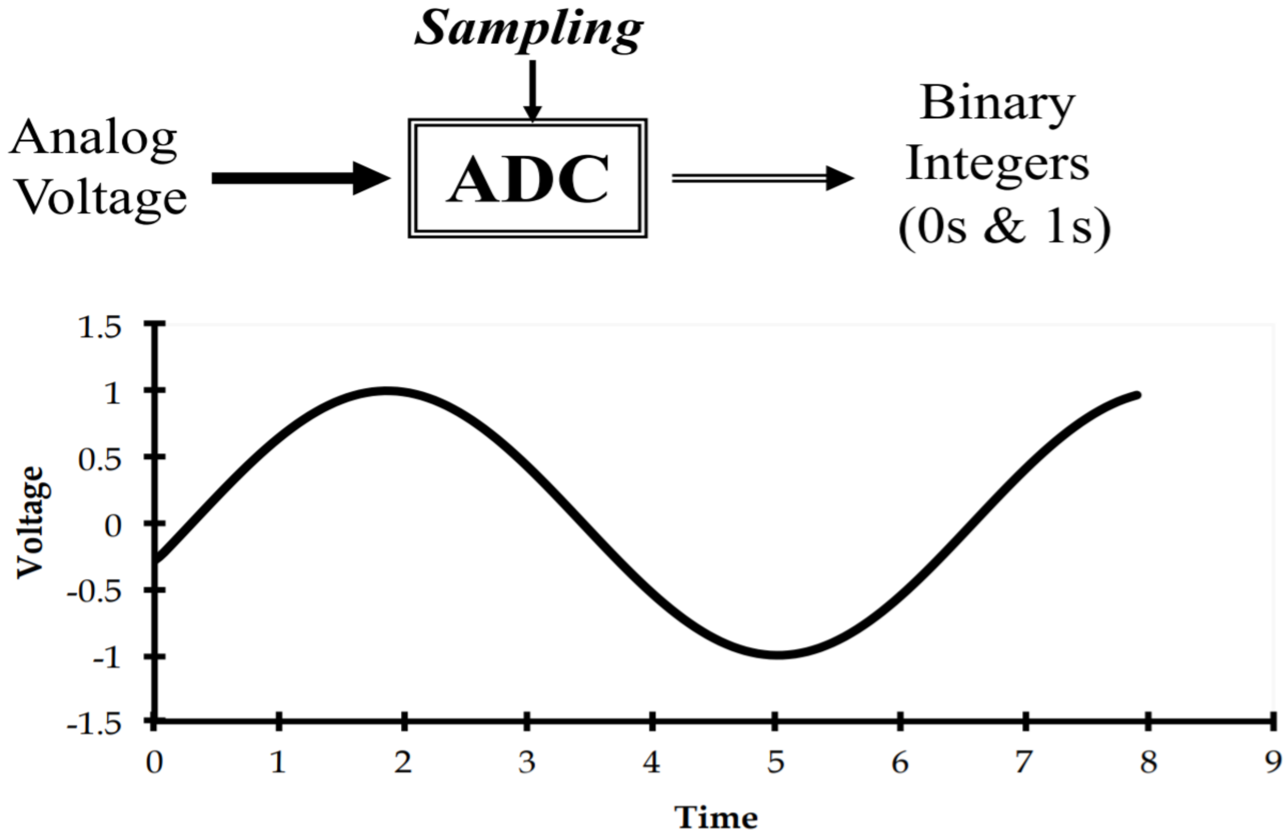
8 Bit Code

0	1	1	1
0	0	0	1
0	1	1	1
1	0	1	1
1	1	0	0
1	1	1	1
0	1	1	0
1	0	1	0
1	1	1	0
1	1	1	1
0	1	1	1
1	1	1	0
1	1	1	1
0	0	1	1
1	1	0	0
0	1	1	1
0	1	1	1
0	1	1	0
0	1	1	0
1	0	1	1
1	1	1	0
0	0	0	1
1	1	1	1
1	0	1	1
0	0	1	0
0	0	1	1
1	1	1	1
1	0	0	1
1	1	0	1
1	1	1	0

Analog signals are continuous.
Digital signals are discrete.

ADC

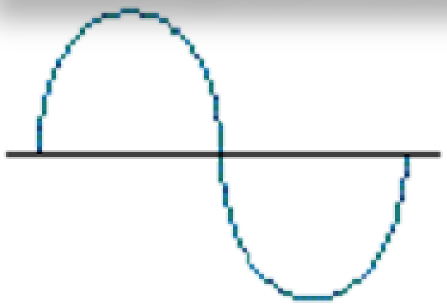
converts analog voltages to binary



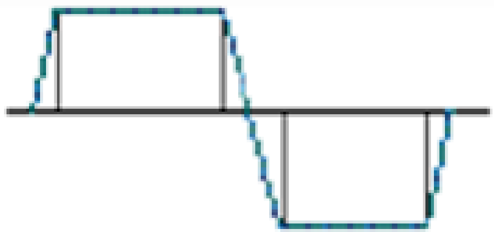
https://link-springer-com.libproxy.mit.edu/content/pdf/10.1007%2F978-3-319-44971-5.pdf

The analog-to-digital converter compares the value of the analog signal at the sample moment to a fraction of the reference quantity (voltage, current, charge, time). **The accuracy of this analog fraction determines the accuracy of the conversion.** This analog fraction is approximated in the digital domain, where the digital code is a fraction of the available word width. The analog-to-digital converter tries to find the digital code that gives an optimum match between these ratios at every sample moment.

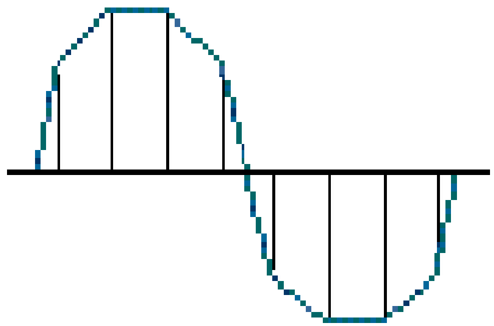
A/D Converter ◆ Sampling Rate



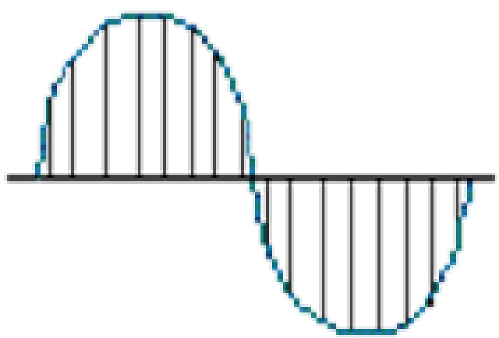
Analog Input



4 samples/cycle



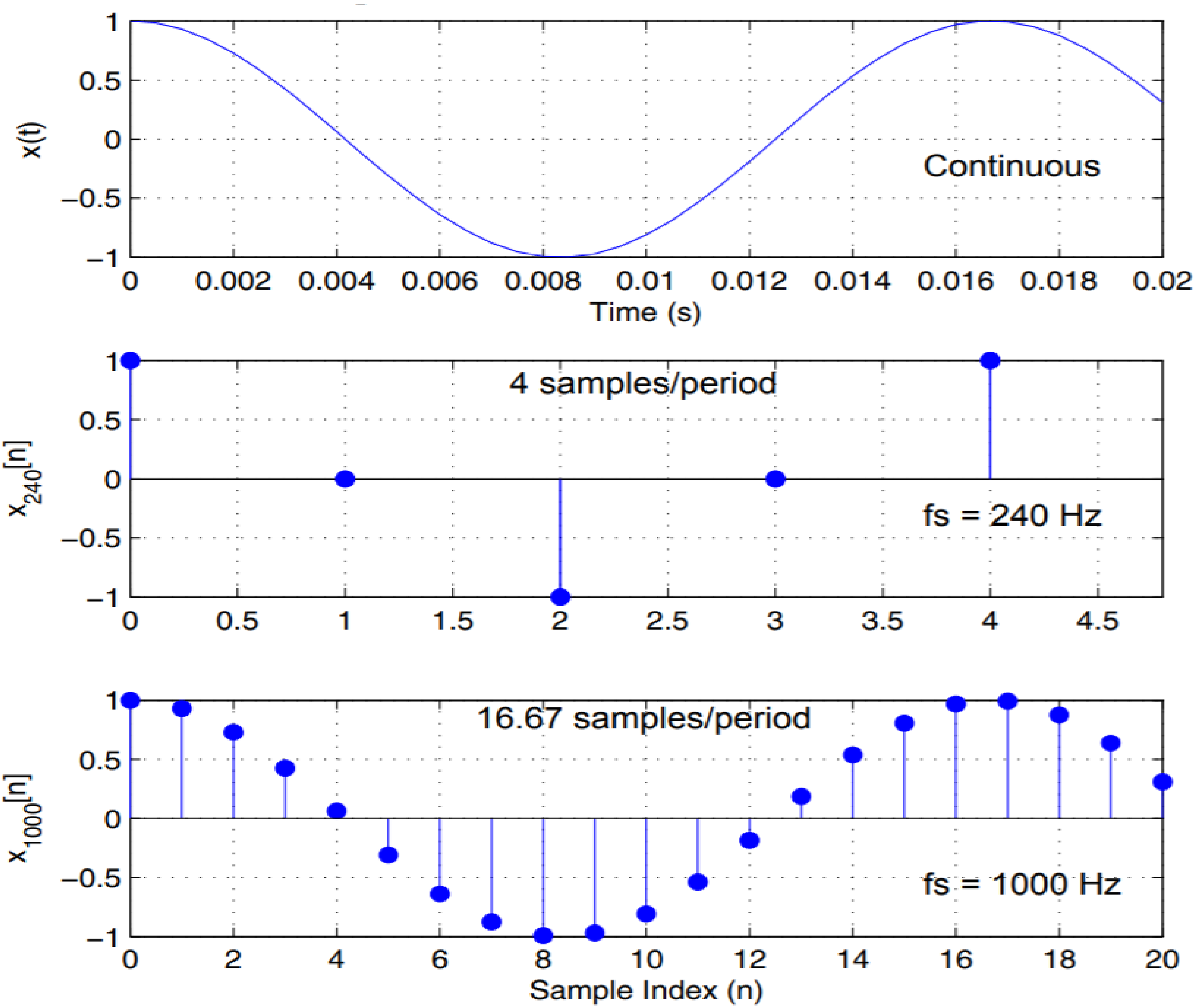
8 samples/cycle



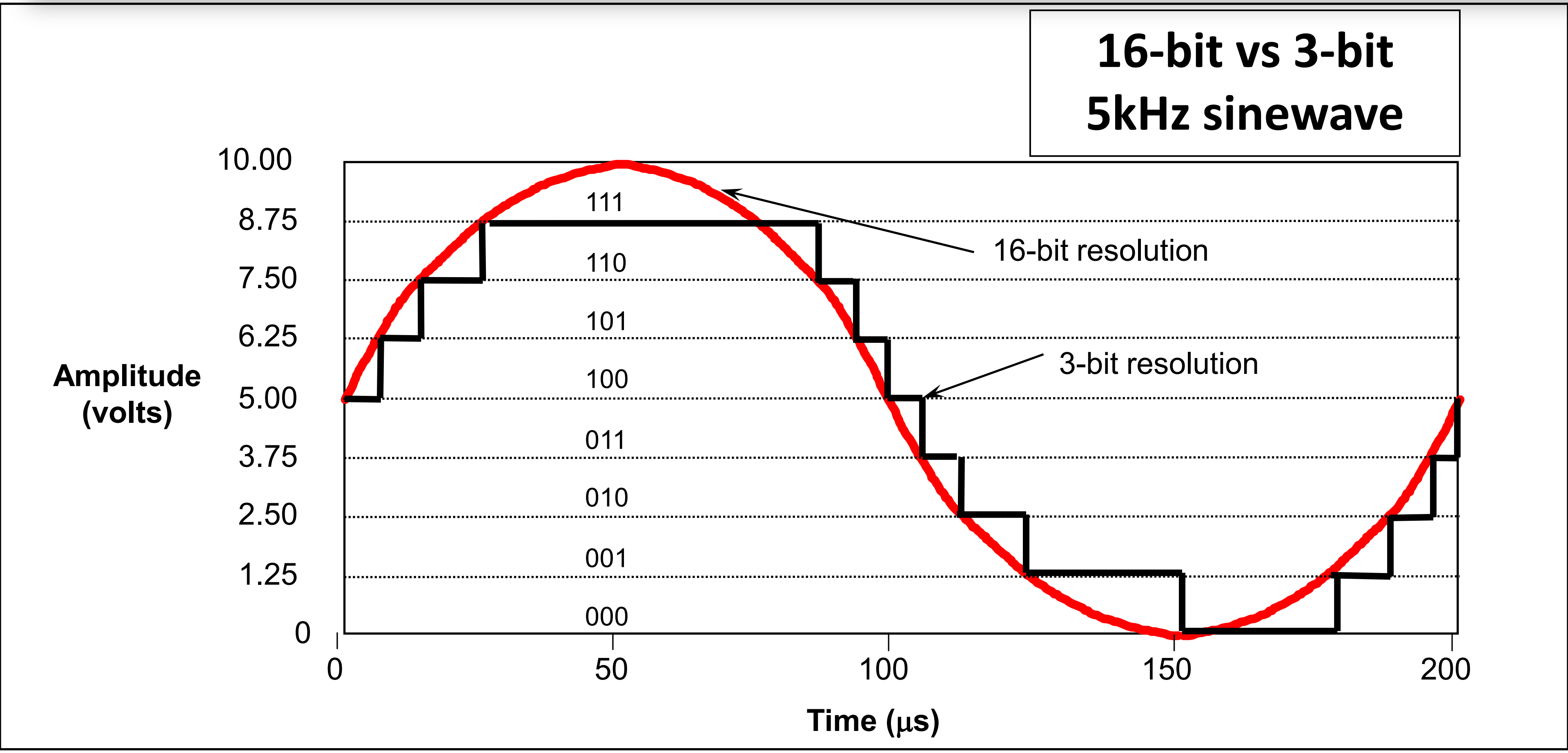
16 samples/cycle

Sampling rate: the speed at which ADC converts the input signal to digital values. Digitizer samples signal after attenuation, gain, and/or filtering has been applied by analog input path, and converts resulting waveform to digital. The sampling rate is based on the sample clock that controls when the ADC converts the analog voltage to digital values.

http://www.ni.com/white-paper/3016/en/

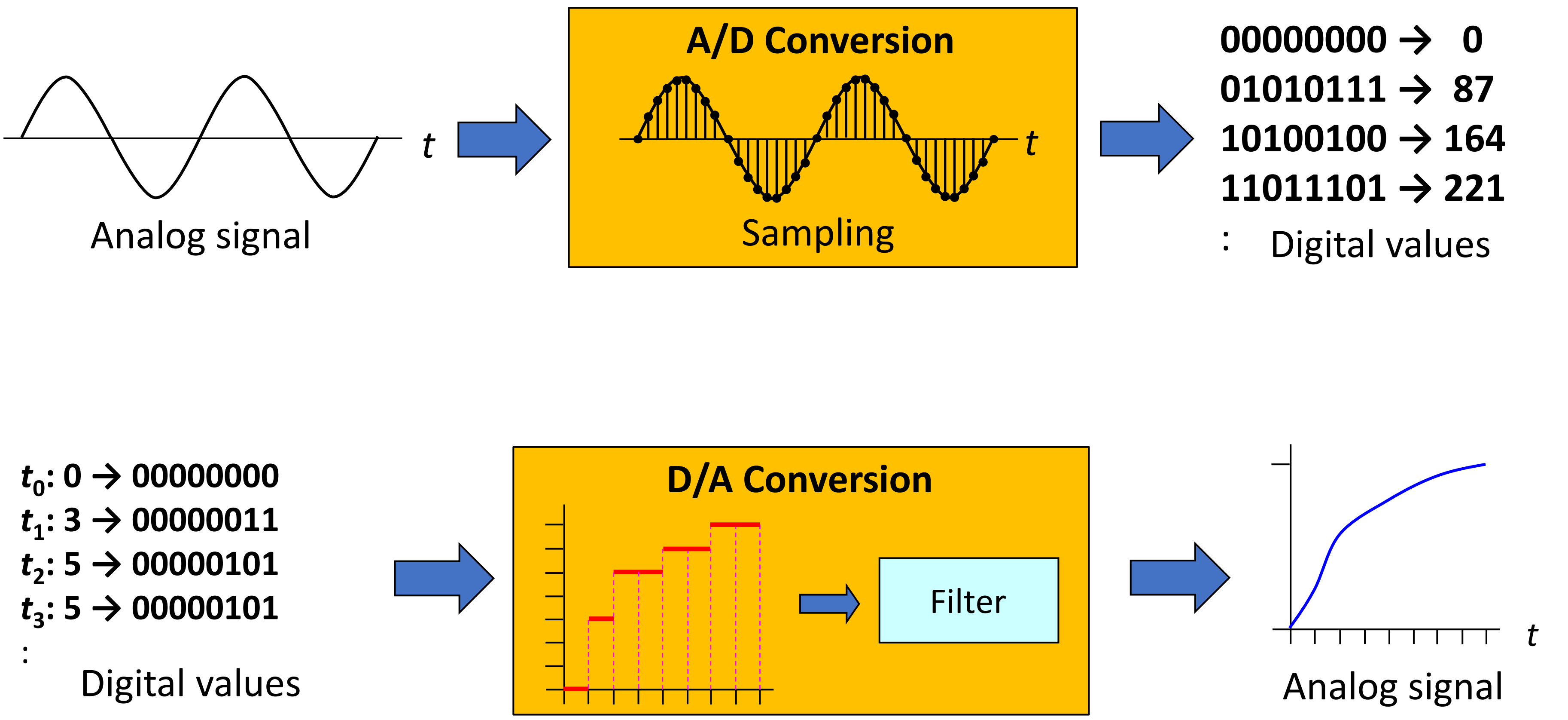

x(t)
Continuous
Time (s)
0
0.002
0.004
0.006
0.008
0.01
0.012
0.014
0.016
0.018
0.02
1
0.5
0
−0.5
−1
$x_{240}[n]$
4 samples/period
fs = 240 Hz
$x_{1000}[n]$
16.67 samples/period
fs = 1000 Hz
Sample Index (n)

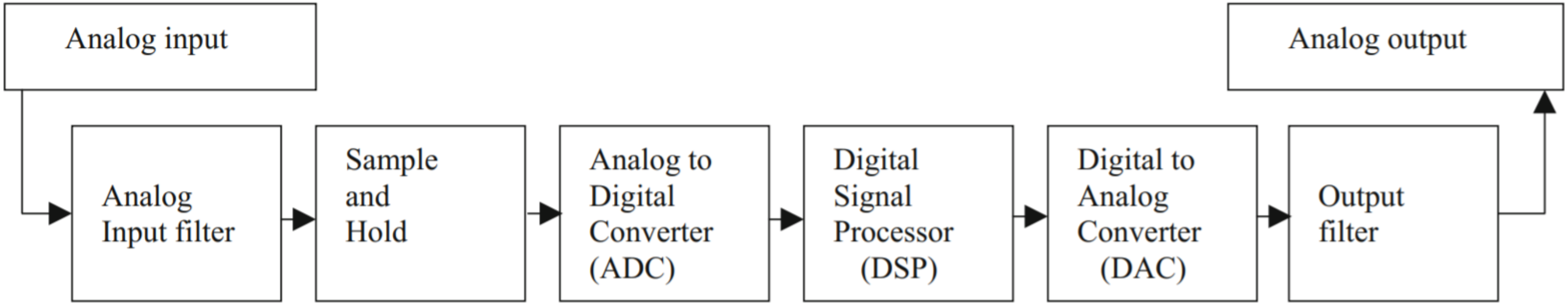
RESOLUTION



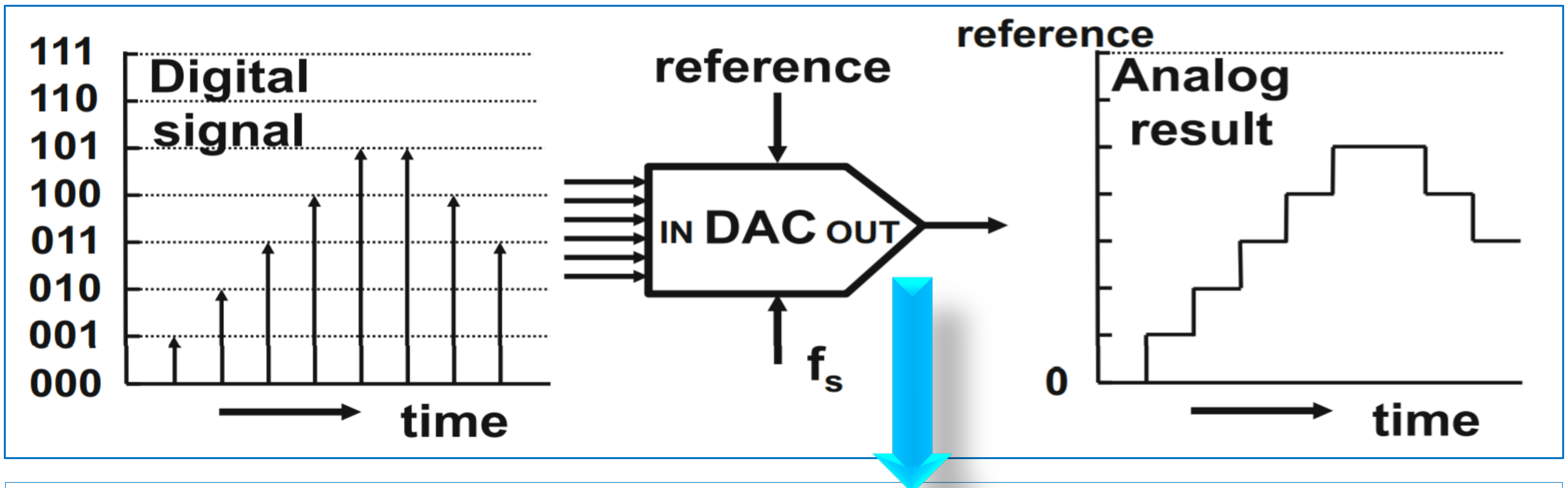
3-bit ADC can represent 2^3=8 and 16-bit ADC can represent 2^{16}=65,536 discrete voltage levels. 3-bit resolution looks like a step function. Resolution is a fixed quantity of an ADC. DAQ devices generally have 8-bit, 12-bit or 16-bit resolution.

Digital Signal Processing

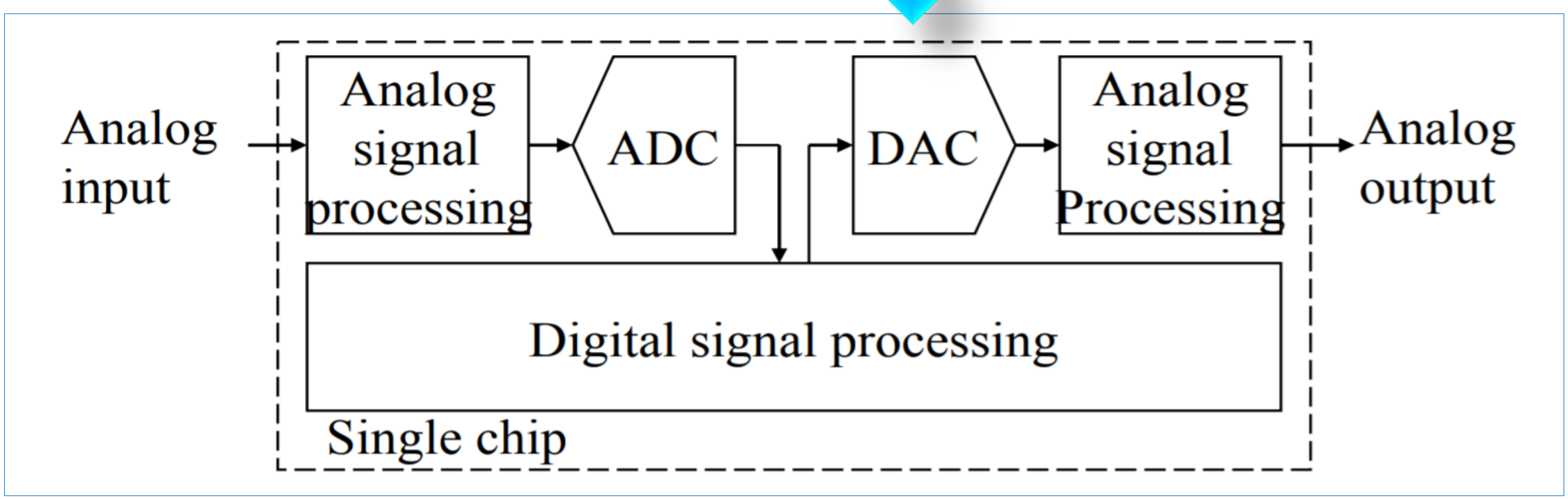




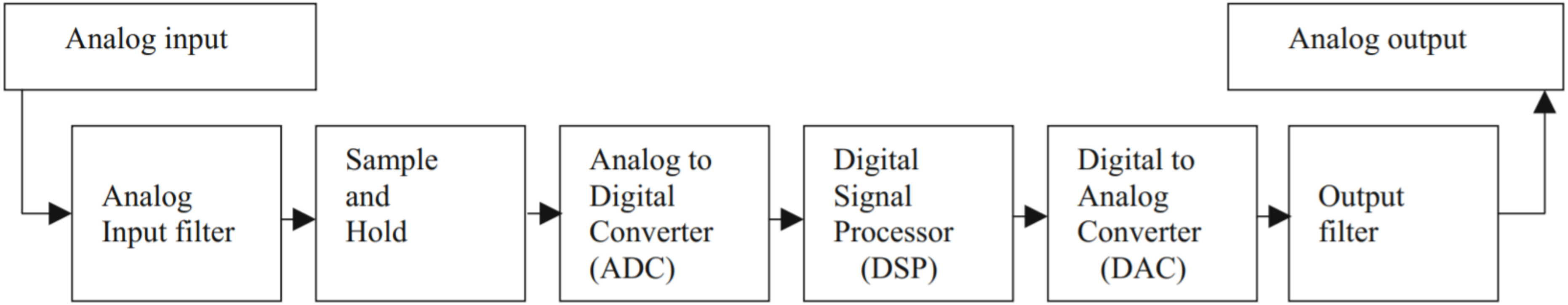
Analog input
Analog output
Analog Input filter
Sample and Hold
Analog to Digital Converter (ADC)
Digital Signal Processor (DSP)
Digital to Analog Converter (DAC)
Output filter



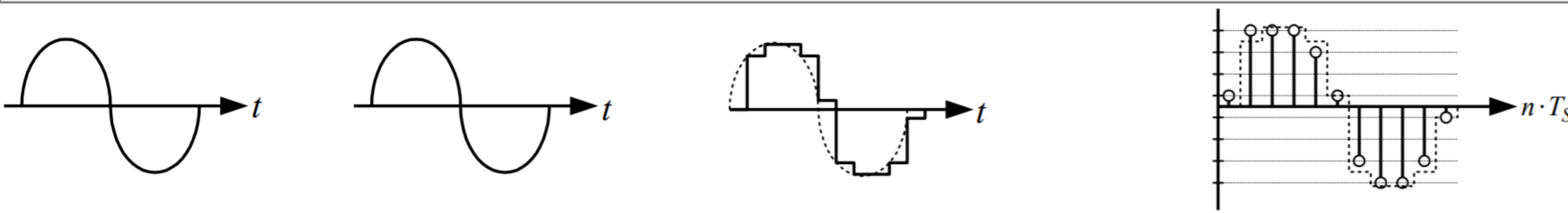
111
110
101
100
011
010
001
000
Digital signal
time
reference
IN DAC OUT
f_s
reference
Analog result
0
time

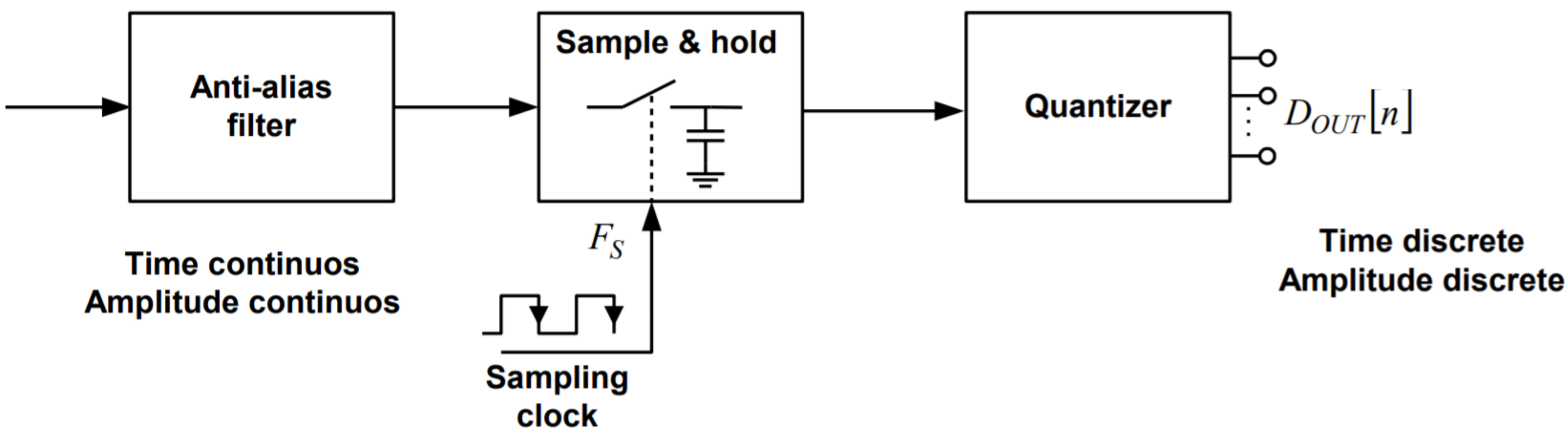


Analog input
Analog signal processing
ADC
DAC
Analog signal Processing
Analog output
Digital signal processing
Single chip



Signals are analog, naturally. Digital artefacts are often corrupted (offset, jitter, distortion, noise).





When converting an analog signal into digital form, the sampling frequency must be greater than twice the bandwidth of the input signal in order to be able to reconstruct the original signal accurately from the sampled version.

https://ieeexplore-ieee-org.libproxy.mit.edu/stamp/stamp.jsp?tp=&arnumber=5055024

Certain Topics in Telegraph Transmission Theory 1 / 28

Certain Topics in Telegraph Transmission Theory

BY H. NYQUIST[1]
Member, A. I. E. E.

Synopsis.—*The most obvious method for determining the distortion of telegraph signals is to calculate the transients of the telegraph system. This method has been treated by various writers, and solutions are available for telegraph lines with simple terminal conditions. It is well known that the extension of the same methods to more complicated terminal conditions, which represent the usual terminal apparatus, leads to great difficulties.*

The present paper attacks the same problem from the alternative standpoint of the steady-state characteristics of the system. This method has the advantage over the method of transients that the complication of the circuit which results from the use of terminal apparatus does not complicate the calculations materially. This method of treatment necessitates expressing the criteria of distortionless transmission in terms of the steady-state characteristics. Accordingly, a considerable portion of the paper describes and illustrates a method for making this translation.

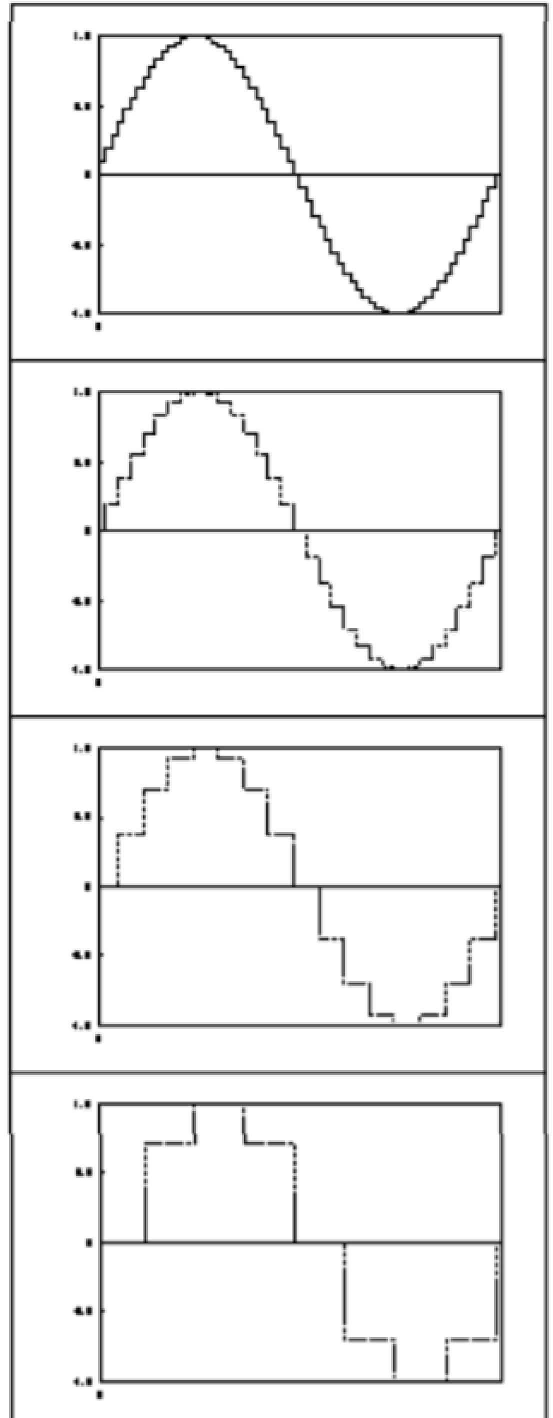
A discussion is given of the minimum frequency range required for transmission at a given speed of signaling. In the case of carrier telegraphy, this discussion includes a comparison of single-sideband and double-sideband transmission. A number of incidental topics is also discussed.

* * * * *

NYQUIST THEOREM – 1928 - NYQUIST PLOT

Full Paper http://bit.ly/NYQUIST-1928 and in zipped folder http://bit.ly/DAS-DAQ

Higher sampling rates allow waveform to be more accurately represented



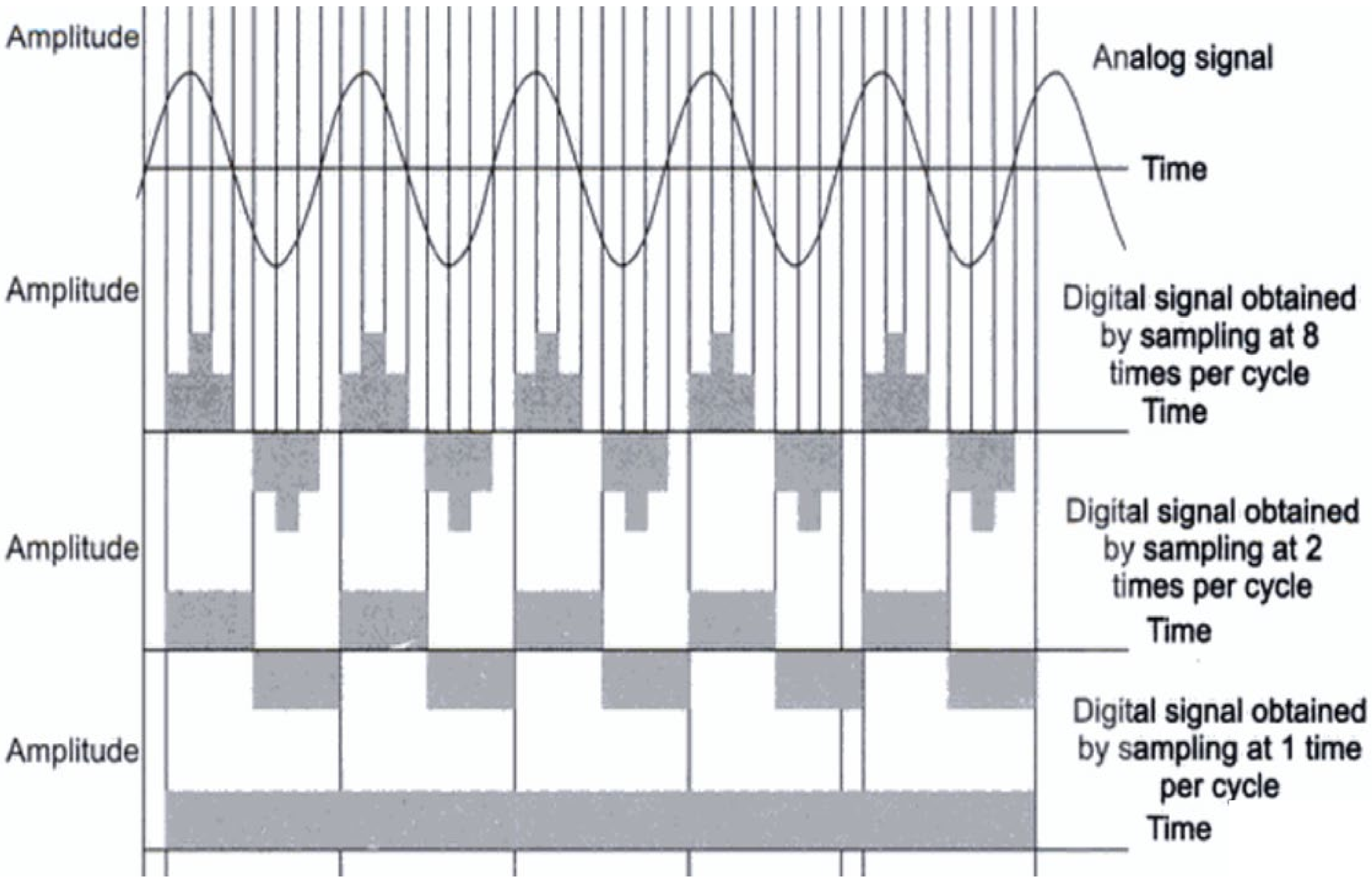
64 samples/cycle

32 samples/cycle

16 samples/cycle

8 samples/cycle

A theorem, developed by Harry Nyquist, and proven by Claude Shannon, which states that an analog signal waveform may be uniquely reconstructed, without error, from samples taken at equal time intervals.



http://math.harvard.edu/~ctm/home/text/others/shannon/entropy/entropy.pdf ● https://www.academia.edu/14891886/Principles_of_Multimedia_2e_2012_

NYQUIST-SHANNON SAMPLING THEOREM

https://ieeexplore-ieee-org.libproxy.mit.edu/stamp/stamp.jsp?tp=&arnumber=1697831

Communication in the Presence of Noise 1 / 12

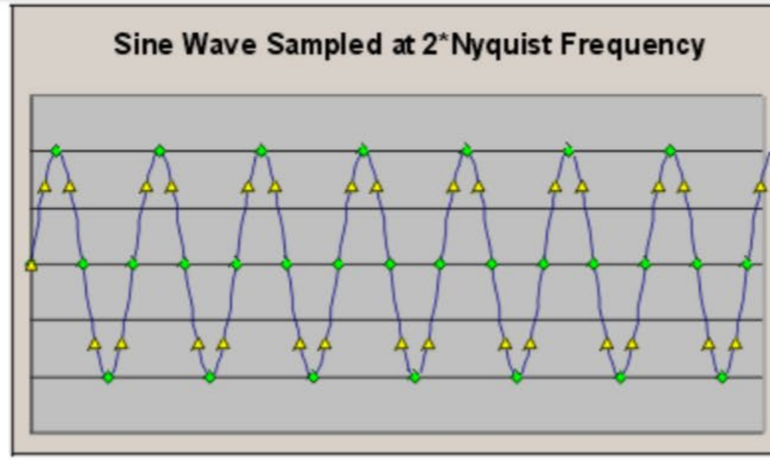
Communication in the Presence of Noise*

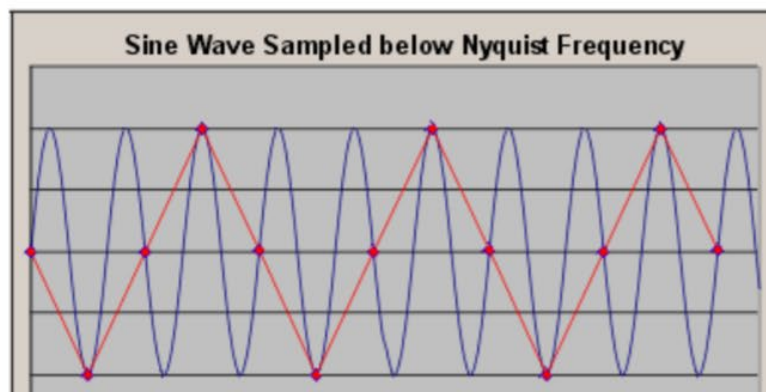
CLAUDE E. SHANNON†, MEMBER, IRE

https://courses.cs.washington.edu/courses/cse466/15au/pdfs/lectures/Sampling.pdf

If a continuous, band-limited signal contains no frequency components higher than f_c, then we can recover the original signal without distortion if we sample at a rate of at least $2f_c$ samples/second

- $2f_c$ is called the Nyquist rate
- Real life
  - Sample at $2.5f_c$ or faster
  - Sample clock should not be coherent with the input signal

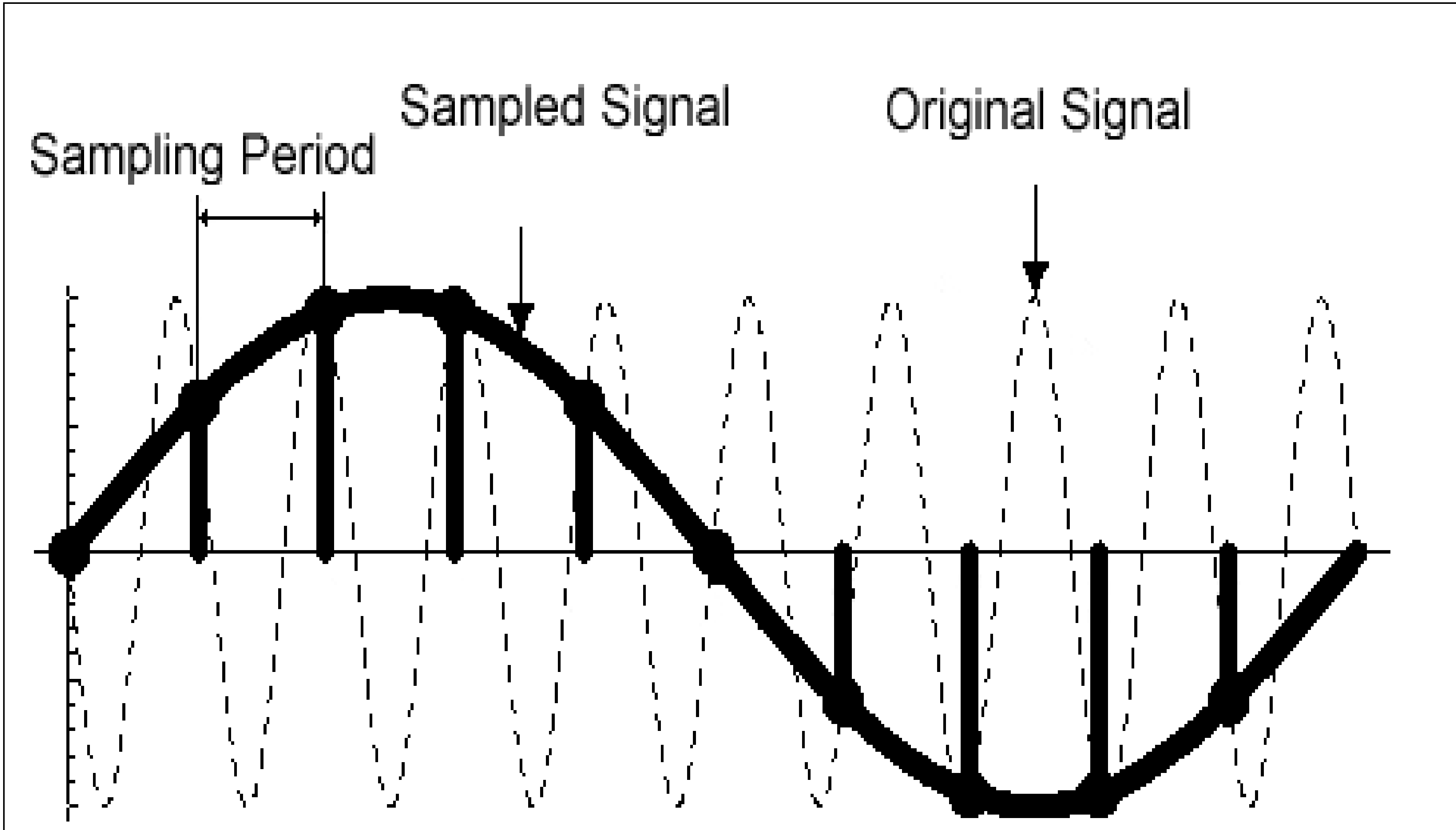




THE SHANNON SAMPLING THEOREM (1940)

- Aliasing

  Signal distortion due to sampling rate



Different signals in time-continuous domain can have same representation in time-discrete domain.

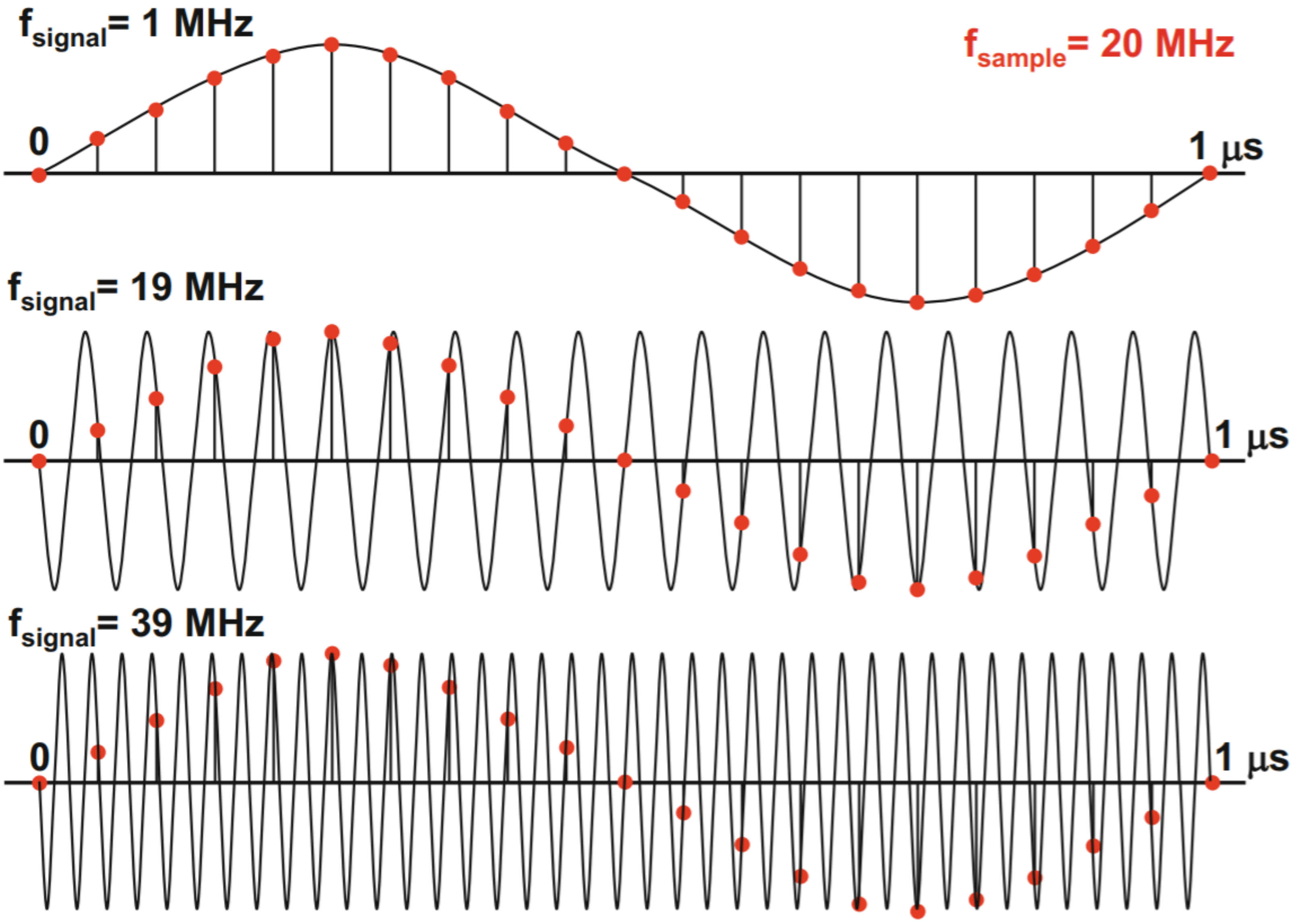
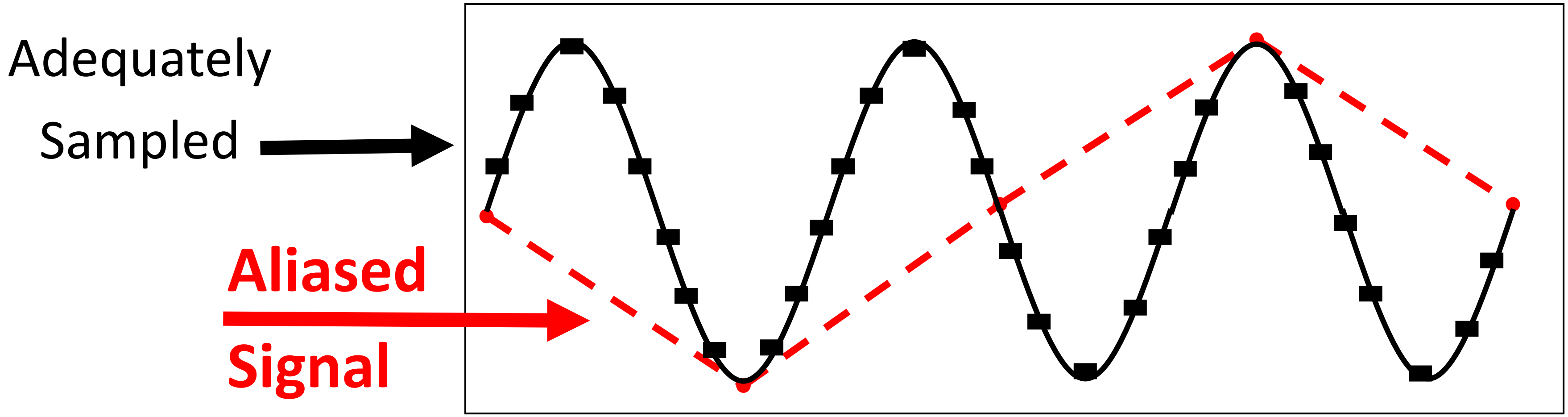
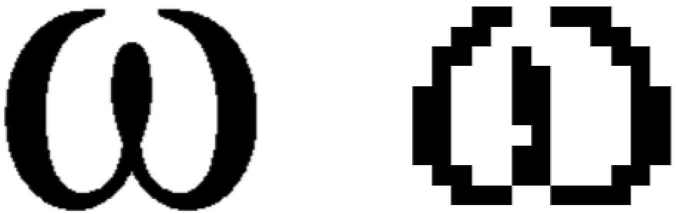


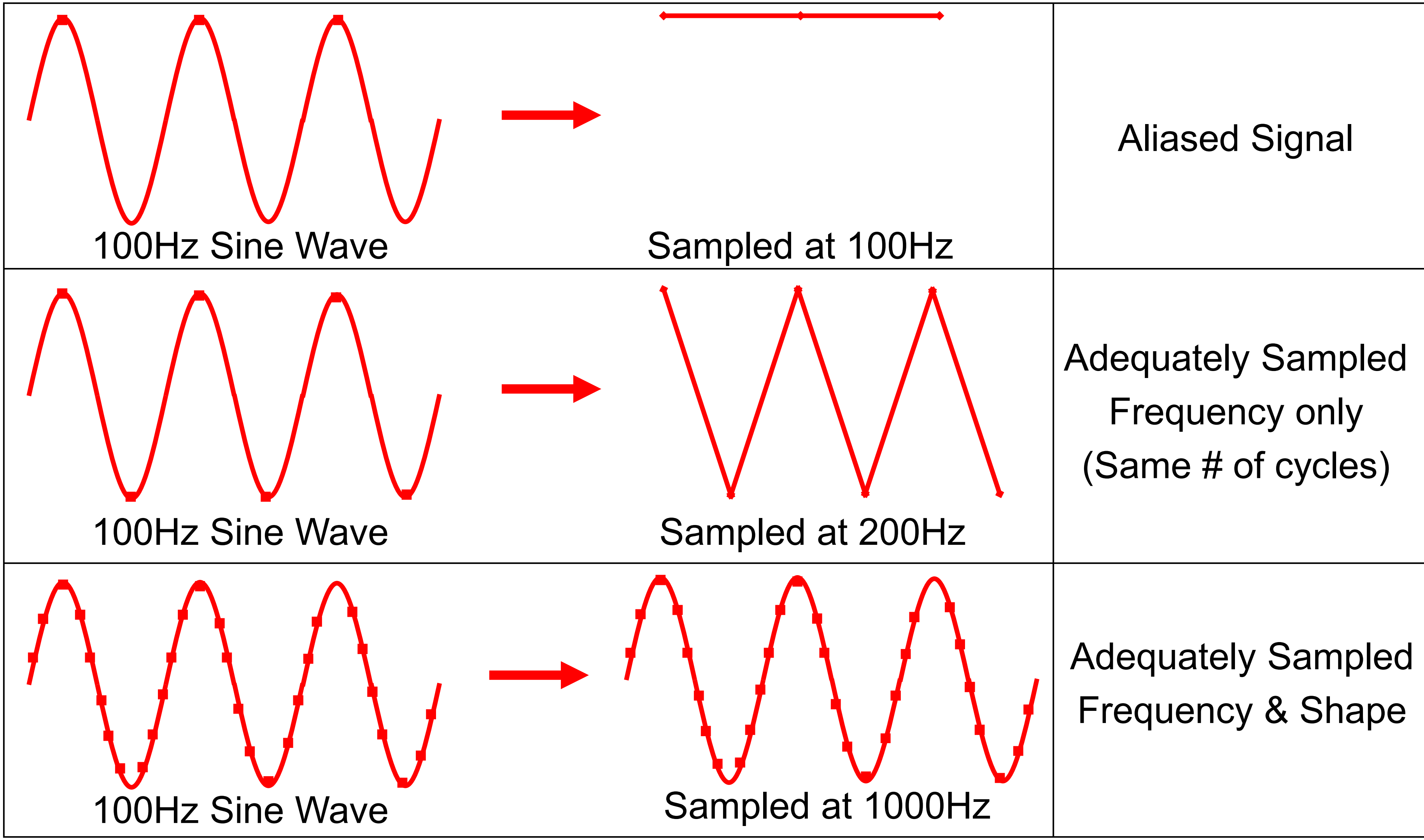
Fig. 2.2 Sampling three time-continuous signals: 1, 19, and 39 MHz sine waves result after sampling with 20 Ms/s in the same sampled data sequence (*dots*) https://link-springer-com.libproxy.mit.edu/content/pdf/10.1007%2F978-3-319-44971-5.pdf

https://ptolemy.berkeley.edu/projects/chess/eecs124/reading/LeeAndVaraiya11.pdf





At the left is an image of the Greek letter omega. At the right is the result of sampling that rendition by taking only one pixel out of every 100 pixels in the original (every 10-th pixel horizontally and vertically), and then rescaling the image so it has the same size as the one on the left. The original image is discrete, and the resulting image is a smaller discrete image (this process is known as **subsampling**).

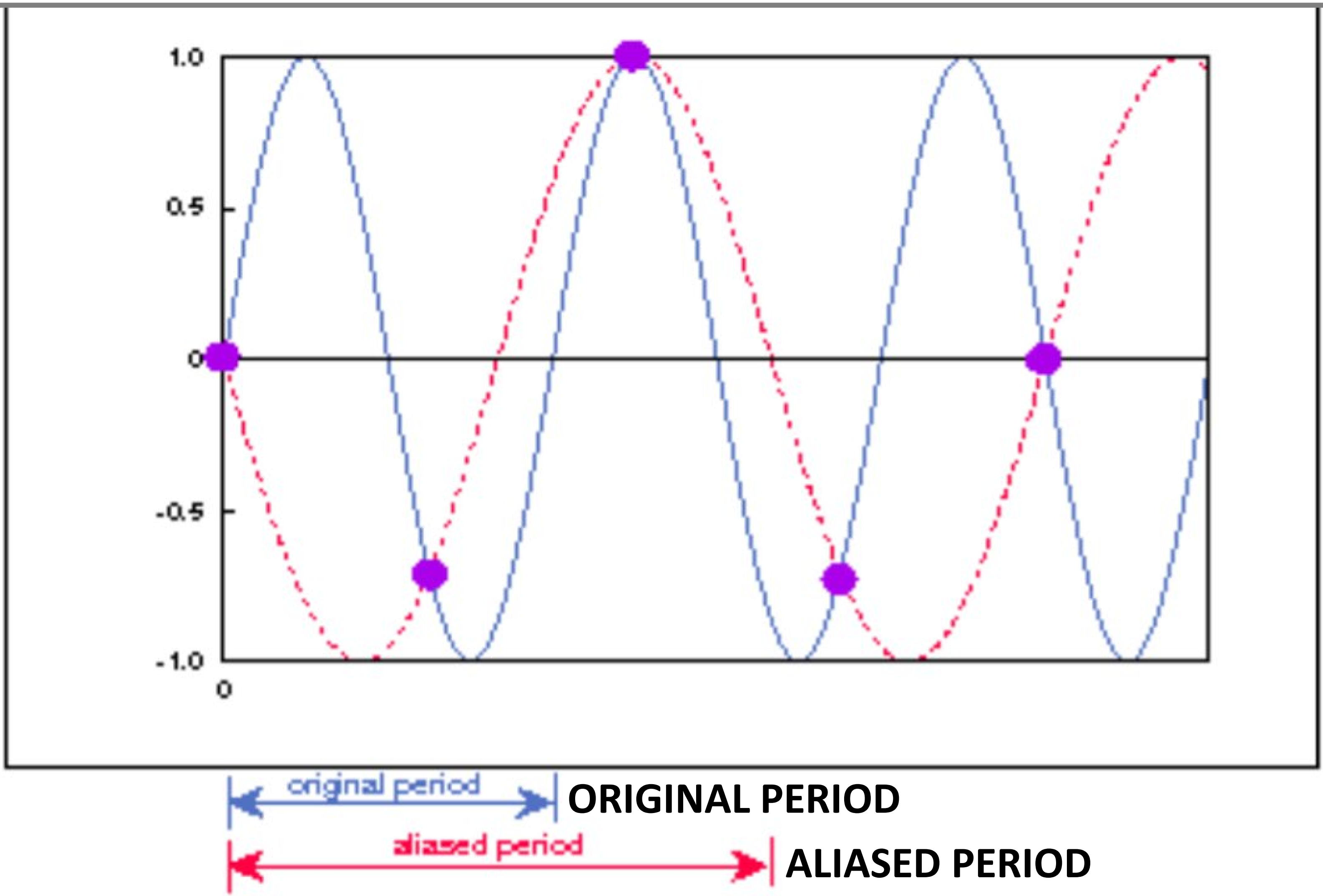


Sample >2 times max frequency of signal to represent FREQUENCY of signal (NYQUIST). Sample >5-10 times max frequency of signal to represent SHAPE of signal.

https://courses.cs.washington.edu/courses/cse466/15au/pdfs/lectures/Sampling.pdf

NYQUIST THEOREM & ALIASING

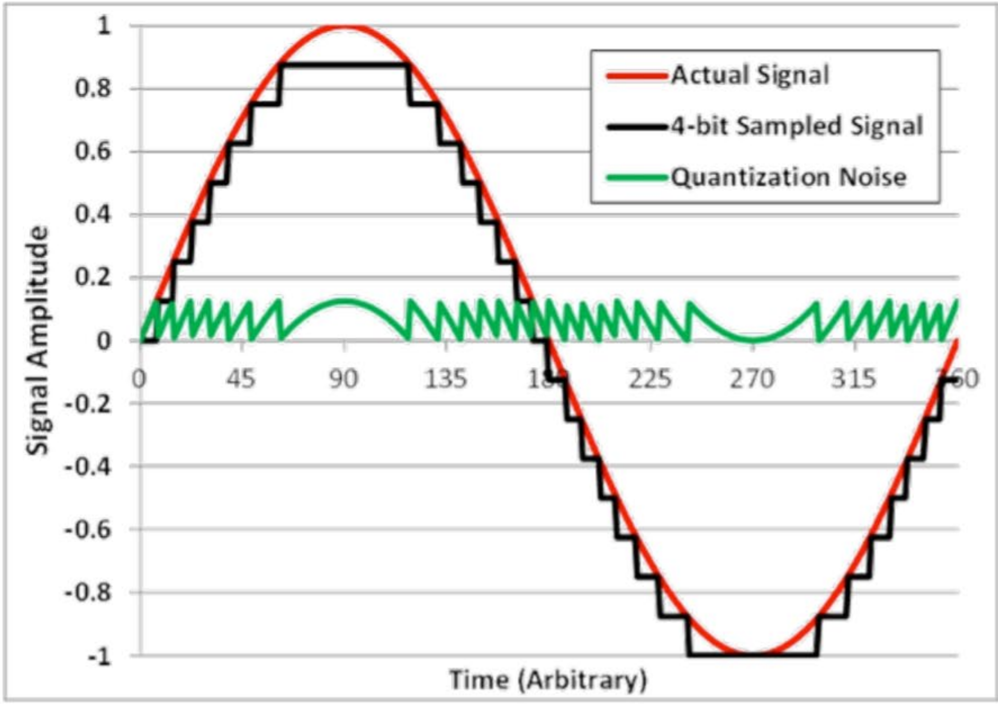
Fitting a sine wave to sampled points gives an aliased waveform



ORIGINAL PERIOD

ALIASED PERIOD

- Sampling theory is a subset of communications theory
  - Same basic math
    - Want to record signal, not noise
  - **Quantization**: Conversion from analog to discrete values
  - **Coding**: Assigning a digital word to each discrete value
    - Thermometer code, Gray code...
- Quantization adds noise
  - Analog signal is continuous
  - Digital representation is approximate
  - Difference (error) is noiselike



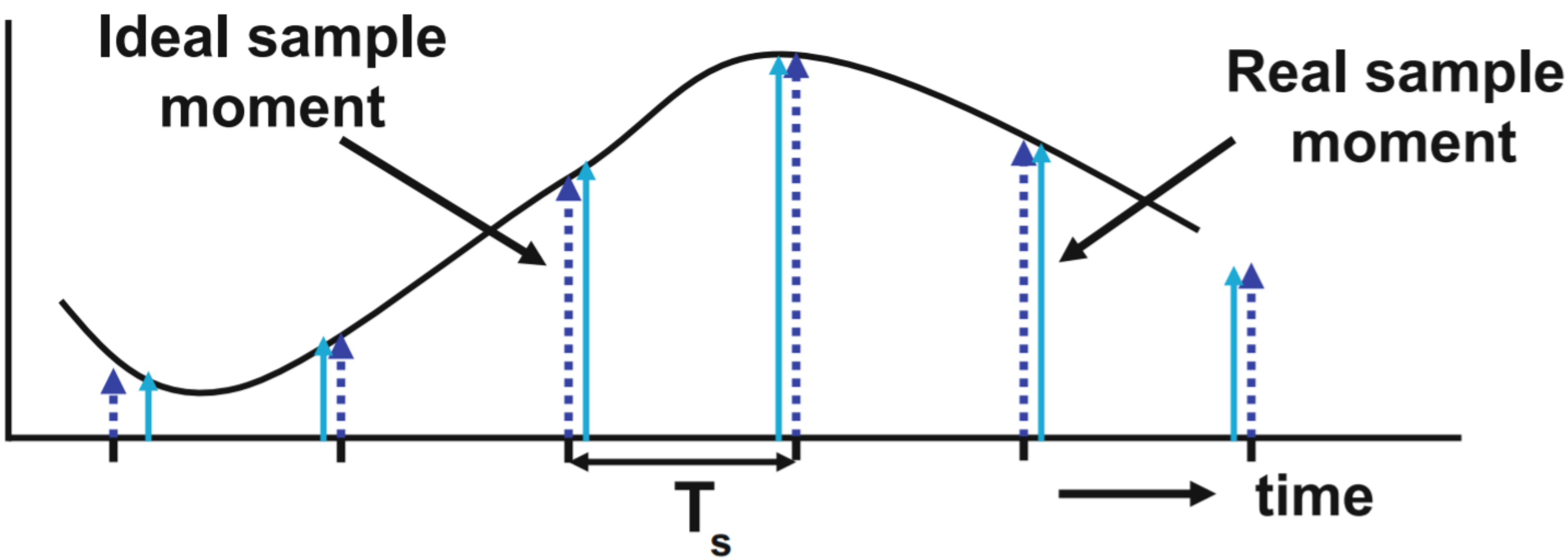
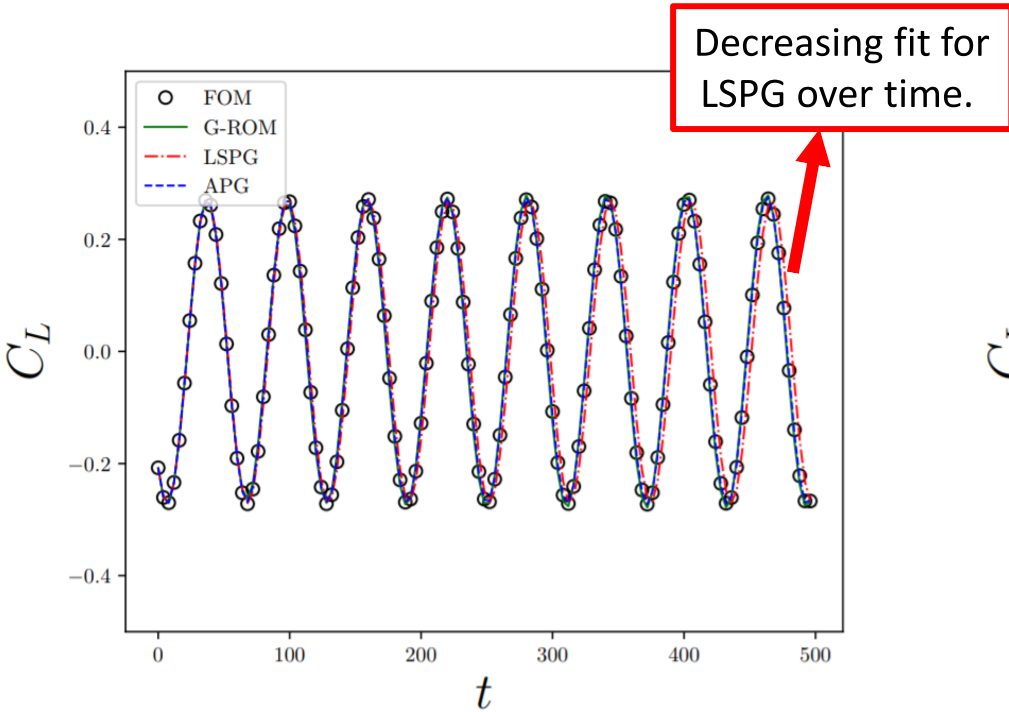


Fig. 2.25 The ideal sampling moments (*dashed*) shift in an arbitrary fashion in time if the sample clock is disturbed by jitter

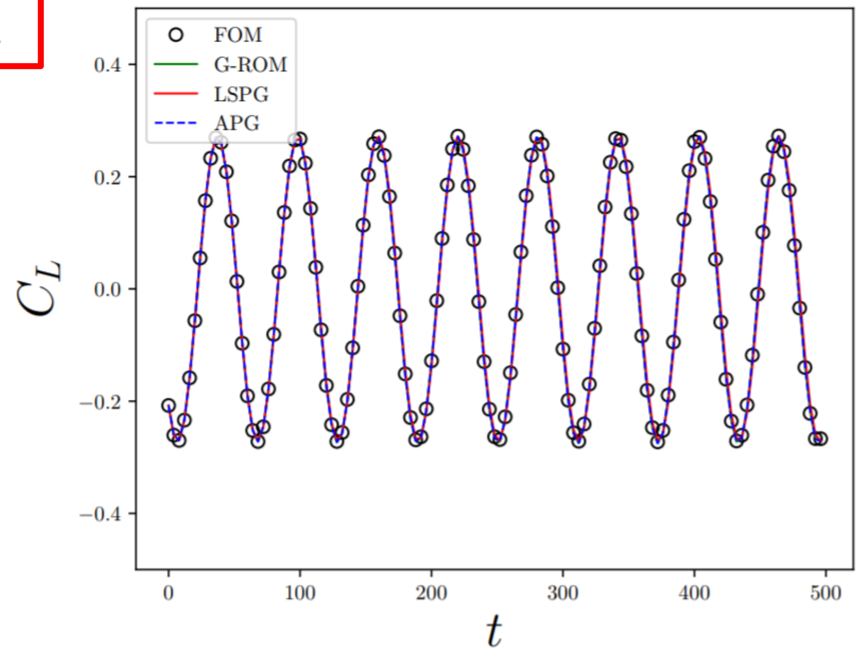
JITTER

If noise changes the switching level of a buffer, the outgoing edge will have a varying delay with respect to the incoming edge. This effect is called: jitter. Jitter causes sample moments to shift from their position, and consequently the sampling circuit will sample the signal at another time moment. Next to noise-like components also signal-related components may influence the clock edge through limited power supply rejection, capacitive coupling, etc. Jitter from noisy sources will result in noise contributions to the signal, jitter from deterministic sources leads to tones (from fixed carriers) or to distortion (if the jitter source is correlated to the signal). Examples of systematic offsets in timing are: skews due to unequal propagation paths of clocks, interference from clock dividers, and clock doubling by means of edge detection. Random "jitter" variations occur not only during the generation of clock signals in noise-sensitive oscillators and PLLs, but also during transportation of timing signals jitter can be added, e.g., in long chains of clock buffers fed by noisy digital power supplies, capacitive coupling, and varying loading. A practical value for jitter on a clock edge coming from a digital CMOS environment[15] is 30–100 ps_{rms}.

Data Fitting Technqiues → https://arxiv.org/pdf/1810.03455.pdf



(c) Lift coefficient as a function of time for Basis # 5.



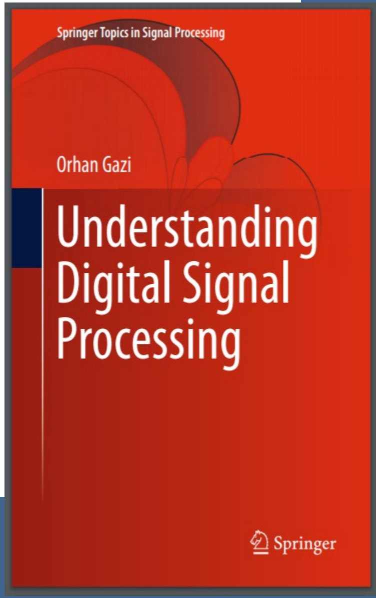
(d) Lift coefficient as a function of time for Basis # 6.

FOM → full-order models (high fidelity)
G-ROM → Galerkin reduced-order model is the simplest approx. solution to a FOM
LSPG → Least-Squares Petrov-Galerkin approach is a tool for non-linear model reduction (least-squares minimization of FOM residual at each time step)
APG → Adjoint Petrov-Galerkin method is a projection-based ROM technique for non-linear dynamical systems. Derived by decomposing generalized coordinates of a dynamical system into a resolved coarse-scale set and an unresolved fine-scale set.

https://link-springer-com.libproxy.mit.edu/content/pdf/10.1007%2F978-981-10-4962-0.pdf

In communication theory; sampling frequency is one of the most important parameters. Sampling frequency is used more than sampling period. Sampling frequency shows the number of samples taken from a continuous time signal per-second. For this reason, it is an indicator of the quality of the continuous-to-digital converters. As sampling frequency increases more samples are taken per-second but this leads to an increase in transmission overhead.

As an example, if the sampling frequency is 1000 Hz i.e., 1 kHz, it means that every second, 1000 samples are taken from continuous time signal.



Difference between digital sample values and the analog waveform is "*quantization* error“ which is experienced as noise. Less bits means less amplitude precision, which means more *digital noise*. More bits means greater precision, hence, less *digital noise*.

https://www.gavtrain.com/?p=3561

Example - Sampling

‘I Remember the First Time I Saw a Teenager Die’

The trauma bay in the emergency department at Temple University Hospital after resuscitation efforts failed. Eric Curran

Saving a patient's life in the OR, MGH, HMS (Julian Goldman)

Medical Devices (Electronics)

The Perils of Data Acquisition Systems?

Actual screen capture from intra-operative EMR during surgery

Julian M. Goldman, MD / MGH, HMS

Medical Devices

These infusion pumps used on ONE patient. Who makes these pumps?

Medical devices provide the "First Mile" data from patient and the "Last Mile" data back to devices.

● 2010 ● OIG HHS bad hospital care deaths about 180,000 patients in Medicare alone in a year

Patient Safety 2013

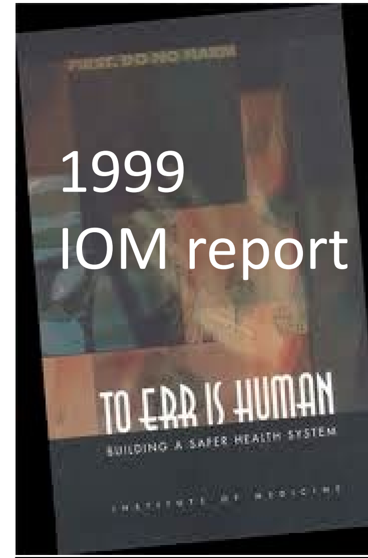
Exploring Quality of Care in the U.S.

How Many Die From Medical Mistakes in U.S. Hospitals?

A New, Evidence-based Estimate of Patient Harms Associated with Hospital Care

John T. James, PhD

Dr Julian Goldman



98,000

deaths due to error

210,000 – 440,000 deaths

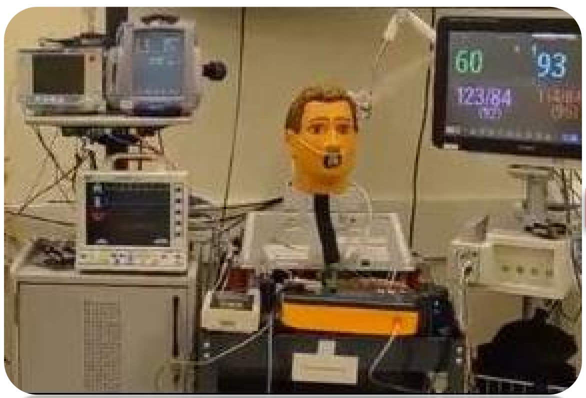
Post-Surgical Morphine Infusion System – Unintegrated Devices

Infusion Pump

Capnometer

PATIENT
Simulator
Ventilator

Intelligent Monitor



- ↓ O_2 Saturation
- ↓ Respiratory Rate
- ↑ end-tidal CO_2

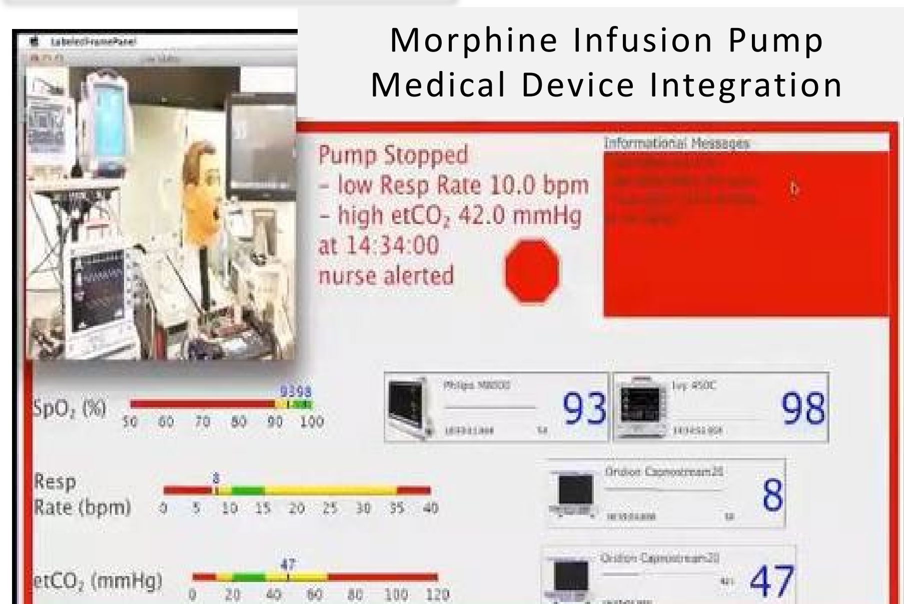
Connected Data
Collective Analysis
Automated Response

Vital Signs Monitor

Simulator connected to vital signs monitor

Fluke ProSim 8 connected to intelligent monitor

Morphine Infusion Pump
Medical Device Integration



Patient Controlled Analgesia Safety Application

Dr Julian M Goldman MD (MDPnP.org and Partners.org)
Massachusetts General Hospital, Harvard Medical School
Harvard – MIT Center for Integrative Medicine and Information Technology

Leading causes of death in the USA

1. 597,689 Heart Disease
2. 574,743 Cancer
3. 138,080 Chronic lower respiratory diseases
4. 129,476 Stroke
5. 120,859 Accidents
6. 83,494 Alzheimer's disease
7. 69,071 Diabetes
8. 56,979 Influenza &Pneumonia
9. 47,112 Kidney diseases
10. 41,149 Suicide

www.cdc.gov/nchs/fastats/deaths.htm

400,000 deaths due to medical mistakes – shared with the US Senate

Deaths by medical mistakes hit records

Tejal Gandhi, MD, president of the National Patient Safety Foundation and associate professor of medicine, Harvard Medical School, spoke at the hearing.

The way IT is designed remains part of the problem

WASHINGTON | July 18, 2014

It's a chilling reality – one often overlooked in annual mortality statistics: Preventable medical errors persist as the No. 3 killer in the U.S. – third only to heart disease and cancer – claiming the lives of some 400,000 people each year. At a Senate hearing Thursday, patient safety officials put their best ideas forward on how to solve the crisis, with IT often at the center of discussions.

Hearing members, who spoke before the Subcommittee on Primary Health and Aging, not only underscored the devastating loss of human life – more than 1,000 people each day – but also called attention to the fact that these medical errors cost the nation a colossal $1 trillion each year.

"The tragedy that we're talking about here (is) deaths taking place that should not be taking place," said subcommittee Chair Sen. Bernie Sanders, I-Vt., in his opening remarks.

https://www.wsj.com/articles/what-your-doctor-isnt-allowed-to-tell-you-11551740732

What Your Doctor Isn't Allowed to Tell You

Badly designed electronic records can be hazardous to your health, but a gag clause protects the makers.

By John Levinson
March 4, 2019 6:05 p.m. ET

It isn't easy to ruffle my friend of 30 years, one of the best gastroenterologists in Boston, a town known for top-notch medicine. But he was ruffled when he told the story of giving a patient anesthesia and performing a medically unnecessary procedure—only he hadn't known it was unnecessary because the patient's electronic health record, or EHR, didn't function as promised.

https://www.beckershospitalreview.com/ehrs/physician-viewpoint-ehr-gag-clauses-perpetuate-patient-safety-hazards.html

Physician viewpoint: EHR gag clauses perpetuate patient safety hazards

Emily Rappleye

Gag clauses in EHR vendor contracts prevent the industry from adequately discussing and addressing EHR usability issues that pose risks to patient safety, according to cardiologist John Levinson, MD, PhD, of Massachusetts General Hospital in Boston.

In an op-ed for *The Wall Street Journal*, Dr. Levinson argues that EHR usability issues are more than "a pain in the neck" for physicians — they pose real risks to patient safety. He cites 2018 studies in *Health Affairs* and *JAMA* that link poor EHR usability to patient harm.

"The problem is that some EHR vendors have such overwhelming market power that they insert gag clauses into their contracts with hospitals, ostensibly to protect their intellectual property. In effect, these vendors have prohibited the free exchange of information — including discussion of safety-related issues," Dr. Levinson writes. "This can't continue."

JAMA 2019 321(8):743-744 doi:10.1001/jama.2019.0161

Health Affairs

TOPICS JOURNAL BLOG

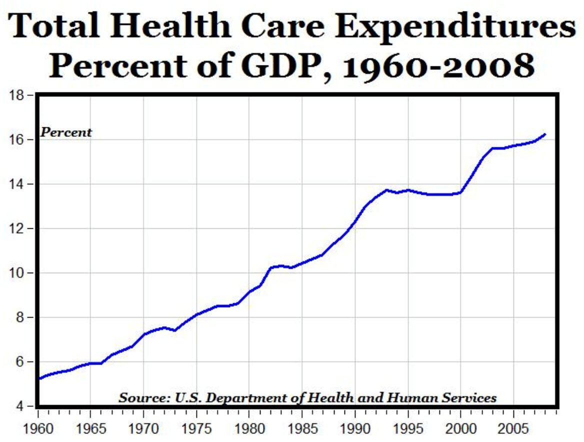
Identifying Electronic Health Record Usability And Safety Challenges In Pediatric Settings

Raj M. Ratwani[1], Erica Savage[2], Amy Will[3], Allan Fong[4], Dean Karavite[5]

Pediatric populations are uniquely vulnerable to the usability and safety challenges of electronic health records (EHRs), particularly those related to medication, yet little is known about the specific issues contributing to hazards. To understand specific usability issues and medication errors in the care of children, we analyzed 9,000 patient safety reports, made in the period 2012–17, from three different health care institutions that were likely related to EHR use. Of the 9,000 reports, 3,243 (36 percent) had a usability issue that contributed to the medication event, and 609 (18.8 percent) of the 3,243 might have resulted in patient harm. The general pattern of usability challenges and medication errors were the same across the three sites. The most common usability challenges were associated with system feedback and the visual display. The most common medication error was improper dosing.https://www.healthaffairs.org/doi/abs/10.1377/hlthaff.2018.0699

Third Leading cause of death in the USA ?

1. 597,689 Heart Disease
2. 574,743 Cancer
3. ***Deaths Due to Medical Errors (180,000 - 210,000 - 440,000)***
4. 138,080 Chronic lower respiratory diseases
5. 129,476 Stroke
6. 120,859 Accidents
7. 83,494 Alzheimer's disease
8. 69,071 Diabetes
9. 56,979 Influenza &Pneumonia
10. 47,112 Kidney diseases
11. 41,149 Suicide



Equivalent to at least one 747 airplane crash every day

Most Medical Devices Today
stand alone, unintegrated, not patient-centric

- Philips Intellivue Series Monitors
- GE Solar 8000x / Dash 4/5000
- Dräger Apollo / EvitaXL / V500
- Nonin Bluetooth OnyxII 9650 / WristOx 3150
- Oridion Capnostream20
- Ivy 450C
- Nellcor N-595
- Masimo Radical-7











ALL MEDICAL DEVICES
MUST USE ANALOG TO DIGITAL CONVERTER

- Philips Intellivue Series Monitors
- GE Solar 8000x / Dash 4/5000
- Dräger Apollo / EvitaXL / V500
- Nonin Bluetooth OnyxII 9650 / WristOx 3150
- Oridion Capnostream20
- Ivy 450C
- Nellcor N-595
- Masimo Radical-7





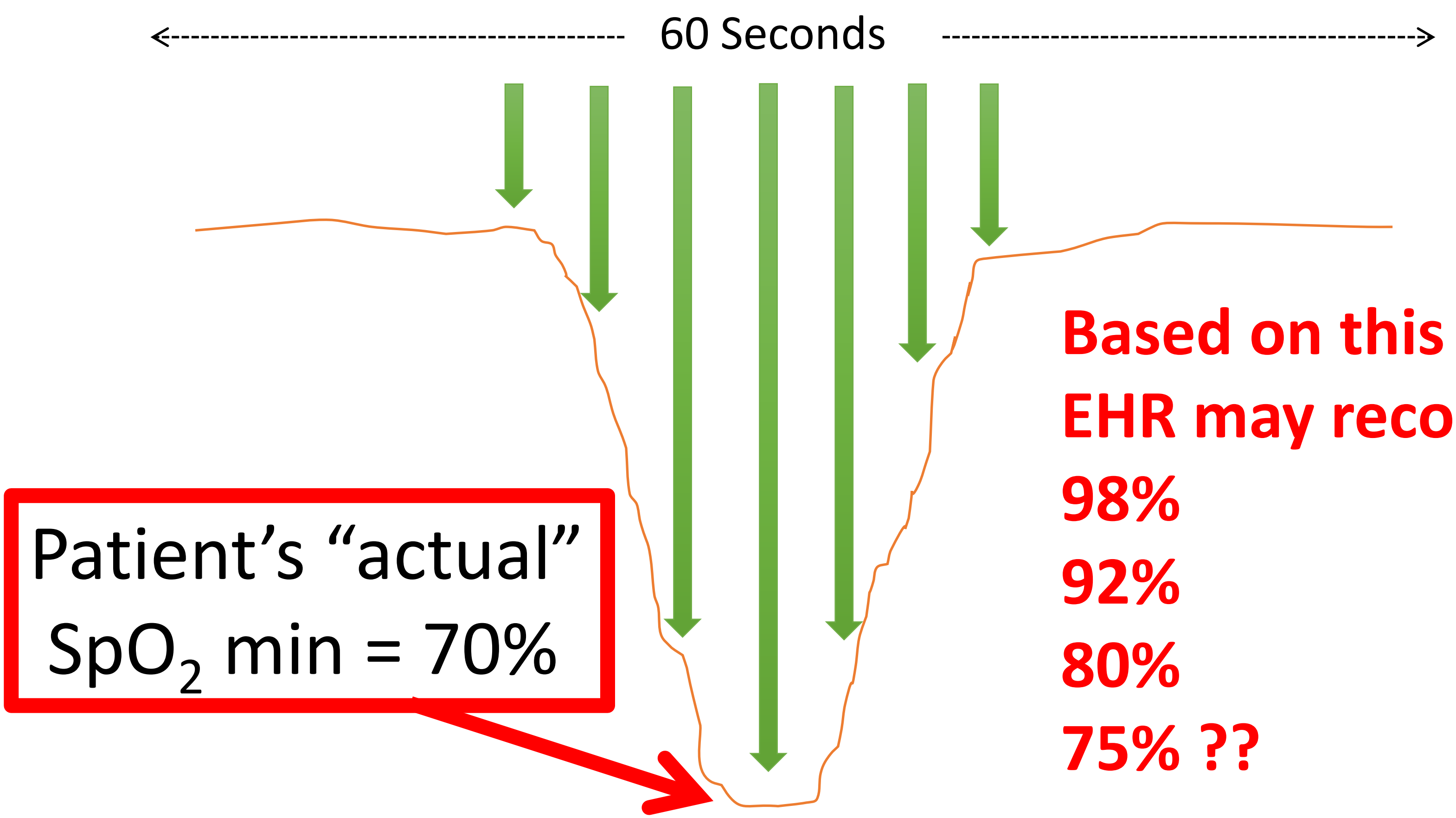






DATA SAMPLING

Example of possible EHR sample points for 1-minute recording



Based on this example, EHR may record SpO_2 as:

98%

92%

80%

75% ??

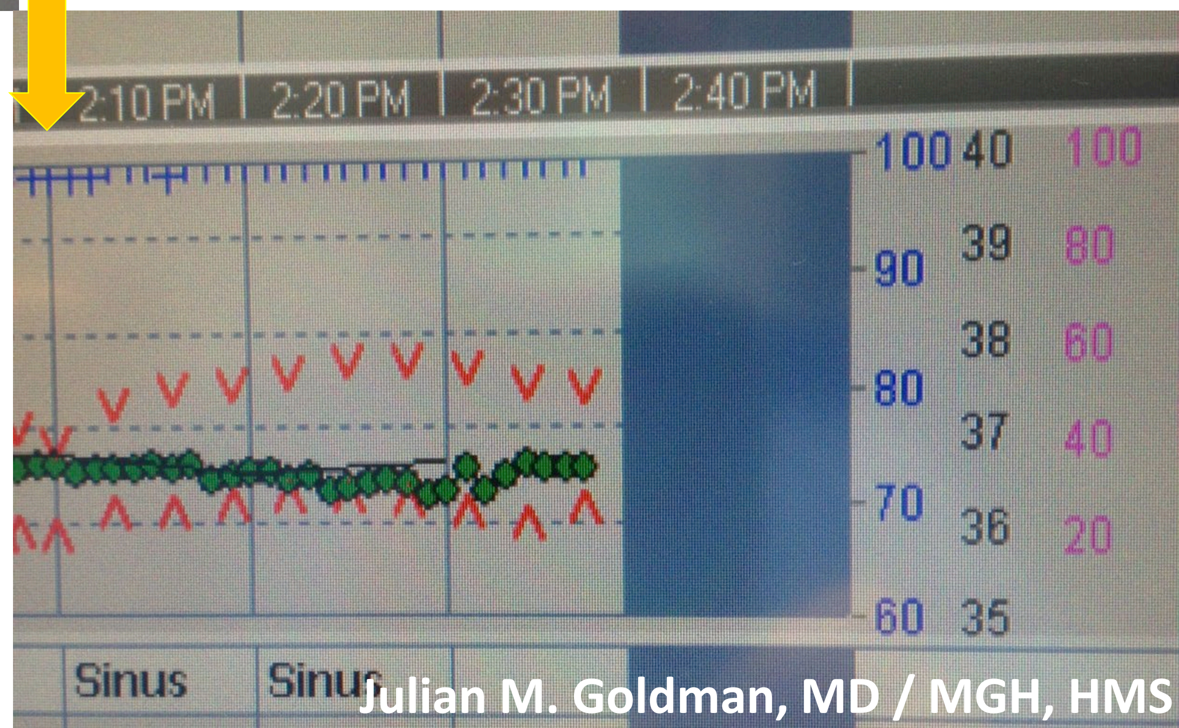
Error prone EHR documentation due to data sampling

All clinical data are <u>not</u> transmitted to EHR

No evidence of 84% SpO_2 in EHR

Blue marks represent SpO_2 values

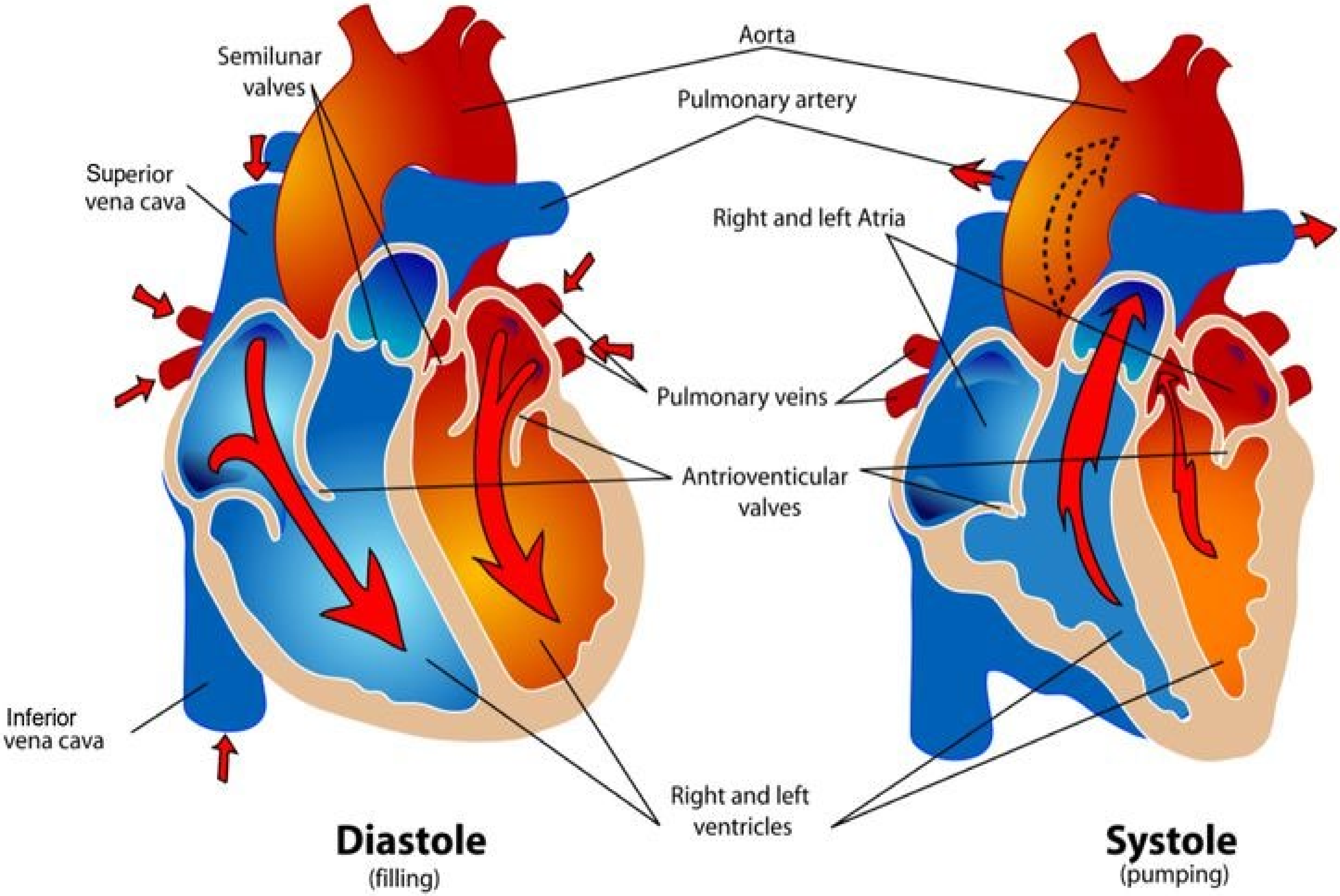
Monitor Displays Low Oxygen Level SpO_2 Alarm Event "84%" at 2:07 PM



Julian M. Goldman, MD / MGH, HMS

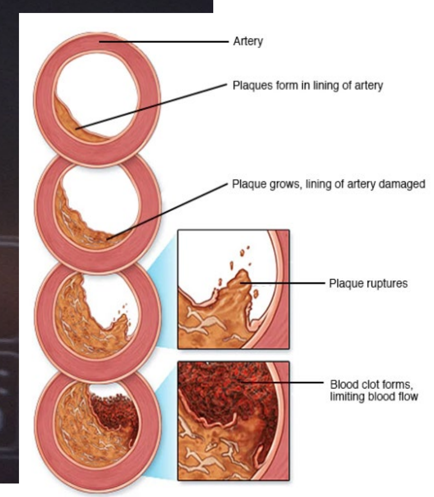
ASYSTOLE ??

Julian M Goldman, MD / MGH, HMS



www.health.harvard.edu/a_to_z/heart-valve-problems-a-to-z

Abnormal ECG - flipped T Waves - cardiac ischemia?



This patient was CURED by changing a device filter setting !!

How can the ECG data be interpreted without ECG filter metadata?

ECG filter setting
Monitoring
vs
"Maximum"

Where is the metadata for ADC filter ?

How can the ECG data be interpreted without ECG filter metadata?

NOT SHARED BY THE MANUFACTURER

Third Leading cause of death in the USA ?

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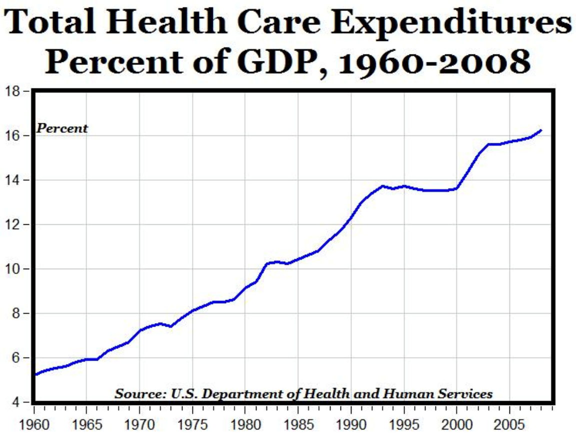
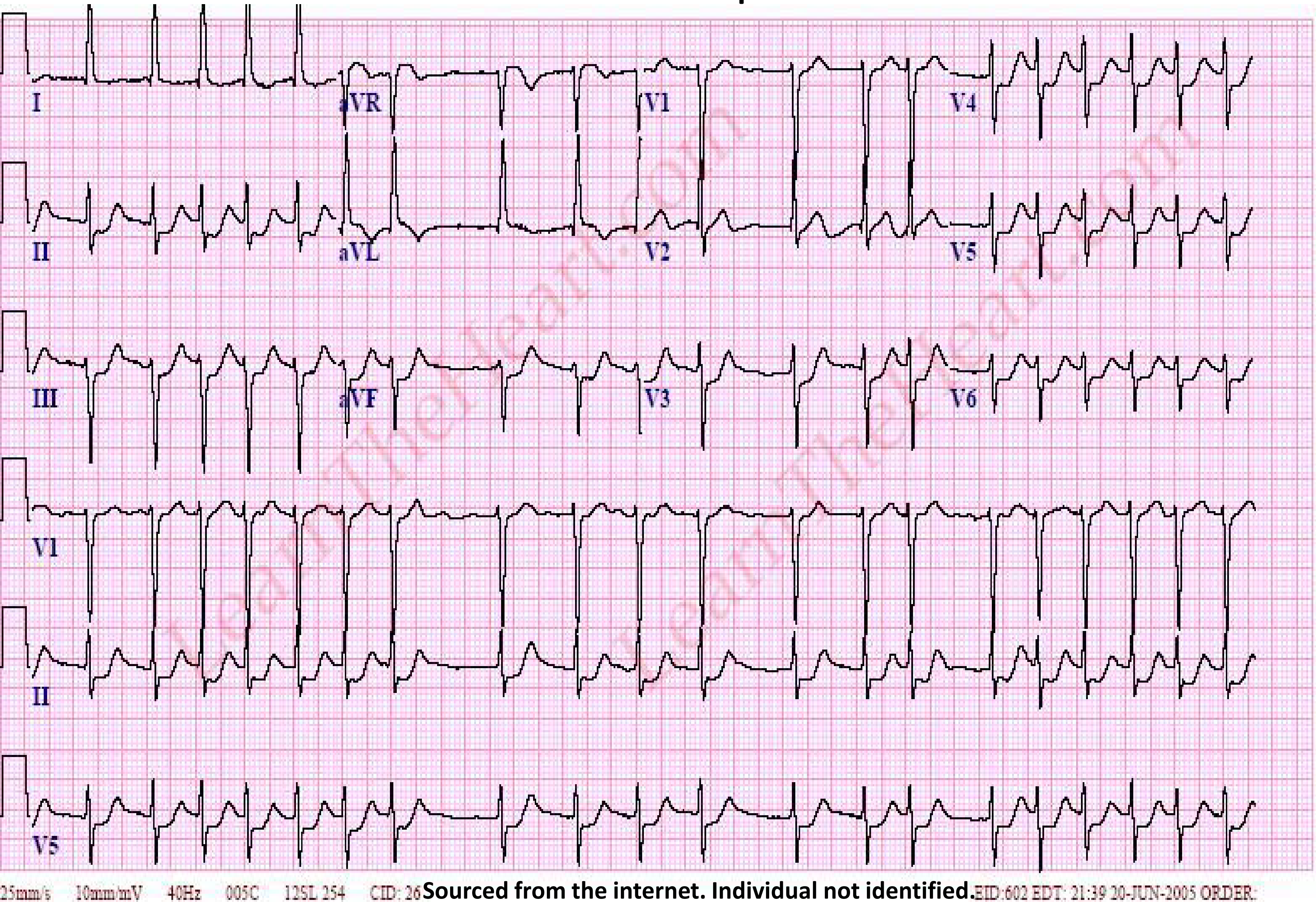
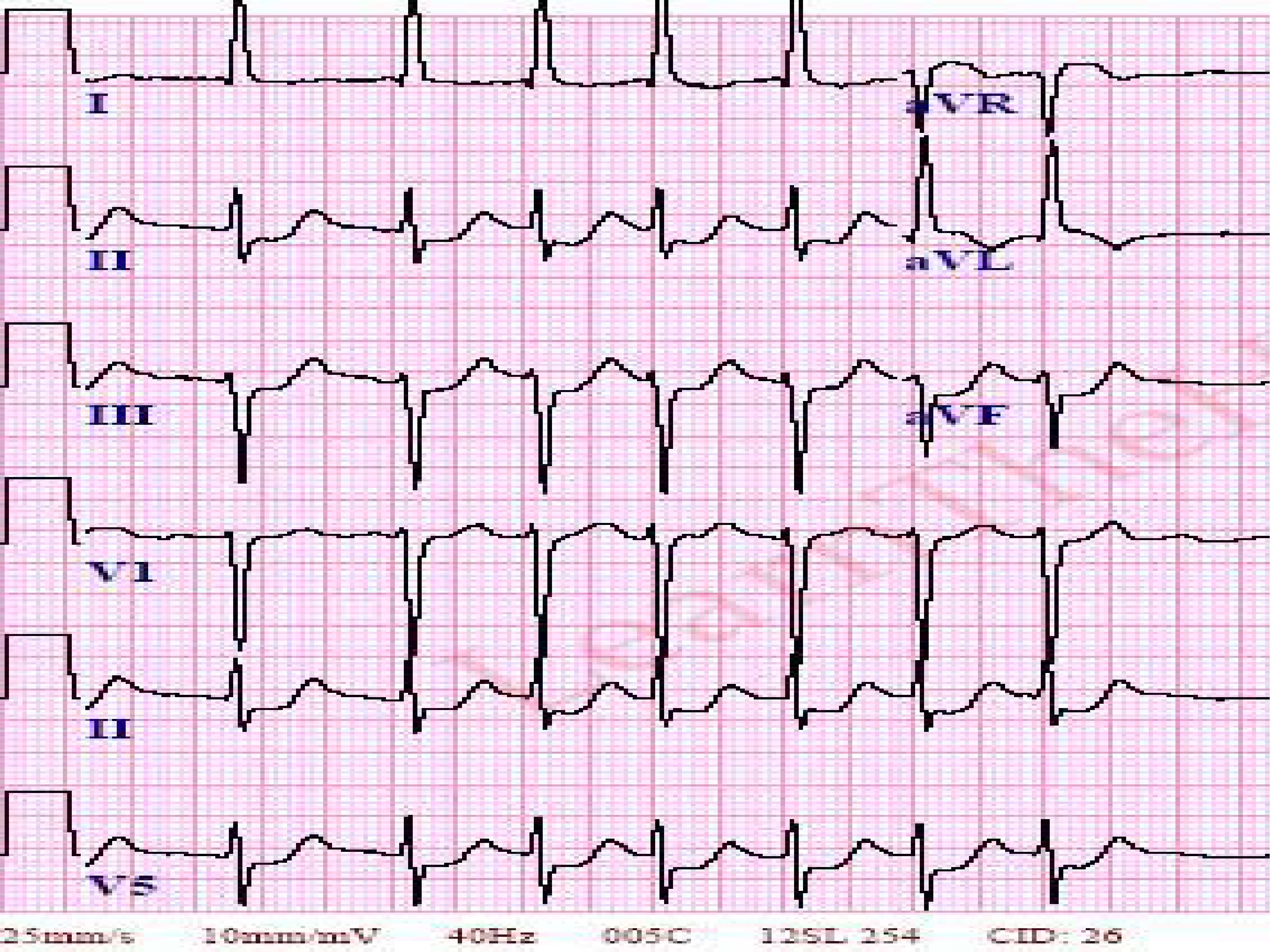


Equivalent to at least one 747 airplane crash every day

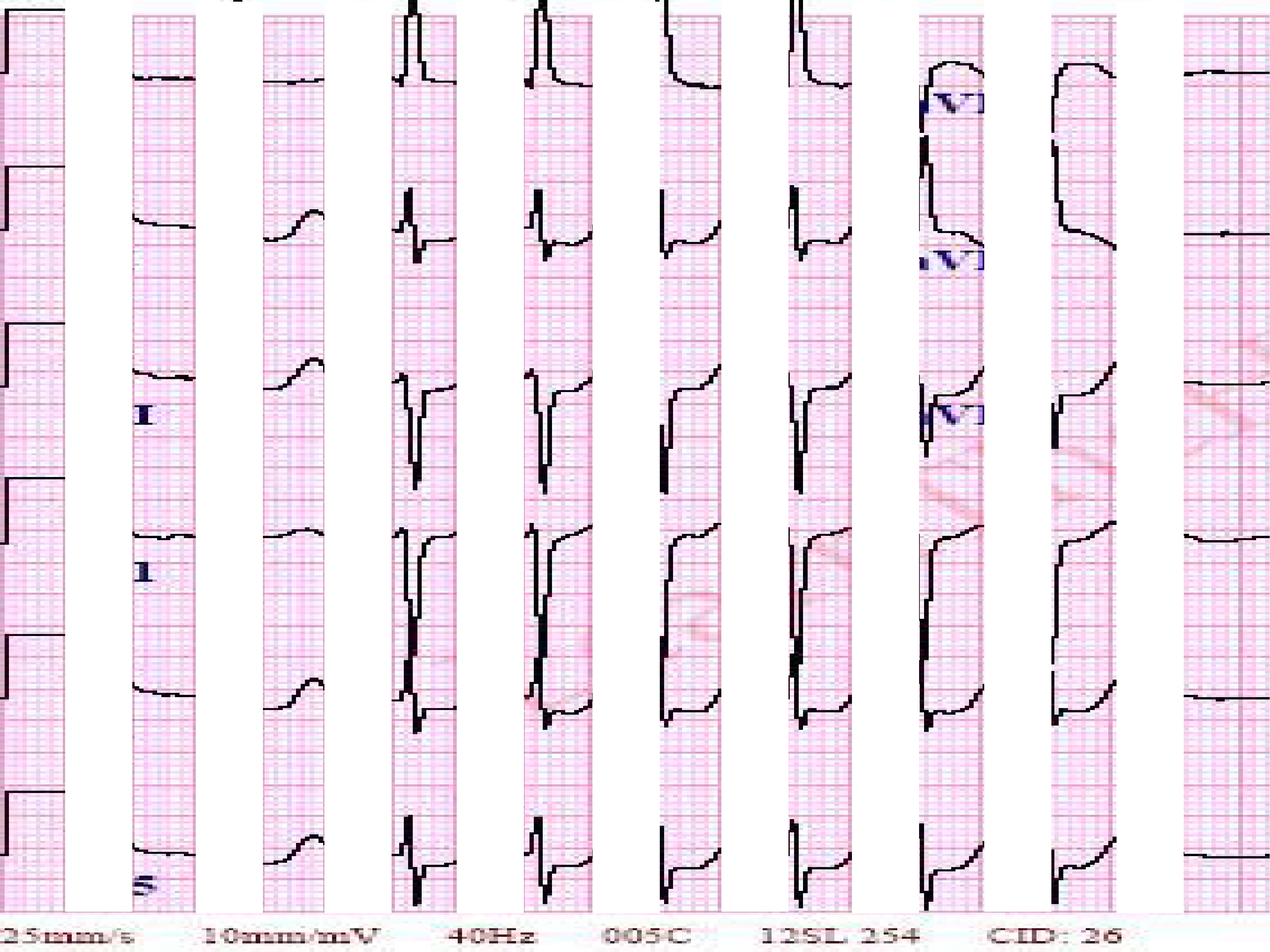
Atrial Fibrillation with Rapid Ventricular Rate



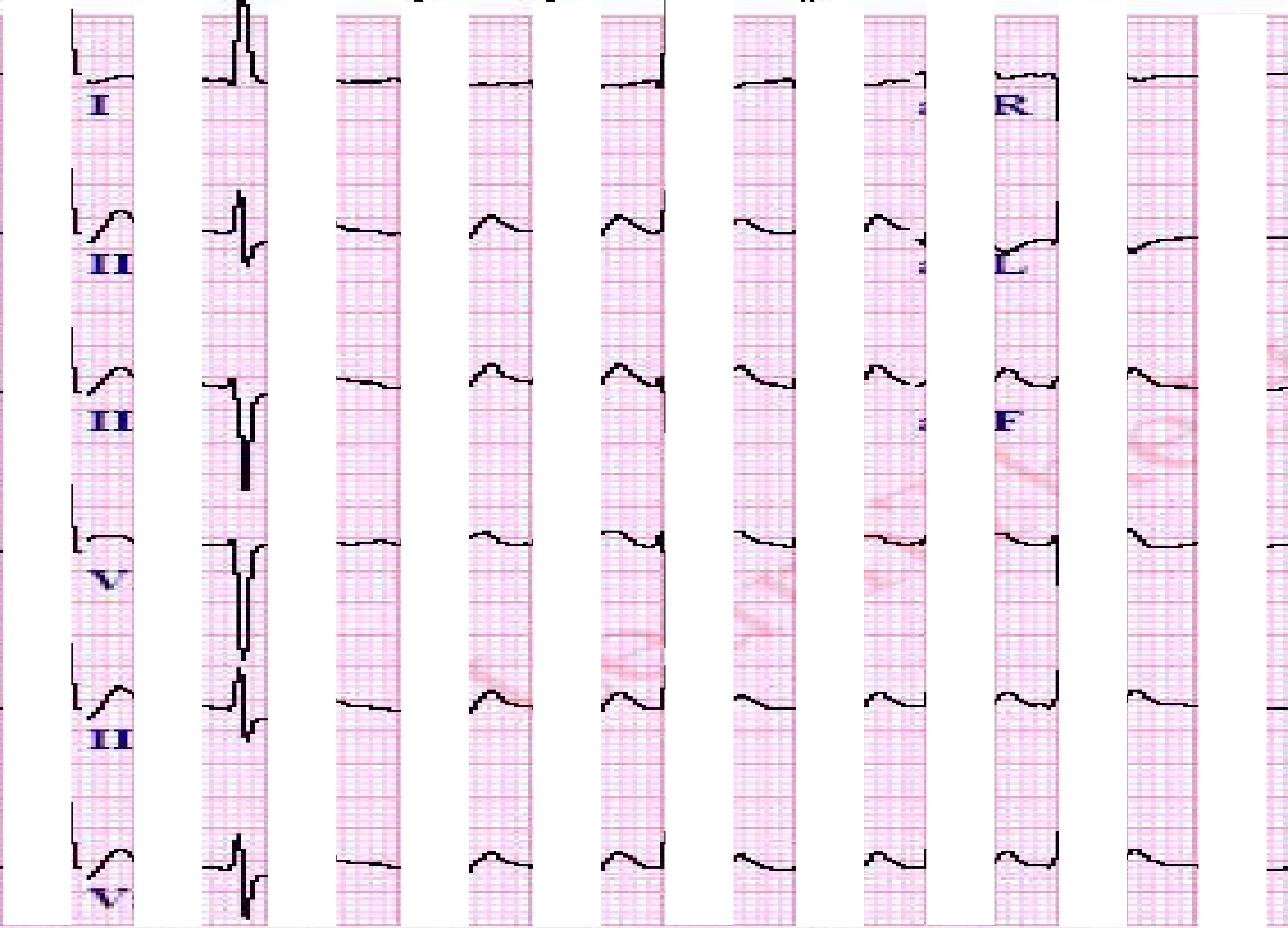
Sourced from the internet. Individual not identified.


I
aVR
II
aVL
III
aVF
V1
II
V5
25mm/s 10mm/mV 40Hz 005C 12SL 254 CID: 26

ECG SAMPLING “A”


25mm/s 10mm/mV 40Hz 005C 12SL 254 CID: 26

ECG SAMPLING “B”

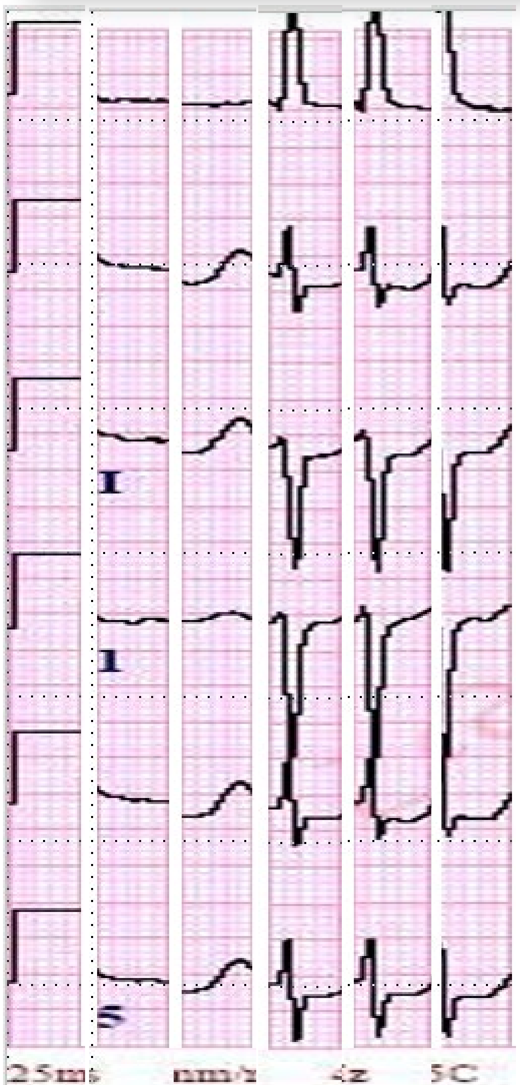


25mm/s 10mm/mV 40Hz 005C 12SL 254 CID: 26

A

Same ECG Different Sampling

B



MIT News

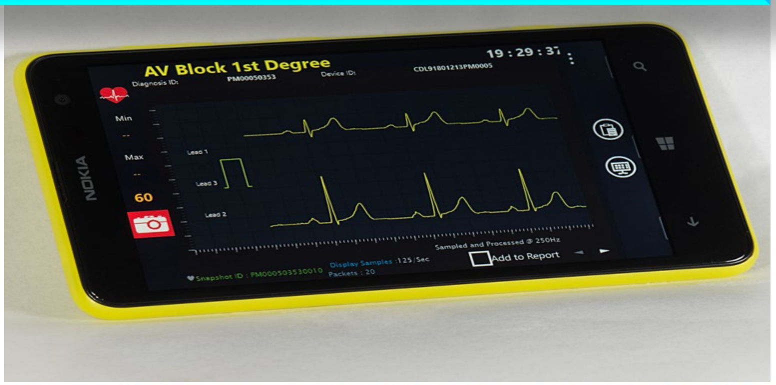
ON CAMPUS AND AROUND THE WORLD

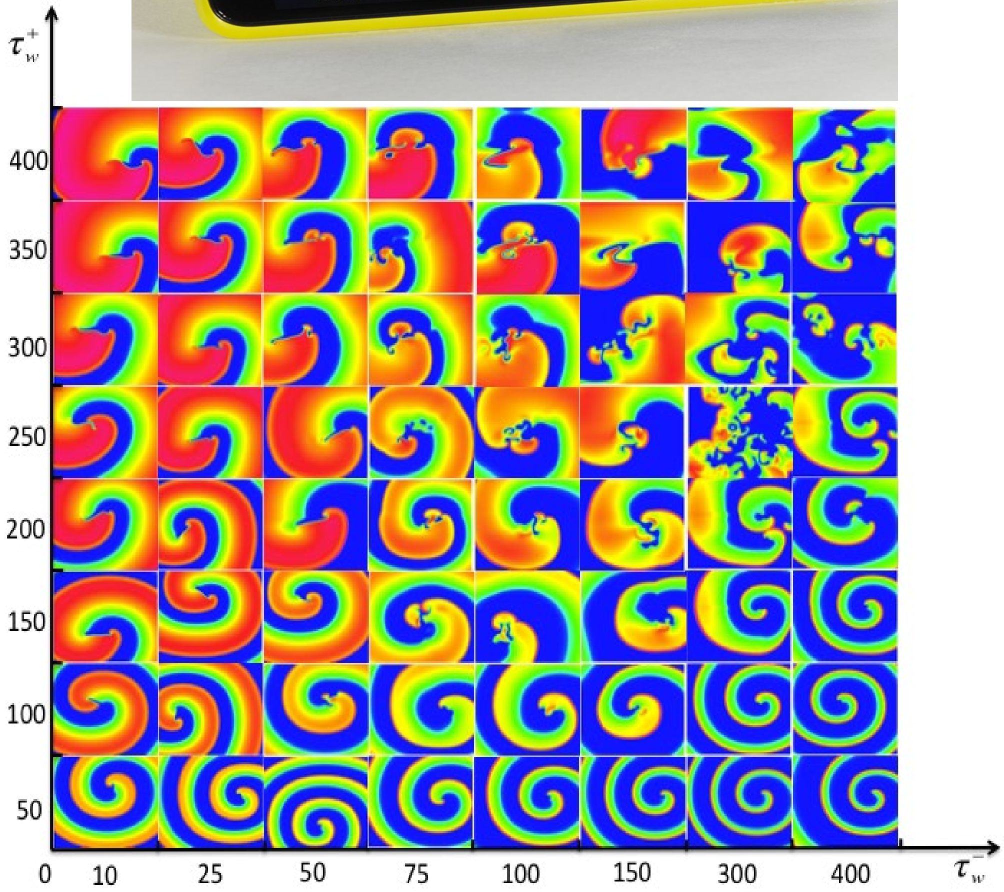
MIT Media Lab spinout Cardiio has developed a mobile app that uses a smartphone camera to detect facial signs of a heart arrhythmia associated with strokes.

Courtesy of Cardiio

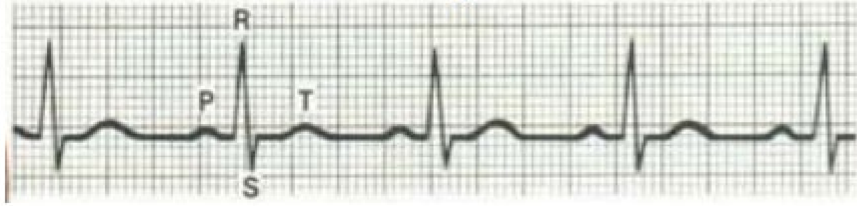
App screens for arrhythmia using smartphone

CARDIAC ARRHYTHMIA DIAGNOSIS & REPORTING CARDIOLOGIST-in-a-POCKET



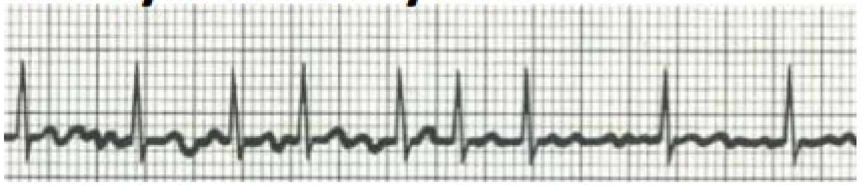


Normal Sinus Rhythm

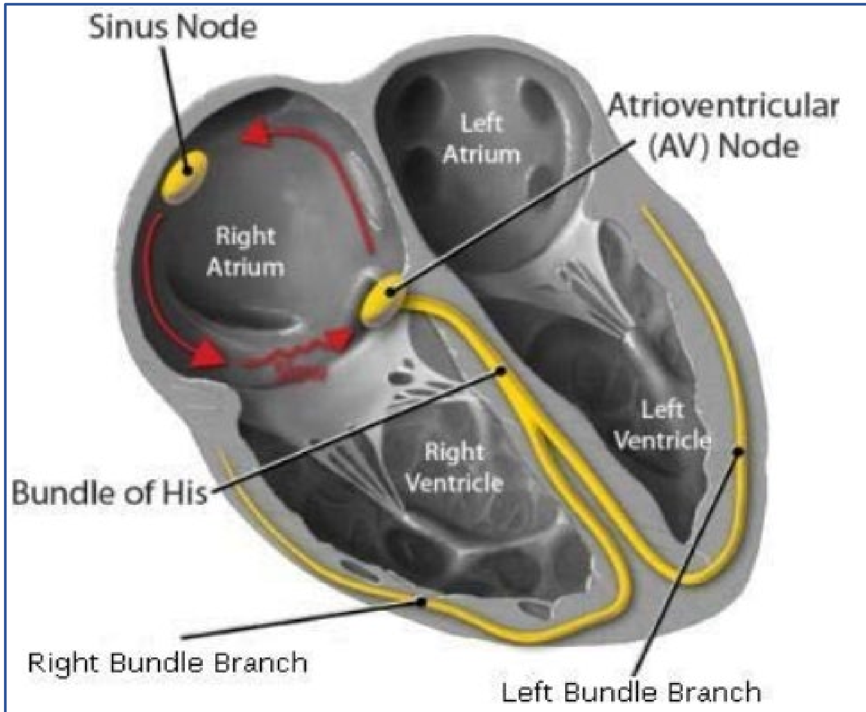


Circular pathways in the heart conduction system is a common cause of arrhythmias

Arrhythmic Rhythm

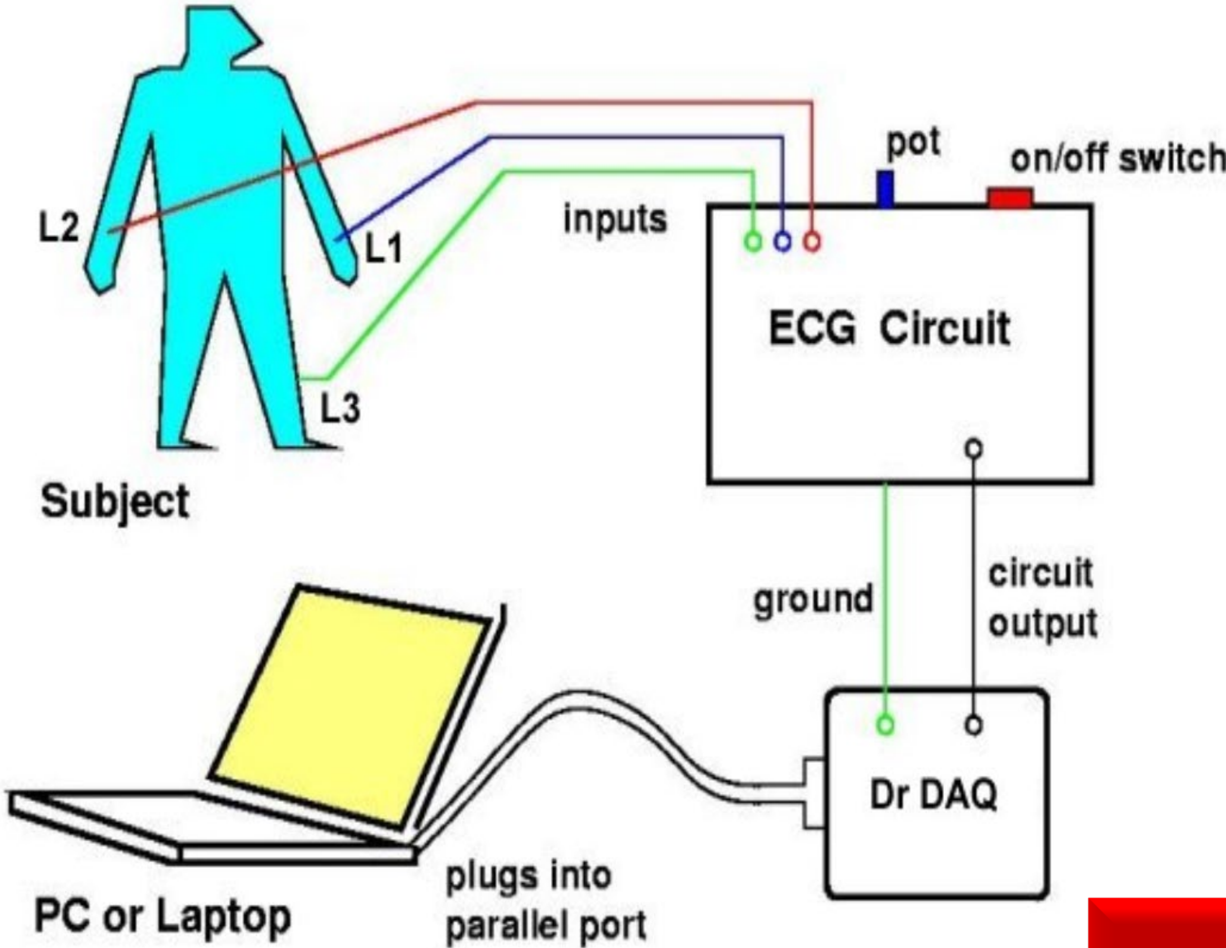


www.seas.upenn.edu/sunfest/docs/slides/MALAMASPETER.pdf



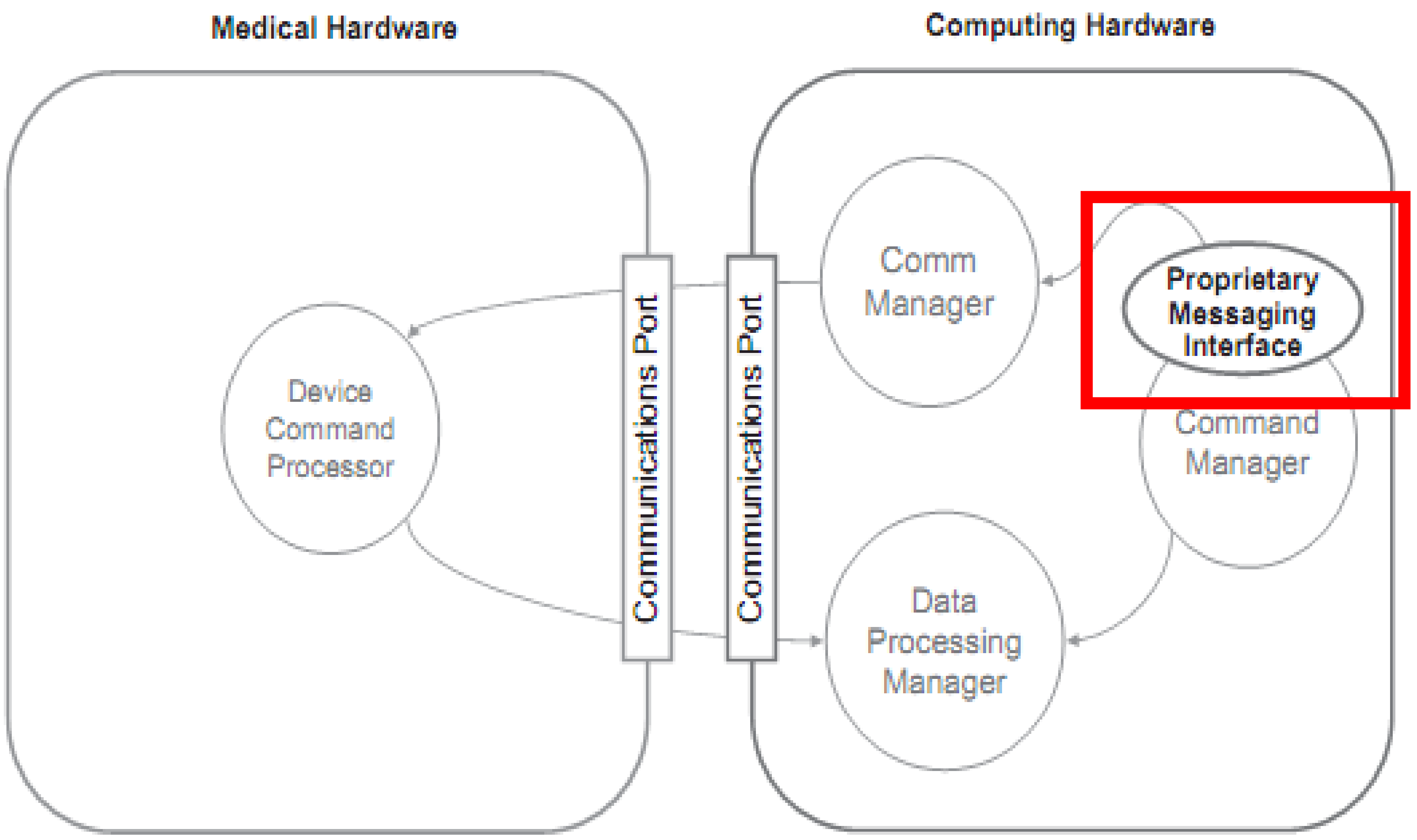
Shouldn’t cardiologists determine optimal sampling rate depending on the context ?

Is common sense relatively uncommon?



Medical professionals must access the data acquisition system to change parameters

http://www.medicine.mcgill.ca/physio/vlab/default.htm

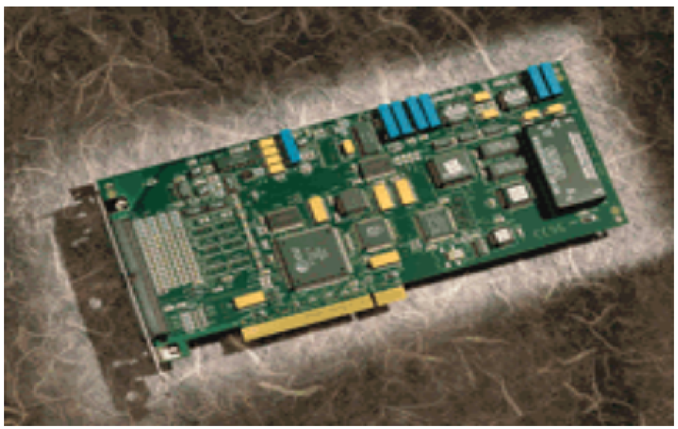


Medical hardware device connectivity when proprietary messaging interfaces are embedded into the processing functionality in the computing hardware

Biomedical Signals Acquisition

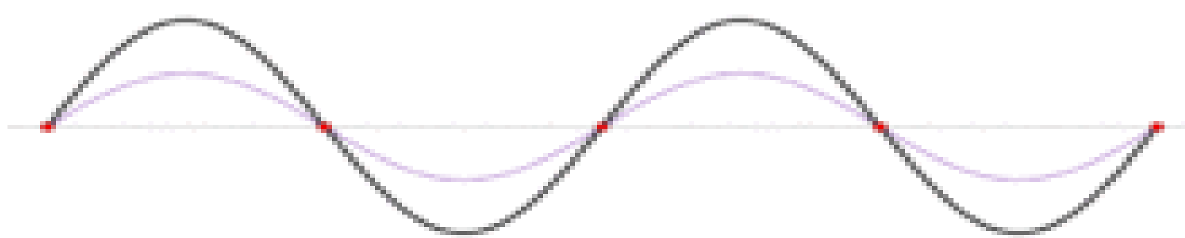
Manufacturers prohibit access to waveform data

In the process of **analogue to digital conversion**, an analogue signal is converted into a digital signal which can then be stored in a computer for further processing. Analogue signals are "real world" signals - for example physiological signals such as electroencephalogram, electrocardiogram or electrooculogram. In order for them to be stored and manipulated by a computer, these signals must be converted into a discrete digital form the computer can understand.



An example of an A/D board which performs the analogue to digital conversion. This board is placed inside the computer where it communicates with the rest of the computer hardware and software. **An alternate way to acquire a signal** is to use an integrated device which comprises the electronics necessary to acquire as well as amplify the signals (shown to the right).

Powerlab* recording system has an A/D board as well as amplifiers and communicates with the computer through its USB port.



ECG SIGNAL ERRORS

The electrocardiogram (ECG) signal recorded from human heart represents the electrical activity of the heart. The processing of ECG signal yields information, such as amplitude and timing, required for a physician to analyze a patient's heart condition [5]. Detection of *R*-peaks and computation of *R*-*R* interval of an ECG record is an important requirement of comprehensive arrhythmia analysis systems.

In practice, various types of externally produced interferences appear in an ECG signal [6]. Unless these interferences are removed, it is difficult for a physician to make a correct diagnosis. A common source of noise is the 60- or 50-Hz power lines. This can be removed by using a notch filter with a notch at 60 or 50 Hz. The other interferences can be removed with careful shielding and signal processing techniques. Data compression finds use in the storage and transmission of the ECG signals. Due to their efficiency for processing non-stationary signals and robustness to noise, wavelet transforms have emerged as powerful tools for processing ECG signals.

Manufacturer’s will not provide access to waveform data

PROPRIETARY

SOFTWARE

“The amount of data we see today is only a fraction of what will exist in five years, and only by managing data better and by using analytics can we gain control of patient outcomes.” GE Healthcare

http://newsroom.gehealthcare.com/picturing-the-path-to-precision-health-and-better-care/

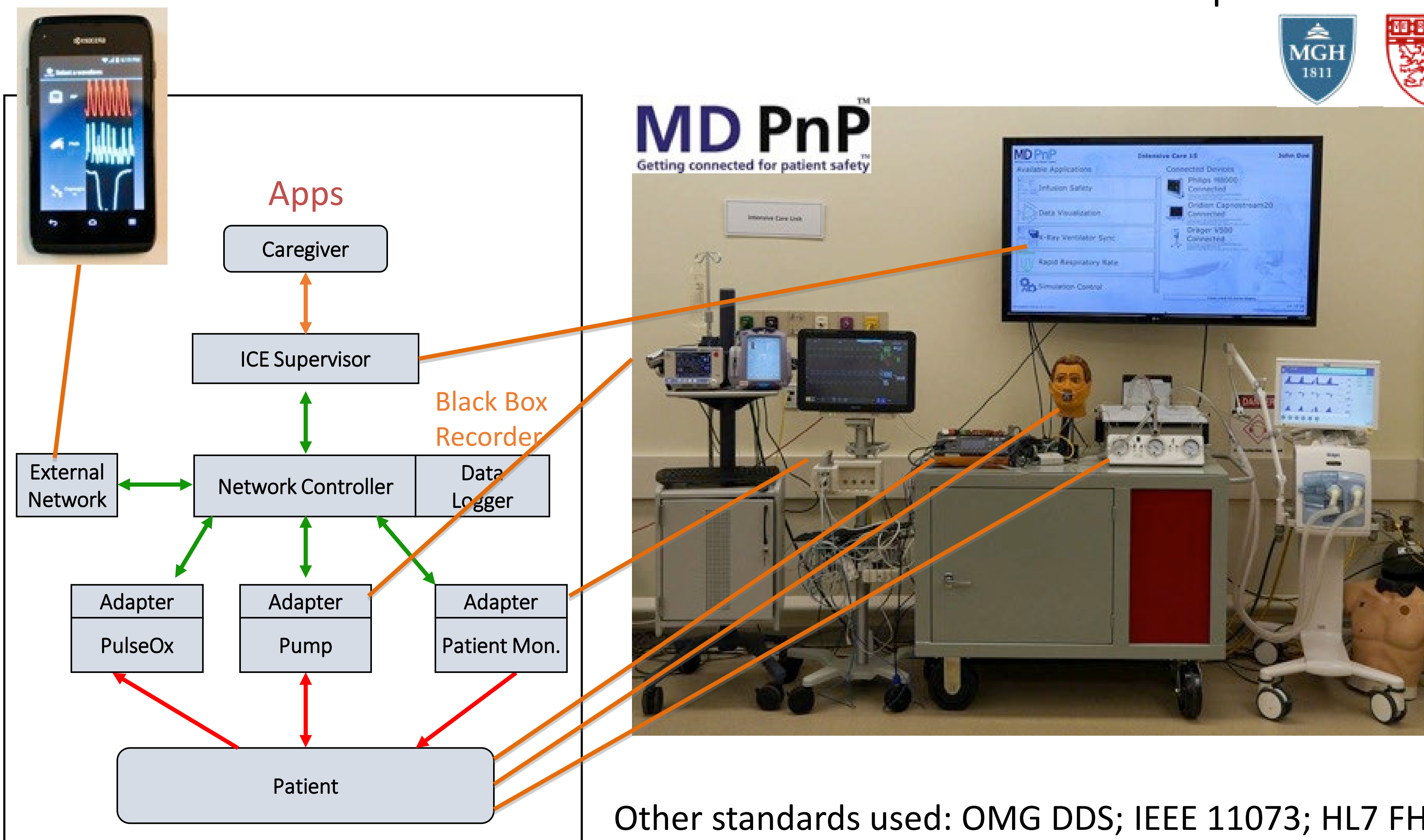
Curing patients is not good for business

Goldman Sachs asks in biotech research report: 'Is curing patients a sustainable business model?'

"Is curing patients a sustainable business model?" Salveen Richter in 4/10/18 report *The Genome Revolution.* "The potential to deliver 'one shot cures' is one of the most attractive aspects of gene therapy, genetically-engineered cell therapy and gene editing. However, such treatments offer a very different outlook with regard to recurring revenue versus chronic therapies," Salveen Richter wrote in the note. "While this proposition carries tremendous value for patients and society, it represent a challenge for genome medicine developers looking for sustained cash flow." Salveen Richter cited Gilead treatment for hepatitis C, which achieved cure rates >90%. The company's US sales for these hepatitis C treatments peaked at $12.5 billion in 2015, but have been falling ever since. Goldman estimates US sales will be less than $4 billion this year. "GILD is a case in point, where the success of its hepatitis C franchise has gradually exhausted the available pool of treatable patients," the analyst wrote. "In the case of infectious diseases such as hepatitis C, curing existing patients also decreases the number of carriers able to transmit the virus to new patients, thus the incident pool also declines. Where an incident pool remains stable (eg, in cancer) the potential for a cure poses less risk to the sustainability of a franchise."

www.cnbc.com/2018/04/11/goldman-asks-is-curing-patients-a-sustainable-business-model.html

Implementation of Integrated Clinical Environment Standards
MD PnP Lab and Cybersecurity Program
Massachusetts General Hospital, Harvard Medical School
www.openice.info

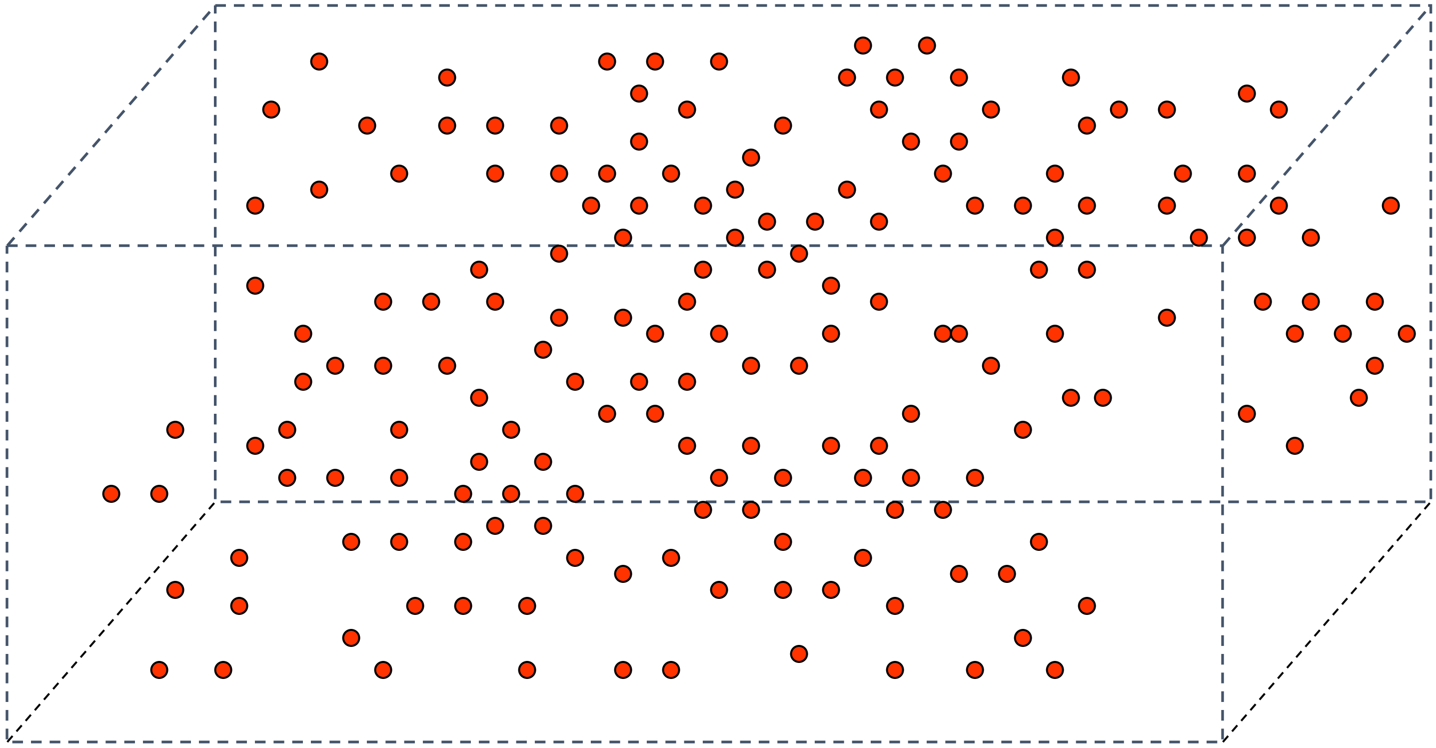


Other standards used: OMG DDS; IEEE 11073; HL7 FHIR

Other Problems with Sampling

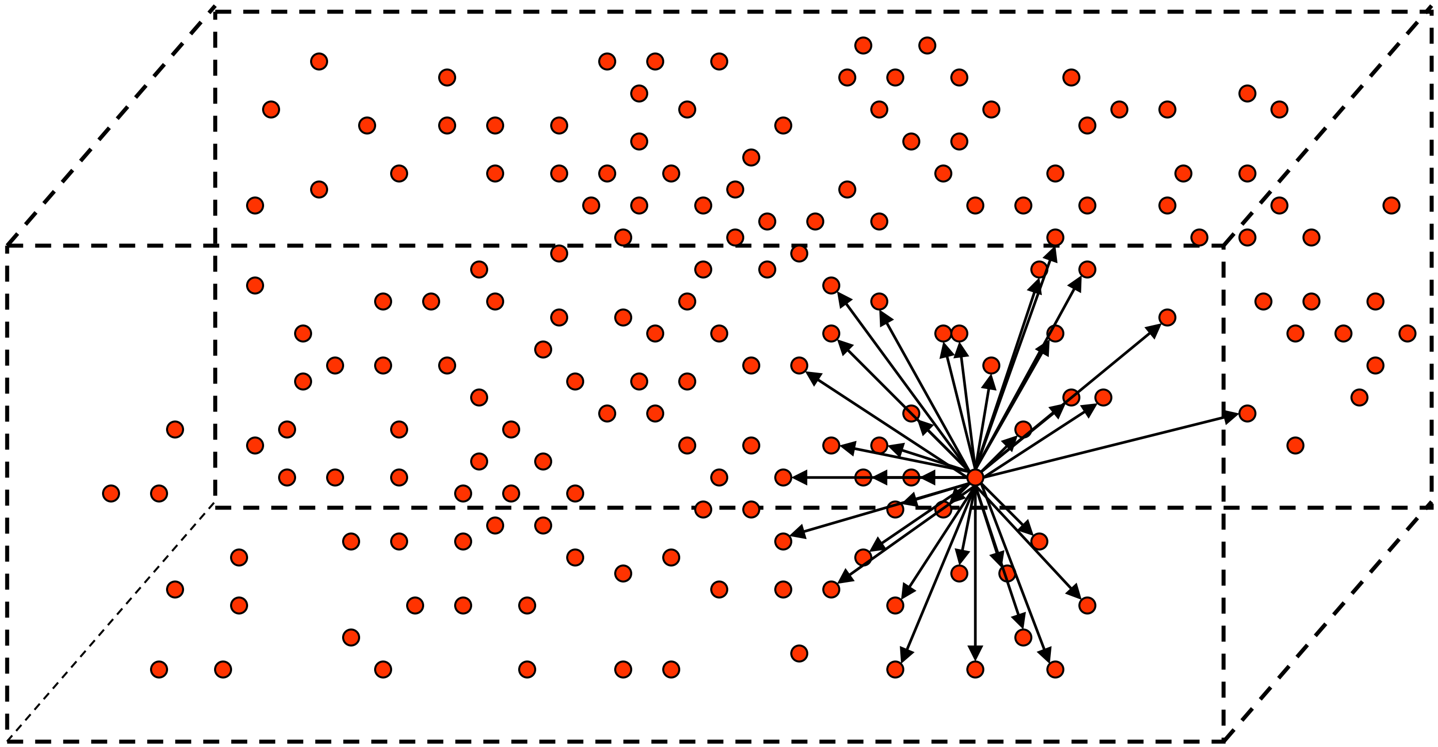
Clustering: Classification by Reduction

Patterns plotted in ‘n’ dimensional space. Each point (pattern) can represent multiple (n) pieces of information (dimensions).



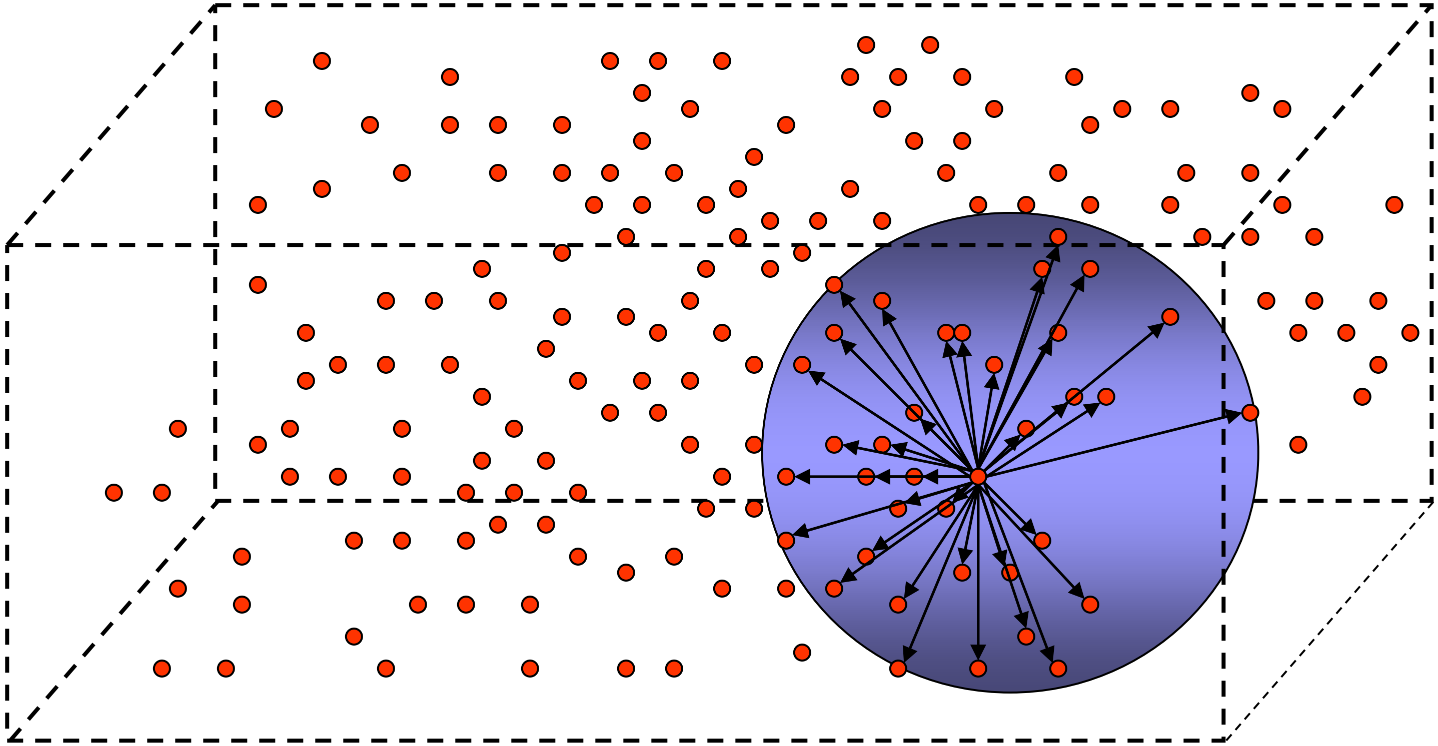
Clusters

Distances are calculated to determine similarity.

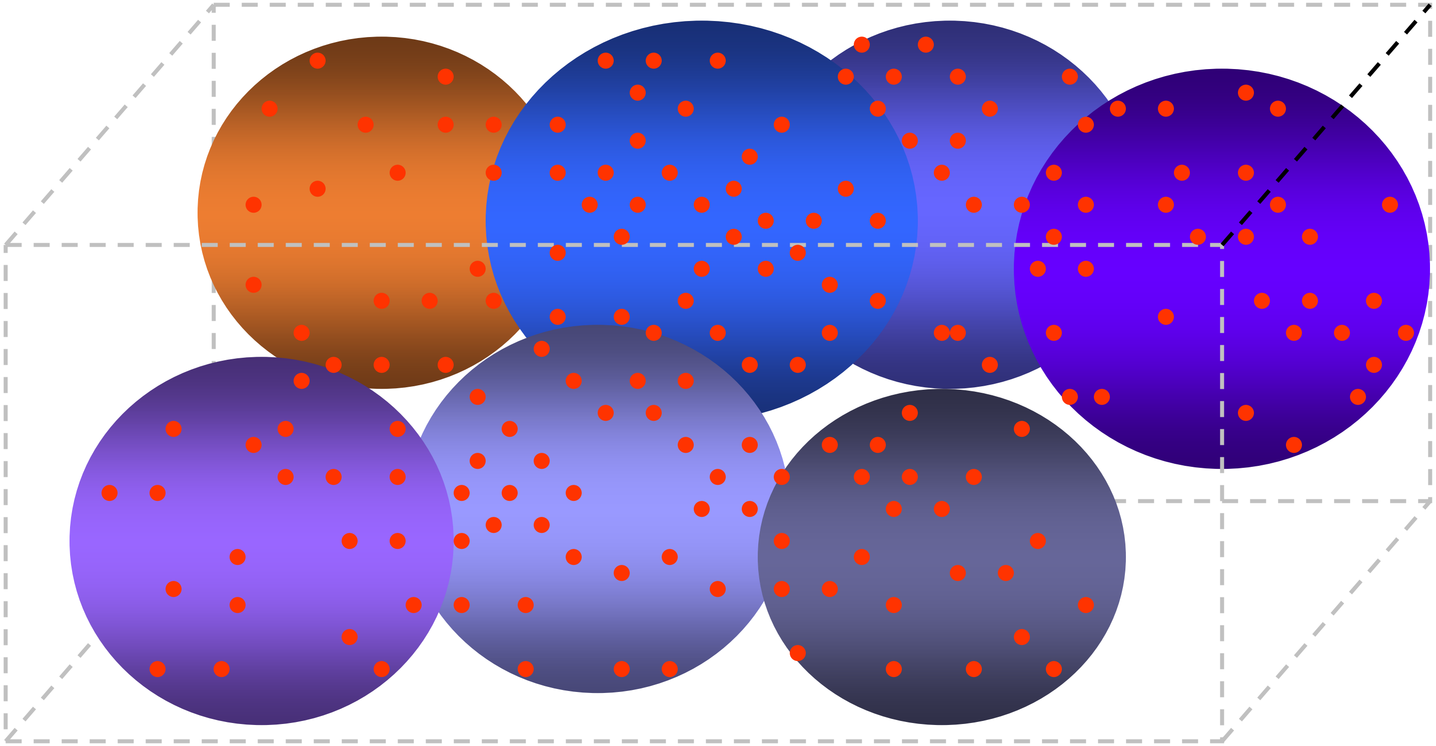


Clustering

Clusters of ‘similar’ patterns are grouped.

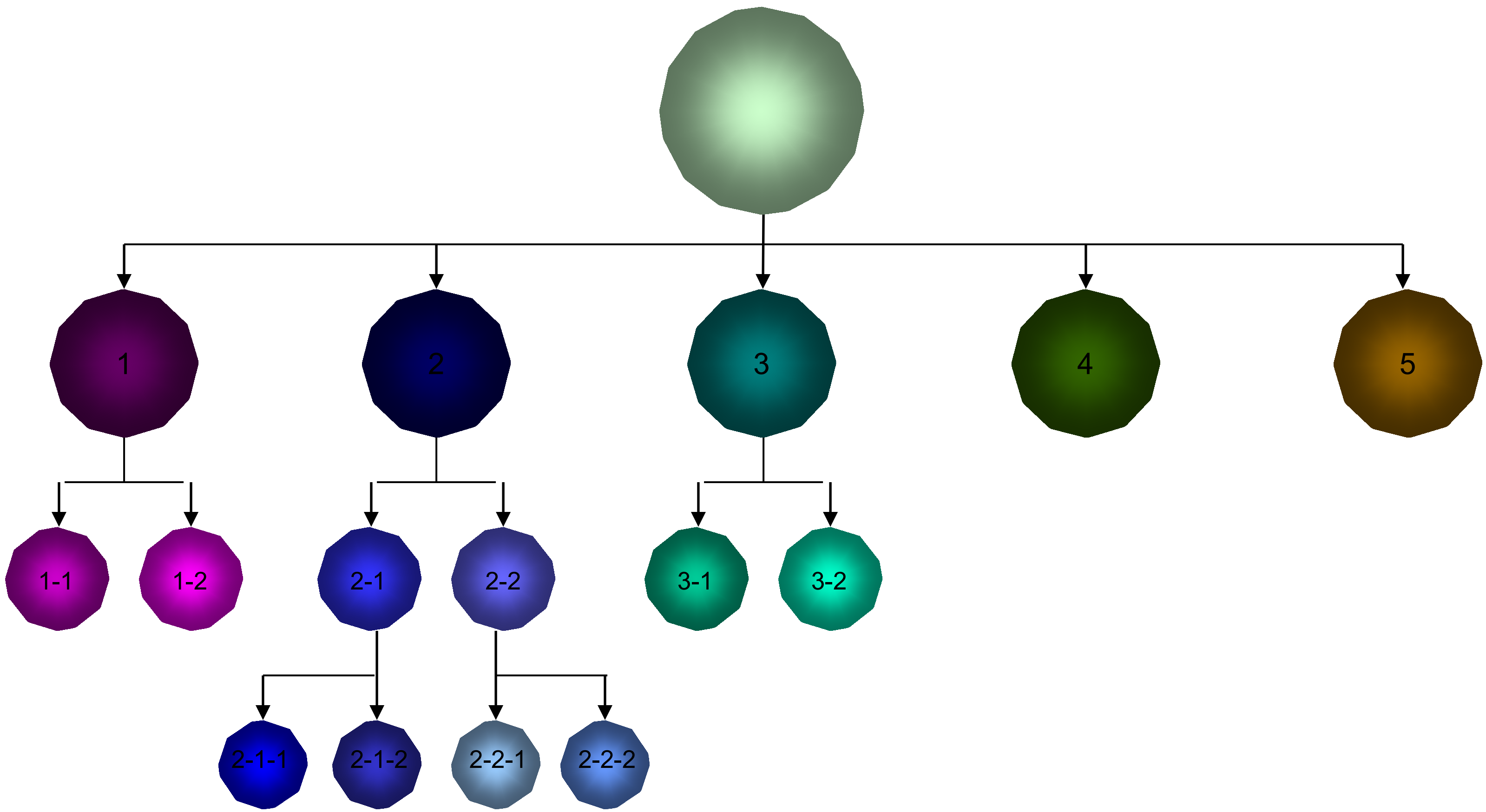


Patterns contained within family of clusters.

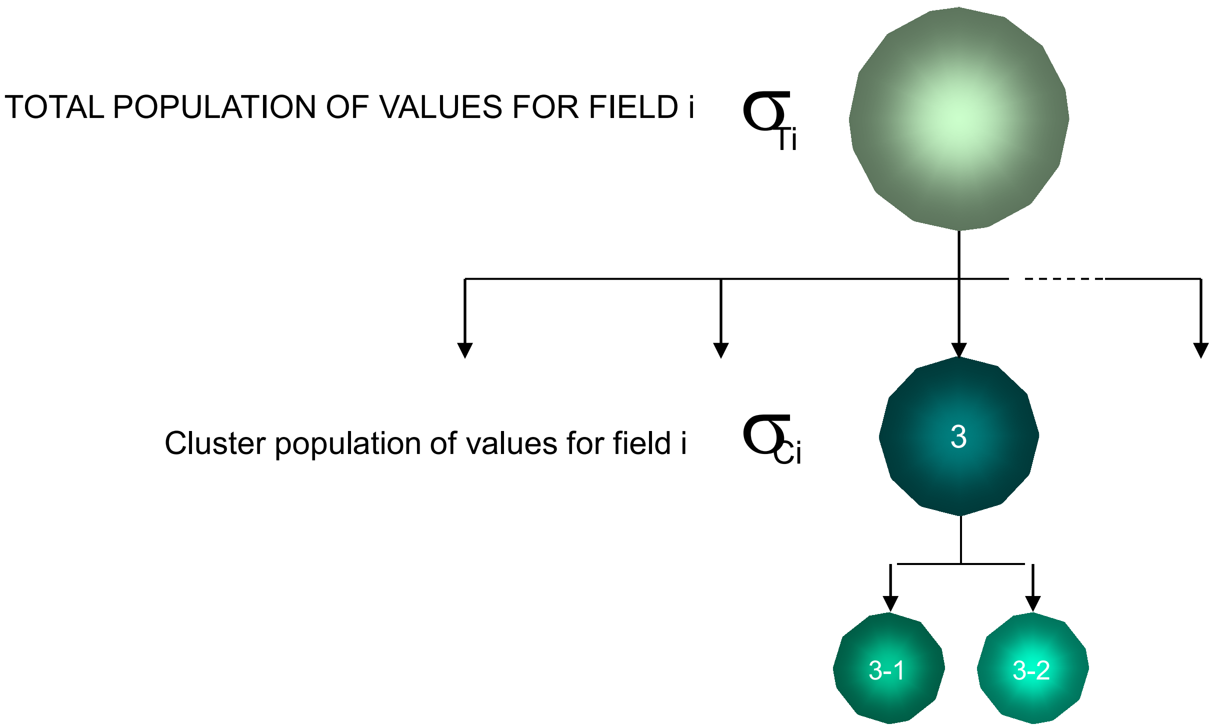


Hierarchical Clustering :

Determines granularity of the clustering

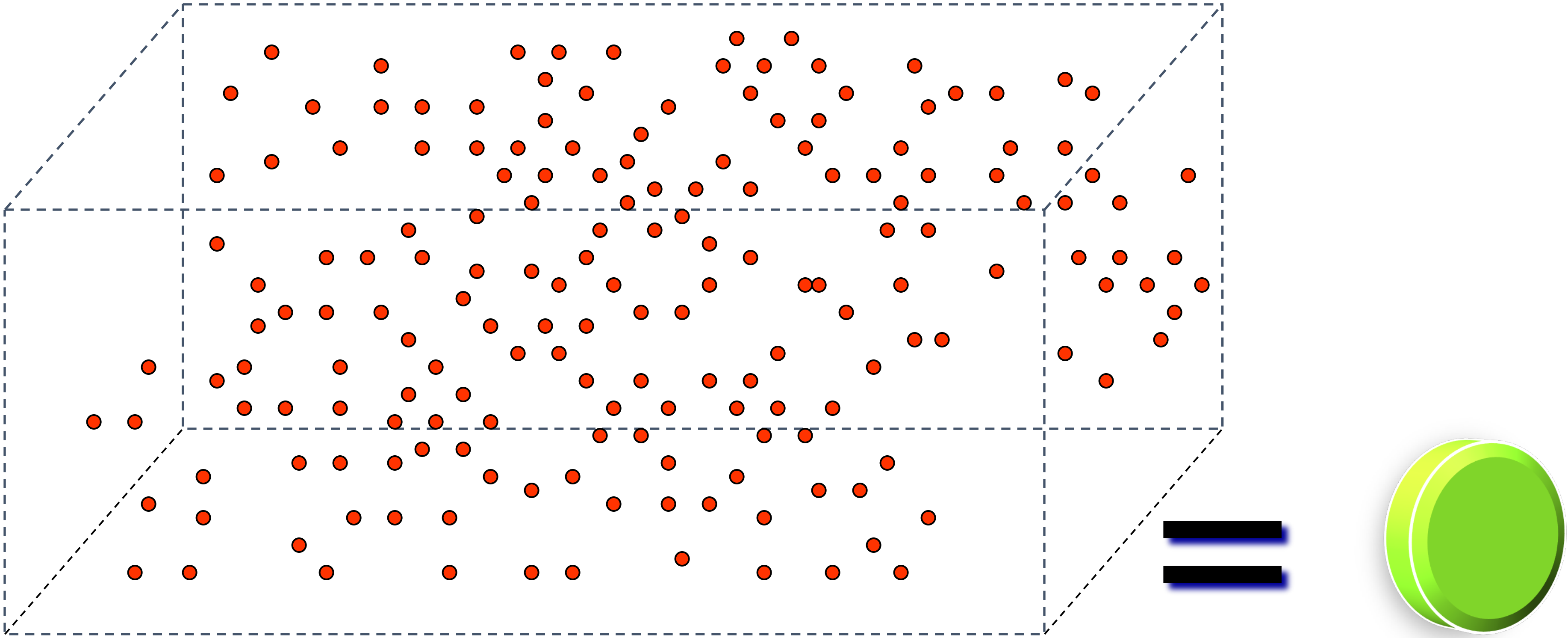


Characterizing Clusters



Standard Deviation Ratio: Identifies how much a <u>field</u> in a particular cluster varies in comparison to all clusters. The standard deviation ratio for field i is calculated by dividing σ_{Ci} by σ_{Ti} . If the standard deviation ratio for a field is small, the field may partly characterize this cluster.

Reductionist Approach



TOTAL POPULATION OF VALUES FOR FIELD i

RF DATA

http://ilp.mit.edu/images/conferences/2015/ict/presentations/Sarma.2015.ICT.pdf

AUTO-ID CENTER

1999

RFID
1999

IoT
1999

Runners passing the control station at the end of the 101st Boston Marathon. In the foreground we can see the mats containing the readers. The times can be displayed on a screen immediately

101st Boston Marathon

Updated April 21, 1997 9:12 p.m. ET

MEN 1. Lameck Aguta, Kenya, 2 hours, 10 minutes, 34 seconds 2. Joseph Kamau, Kenya, 2:10:46 3. Dionicio Ceron, Mexico, 2:10:59 4. German Silva, Mexico, 2:11:21 5. Moses Tanui, Kenya, 2:11:38 6. Gilbert Rutto, Kenya, 2:12:30. 7. Jimmy Muindi, Kenya, 2:12:49 8. Andre Ramos, Brazil, 2:13:10 9. Jose Molina, Costa Rica, 2:13:24 10. Bekele Tesfaye, Ethiopia, 2:14:02 11. Nelson Ndereva, Kenya, 2:14:12 12. Charles Tangus, Kenya, 2:14:34 13. Ezekiel Bitok, Kenya, 2:14:57 14. Joshua Kimaiyo, Kenya, 2:15:29 15. Andres Espinosa, Mexico, 2:16:19

RFID
1997

Radio Frequency Identification – RFID Timeline

1940	1950	1960	1970	1980	1990	2000
RFID born out of MIT Radar effort	RFID crawls out	Theories of RFID field trials planned	Early adopters implement RFID	Commercial RFID endeavors sprout	Many RFID standards	RFID hype, peaks
1948 Harry Stockman invents RFID. Publishes paper, "Communication by Means of Reflected Power"	1950 D.B. Harris patents RFID. "Radio transmission systems with modulatable passive responder" 1952 F.L. Vernon "Application of the microwave homodyne" 1959 Identification of Friend or Foe long-range transponder system reaches breadboard demonstration stage.	1963-1964 R.F. Harrington advances theory with "Field measurements using active scatterers" and "Theory of loaded scatterers" 1966 Commercialization of EAS, 1-bit Electronic Article Surveillance	1973 Raytheon's "Raytag" 1977 RCA develops "Electronic identification system" 1975 Los Alamos National Lab releases RFID research to public sector, publishes "Short-range radio-telemetry for electronic identification using modulated backscatter" 1976-1977 LANL RFID spin-offs Indentronix and Amtech	1982 Mikron founded; bought by Philips 1987 First RFID road toll collection implemented in Norway	1991 TI creates TIRIS to develop and market RFID 1992-1995 Multi-protocol traffic control and toll collection implemented in TX, OK and GA. 1998 David Brock and Sanjay Sarma of MIT publishes an idea: 'Internet of Things' 1999 Auto ID Center created at MIT. Retailers drive to standardize EPC	2003 UPC and EAN forced by US retailers to promote EPC 2005 Wal-Mart and US DoD fuels the hype curve by demanding suppliers use passive RFID and EPC. https://www.rfidjournal.com/articles/view?572 And www.zdnet.com/article/did-wal-mart-love-rfid-to-death/

Table was modified from the version created by Han Pang Huang, National Taiwan University
1948 - DISCOVERY - https://ieeexplore.ieee.org/document/1697527
HISTORY - http://www.u.arizona.edu/~obaca/rfid/sources.html
https://www.transcore.com/wp-content/uploads/2017/01/History-of-RFID-White-Paper.pdf

Vast number of RFID companies and 'short-sight' enters market.

Published October 1, 2000. Distribution restricted to Sponsors until January 1, 2001.

https://pdfs.semanticscholar.org/88b4/a255082d91b3c88261976c85a24f2f92c5c3.pdf

RFID
1999

TO-ID CENTER

WHITE PAPER

The Networked Physical World

Proposals for Engineering the Next Generation of Computing, Commerce & Automatic-Identification

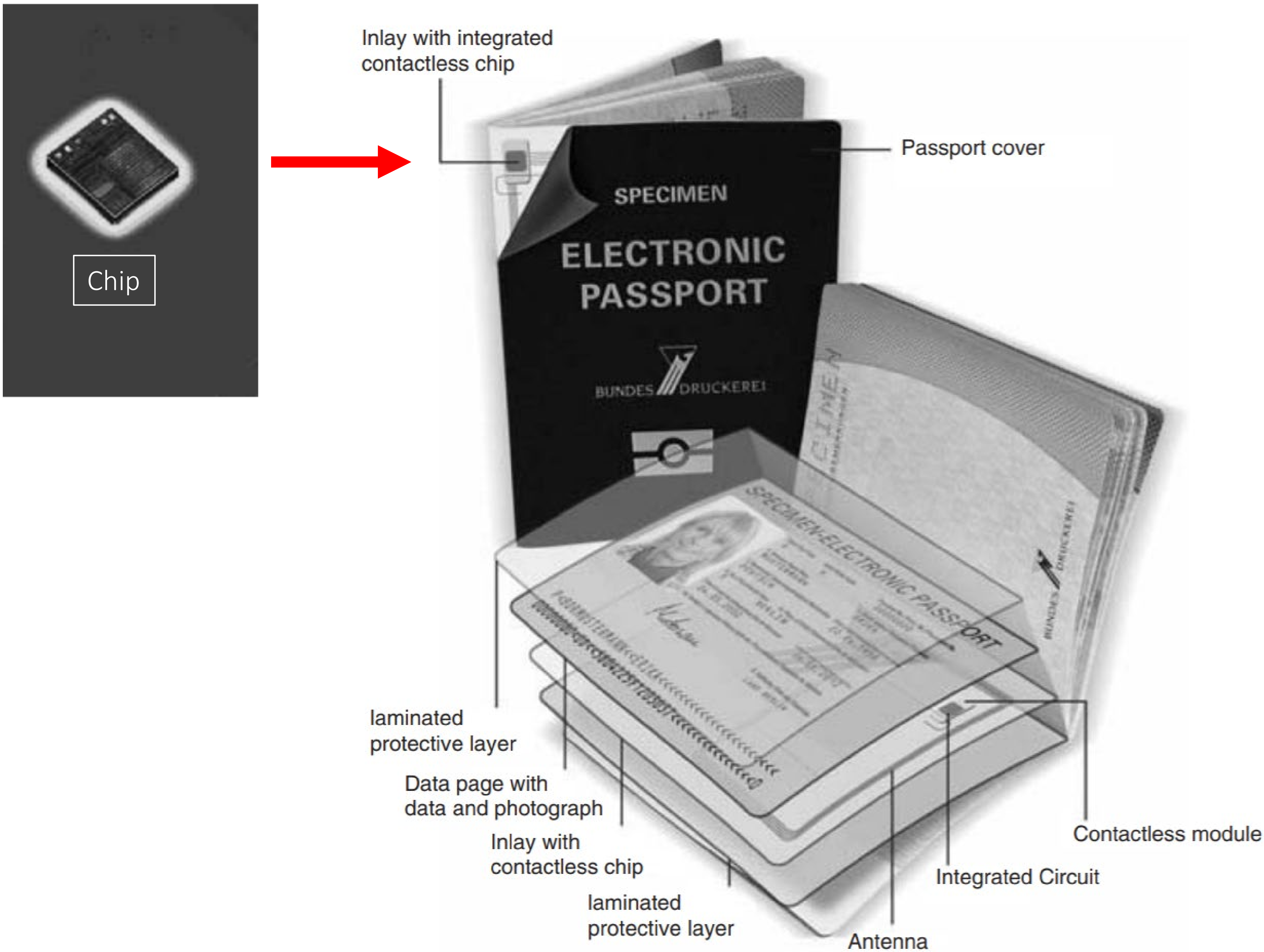
Sanjay Sarma, David L. Brock & Kevin Ashton

AUTO-ID CENTER MASSACHUSETTS INSTITUTE OF TECHNOLOGY, 77 MASSACHUSETTS AVENUE, BUILDING 3-449G, CAMBRIDGE, MA 02139-4307

IoT

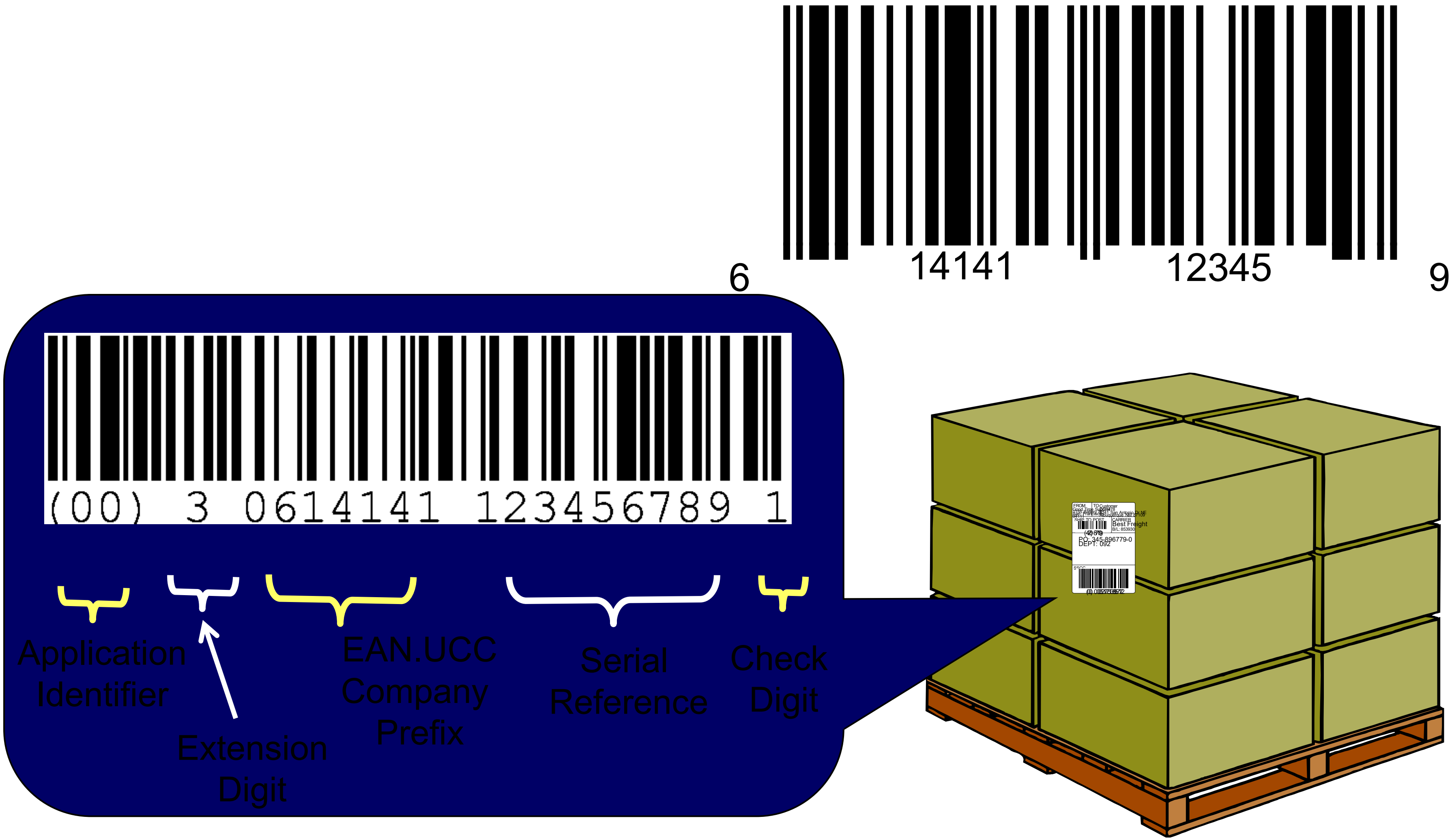
ABSTRACT

The Auto-ID Center at the Massachusetts Institute of Technology is a new industry sponsored lab charged with researching and developing automated identification technologies and applications. The Center is creating the infrastructure, recommending the standards, and identifying the automated identification applications for a networked physical world. All technologies and intellectual property developed at the Auto-ID Center are freely distributed. This white paper outlines the Auto-ID Center's key conclusions and research progress after its first year of research.

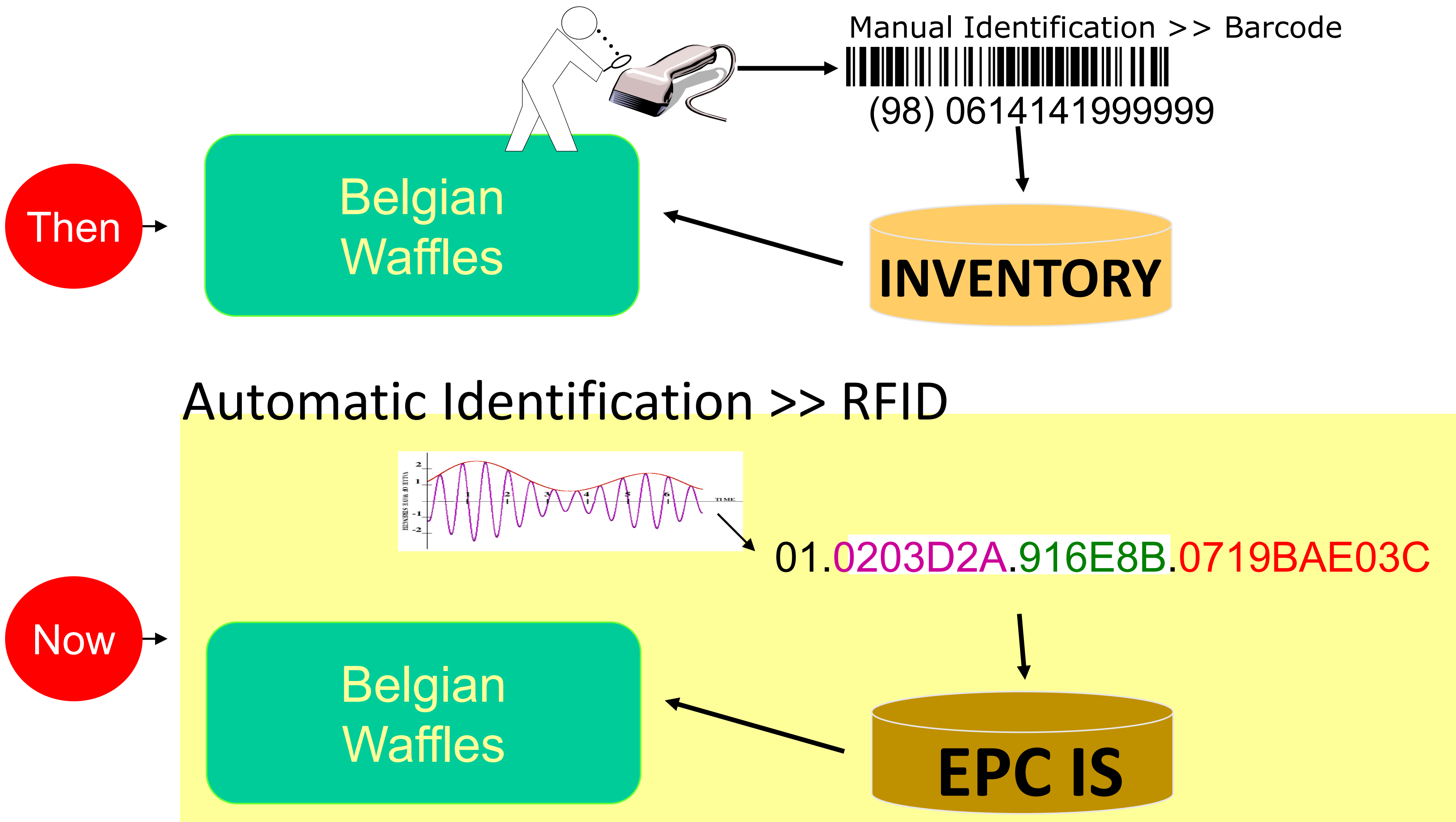

Chip
Inlay with integrated contactless chip
Passport cover
SPECIMEN
ELECTRONIC PASSPORT
BUNDESDRUCKEREI
SPECIMEN-ELECTRONIC PASSPORT
laminated protective layer
Data page with data and photograph
Inlay with contactless chip
laminated protective layer
Antenna
Integrated Circuit
Contactless module

Smart label transponders are thin and flexible enough to be attached to luggage
label (reproduced by permission of i-code-Transponder, Philips Semiconductors,

30 years ... Behind Bars

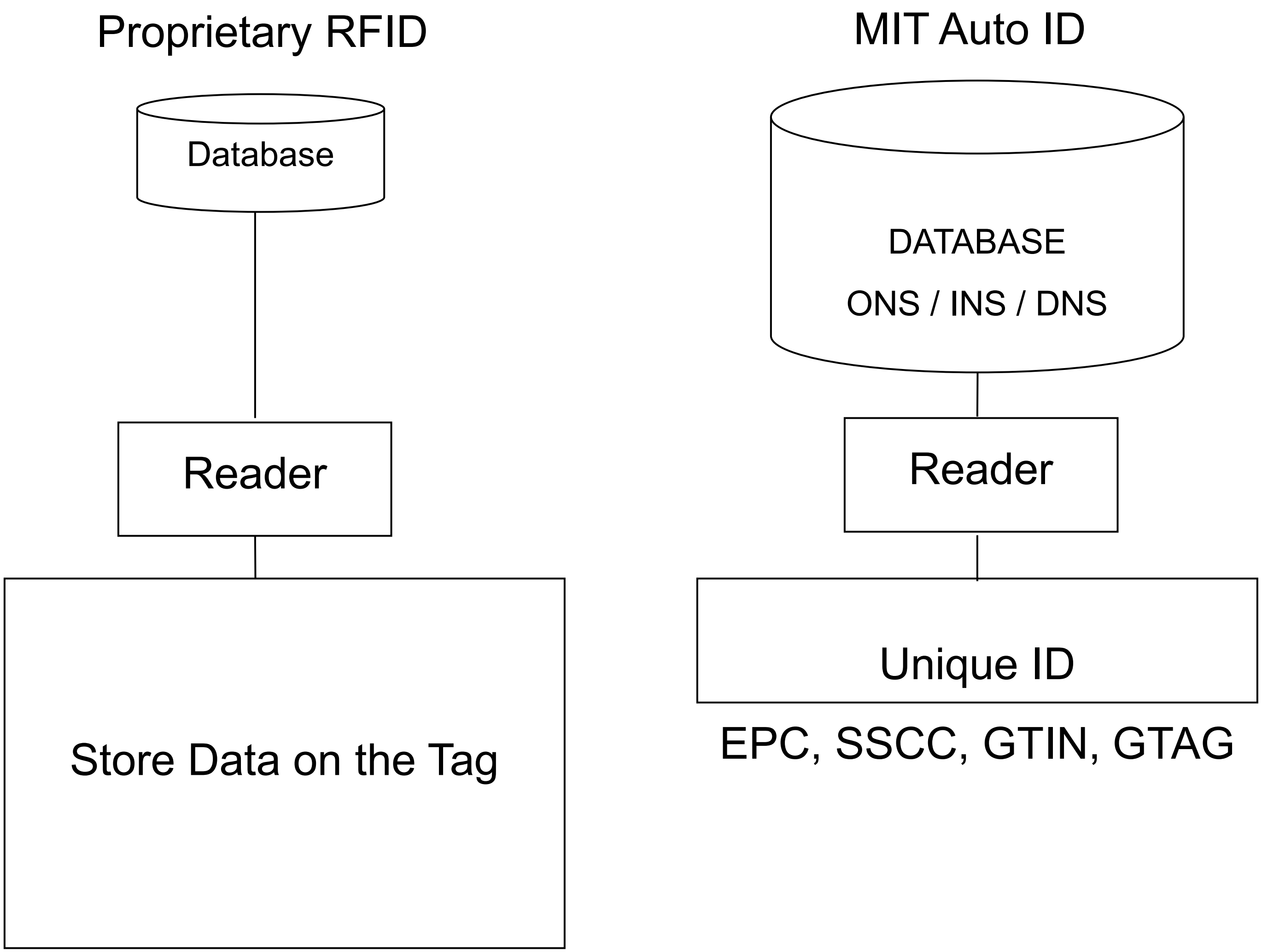


Data Acquisition



Paradigm Shift?

Internet-Catalysed Evolution: Relevant RFID Data



Dr Shoumen Datta, MIT
shoumen@mit.edu

Dublin 2 Boston

151.193.204.72

Heathrow 2 Logan

151.193.204.62

Beyond Barcode

Electronic Product Code (EPC) 96 bits

268 million companies can each categorize 16 million different products and each product category may contain over 68 billion individual items !!

Header ePC Manager Object Class Serial Number

01.0203D2A.916E8B.0719BAE03C

Header: 8 bits = 256

ePC Mgr: 28 bits = 268, 435,456

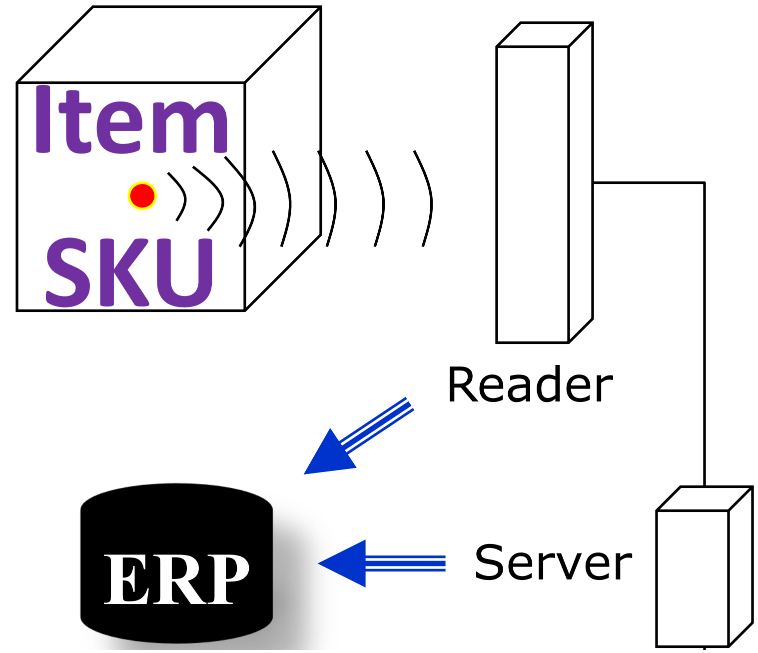
Object Class: 24 bits = 16,777,216

Serial Number: 36 bits = 68,719,476,736

Dr Shoumen Datta, MIT
shoumen@mit.edu

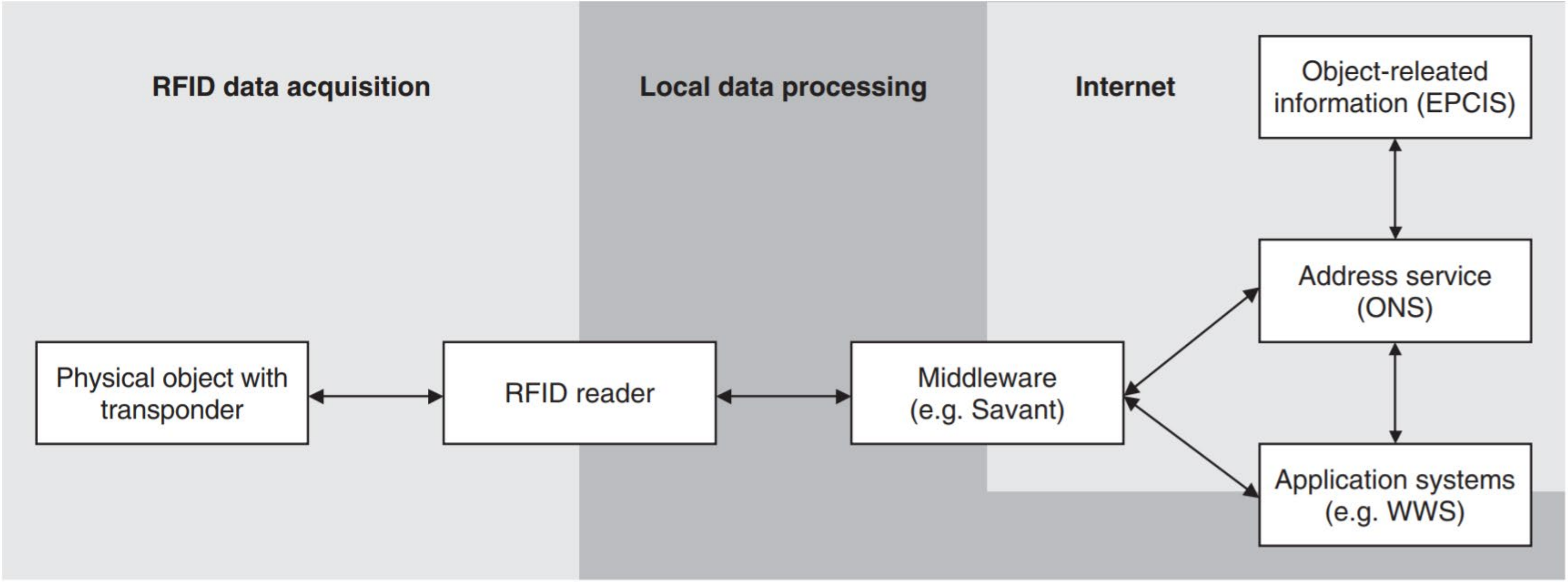
Radio Frequency Identification

- **RFID Tag (Active UWB)**
  - Radio Frequency Identification
  - Electronic Product Code (EPC)

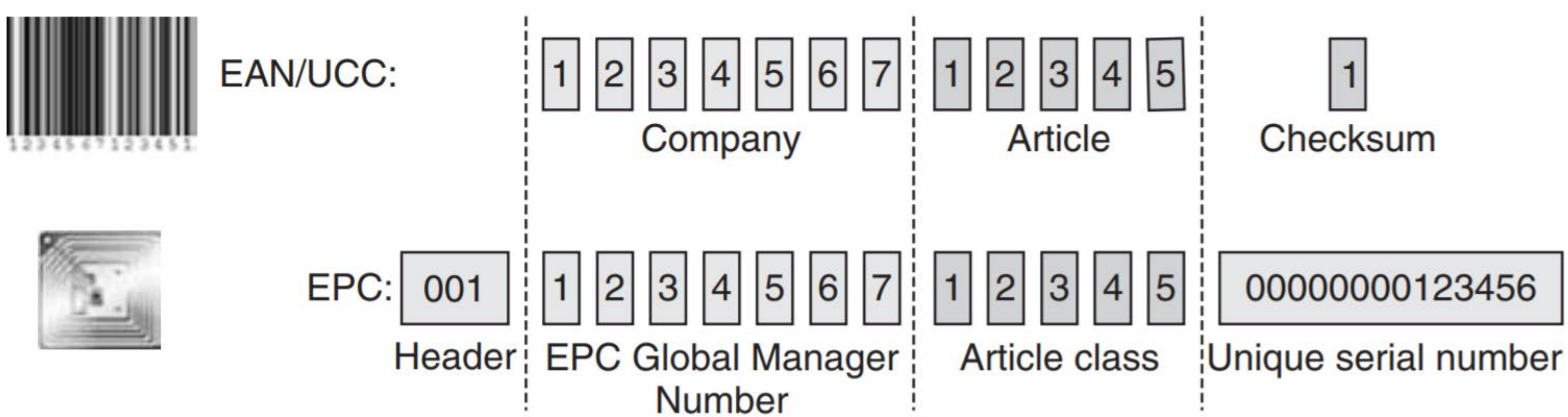


- RF waves transfer data (object to reader)
- Re-writable secure data
- Identify individual items
- Line of sight not required
- Stable in variety of conditions
- Read through most non-metals
- RFID transponders 5 cents ? ($0.25 - $150)
- RFID readers: $2000 to $10 (SDR?)
- Infrastructure: Profit over Physics?
- RFID Interface (Real-time data) to ERP (?)
- Can RDBMS handle data flow? Streaming DB.
- Auto ID standard Global EPC at UCC.EAN
- Limited spatial capacity of 1 kbpsm^2

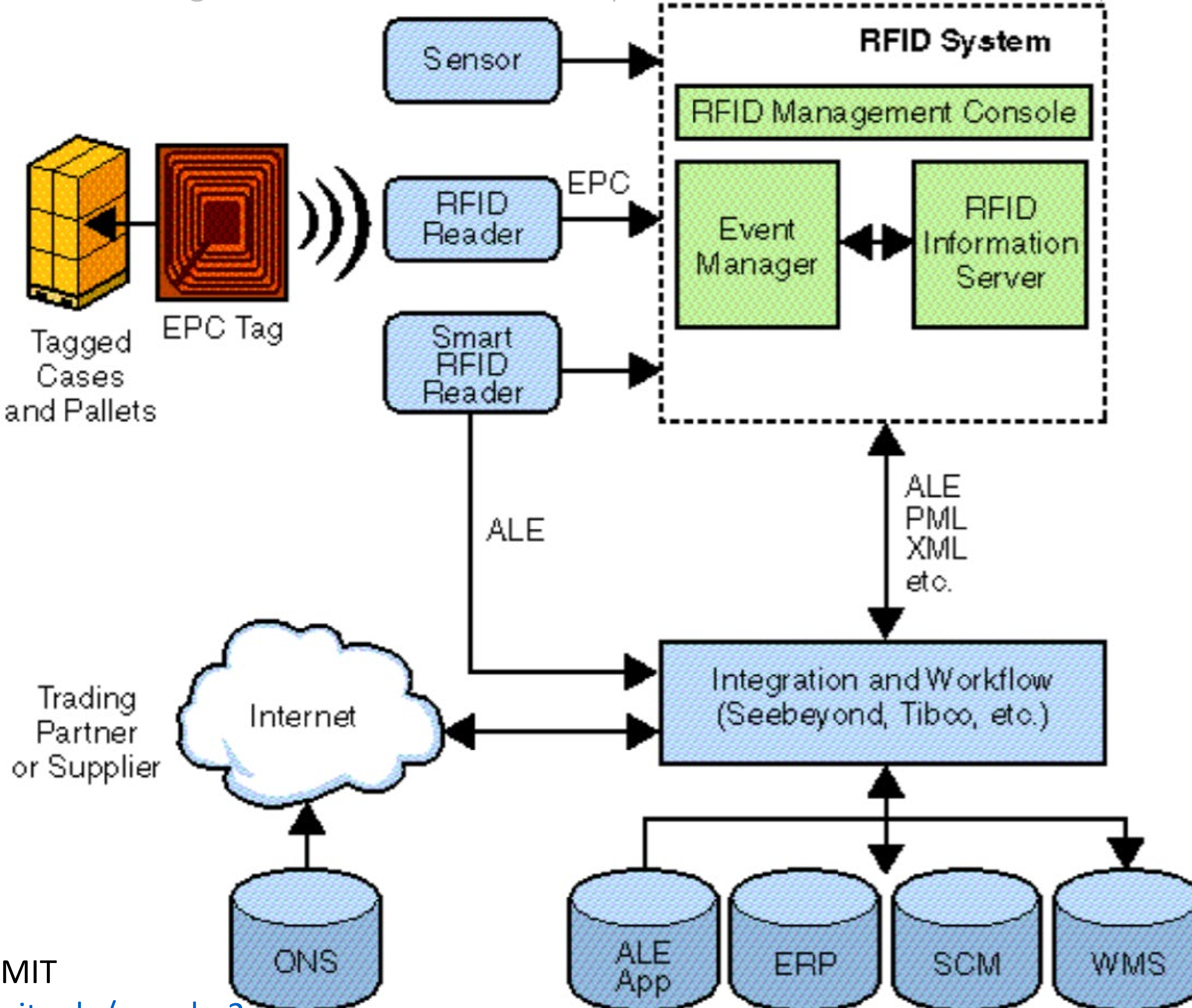
Paradigm Shift?



Interaction of different components of the EPCglobal Network (WWW: Warenwirtschaftssysteme), according to EPC Forum (n.d.)

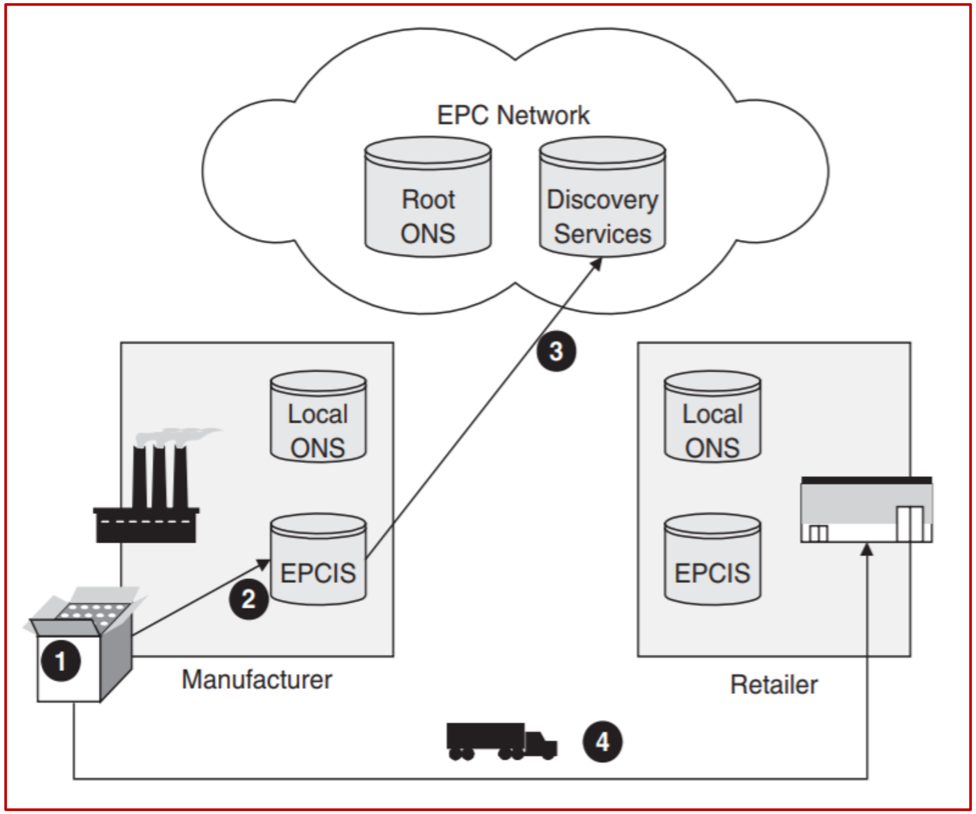


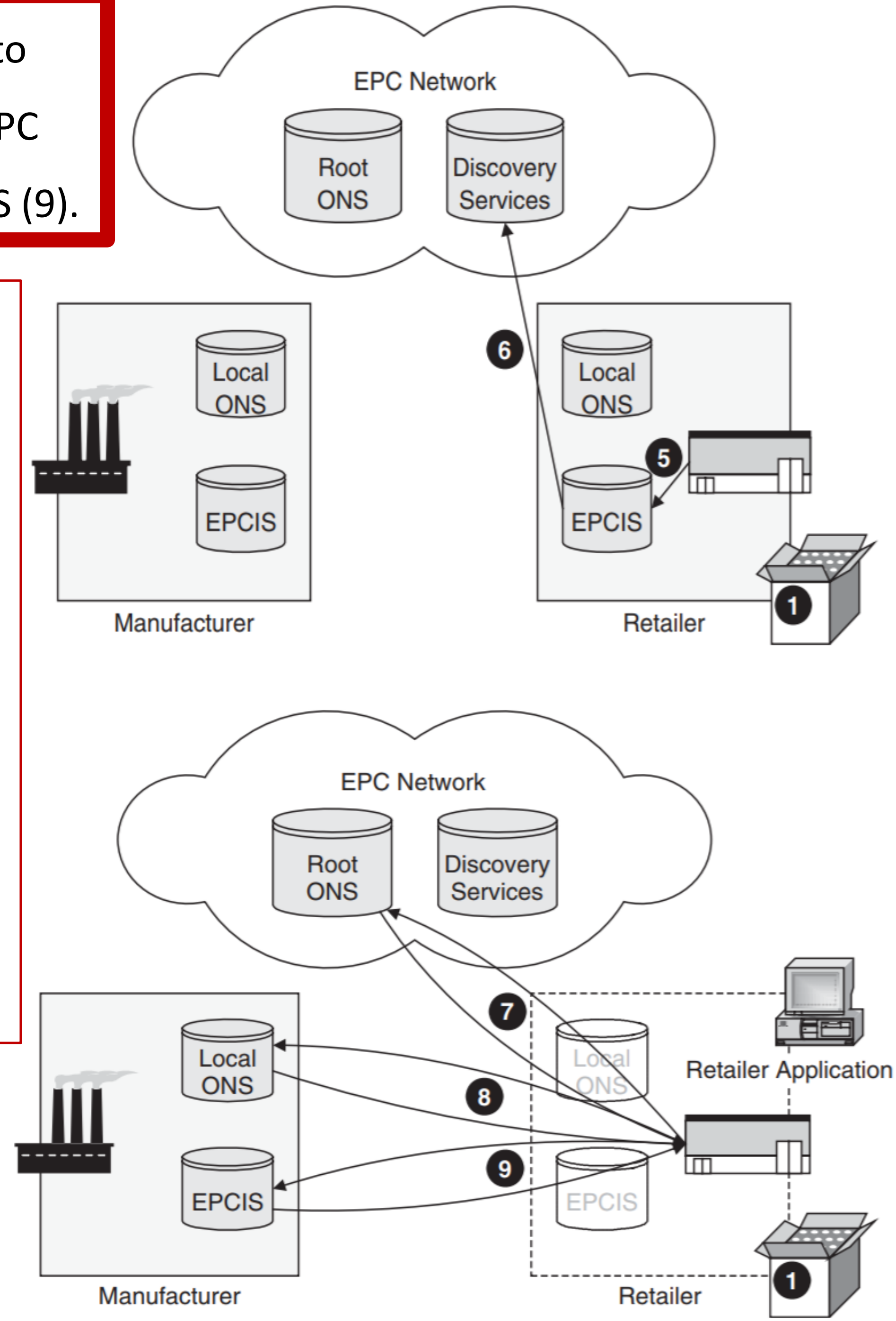
Comparison of the encoding of common EAN/UCC barcodes and an SGTIN-encoded EPC



Sanjay Sarma, MIT
http://autoid.mit.edu/people-2

EPC life cycle starts with transponder(1) attached to object. Acknowledgment stored EPCIS (5) and 6. EPC product data requested from manufacturer’s EPCIS (9).

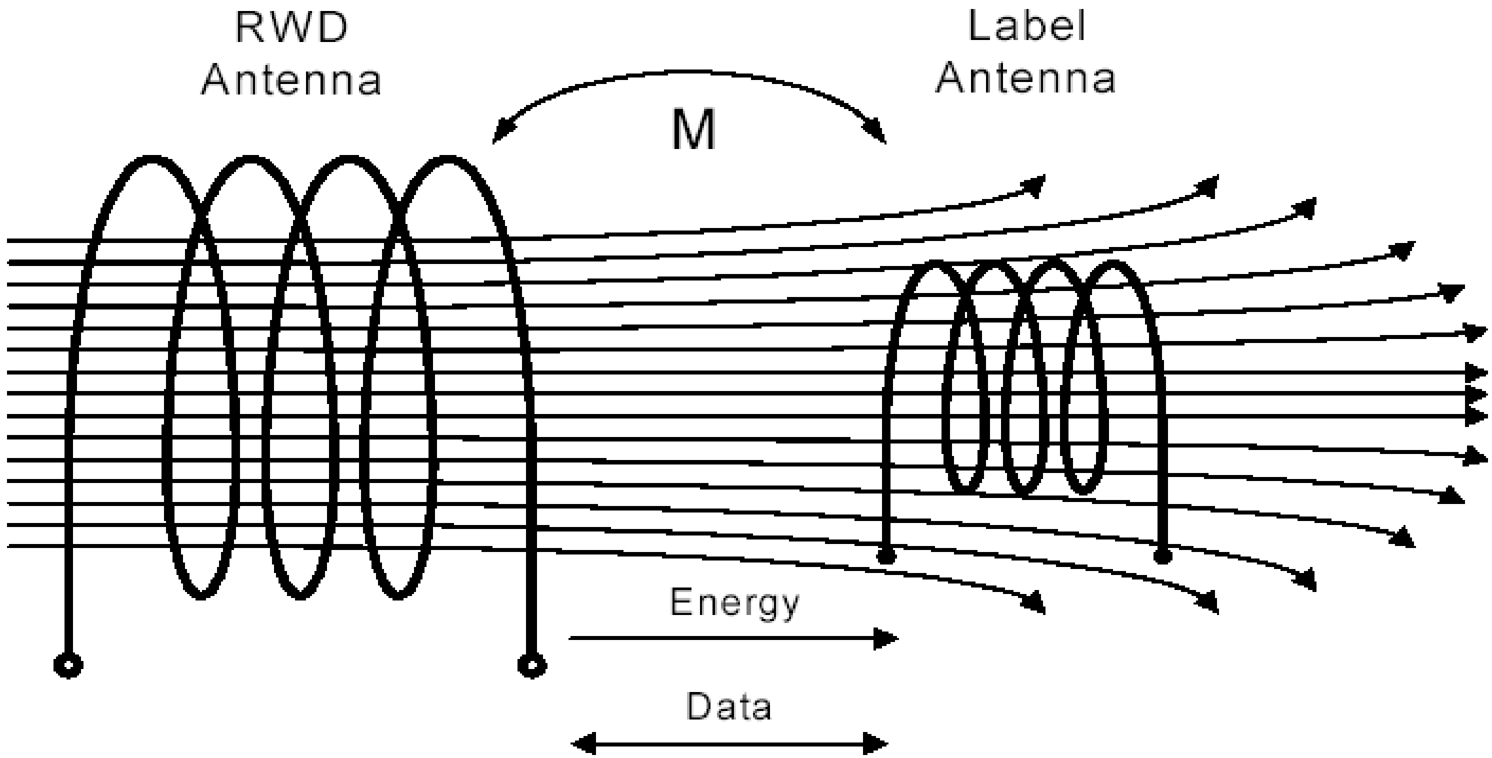




MIT Auto-ID Center, MIT Auto-ID Labs

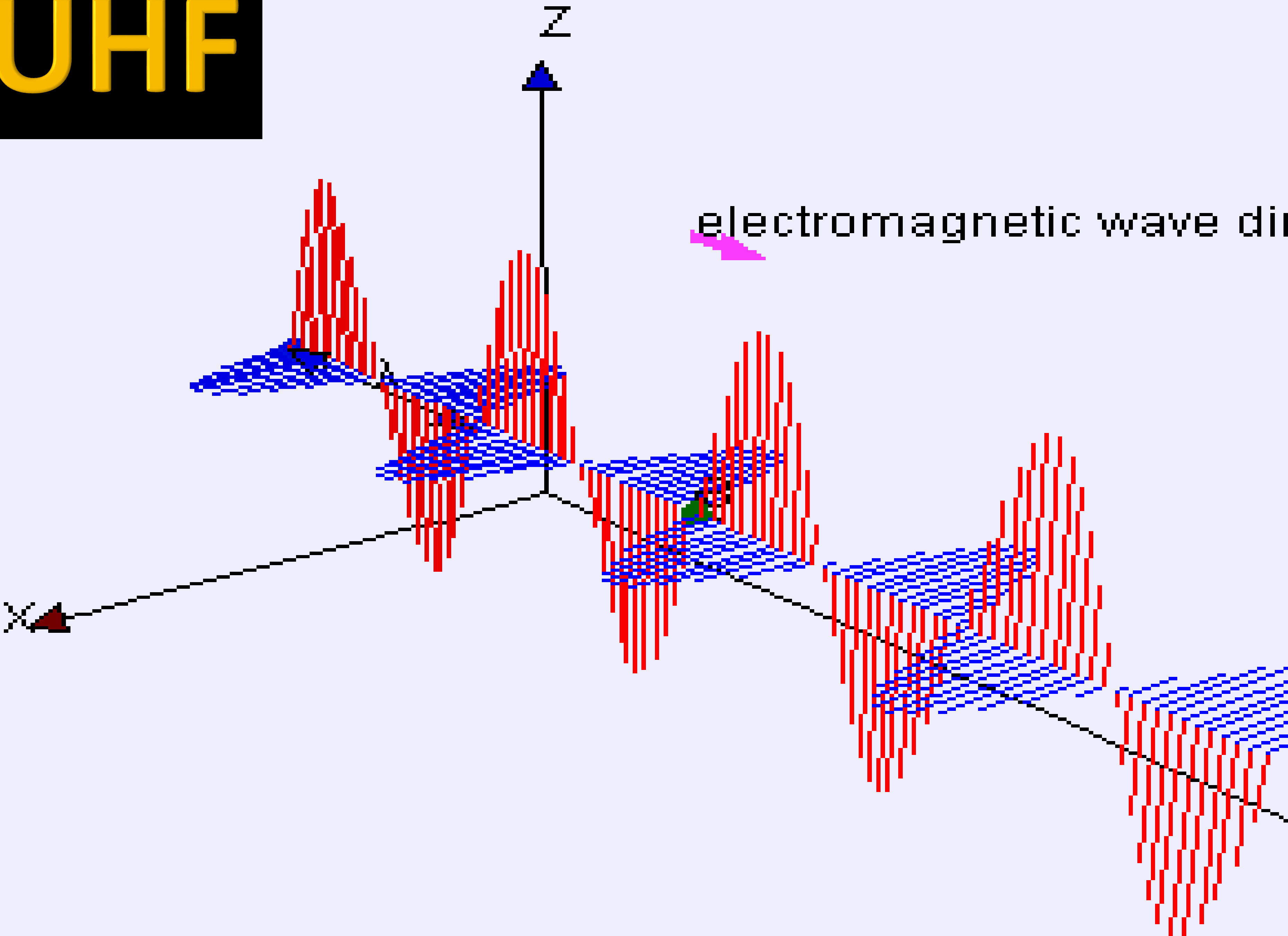
RF – Frequency, Spectrum

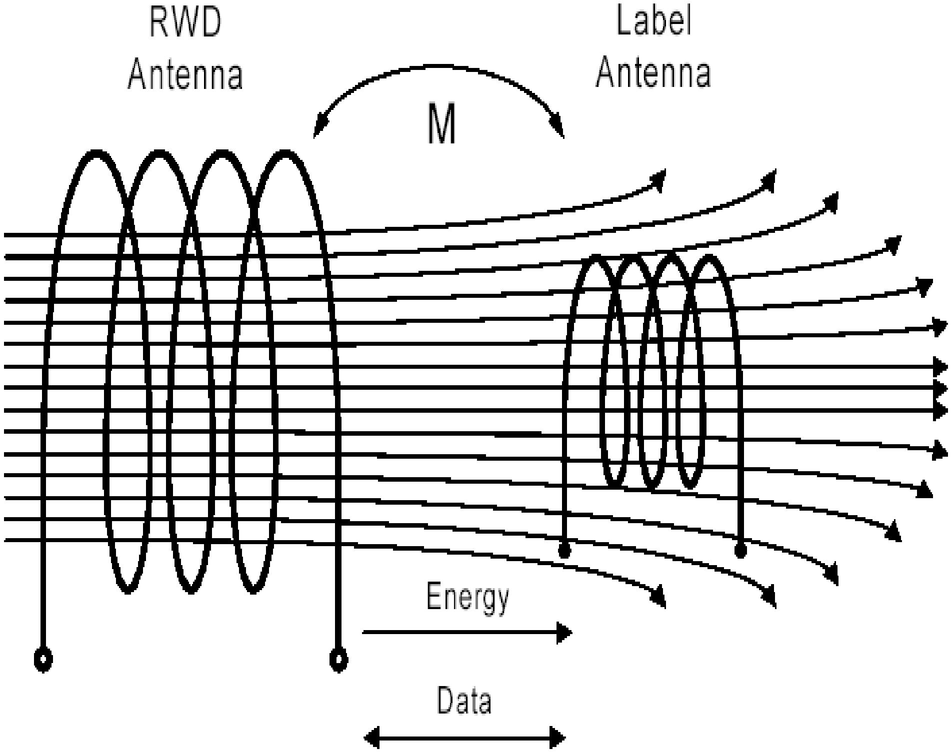
Inductive Passive 13.56 MHz and <135 KHz



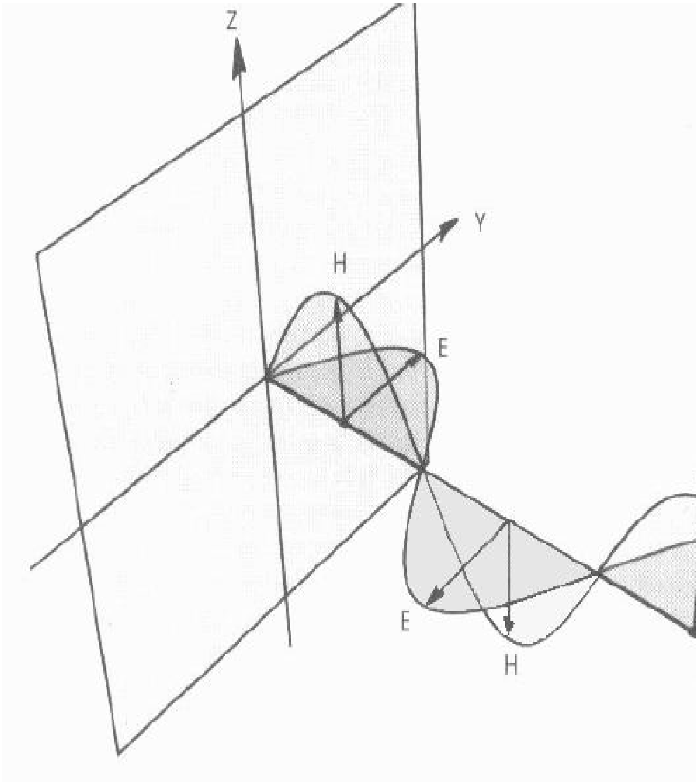
Near Field
ASK, PSK

UHF

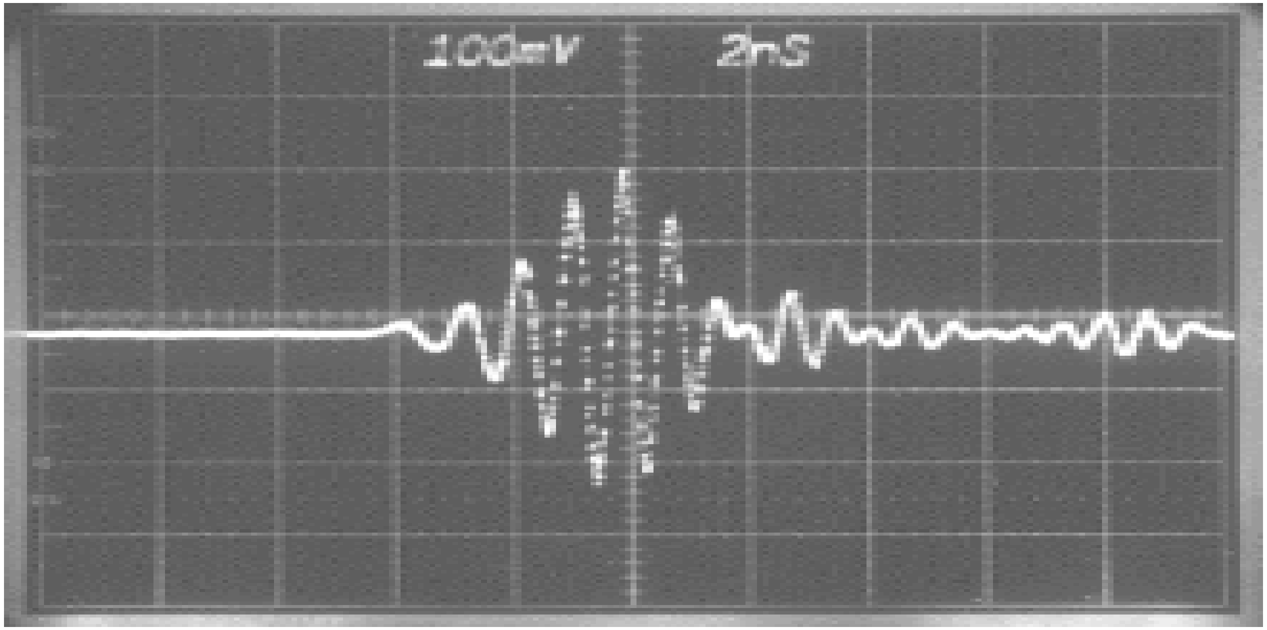




Passive 13.56 MHz



UHF



Ultrawideband

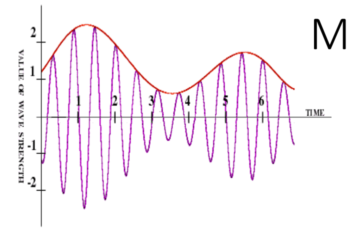
UWB – Pulse Transmission
Marconi's (1894) "Spark-Gap"

Geographic Specificity

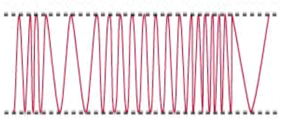
Longer Range from Less Power

Continuous wave RF modulates data signals over carrier waves.

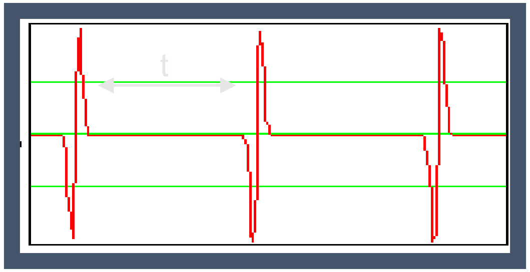
Amplitude Modulation (AM)

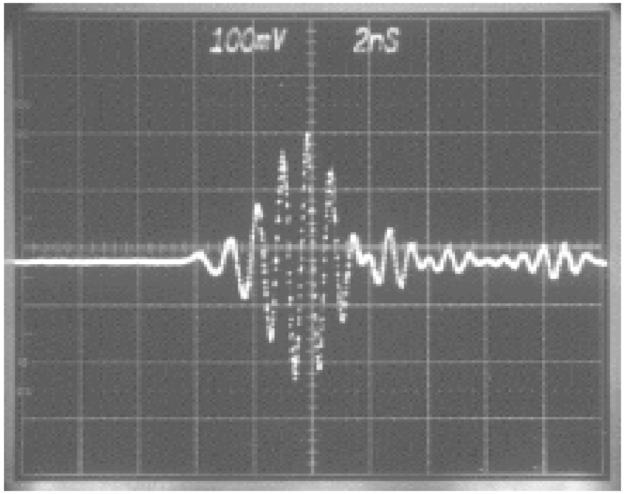


Frequency Modulation (FM)



- UWB encodes information as pulse of RF energy
- Timing of pulses is used to relay information





Global Power Regulation in RFID Technology Impacts Business

UHF (400-1000 MHz)

Band	Region	Max. Power EIRP
433.05-434.79 MHz	Europe	25mW
865-868 MHz	Europe	4 Watts FHSS (proposed by ETSI for Europe
868-870 MHz	Europe	500mW* Still under consideration
870-875.4 MHz	Europe	4 Watts FHSS (proposed by ETSI for Europe
902-928Mhz	USA/Canada	50mV/m at 3 meters (Single freq. Systems)
	USA/Canada	4W using spread spectrum
	USA/Canada	30W FCC Part 90, LMS (3W conducted)
918-926MHz	Australia	1W all new equipment designs
915.3-915.6 MHz	South Africa	15W (5 Watt conducted)
915-921 MHz	Europe	4 Watts FHSS (proposed by ETSI for Europe

Microwave

2.4-2.4835 GHz	Europe	25 mW
	Europe	500mW spread spectrum
	USA/Canada	50mV/m at 3 meters (Single freq. Systems)

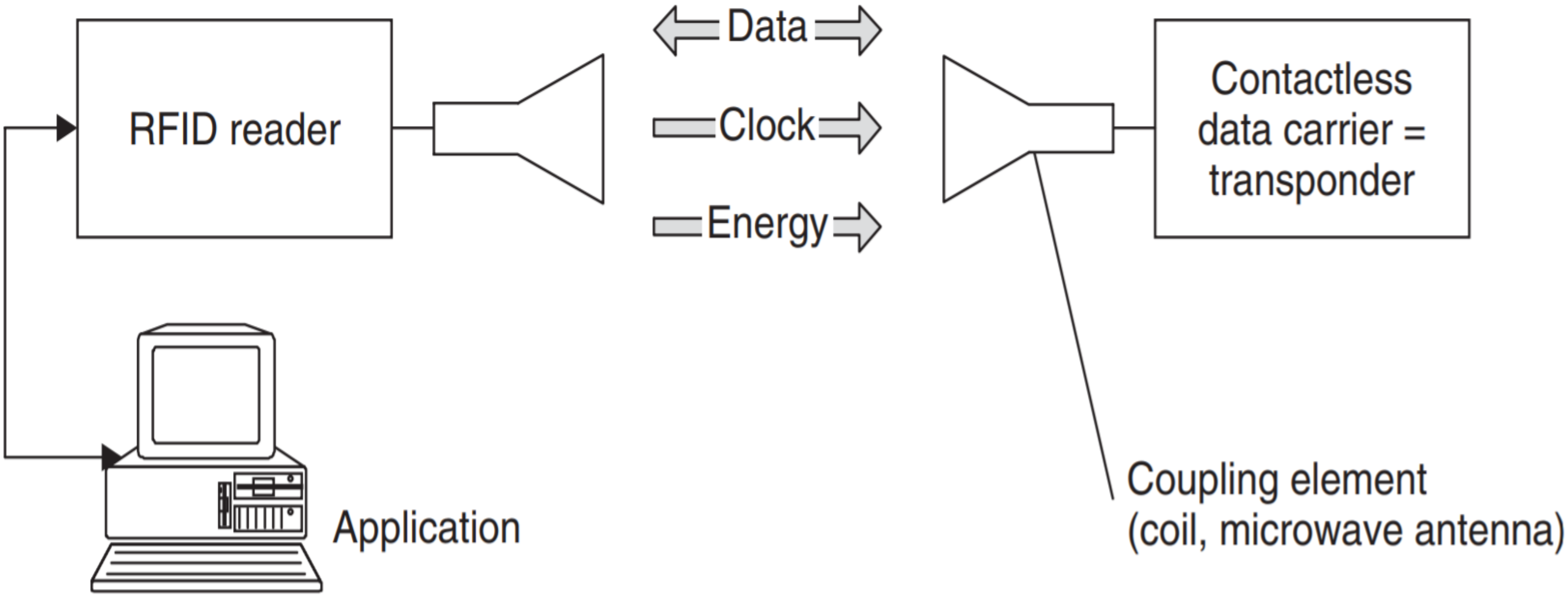
Where	Approved EIRP* Radiated Power from Reader	Distance
EU	0.5 Watt	0.7 metres
US & Canada	4.0 Watt	2.0 metres
US site license	30 Watt	5.5 metres

Data: AIM

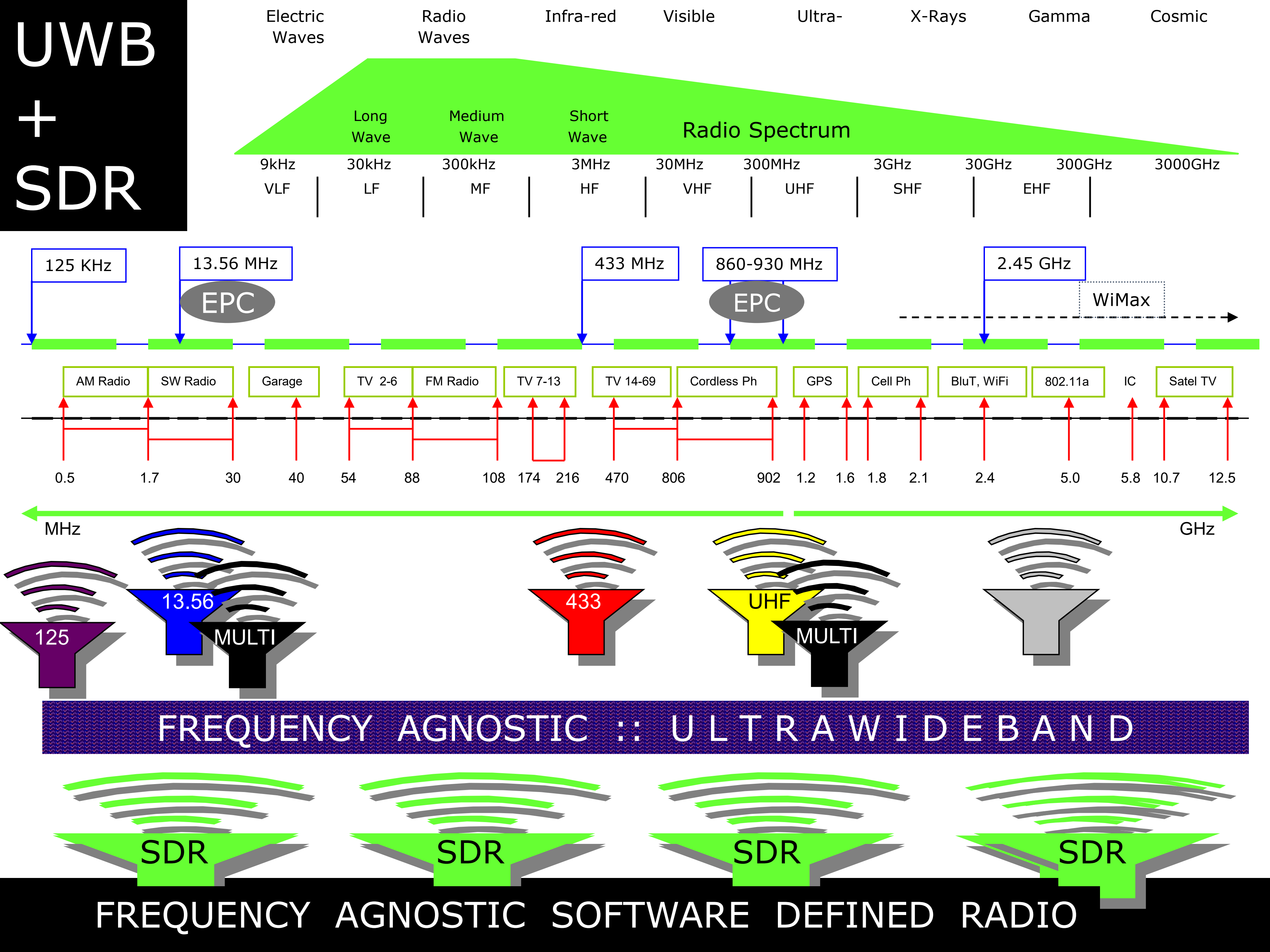
Radiated Power ≈ Energy Field » Read Range

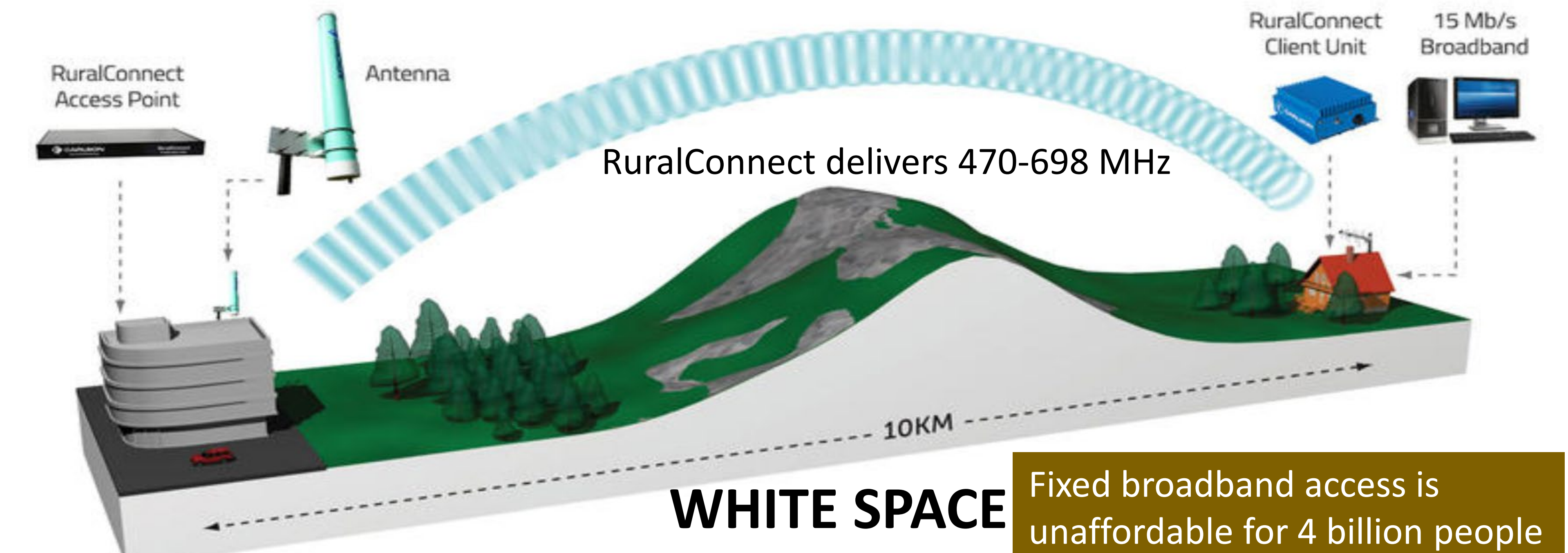
* EIRP - effective isotropic radiated power

Which frequency? Which reader? Which geography?



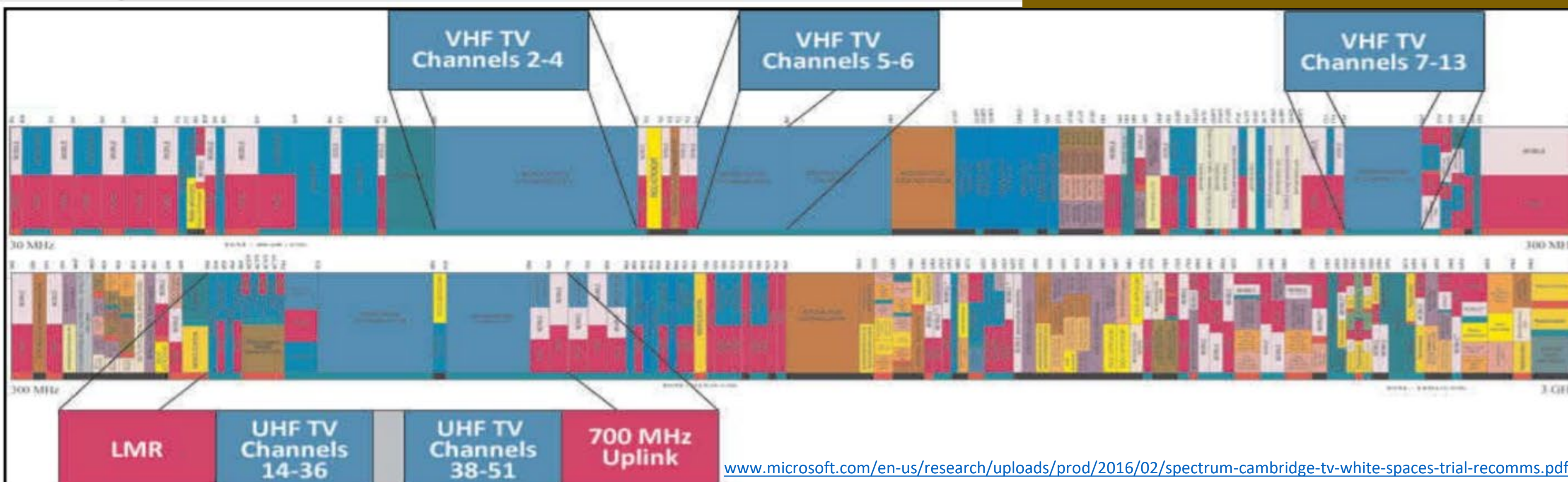
The reader and transponder are the main components of every RFID system


UWB
+
SDR
Electric Waves
Radio Waves
Infra-red
Visible
Ultra-
X-Rays
Gamma
Cosmic
Long Wave
Medium Wave
Short Wave
Radio Spectrum
9kHz
30kHz
300kHz
3MHz
30MHz
300MHz
3GHz
30GHz
300GHz
3000GHz
VLF
LF
MF
HF
VHF
UHF
SHF
EHF
125 KHz
13.56 MHz
EPC
433 MHz
860-930 MHz
EPC
2.45 GHz
WiMax
AM Radio
SW Radio
Garage
TV 2-6
FM Radio
TV 7-13
TV 14-69
Cordless Ph
GPS
Cell Ph
BluT, WiFi
802.11a
IC
Satel TV
0.5
1.7
30
40
54
88
108
174
216
470
806
902
1.2
1.6
1.8
2.1
2.4
5.0
5.8
10.7
12.5
MHz
GHz
125
13.56
MULTI
433
UHF
MULTI
FREQUENCY AGNOSTIC :: U L T R A W I D E B A N D
SDR
SDR
SDR
SDR
FREQUENCY AGNOSTIC SOFTWARE DEFINED RADIO



WHITE SPACE

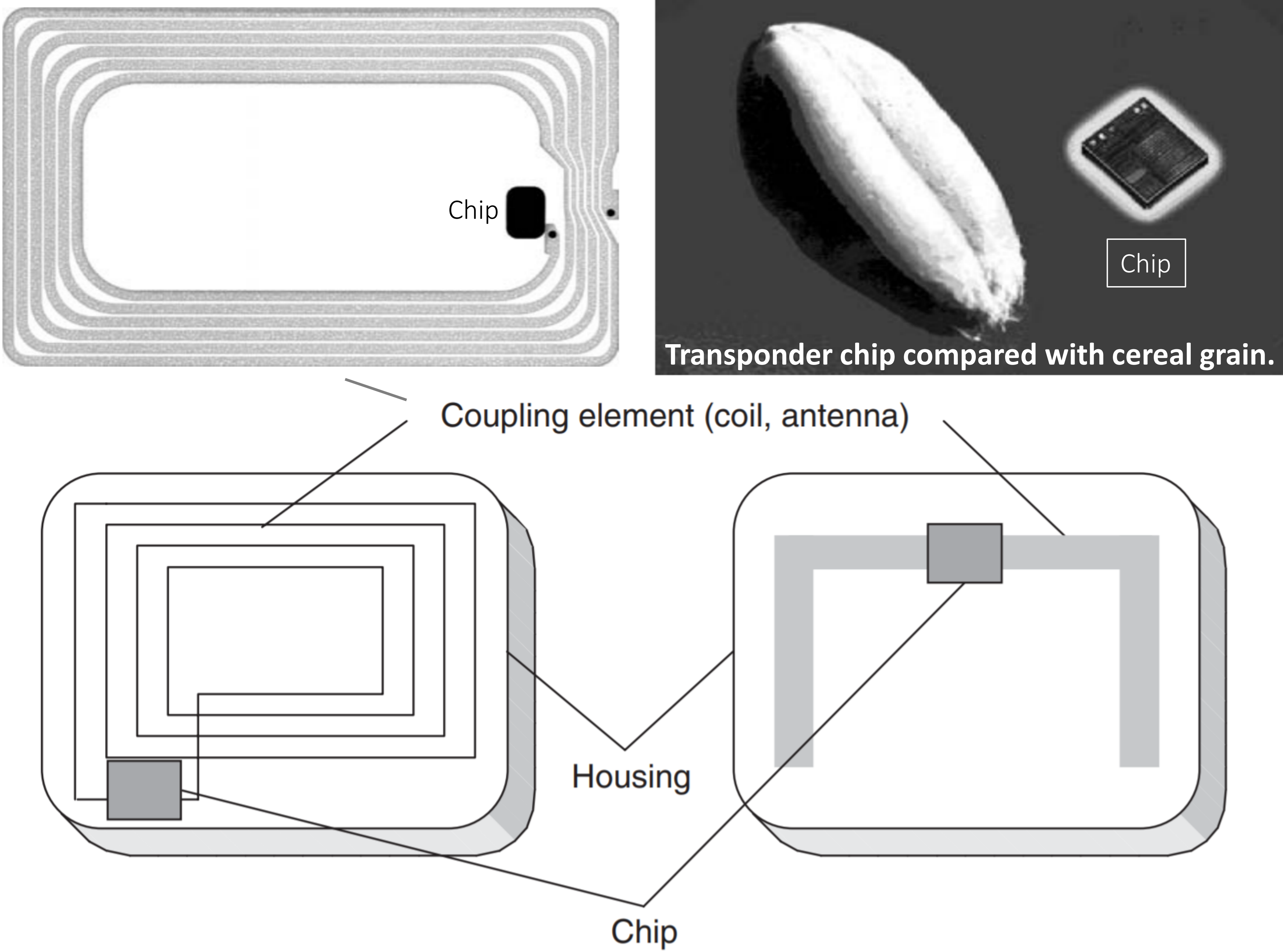
Fixed broadband access is unaffordable for 4 billion people

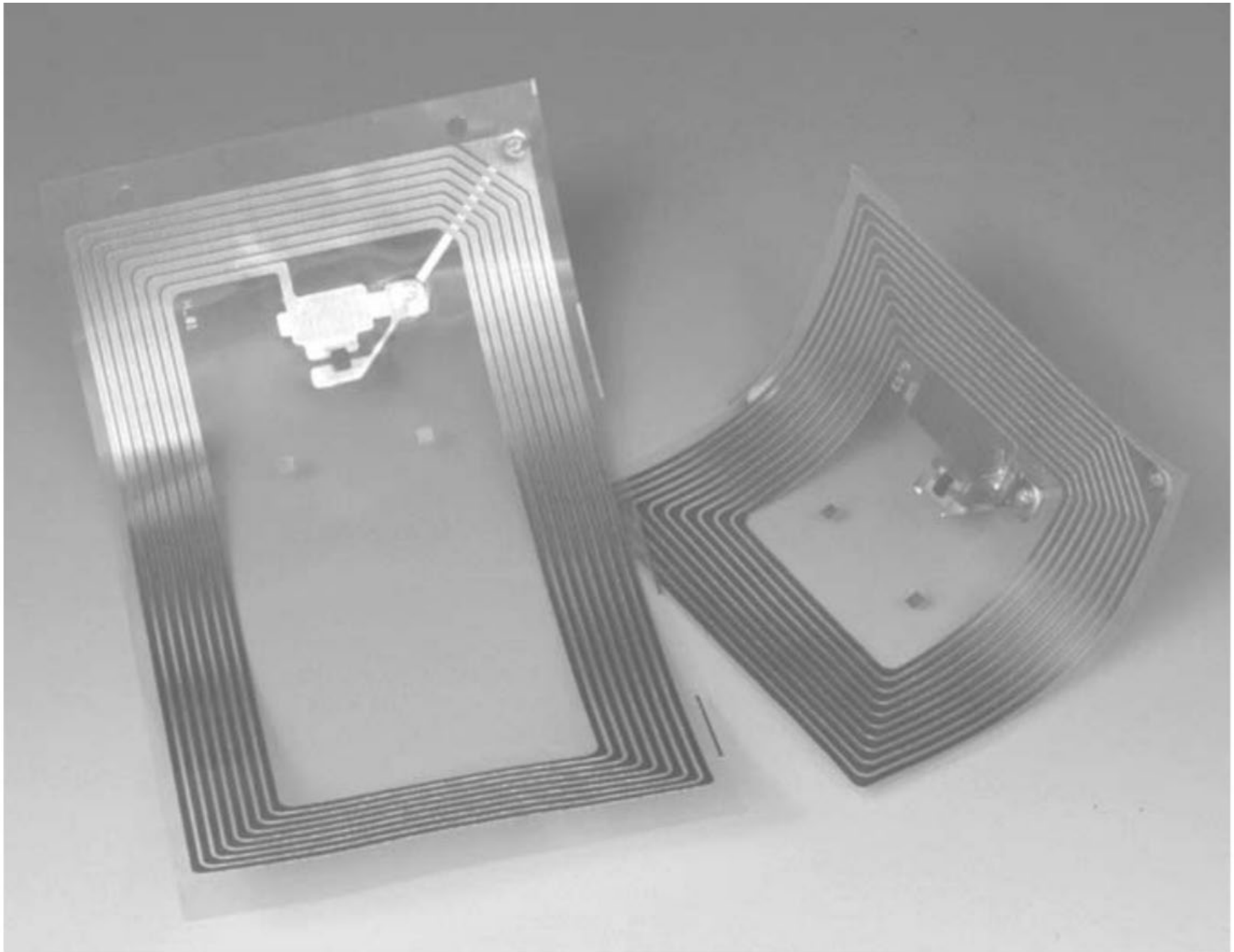


www.microsoft.com/en-us/research/uploads/prod/2016/02/spectrum-cambridge-tv-white-spaces-trial-recomms.pdf

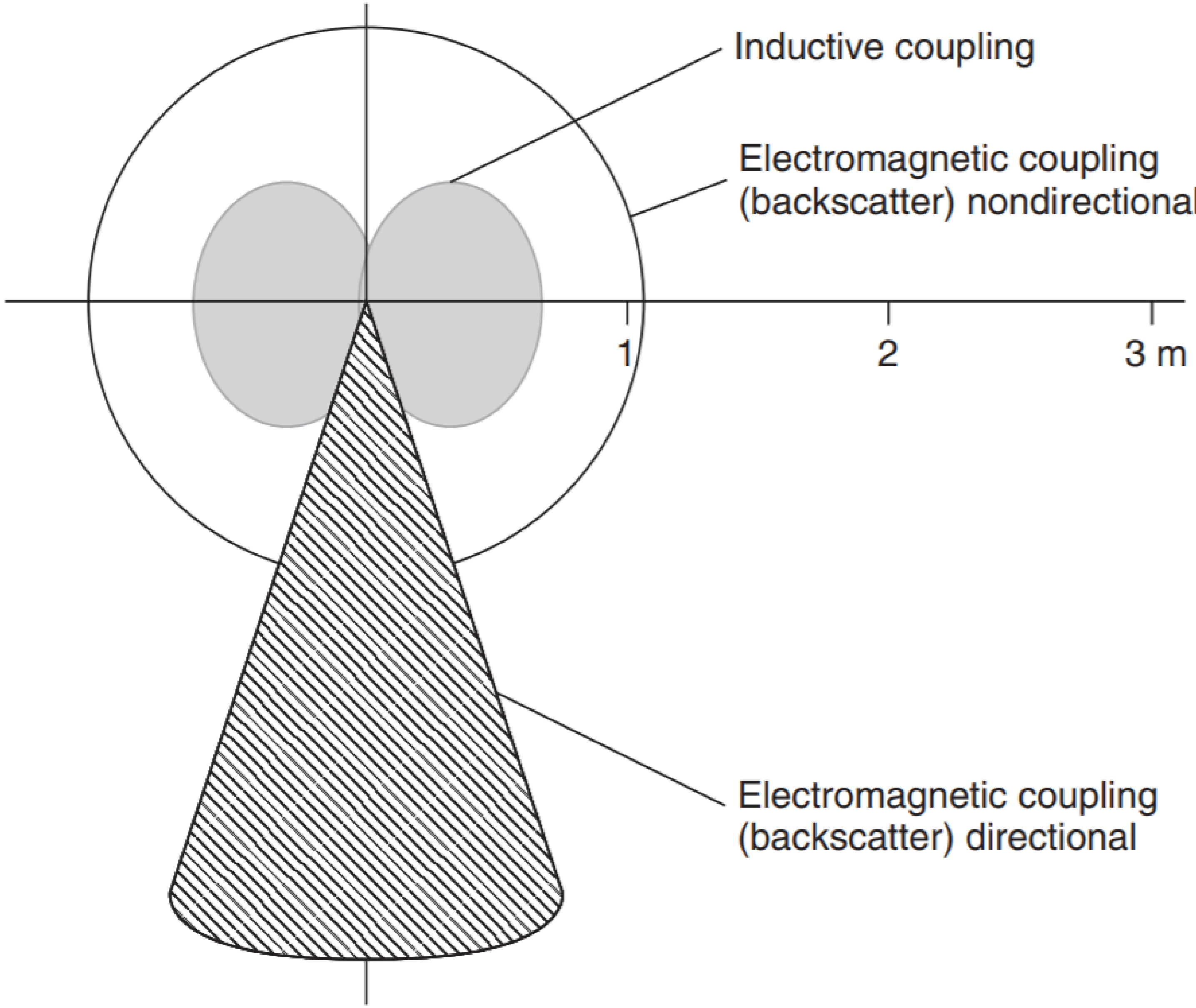
60 million people in US are living without it. White Space refers to the unused broadcasting frequencies in the wireless spectrum. TV networks leave gaps between channels. This space in the wireless spectrum is similar to what is used for 4G. It can be used to for broadband internet.

RF - Transponder, Range


Chip
Chip
Transponder chip compared with cereal grain.
Coupling element (coil, antenna)
Housing
Chip

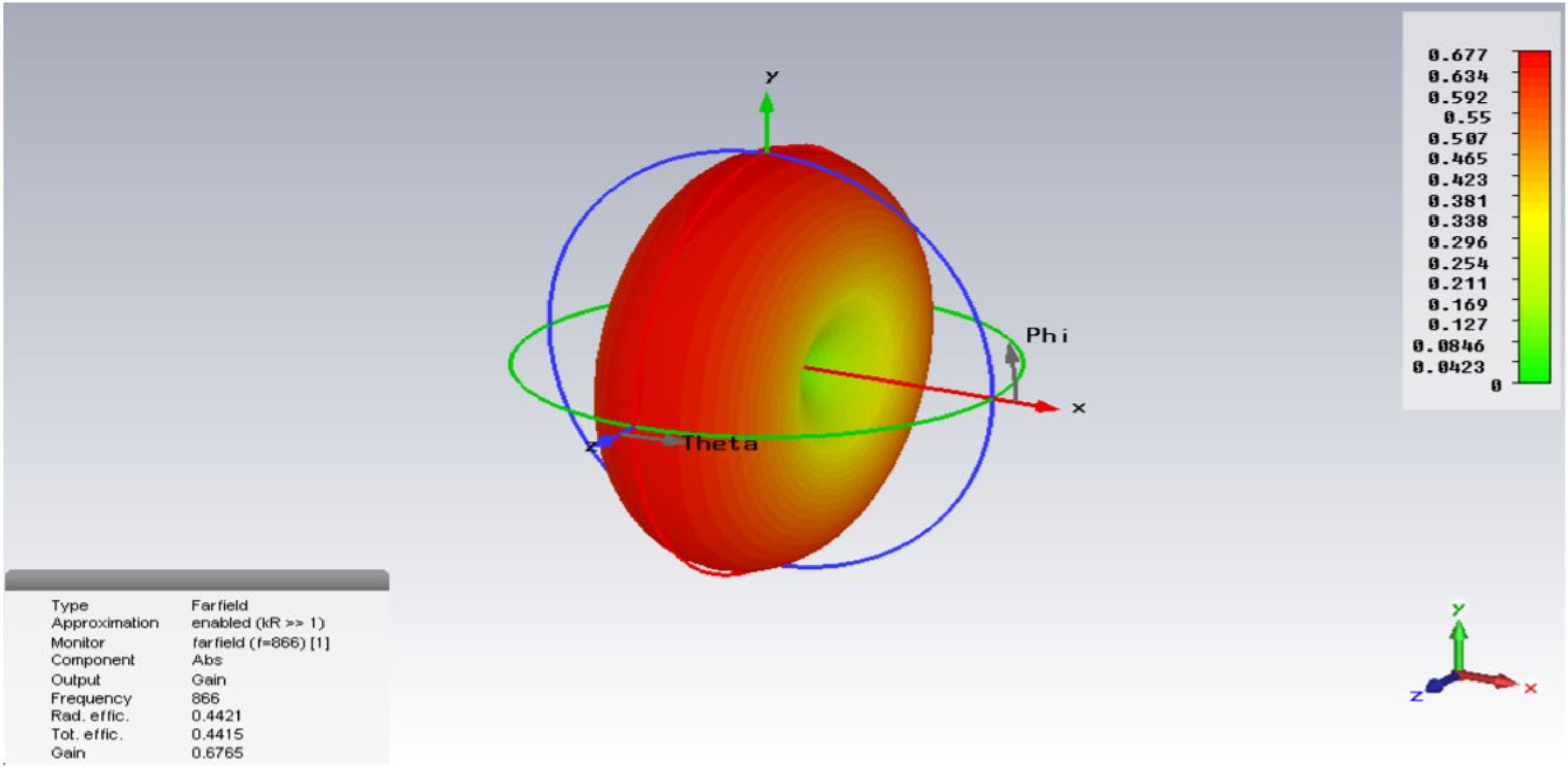


A smart label primarily consists of a thin paper or plastic foil onto which the transponder coil and transponder chip can be applied (Tag-It Transponder, reproduced by permission of Texas Instruments,



Comparison of the relative interrogation zones of different systems

Radiation Pattern: UHF Tag Antenna in Free Space



http://researchopen.lsbu.ac.uk/1342/1/ICCE%20Submitted.pdf

Not secure | aries.ektf.hu/~dream/e107/e107_files/downloads/rfidhand.pdf

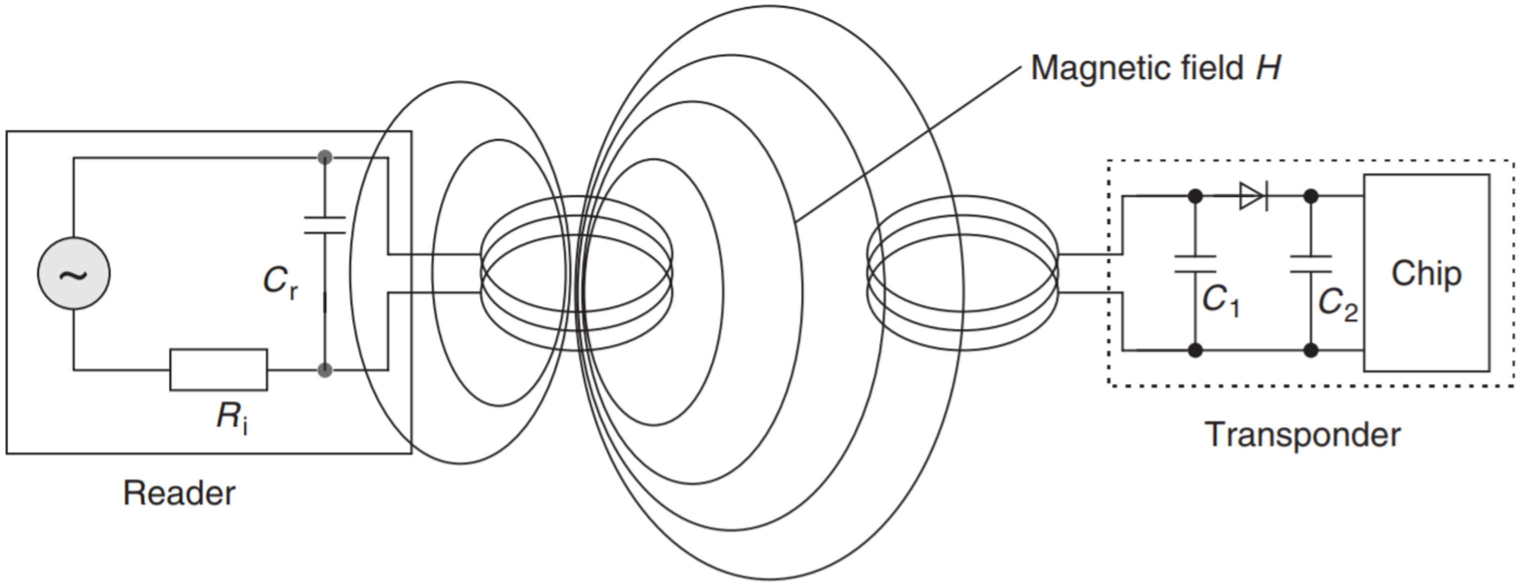
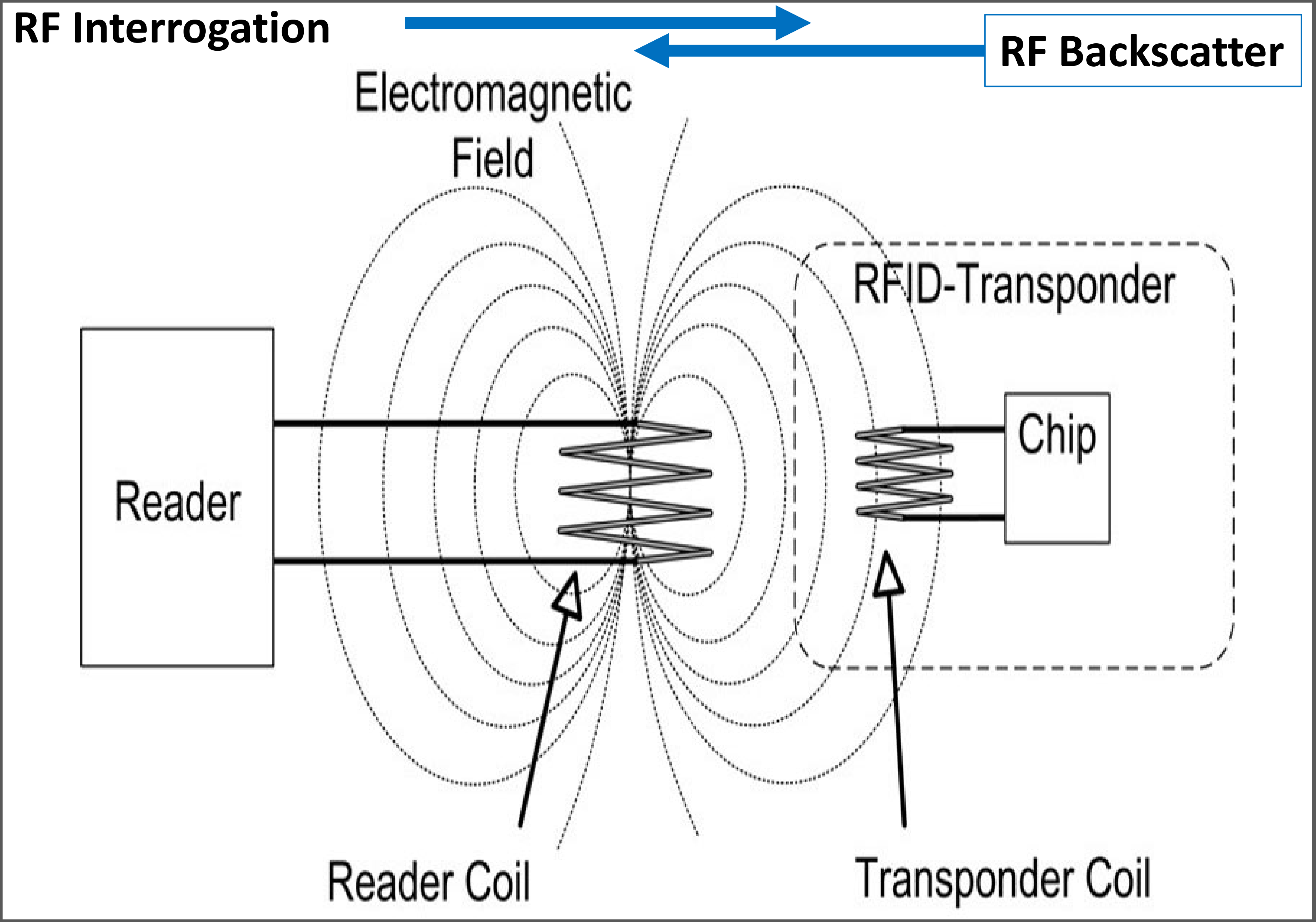
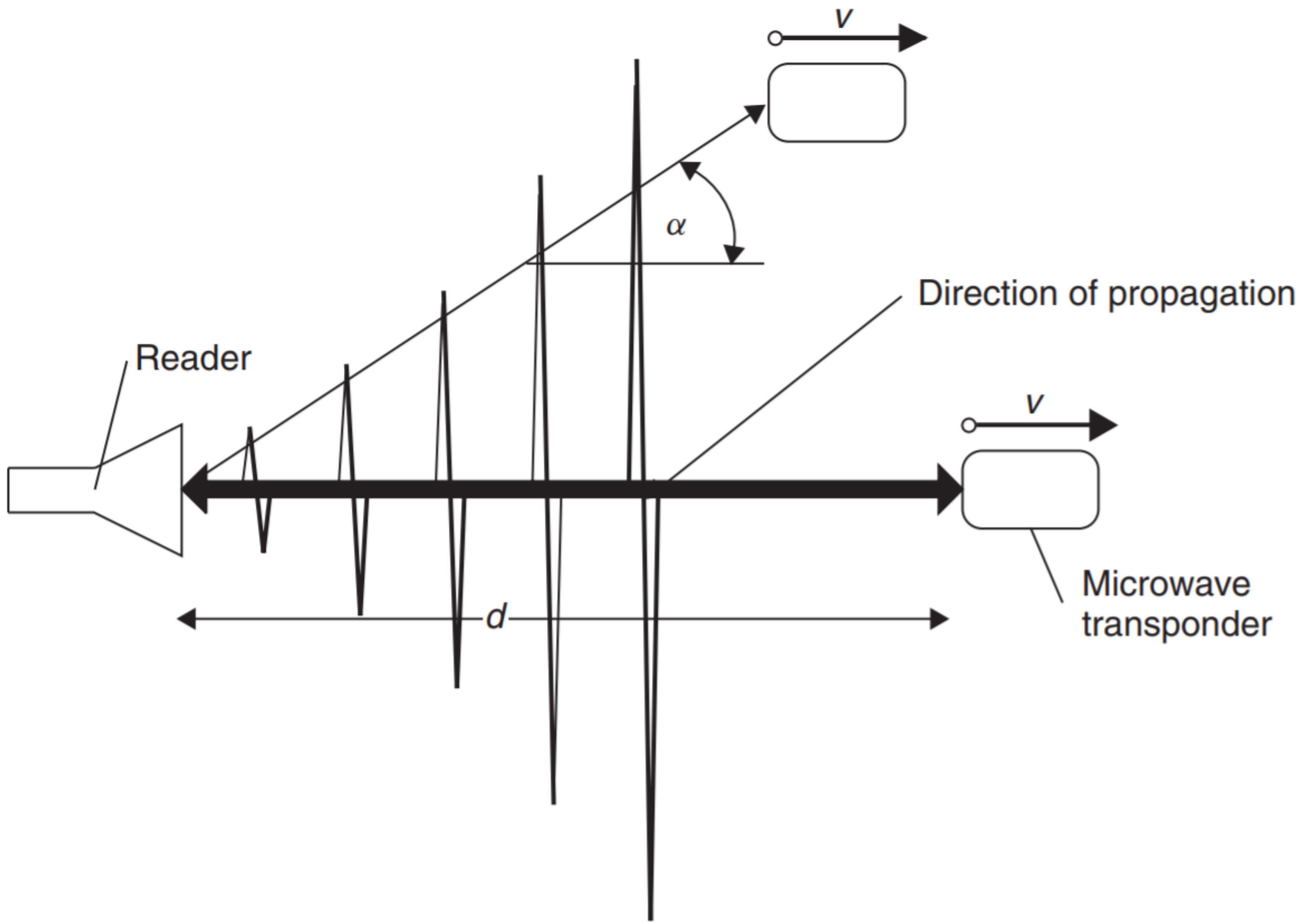
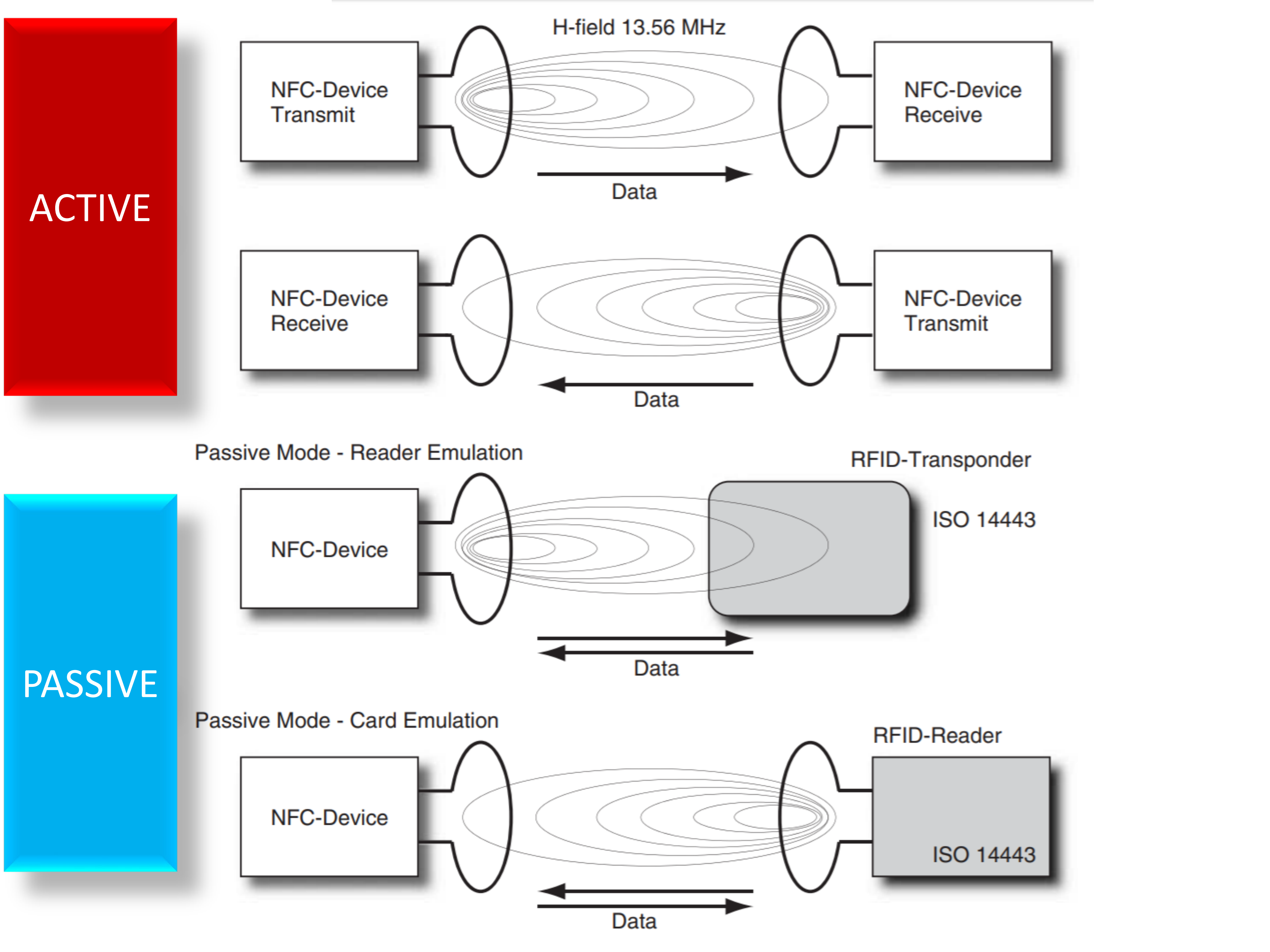


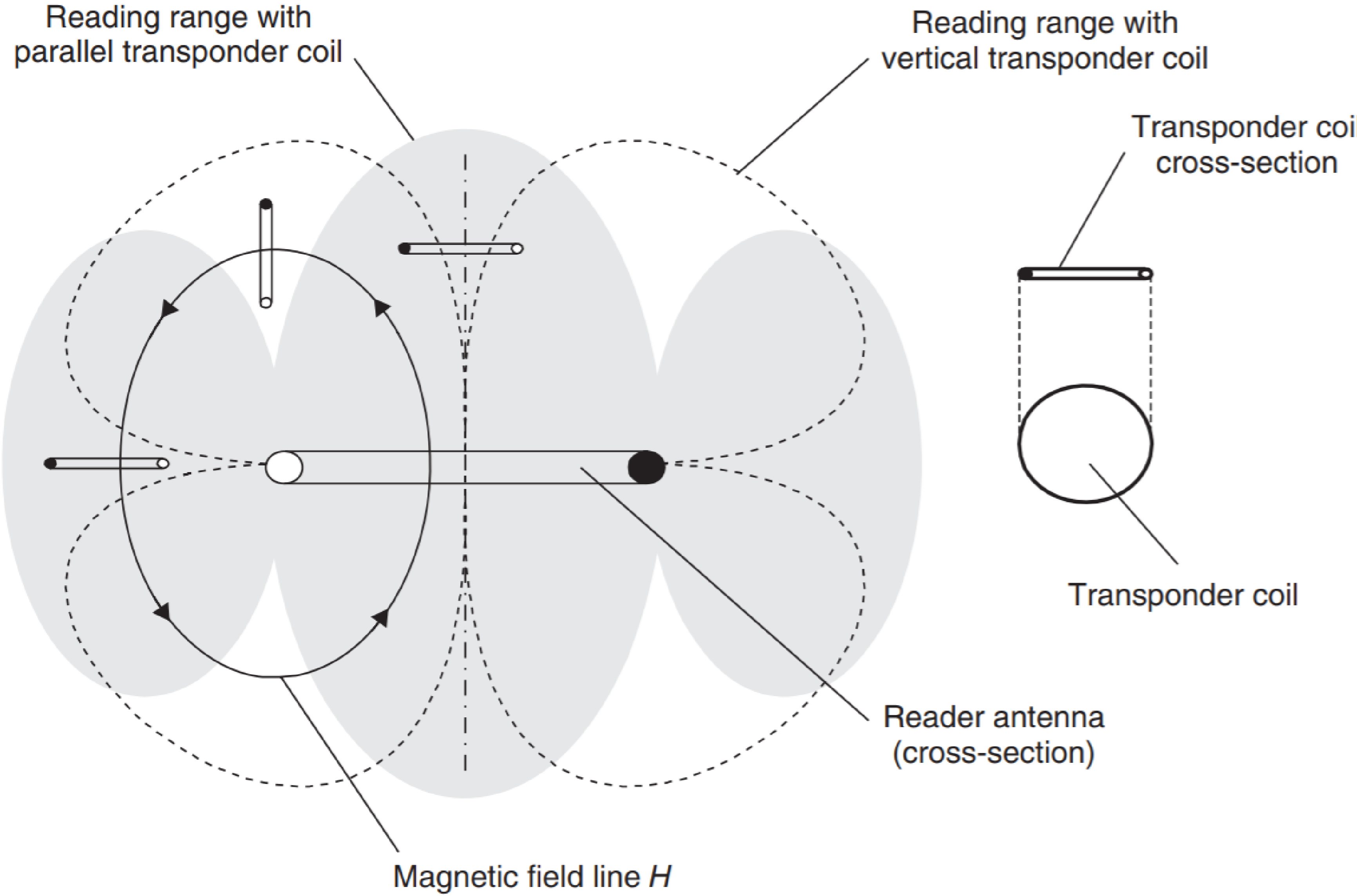
Figure 3.13 Power supply to an inductively coupled transponder from the energy of the magnetic alternating field generated by the reader

http://aries.ektf.hu/~dream/e107/e107_files/downloads/rfidhand.pdf

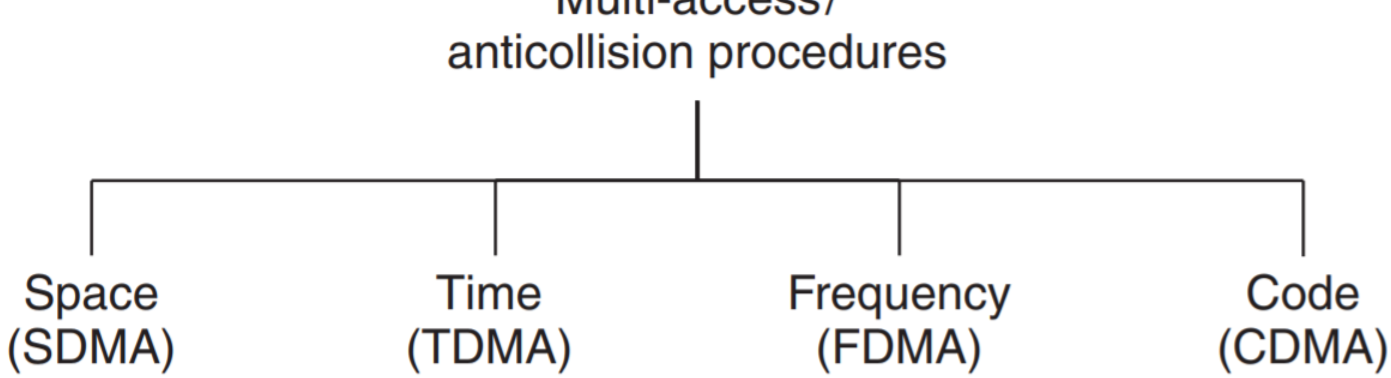

RF Interrogation
RF Backscatter
Electromagnetic
Field
RFID-Transponder
Reader
Chip
Reader Coil
Transponder Coil


v
α
Direction of propagation
Reader
v
d
Microwave
transponder

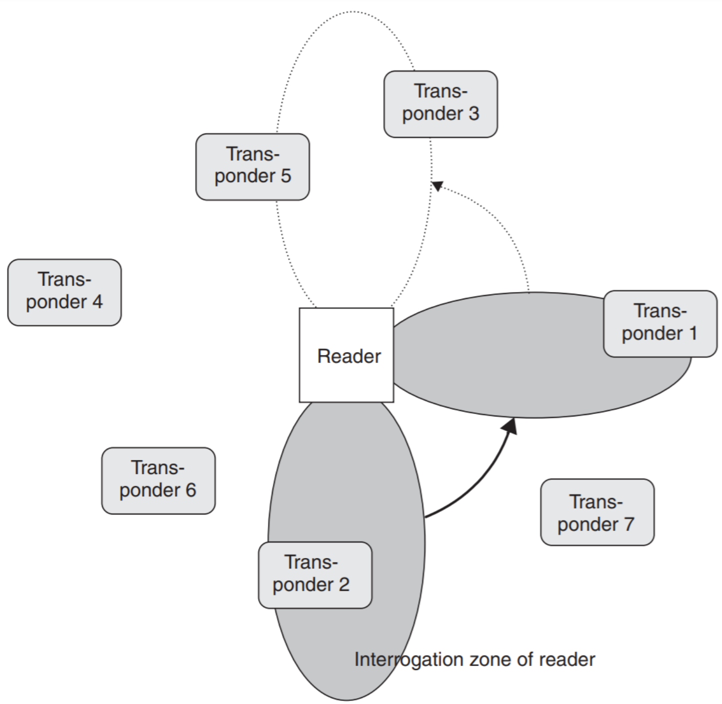

ACTIVE
H-field 13.56 MHz
NFC-Device Transmit
NFC-Device Receive
Data
NFC-Device Receive
NFC-Device Transmit
Data
PASSIVE
Passive Mode - Reader Emulation
RFID-Transponder
ISO 14443
NFC-Device
Data
Passive Mode - Card Emulation
RFID-Reader
NFC-Device
ISO 14443
Data



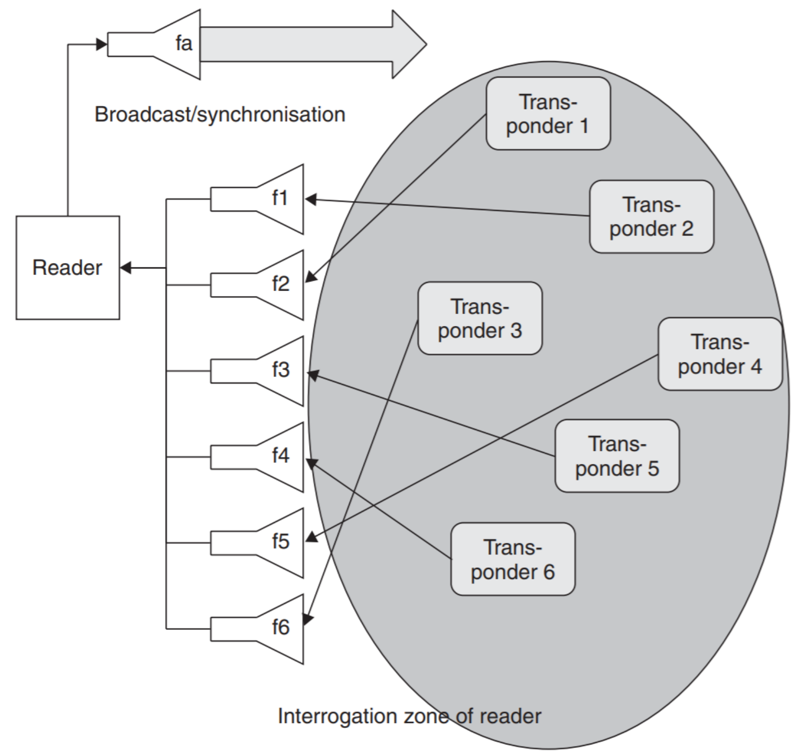
Interrogation zone of a reader at different alignments of the transponder coil

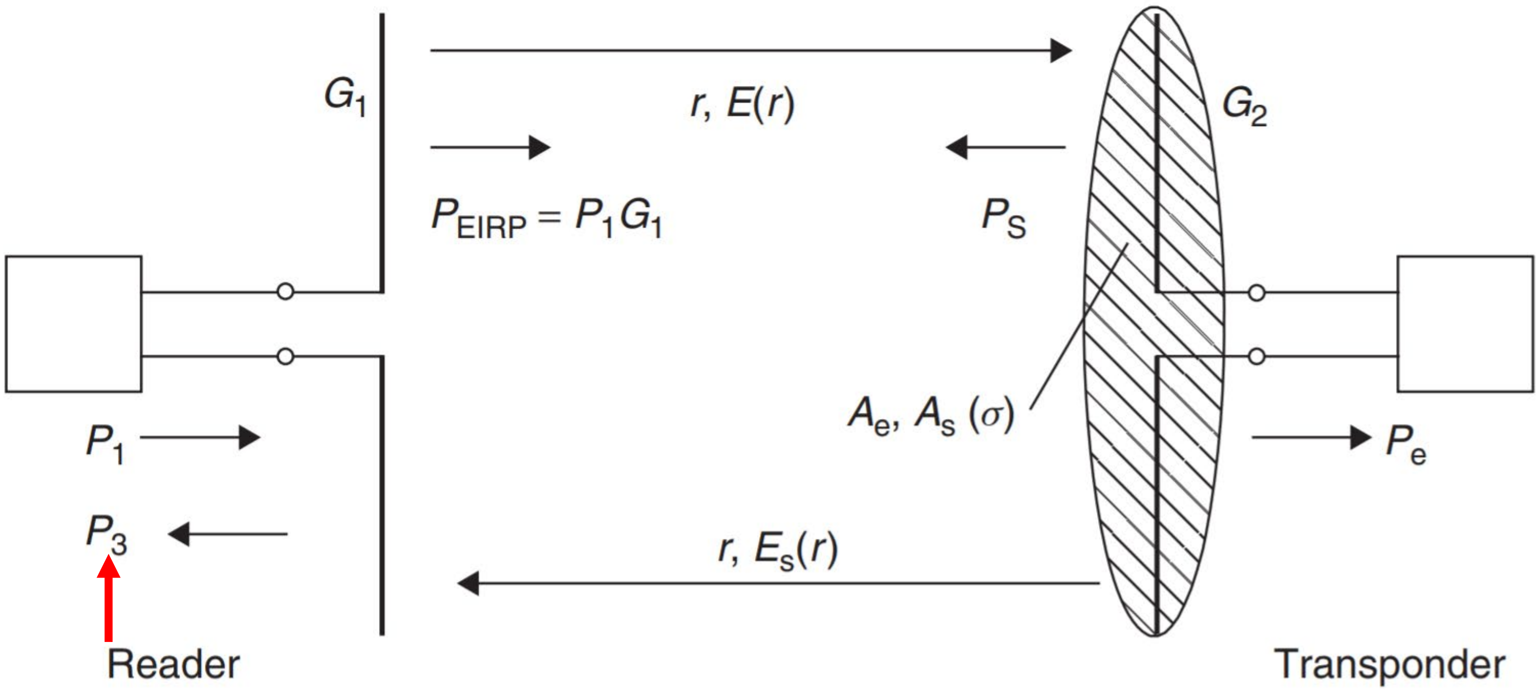


Multi-access and anticollision procedures are classified on the basis of four basic procedures

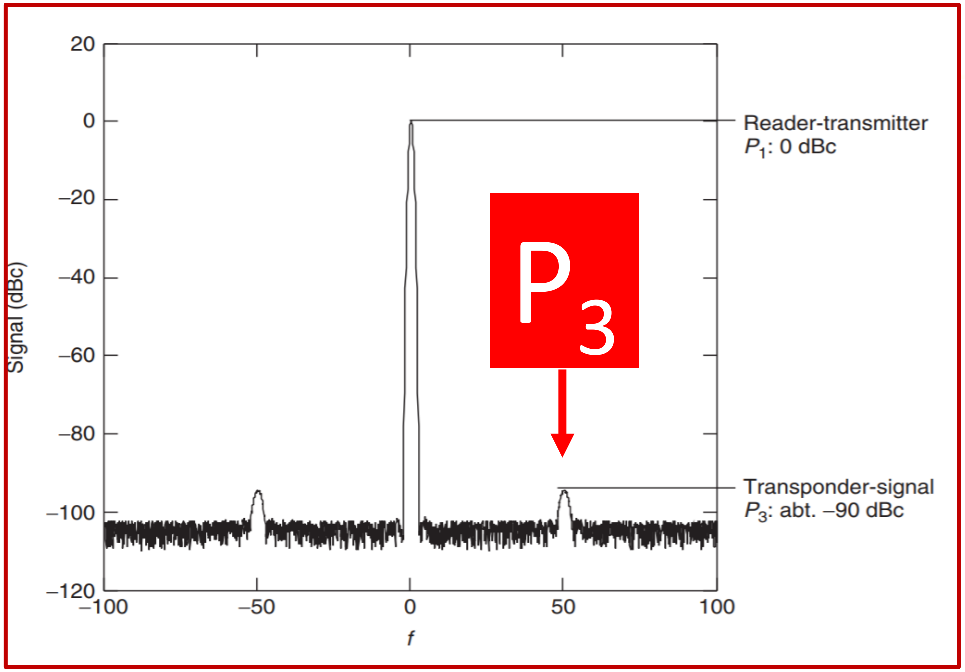


Adaptive SDMA with an electronically controlled directional antenna.





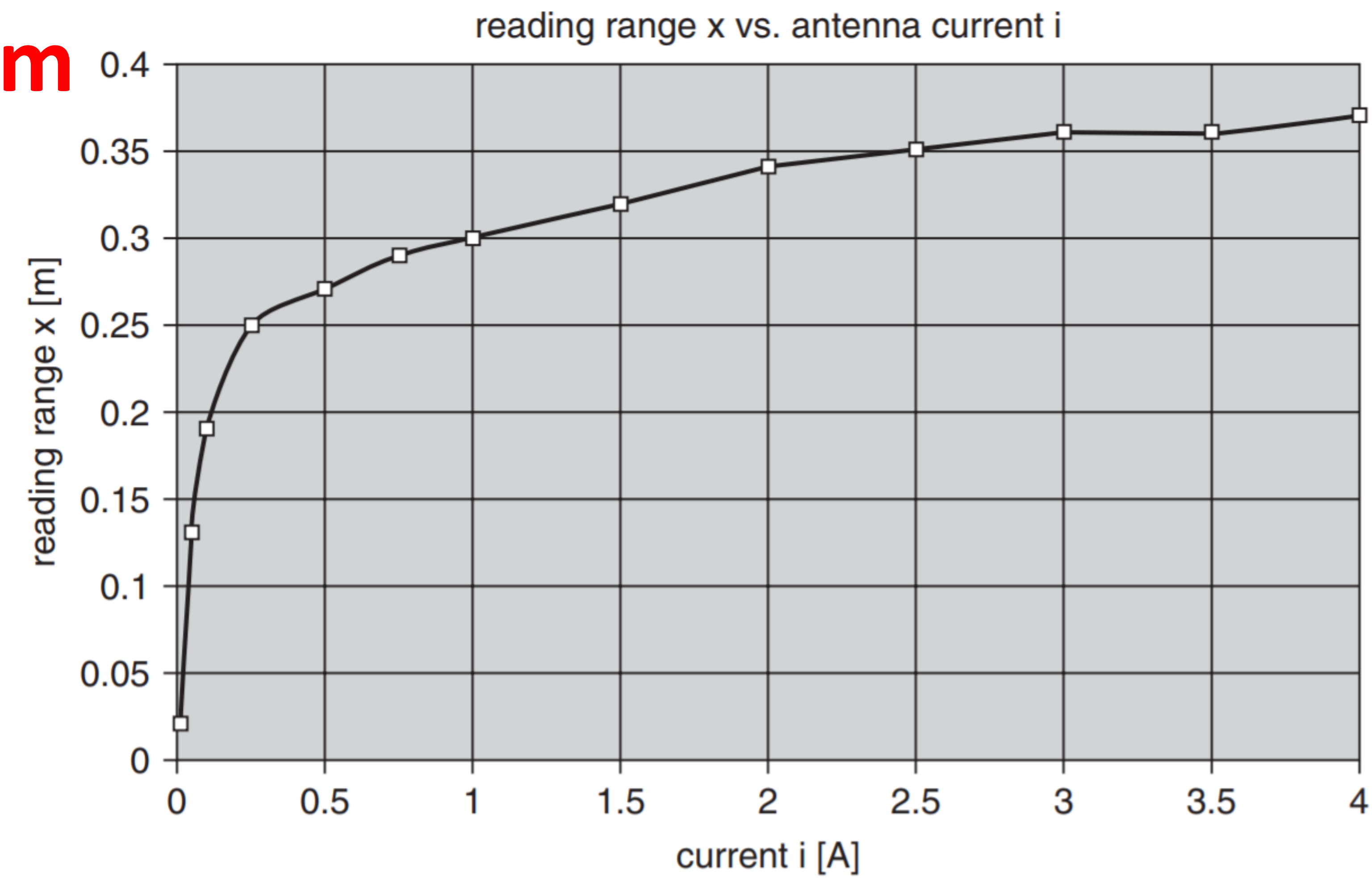
Microwave RFID System



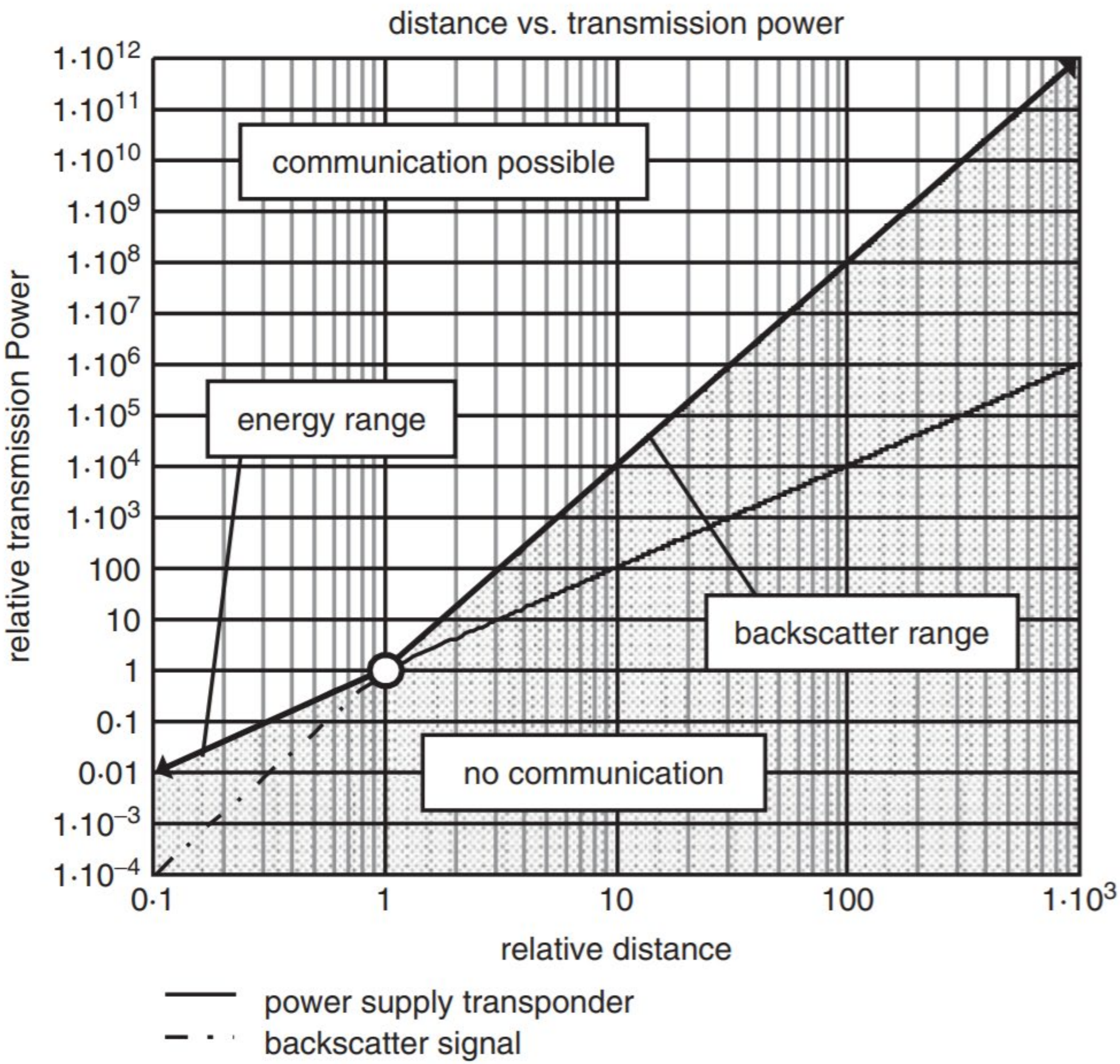
Simplified model of backscatter. The reader emits an electromagnetic wave with the effective radiated power $P_1 \cdot G_1$ into the surrounding space. Of this, a transponder receives power $P_2 = P_e$, proportional to the field strength E, at distance r. Power P_S is also reflected by the transponder's antenna, of which P_3 is received by reader at distance r.

Read range restricts eavesdropping at a distance

40cm



Even for an increasing antenna current (*x* axis) and optimized antenna diameter, the read range of an ISO/IEC 14443 system reaches its limits at a distance of 40 cm

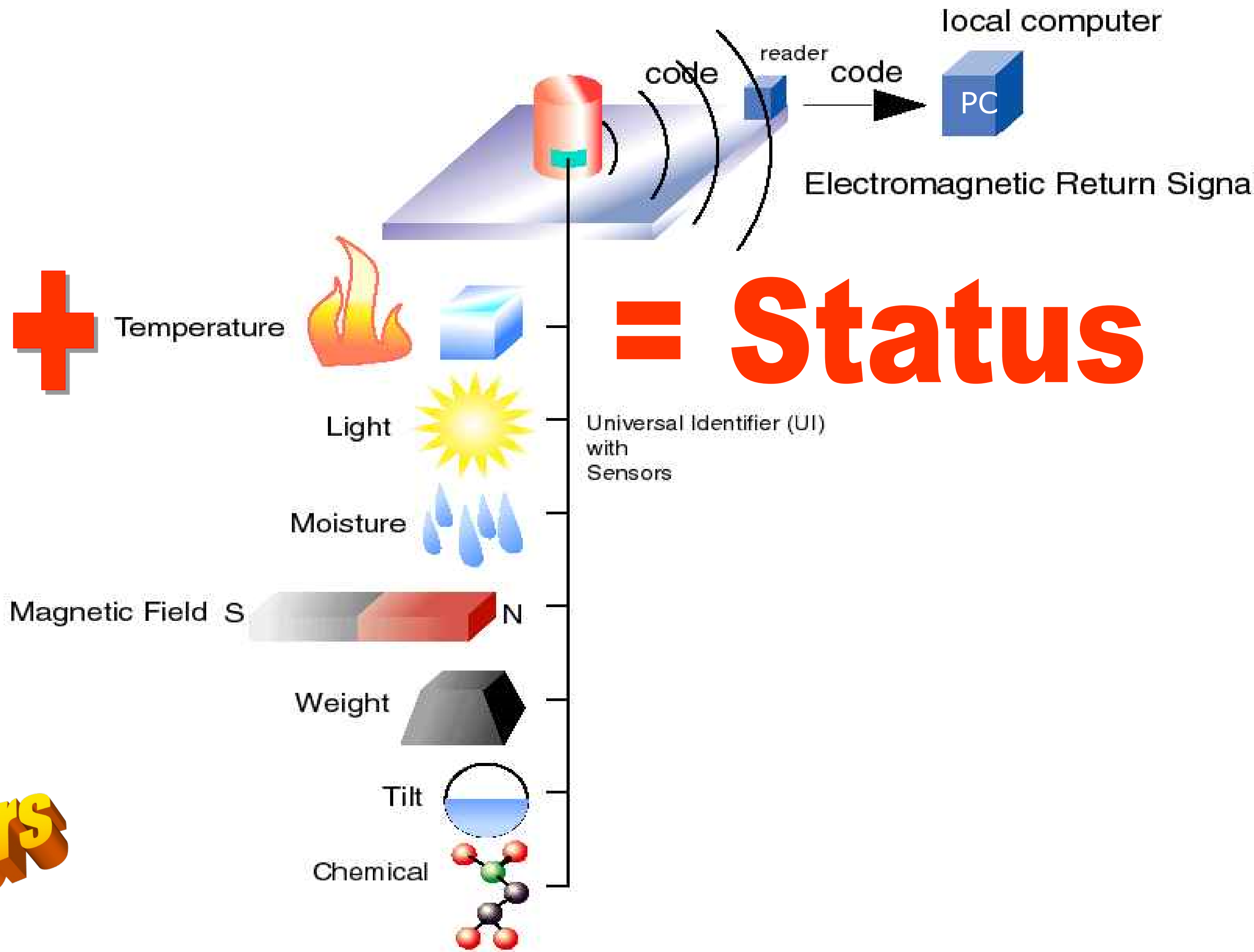


The necessary transmission power as a function of energy range (power supply transponder) and backscatter range (backscatter signal)

Example of
RFID Application

Data is not Information

ID + **= Status**



GC/MS in every pocket!

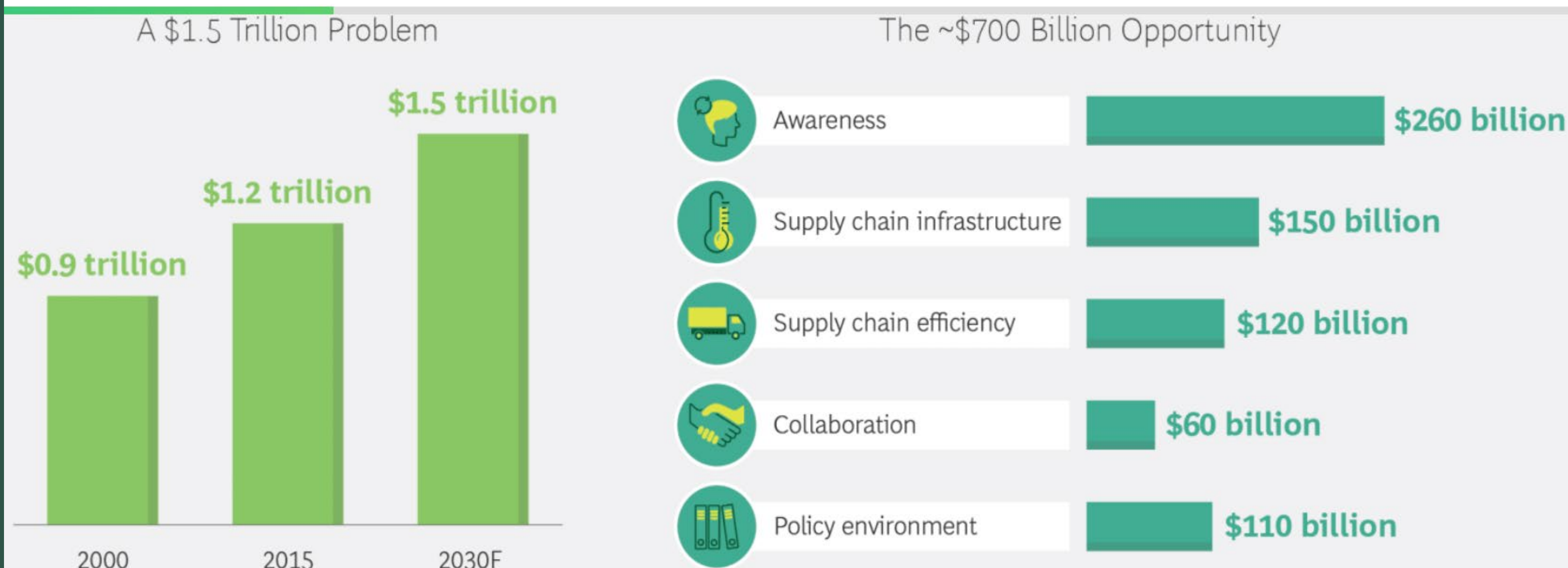
Matchbox Size Gas Chromatography and Mass Spectrometer

Professor Akintunde Ibitayo Akinwande, Microsystems Tech Lab, MIT

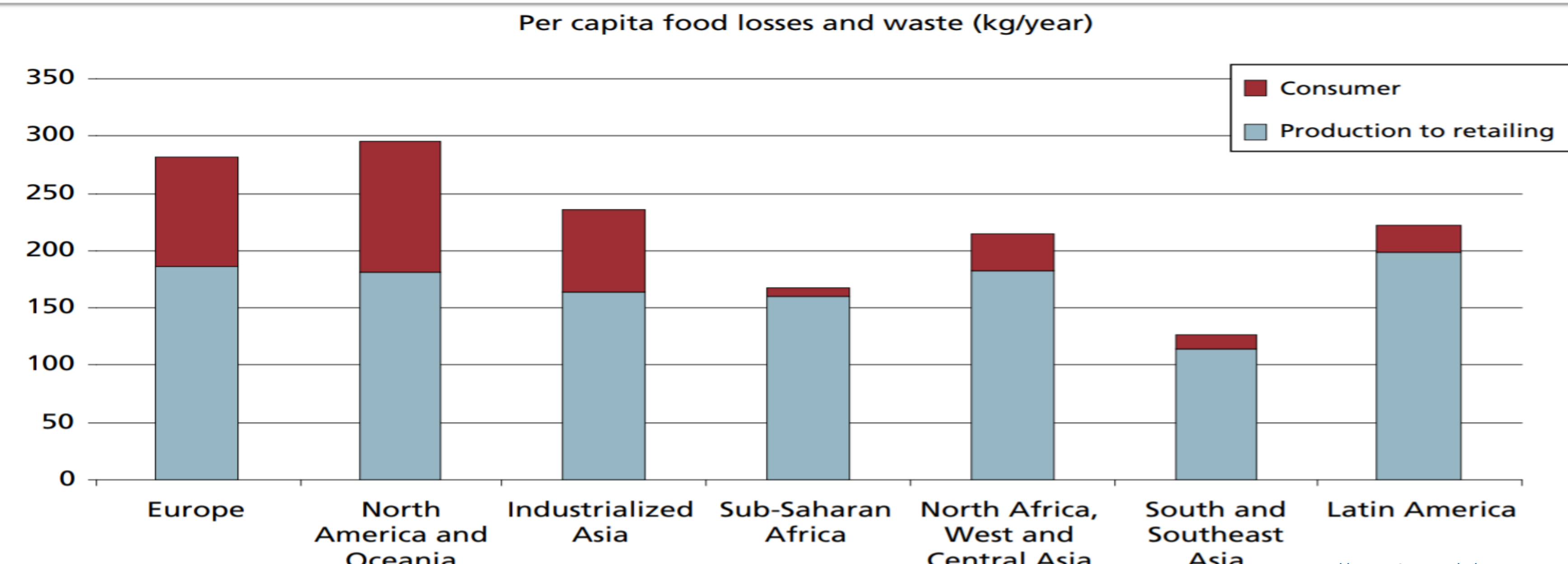
Dr Luis Velasquez-Garcia, MTL (Microsystems Technology Lab), MIT

Perishables

1.6 billion ton food loss and waste



www.bcg.com/en-us/publications/2018/tackling-1.6-billion-ton-food-loss-and-waste-crisis.aspx



http://www.fao.org/3/a-i2697e.pdf

Sensors and Shelf Life

- 76 million foodborne illness
- 1.8 million deaths worldwide
- 325,000 hospitalizations in US
- 5000 deaths in US

- 91 million tons of food disposed to landfills in US
- 26% of US food supply
- 824 million ‘hungry’ per year

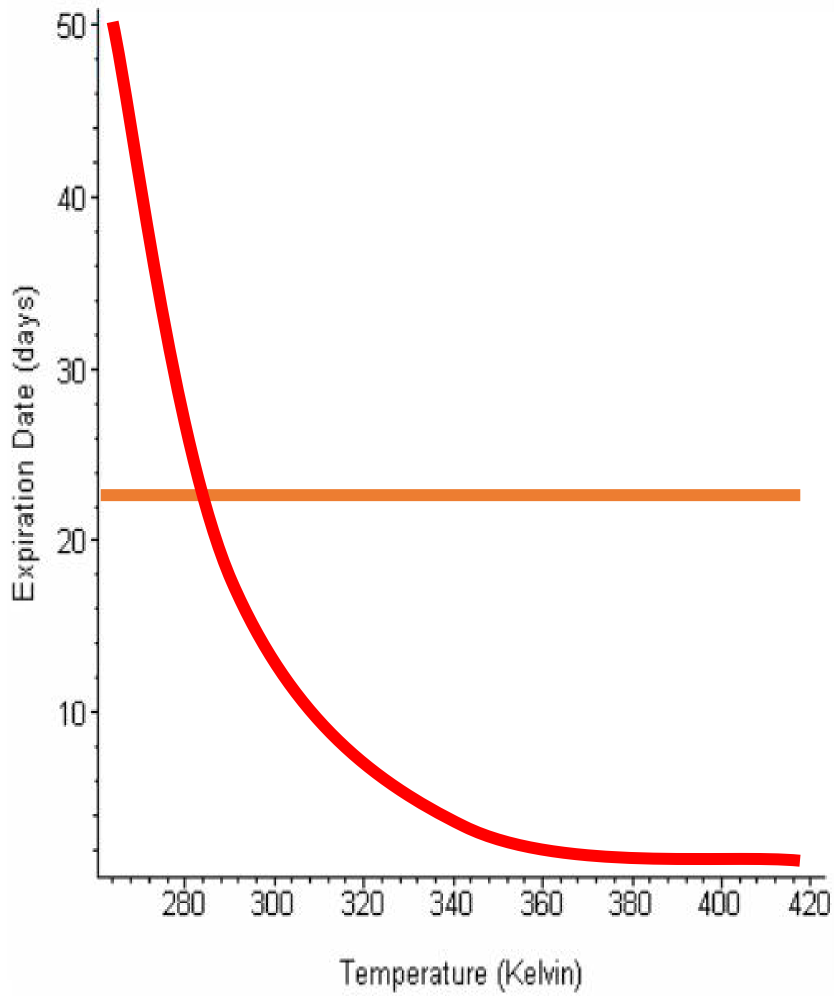
https://www.mdpi.com/2079-6374/8/2/42

Shelf Life

$$\frac{\partial Q}{\partial t} = -k_1 e^{\left[-\frac{E_a}{R_g T(t)}\right]} Q^n$$

- E_a Activation energy
- k_1 Arrhenius constant
- n Order of the reaction
- T Temperature
- Q Quality
- t Time

Shelf Life



Dr Shoumen Datta, MIT
shoumen@mit.edu

Shelf Life

Name: Activation Energy

Name: Arrhenius Constant

Name: Temperature

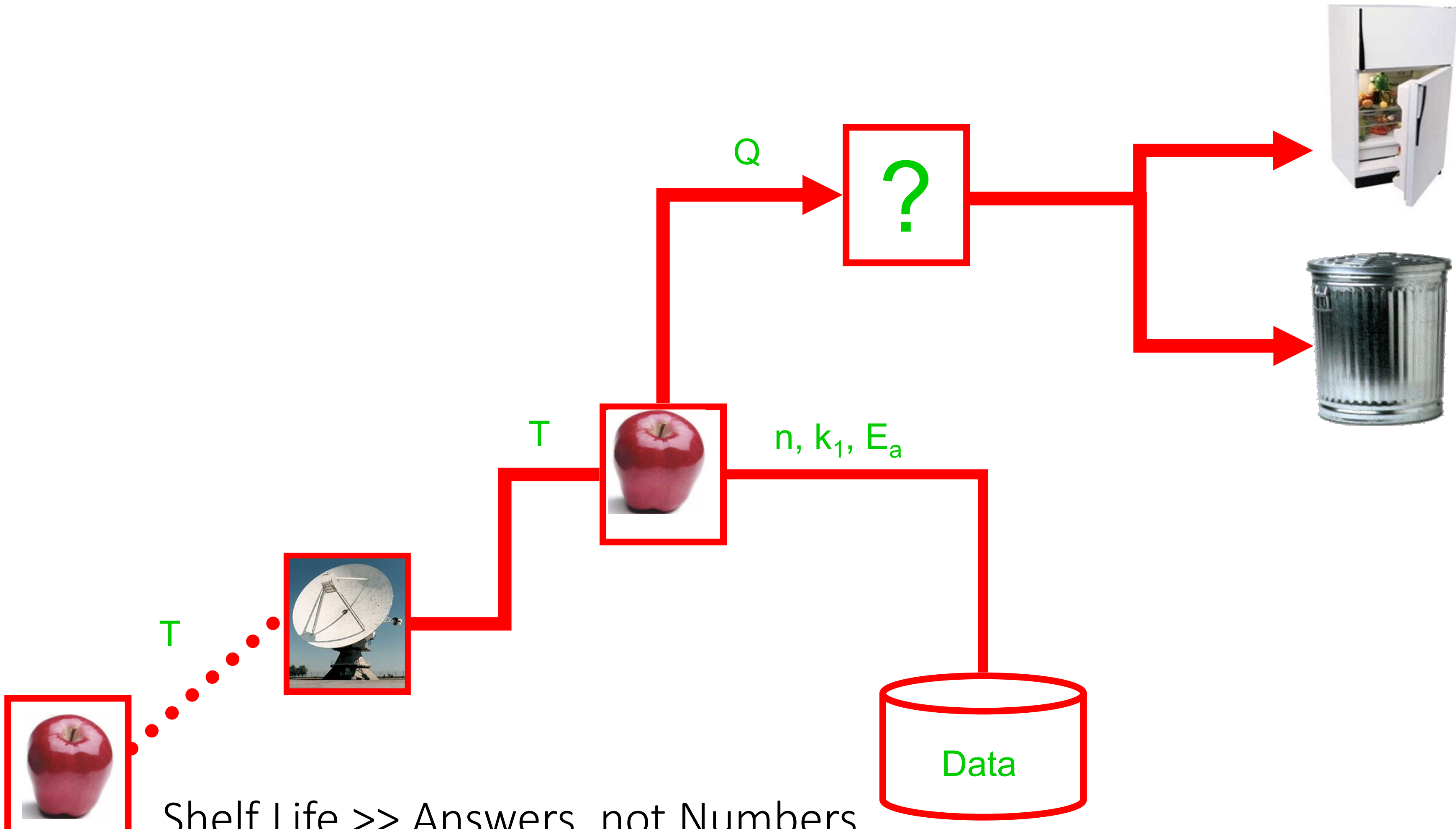
Name: Quality

Name: Order of Reaction
Description: Order of Reaction
Symbol: n
Access: Read
ID: EPC: 01020084191000001289731
Class: Scalar
Type: Int
Unit:
Default: 1

Food Quality

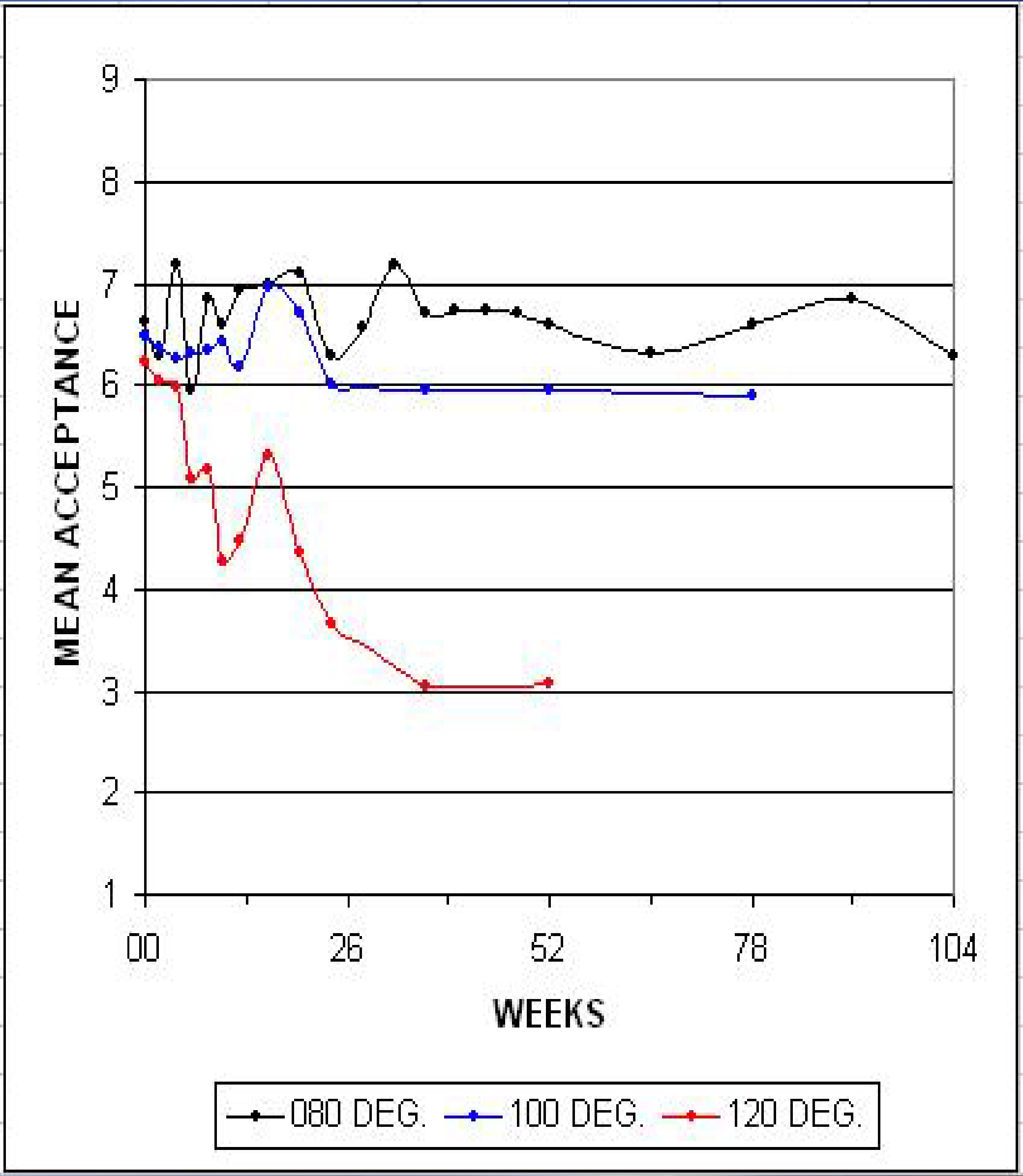
Name: Food Quality
Description: Food Quality based Arrhenius
Developer: Natick Army Laboratories
ID: EPC: 010300908808BF60000000AA
Comp: $0.25 per month
Type: Analytic
Rate: 1 to 10,000 sec
Algorithm:

Shelf Life



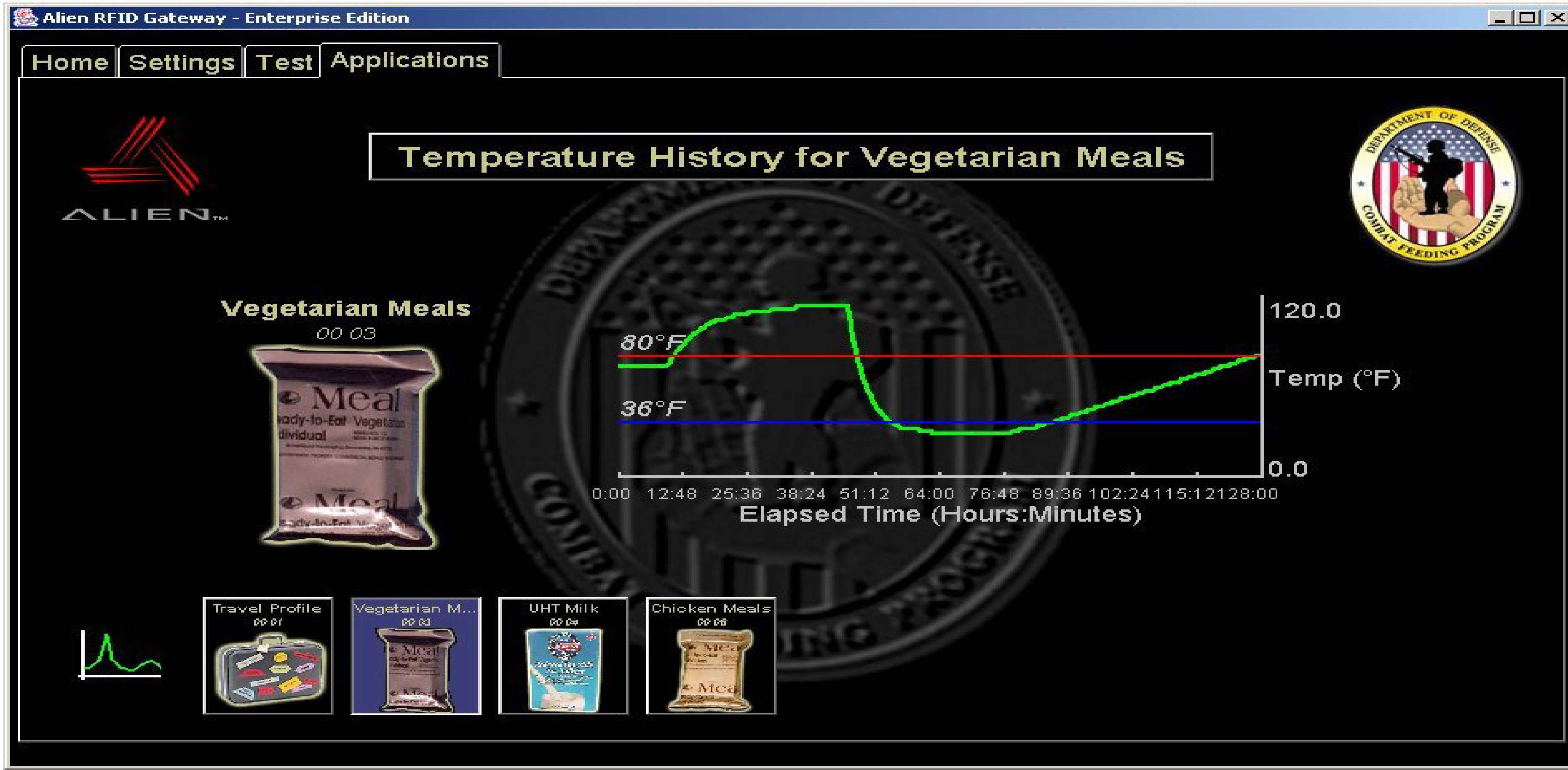
Shelf Life >> Answers, not Numbers

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			



RFID Monitoring Perishables (MRE)

RFID Temperature Sensor ● DoD MRE Status

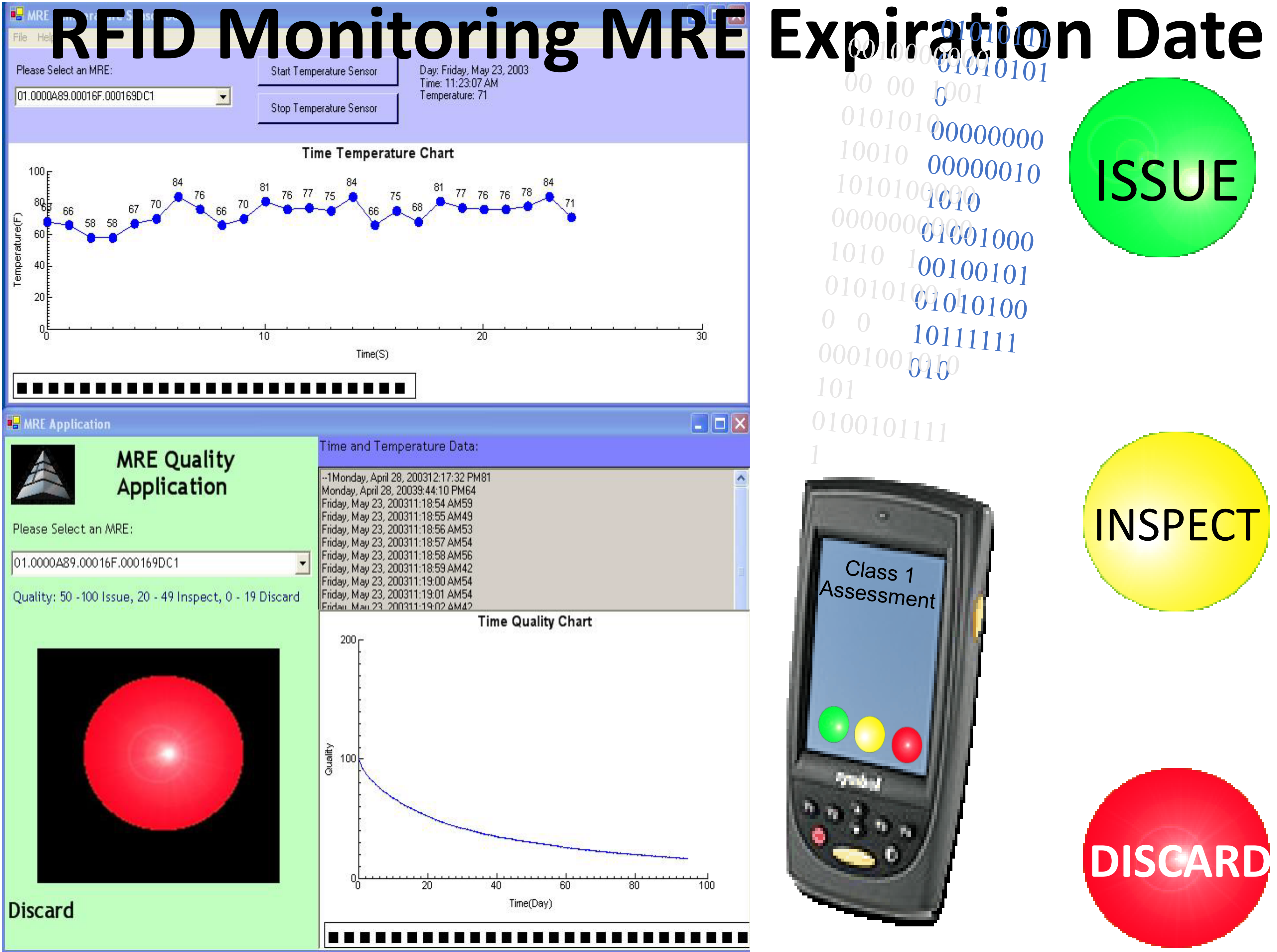


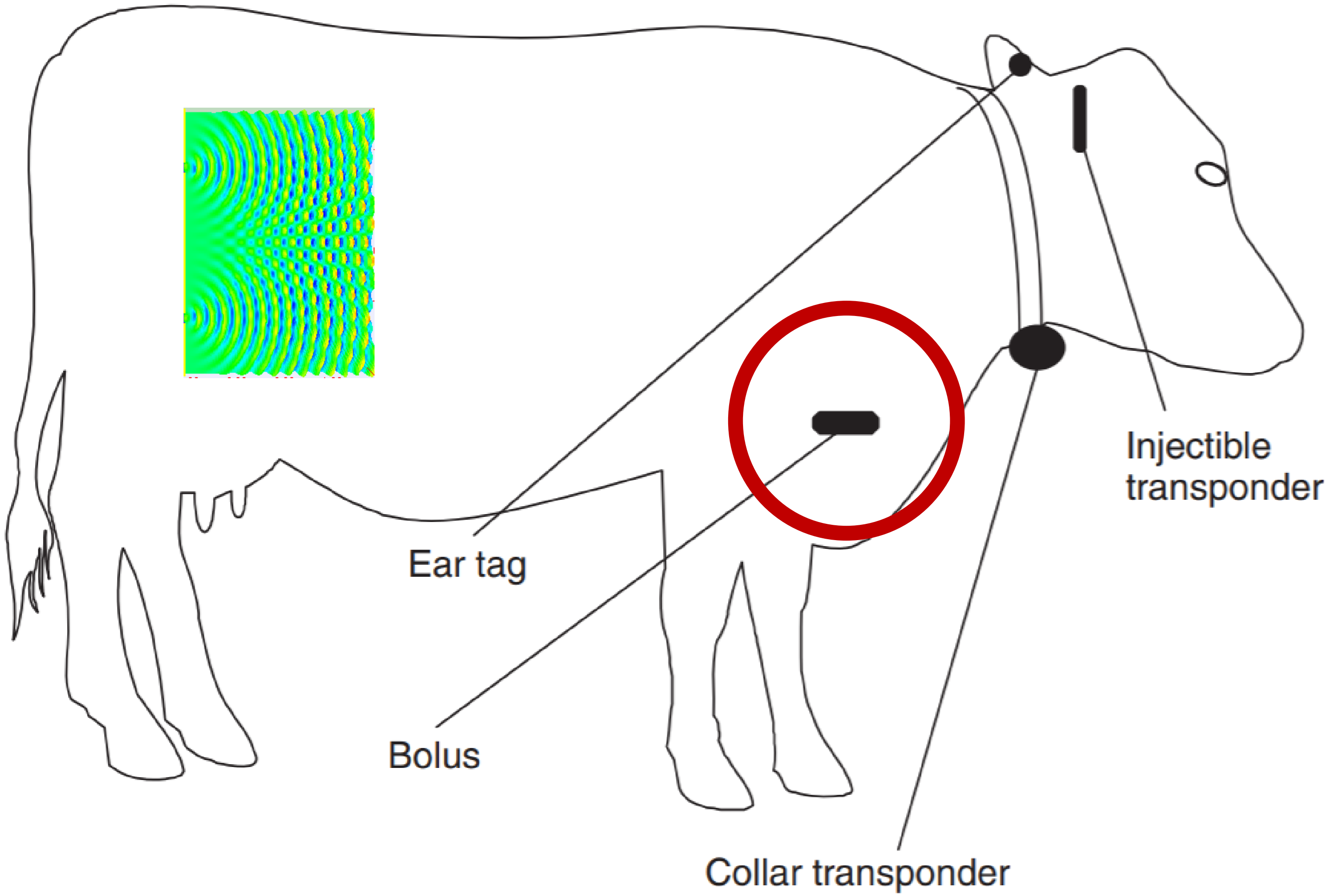
AUTO-ID CENTER

Data

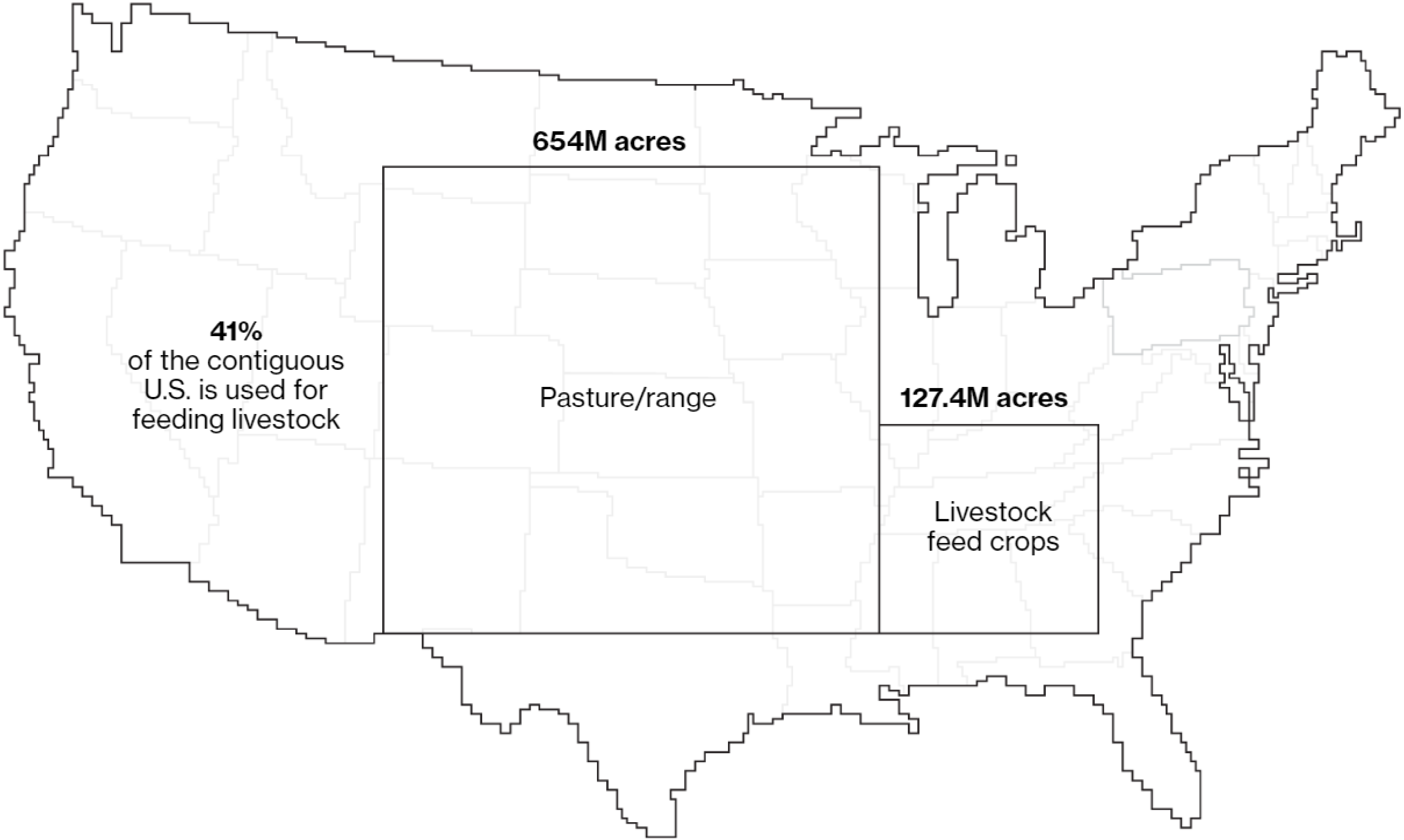
in the context of end-user value

RFID Monitoring MRE Expiration Date





Data Acquisition from Ruminants

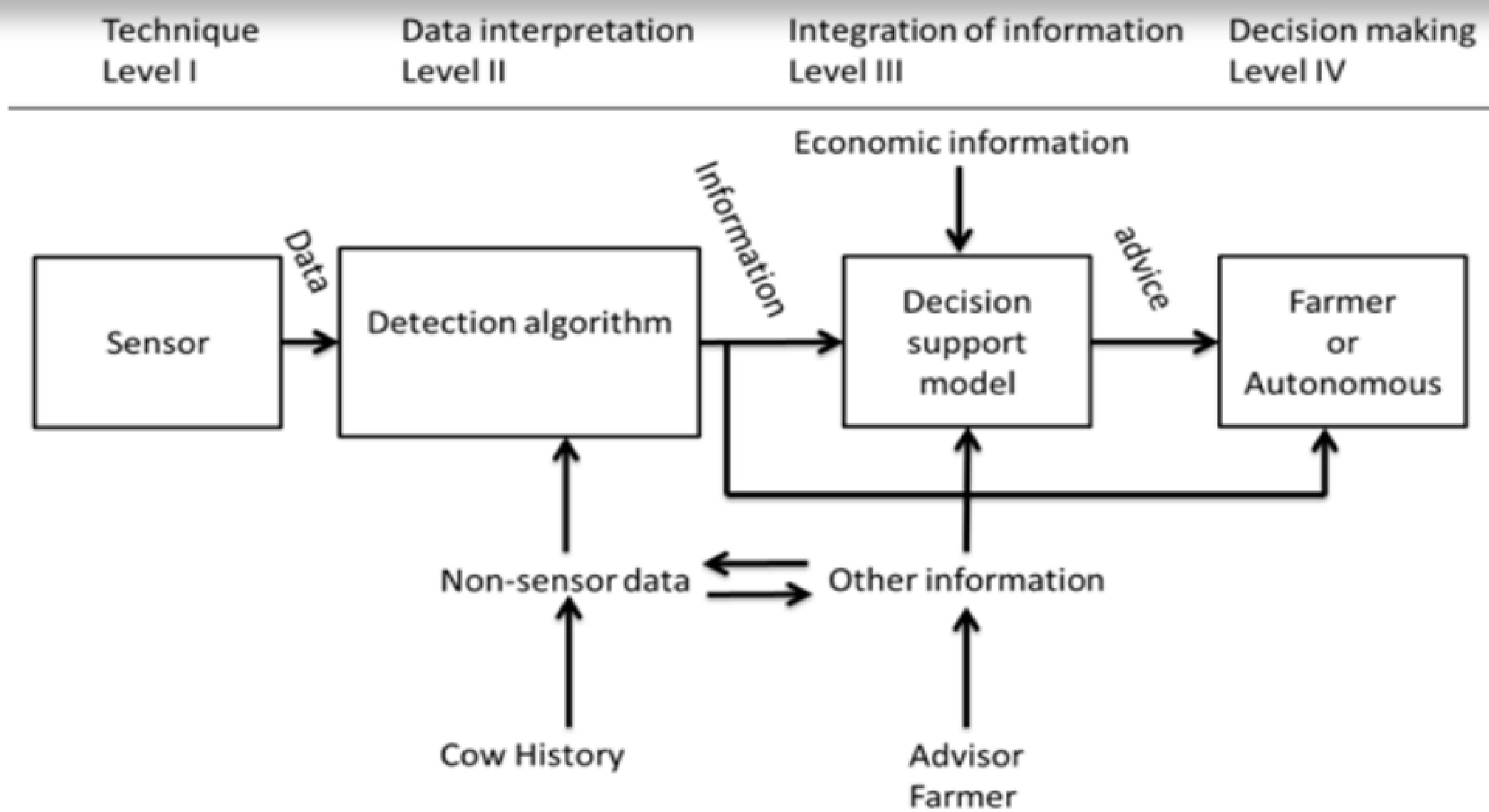


There's a single, major occupant on all this land: cows. Between pastures and cropland used to produce feed, 41 percent of U.S. land in the contiguous states revolves around livestock.

https://www.bloomberg.com/graphics/2018-us-land-use/

Closed Loop CPS Model for Precision Agriculture

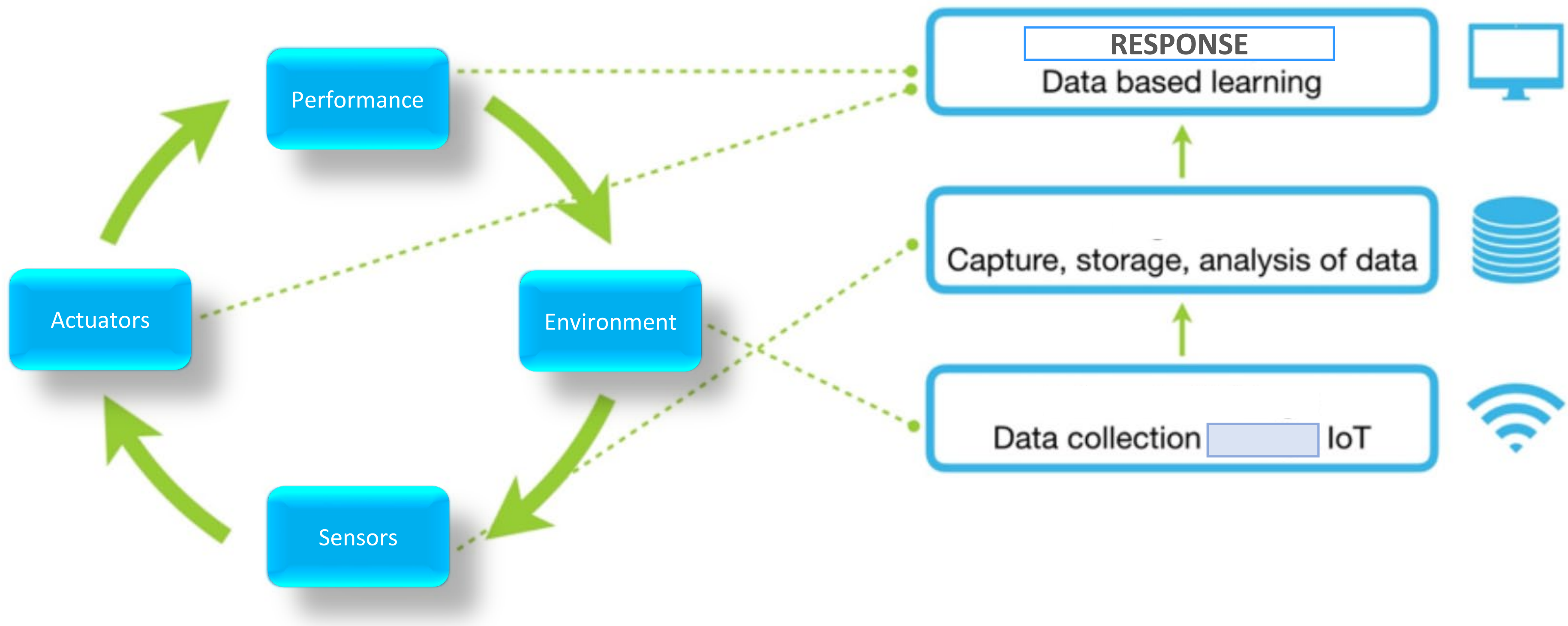
WHY DEVELOP CPS MODEL FOR PRECISION AGRICULTURE & FARM IOT ?

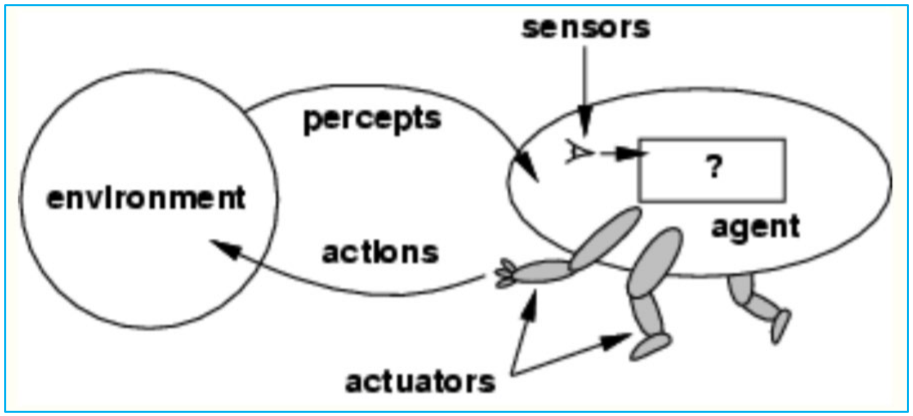


From 126 papers, 139 dairy sensor systems (2002-1212) were compared based on 4 levels above: (I) technique, (II) data interpretation, (III) integration of information, and (IV) decision making. **NONE** included integration of sensor data with other farm data for decision support or automated decision making (Rutten *et al*). We need for sustainable dairy CPS. Mobile sensing, data analytics, controls and networking advances are ripe enough to develop CPS for precision animal agriculture.

Rutten, N., A. G. J. Velthuis, W. Steeneveld, H. Hogeveen (2013) *Sensor systems for dairy cow health management: A review*. In Proceedings of the Precision Dairy Conference and Expo. Mayo Civic Center, pp 89–90. www.precisiondairyfarming.com/2015/wp-content/uploads/2015/08/2013-Precision-Dairy-Proceedings.pdf

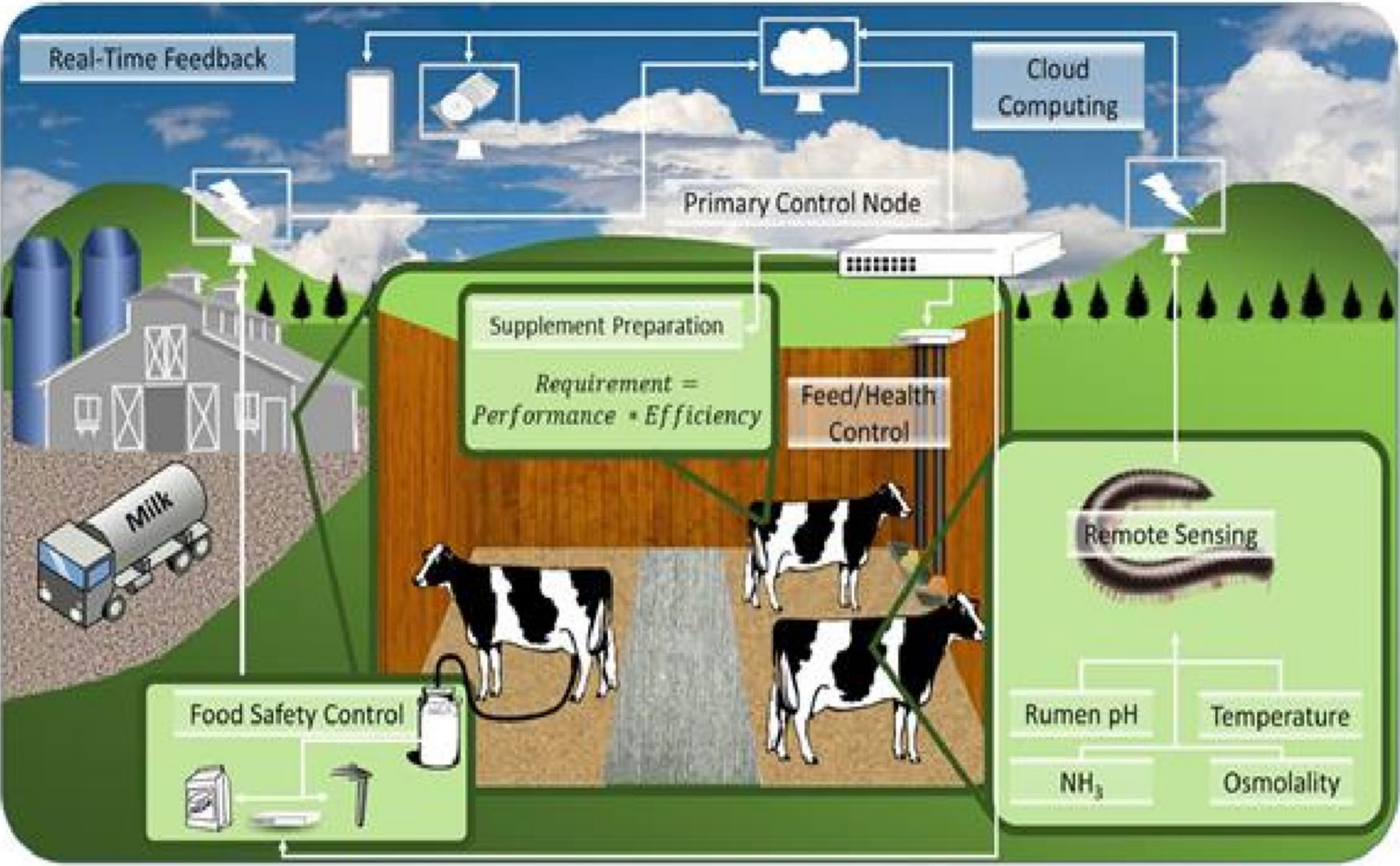
Intelligent Information Arbitrage



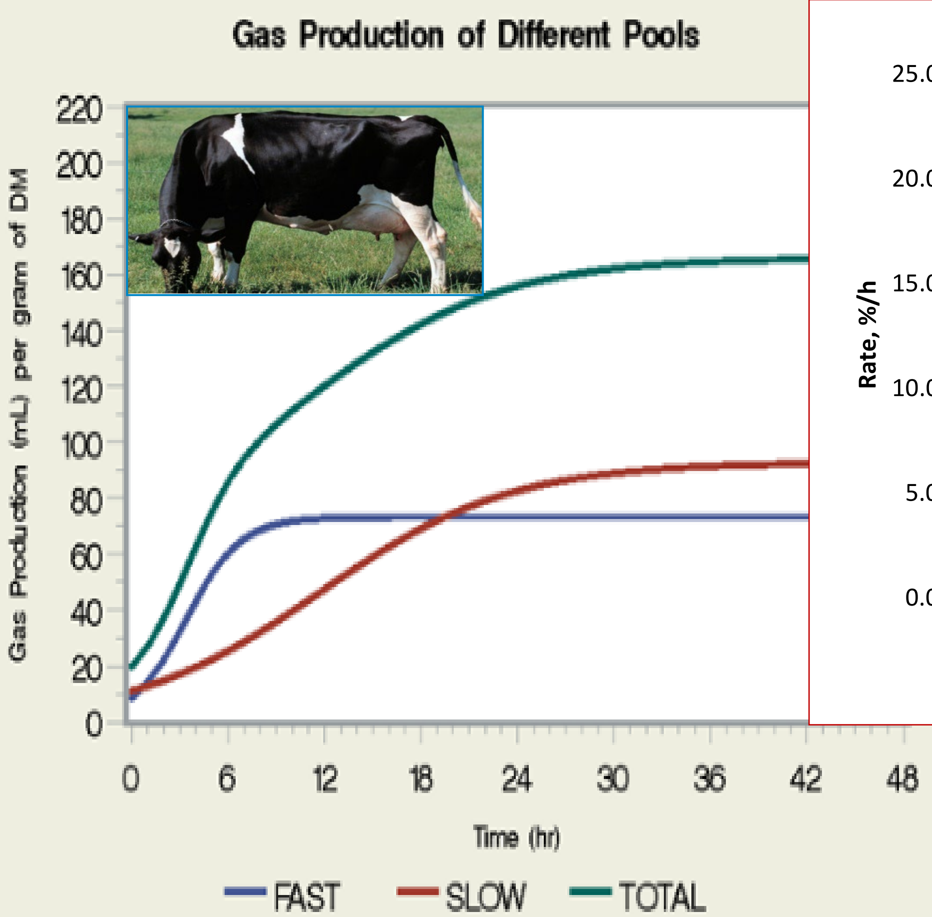


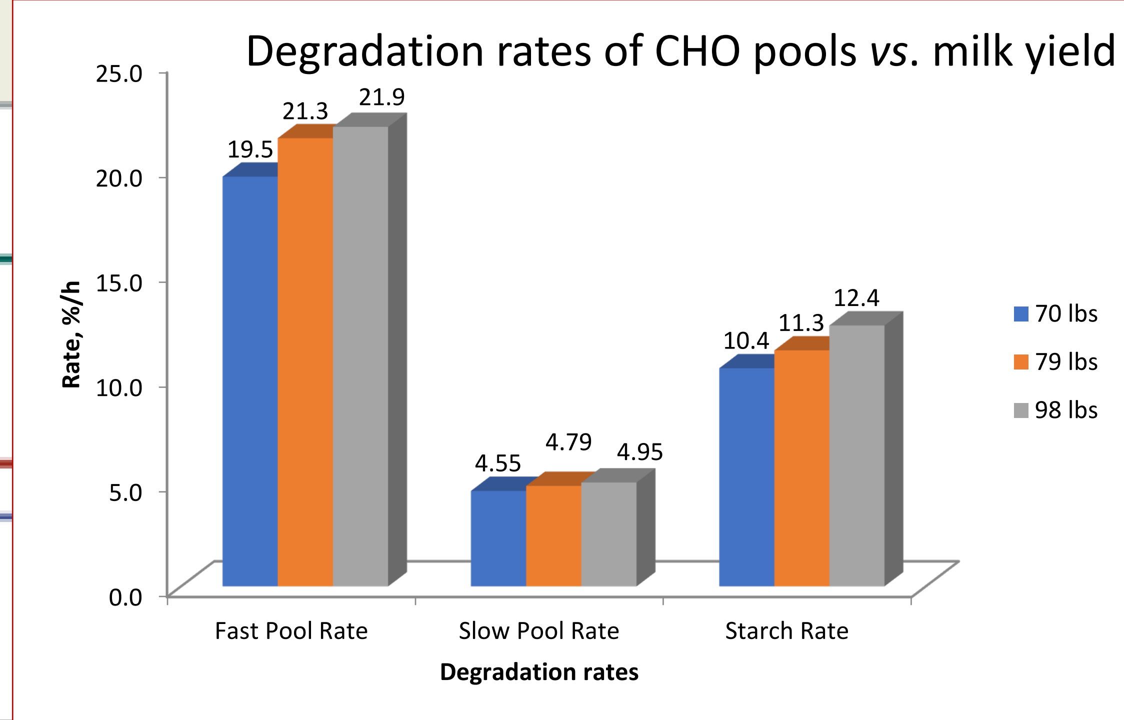
https://www.ics.uci.edu/~welling/teaching/ICS171fall10/Agents171Fall10.pdf

https://courses.edx.org/asset-v1:ColumbiaX+CSMM.101x+1T2017+type@asset+block@AI_edx_intelligent_agents_new__1_.pdf



Digital Dairy Supply Chain – *in vivo* rumen sensors monitor animal metabolomics. Collar sensor data analytics reveal herd behavior. Sensors in milking parlor offer data on milk quality, volume and Pavlovian responses. Data analytics to enable self-adaptation of network topology (create alerts for emergencies and inform supply chain decision support). Monitoring of animal health coupled with automated feeding control and milk distribution in closed-loop fashion to optimize productivity, maintain food safety and better empower sustainable practices.





	Digestion rate	Relative proportion of pools	
		mL gas/ g OM	% Total
Starch (Kd/hr)	10.09		
Fast Pool(Kd/hr)	14.75	73.2	44.1
Slow Pool (Kd/hr)	4.27	92.9	55.9
2-Pool Total		166.1	100.0

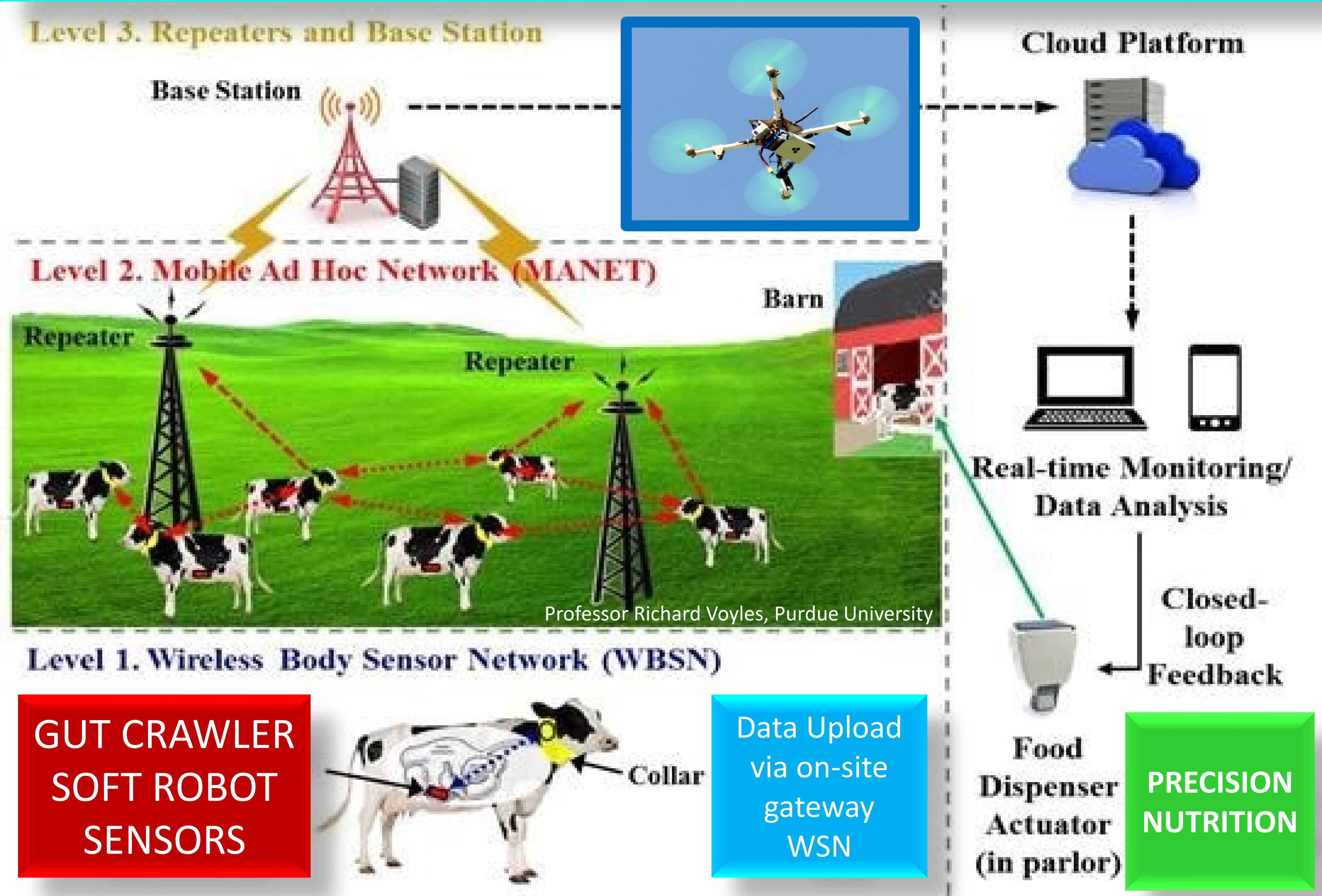
ADMD (%DM)	54.1
TDMD (%DM)	70.0
aPF	4.22
Microbial protein (mg/g TDDM)	128.6

Total VFA mM	38.08
VFA, % of Total	
Acetic acid	45.30
Propionic acid	17.86
Isobutyric acid	1.14
Butyric acid	13.56
Isovaleric acid	2.90
Valeric acid	2.57

In vitro digestion model (IFM)
Measuring Dynamic Digestion

Volatile (Short Chain) Fatty Acids: Methane Estimator

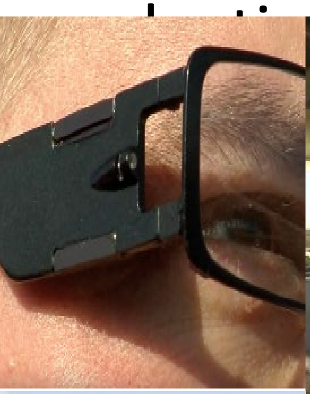
Internet of Connected Cows – Sustainable Practices for Precision Animal Agriculture



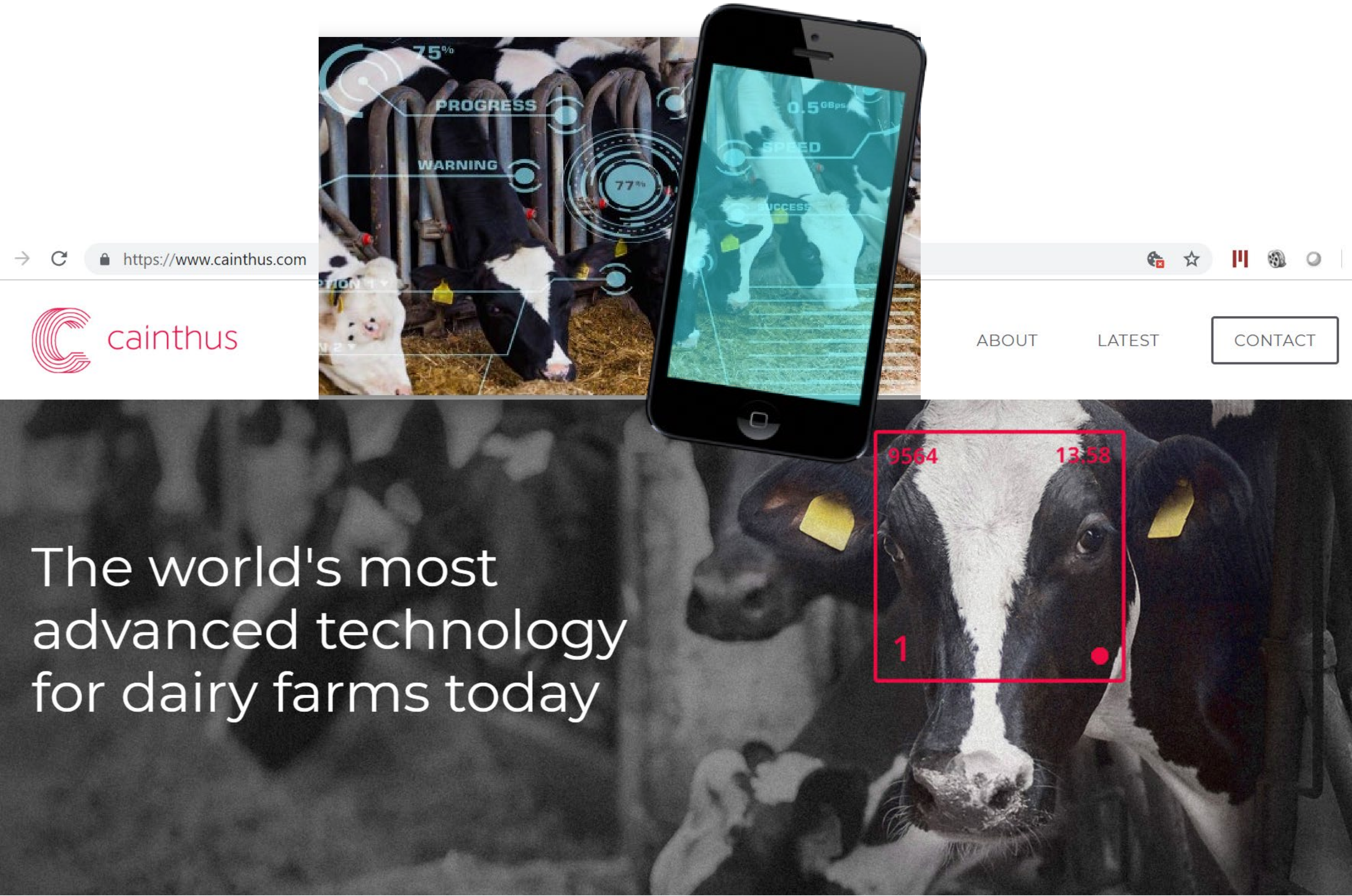
SYNERGISTIC SYSTEMS INTEGRATION ?

Nutritional SARA⇨ Real-Time Digestive Analytics
Nutritional ⇨ sense, analyze, respond, actuate

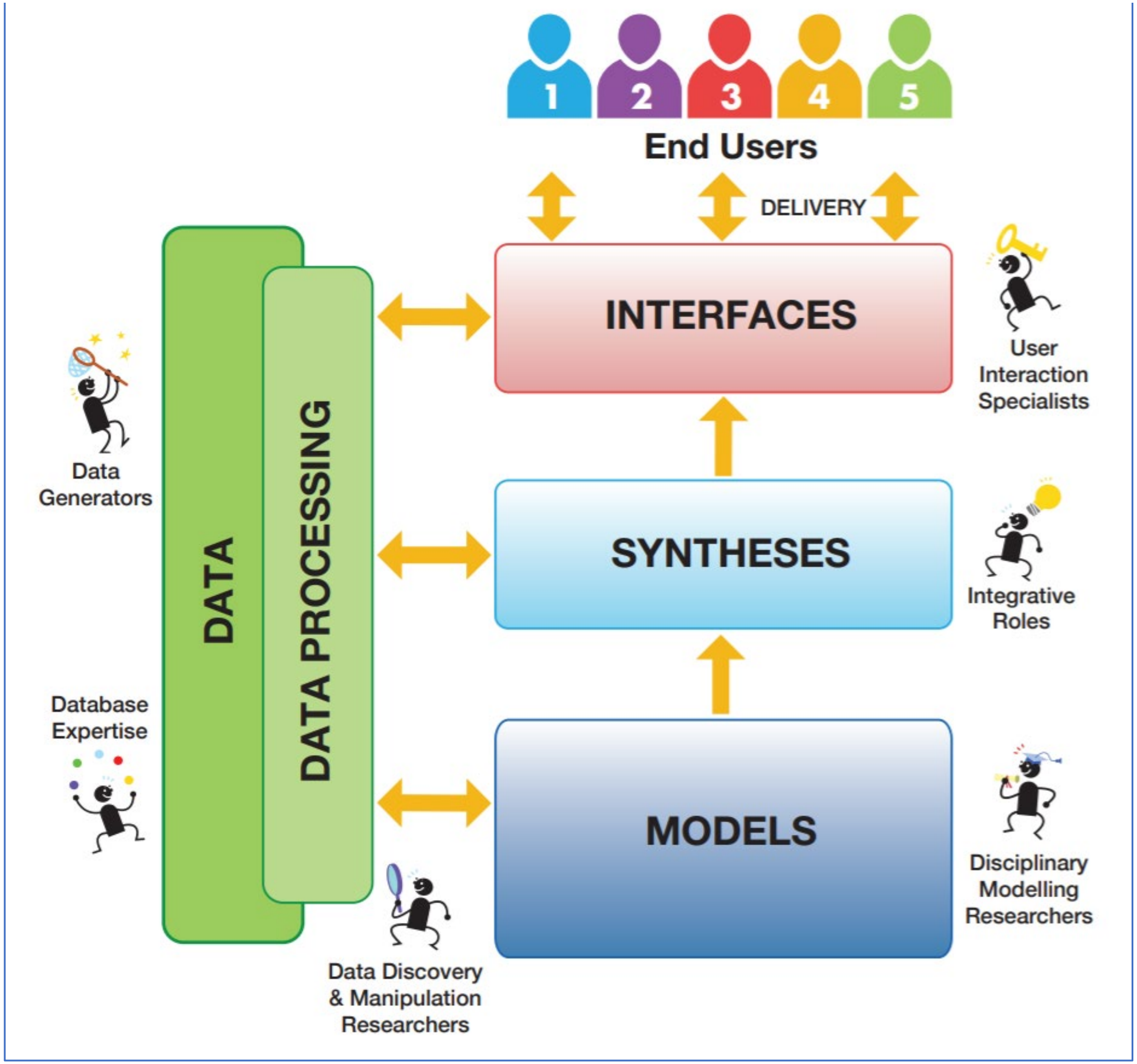
In vivo rates of digestion will enable precision mixed ration formulation and better dairy health to increase milk



Pursuit of Happyness – for cows

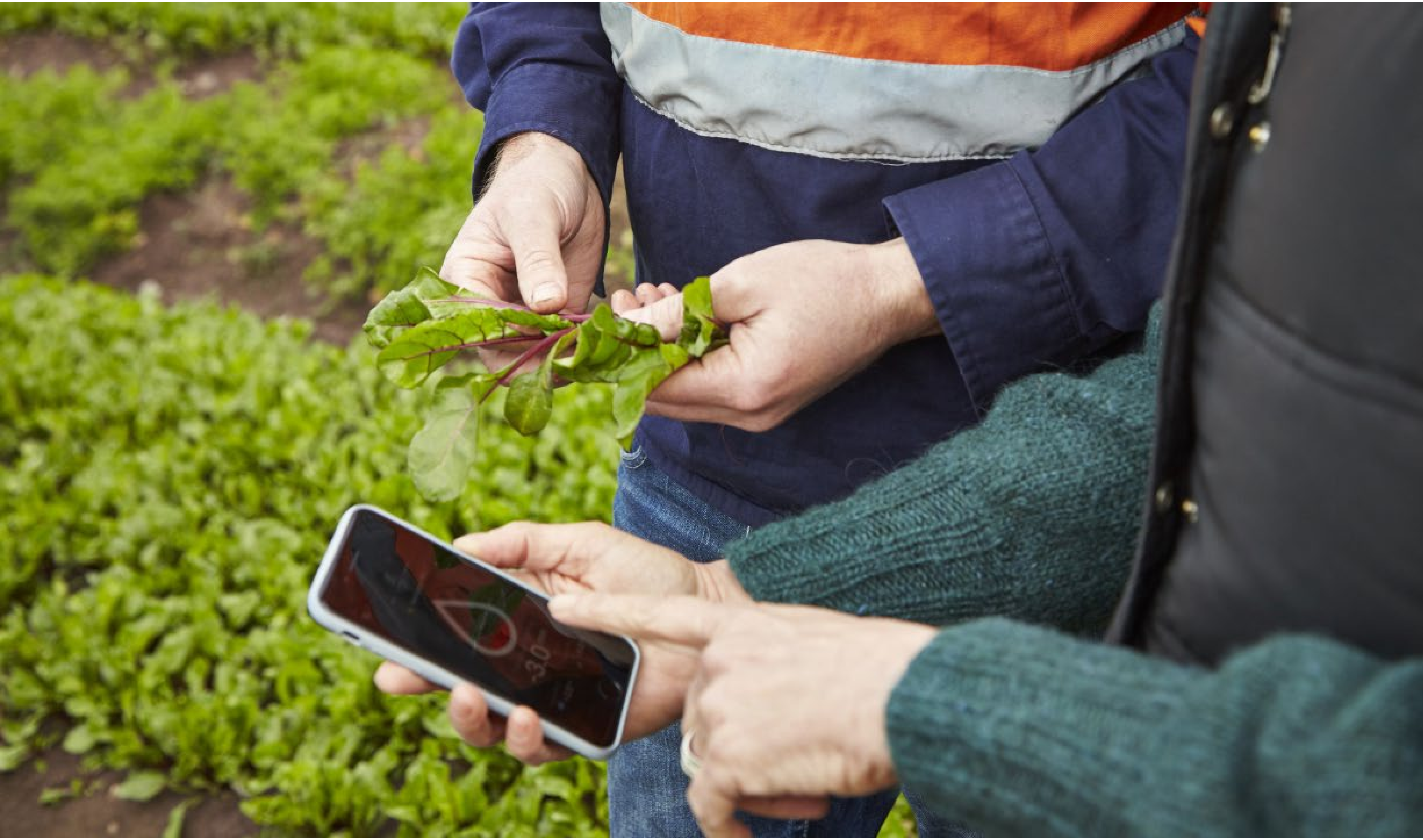


Intelligent Information Arbitrage



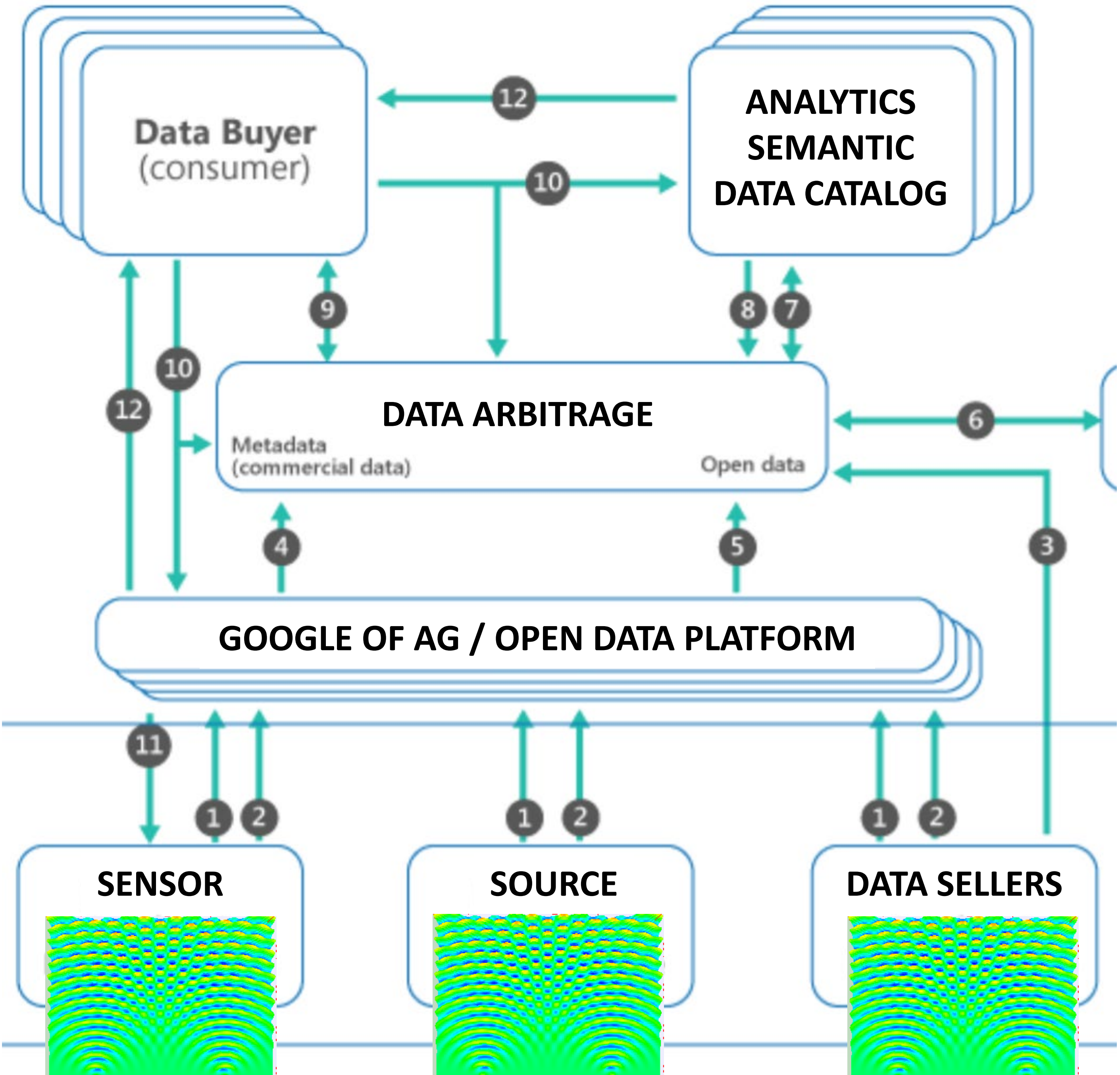
Page 98 in www.agmip.org/wp-content/uploads/2015/04/Towards-a-New-Generation-of-Ag-Systems-Complete.pdf

Intelligent Information Arbitrage



HARVEST and INVEST in UNSTRUCTURED DATA and (MERGE DATA IN CONTEXT FOR INTELLIGENT) DATA ANALYTICS

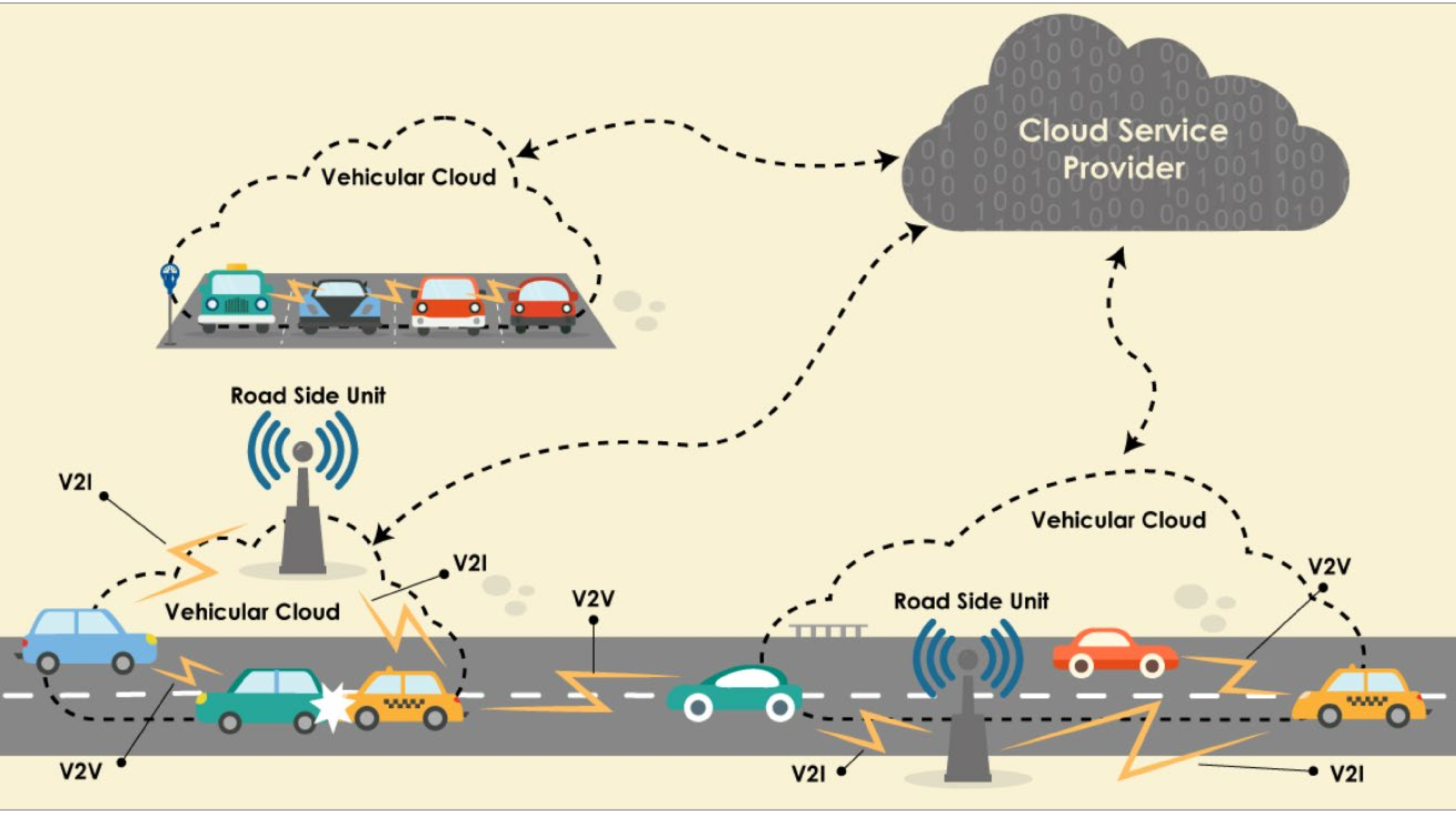
Intelligent Information Arbitrage



- Weather Data
- Crop Rotation
- Fertilizer Data
- Bacterial Flora

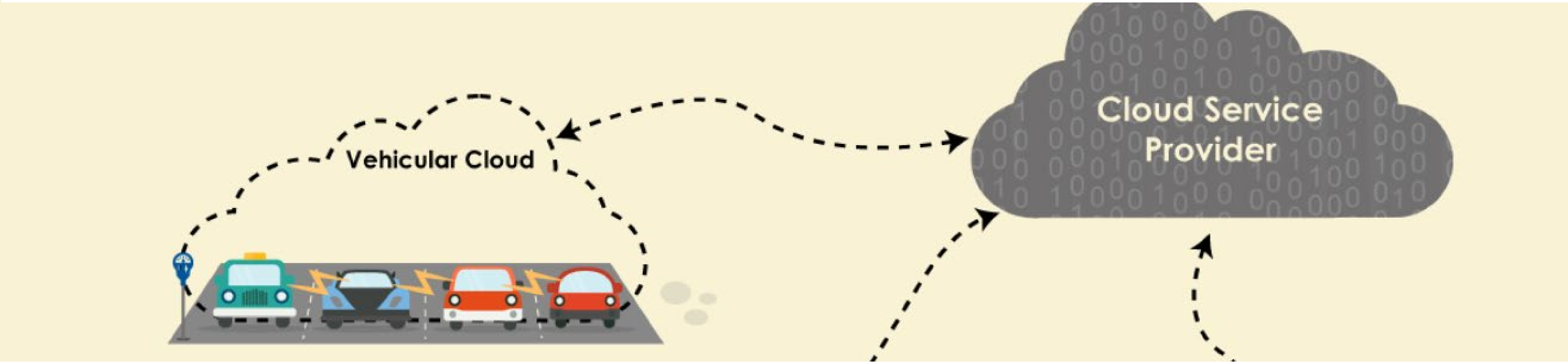
https://aioti.eu/wp-content/uploads/2019/02/IoT-data-market-places-drivers-and-architechtures-white-paper-Elloumi-De_Block-Samovicz.pdf

Intelligent Information Arbitrage



Merge Unstructured Data – Extract Sense

Are you feeling jittery?



G! What a difference @ 60mph = 88 feet/sec

Latency ~100ms (3G) = 8.8’ = 106” = 268cm

Latency ~10ms (4G) = 0.88’ = 10.6” = 26.8cm

Latency ~1ms (5G) = .088’= 1.06” = 2.68cm

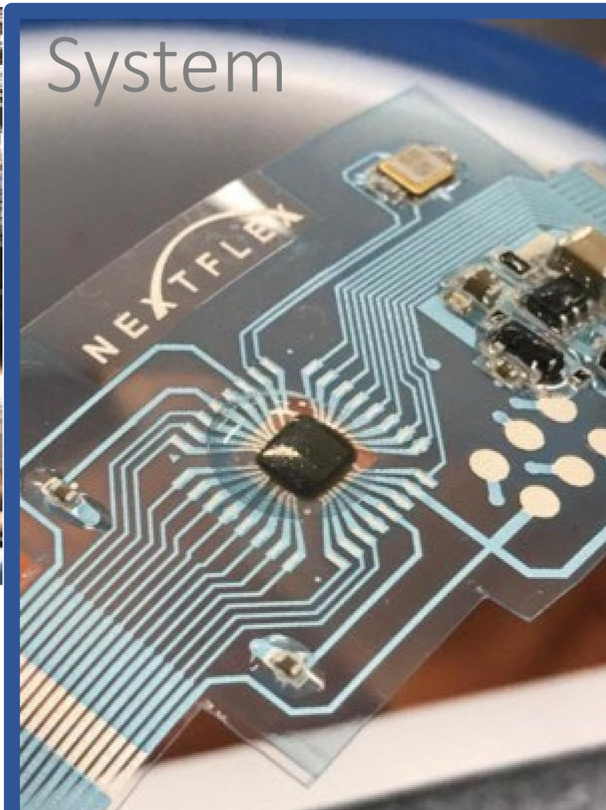
Data and Information Arbitrage

Diode fibres for fabric-based optical communications

A unique code is woven into the fabric material of the backpack given to each first-year student at MIT. Unlike a QR code, this fabric-based coding system is subtle to the eye but immediately recognizable by an app called AFFOA LOOKS. The owner can link her backpack to their mobile device and program it to display a song, a cause, or anything the owner wishes to share.

http://news.mit.edu/2017/back-to-school-special-affoa-smart-fabric-backpacks-for-mit-freshmen-0829
http://news.mit.edu/2018/optoelectronic-diodes-fibers-fabrics-soft-hardware-0808
http://news.mit.edu/2018/inventing-future-fabrics-affoa-mit-fit-workshop-0731
https://dmse.mit.edu/news/affoa-offers-special-backpacks-class-2021
https://nvlpubs.nist.gov/nistpubs/ams/NIST.AMS.600-3.pdf
https://www.nature.com/articles/s41586-018-0390-x
https://looksapp.affoa.org/
http://go.affoa.org/

Flexible Arduino System

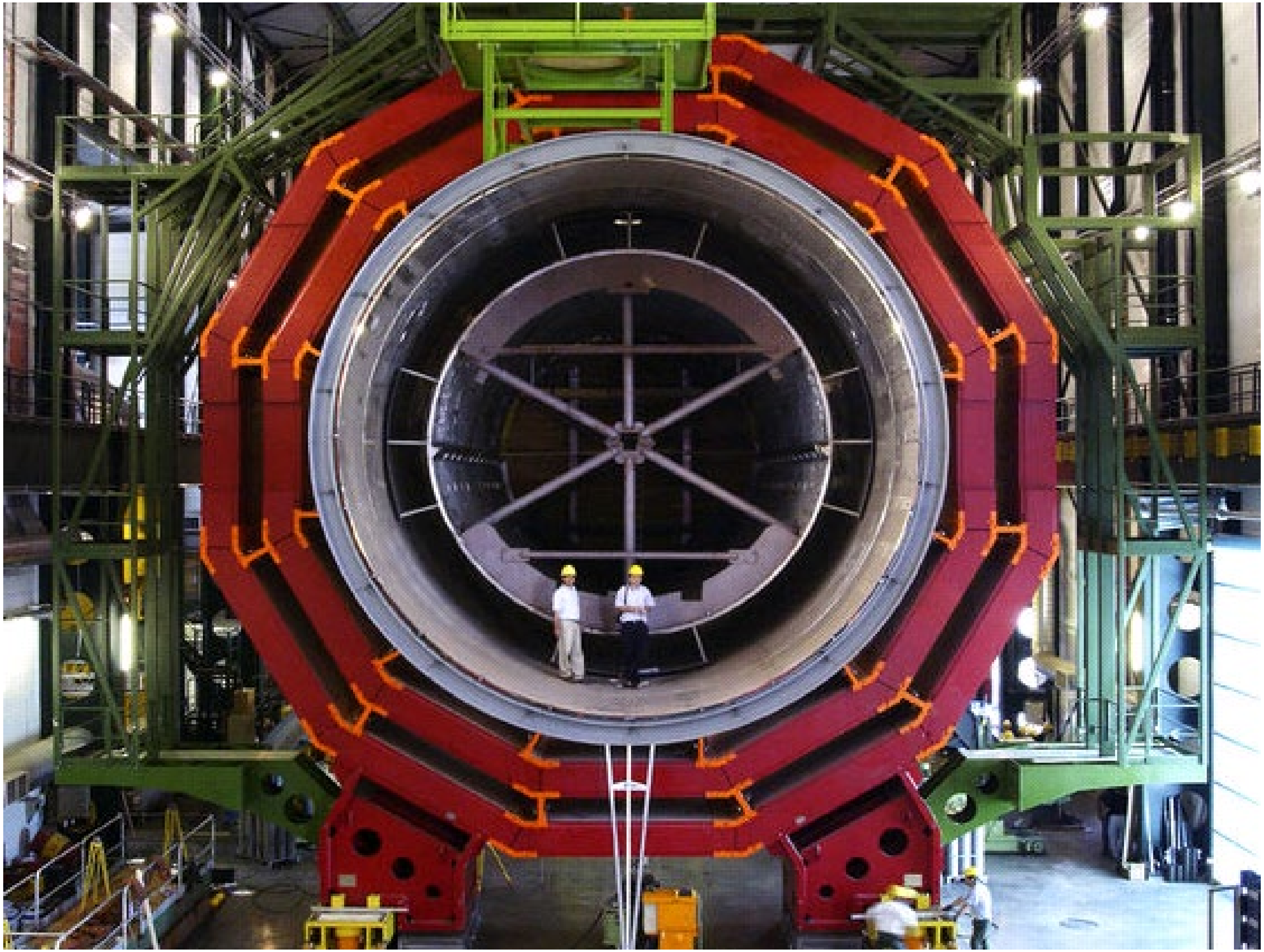


https://blog.arduino.cc/2018/06/05/a-flexible-arduino-prototype/

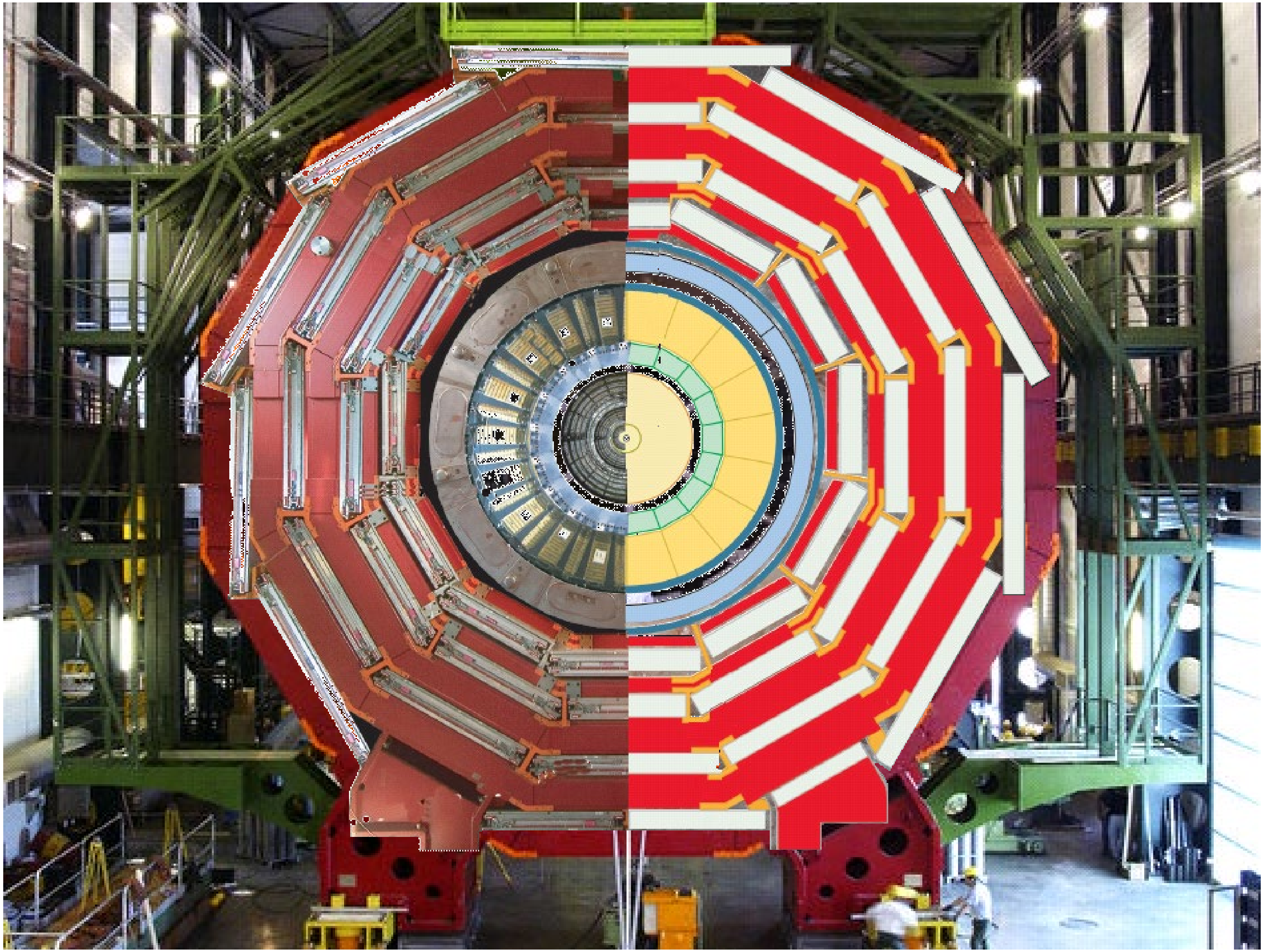
New Materials, New Tools, New Outcomes

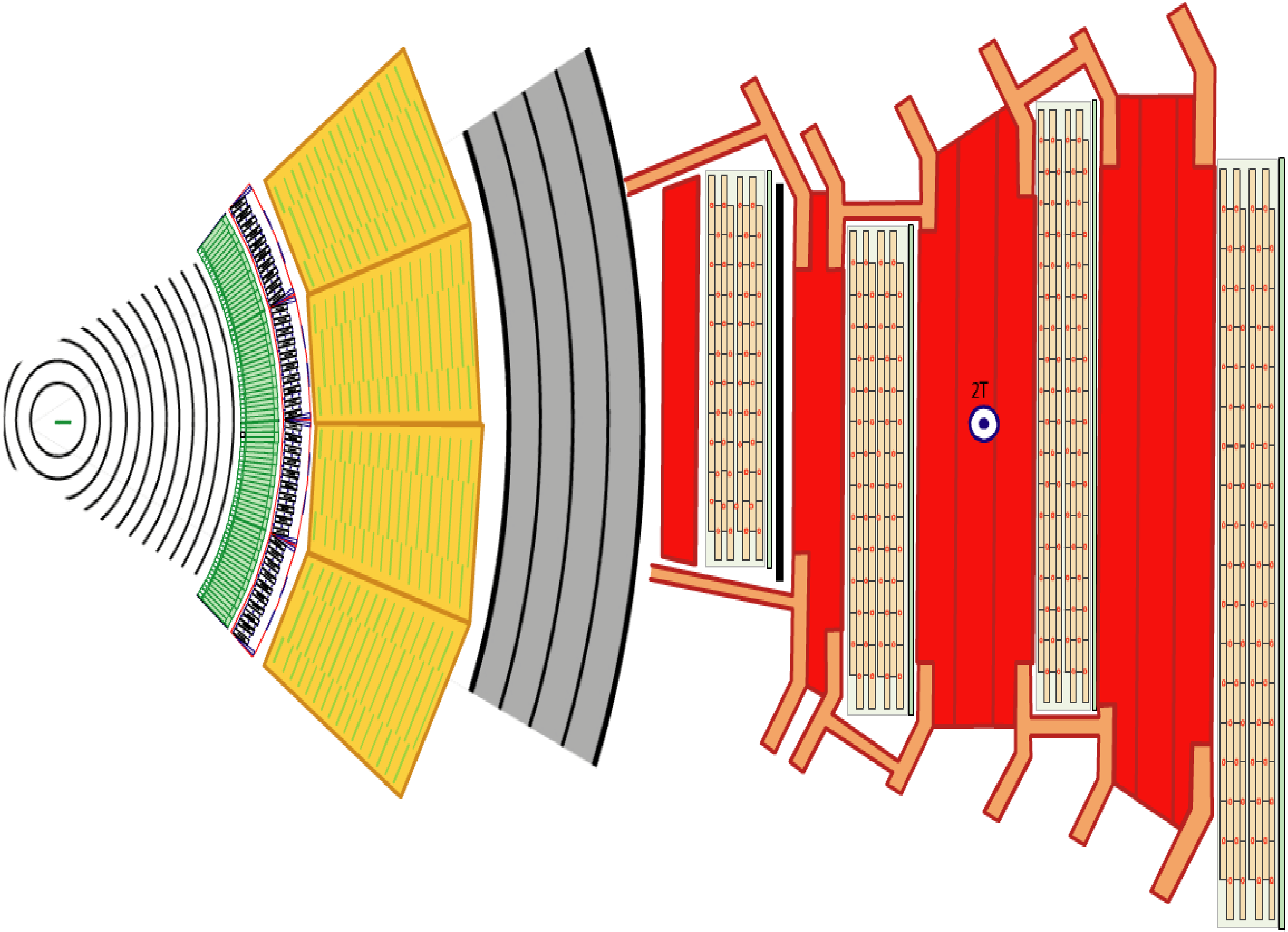
Data Acquisition for Large Experiments

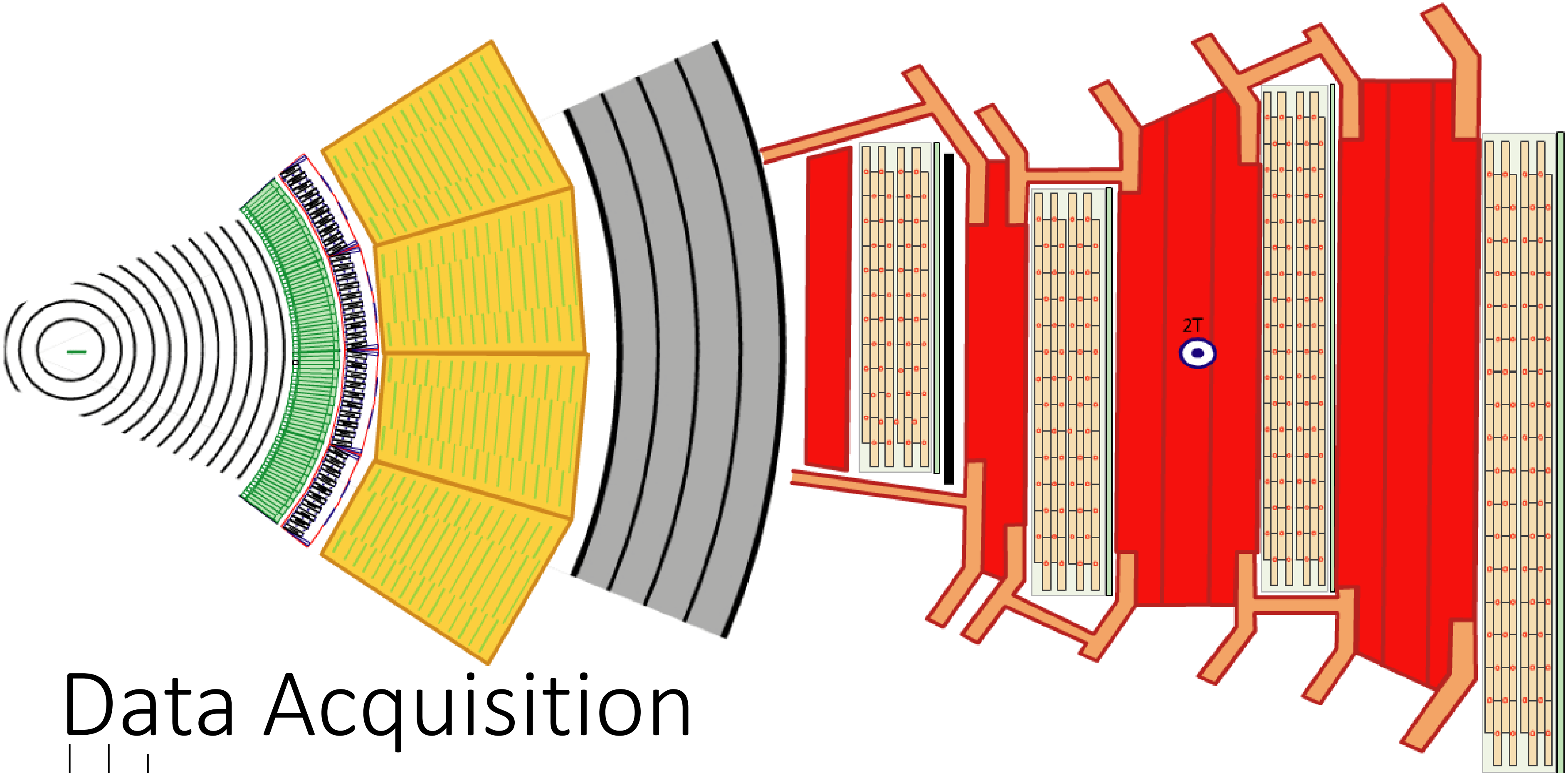
Compact Muon Solenoid (CMS) experiment is one of two large general-purpose particle physics detectors built on the LHC.



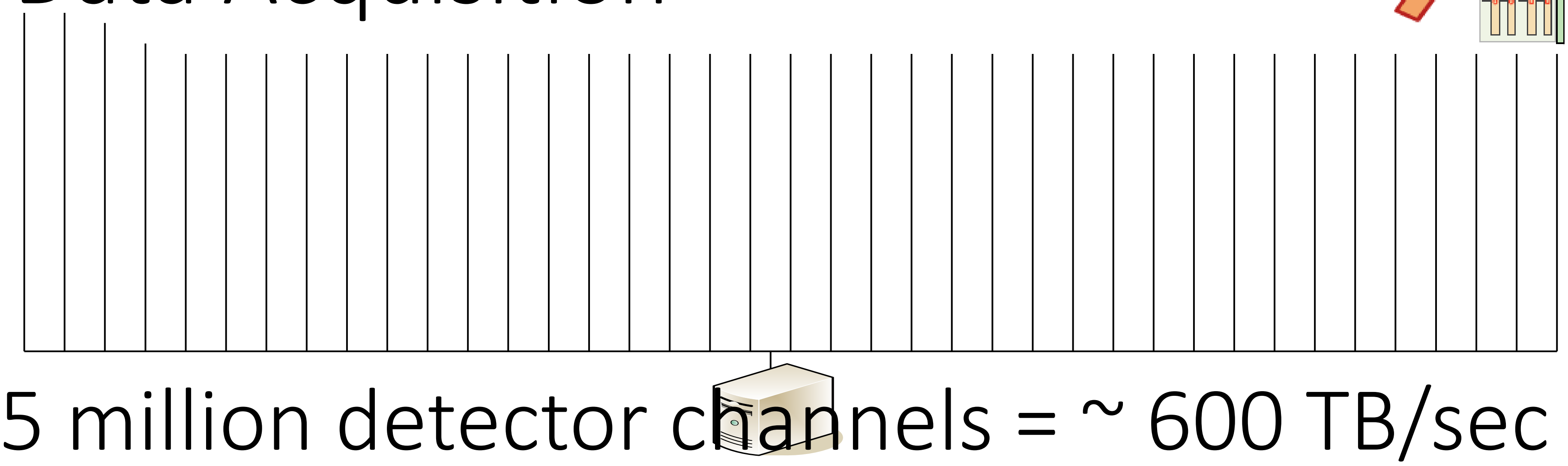
Compact Muon Solenoid (CMS) experiment is one of two large general-purpose particle physics detectors built on the LHC.




2T

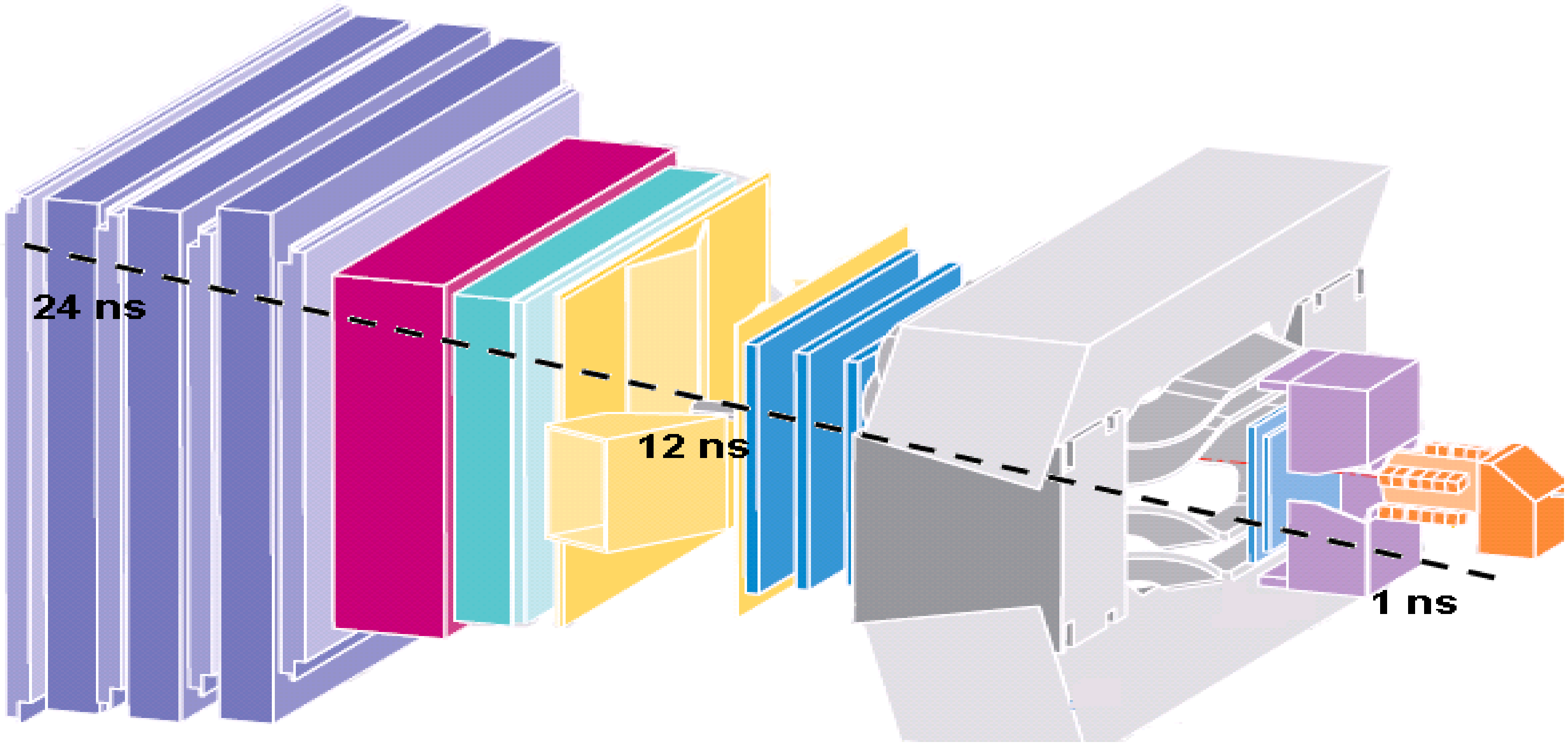


Data Acquisition



15 million detector channels = ~ 600 TB/sec

LHC Challenges ≈20 interactions every 25 ns



N. Neufeld CERN
Summer Student
Lectures 2009

Marvin Minsky ● Cube-on-Cube ● 1959, MIT

https://devblogs.nvidia.com/video-mixed-precision-techniques-tensor-cores-deep-learning

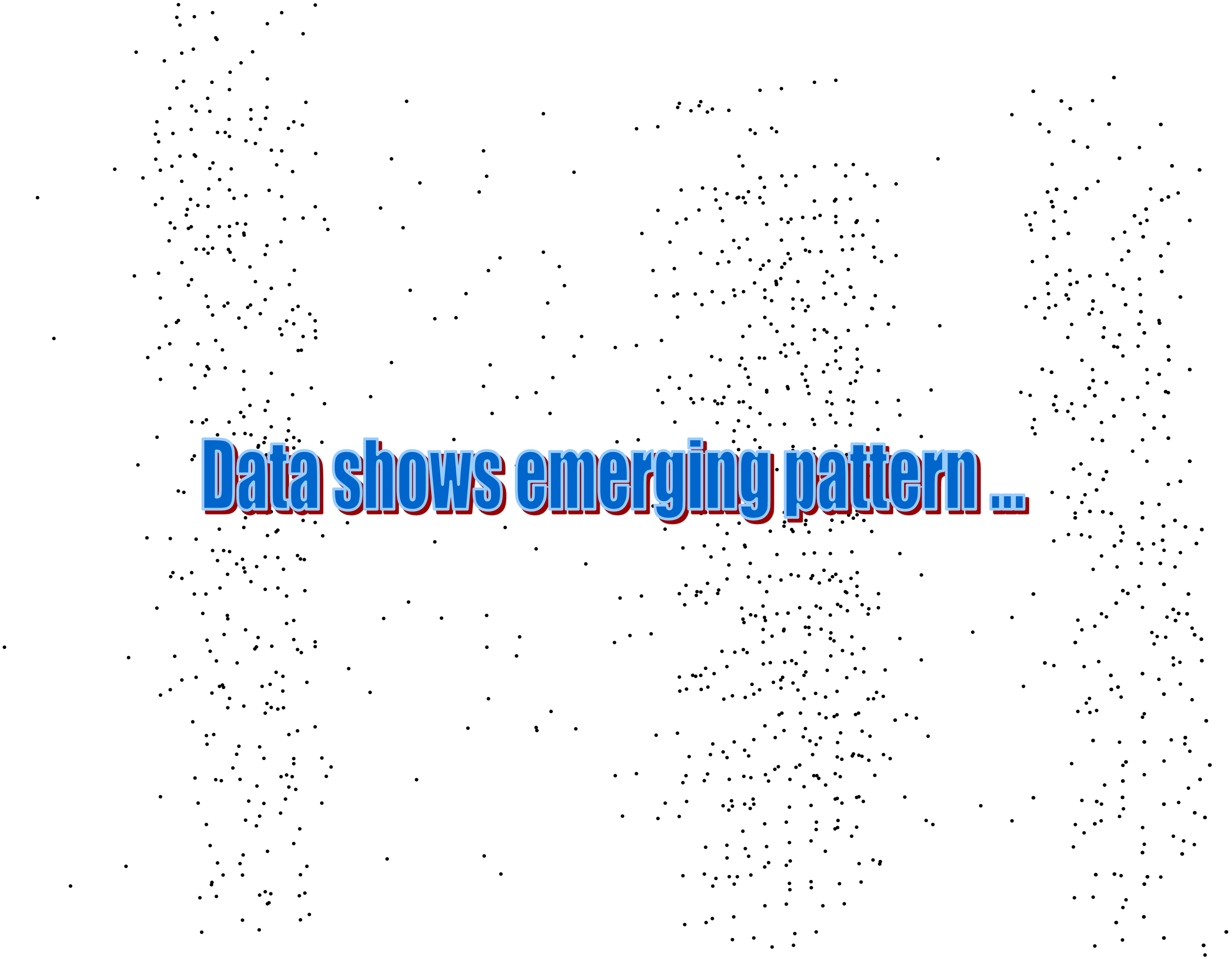
You can't build an elephant using the mouse as a model

Data

There are no short cuts

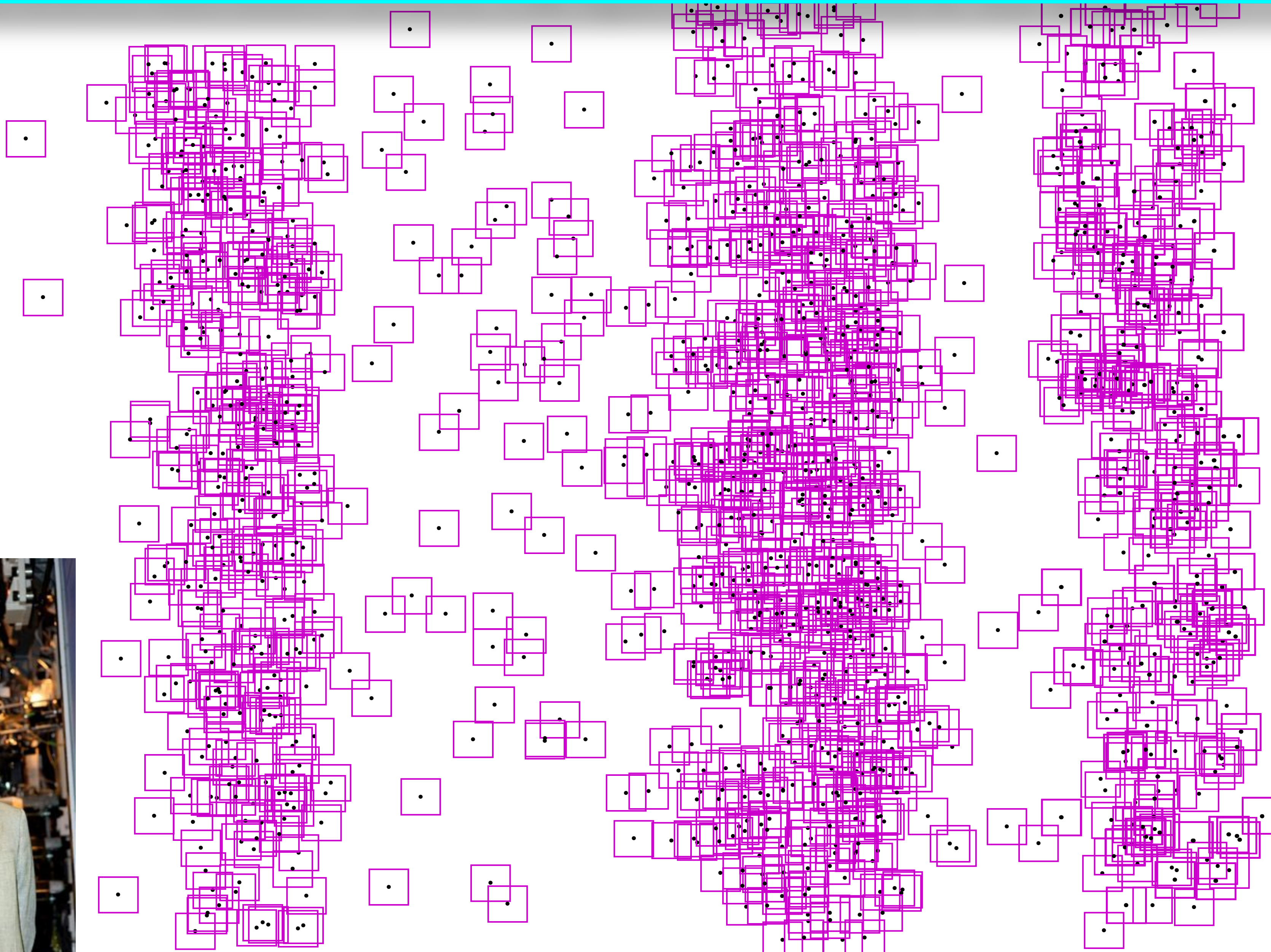
Data...

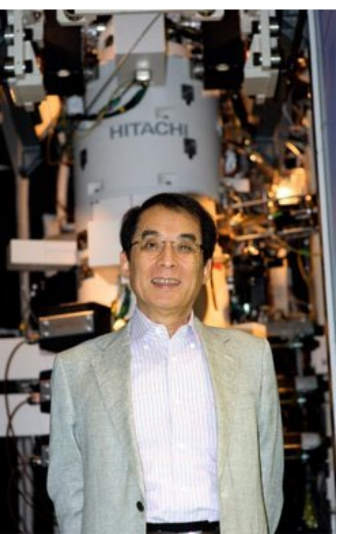

More data points ...


Data shows emerging pattern ...

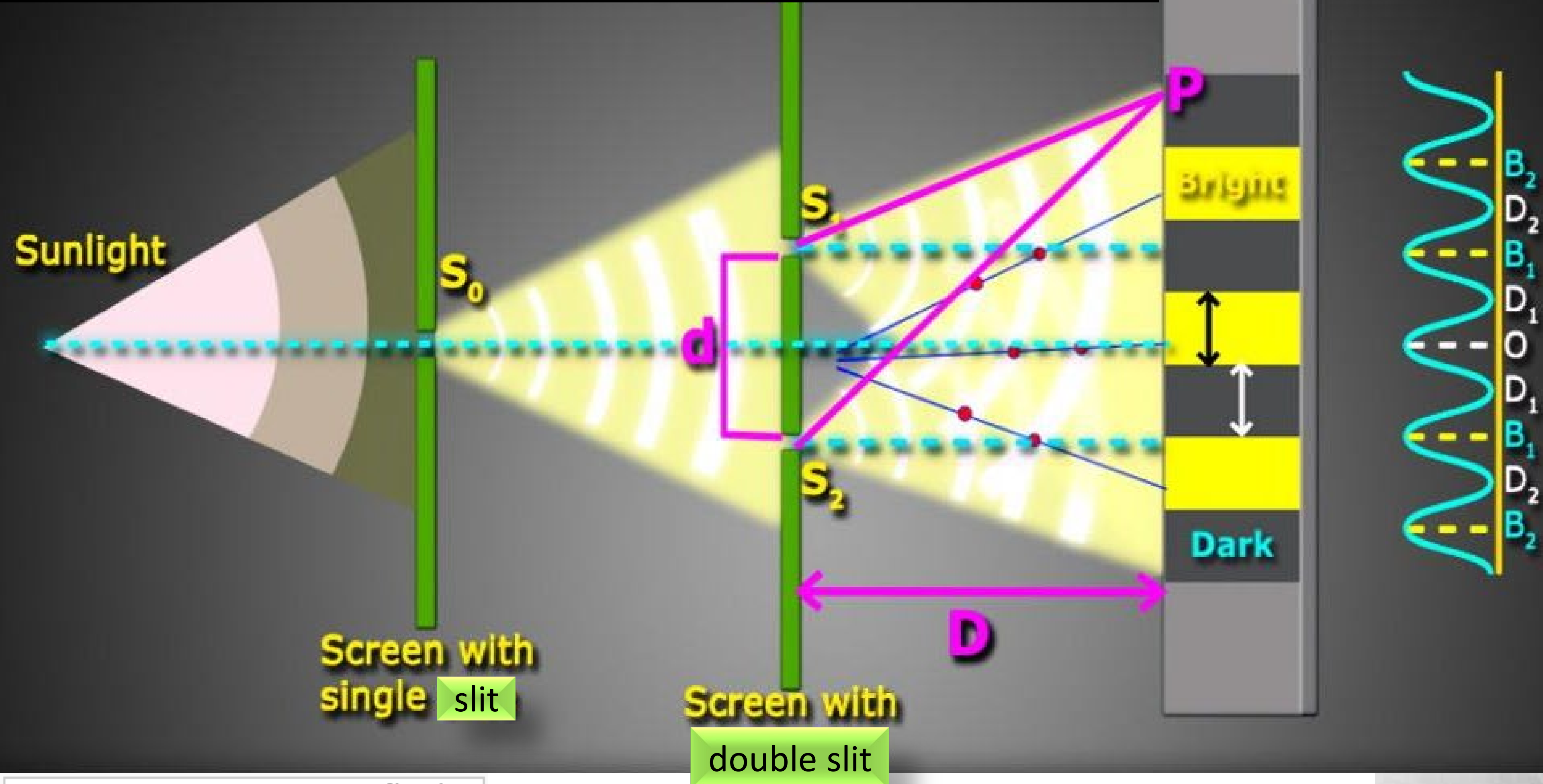
Young’s Double Slit Experiment with Electrons

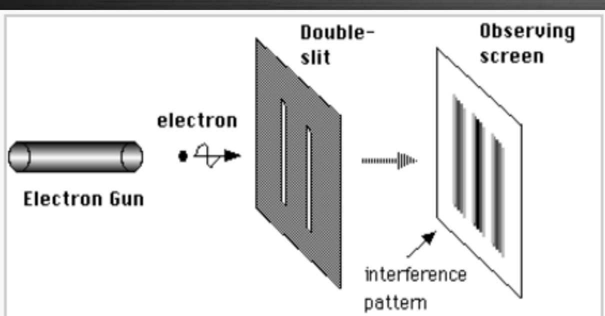
Dr. Akira Tonomura, Hitachi Research Laboratories, 1-280, Higashi-Koigakubo, Kokubunji-shi, Tokyo 185-8601, Japan



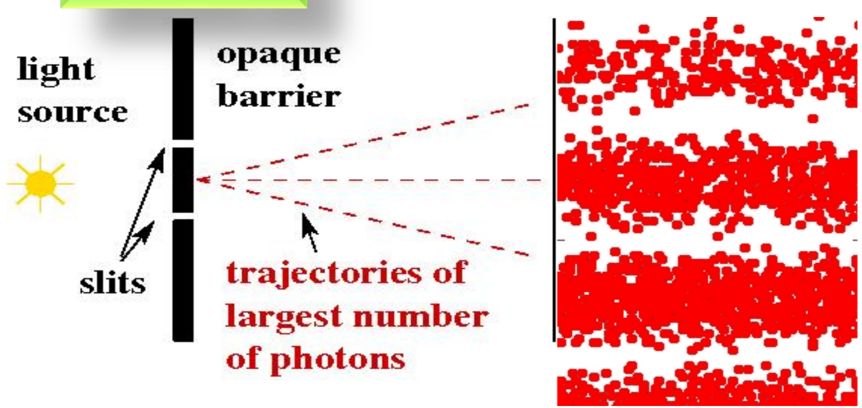


http://blogs.scientificamerican.com/guest-blog/what-does-the-new-double-slit-experiment-actually-show/





Photons or particles of matter (like an electron) produce a wave pattern



Data is the glue

Satellites, UAVs, Automobiles, Agriculture, Finance and everything else, needs, anomaly-free data

http://cucis.ece.northwestern.edu/projects/DMS/publications/AnomalyDetection.pdf

Data Analytics is the gluon

acquire and use data to generate information of value

Think this https://en.wikipedia.org/wiki/Gluon **not that** https://github.com/gluon-api/gluon-api/

Digital Transformation (PDF from MIT Library)

“ Haphazard Reality - IoT is a Metaphor”

https://dspace.mit.edu/handle/1721.1/111021