# Following edited section is part of a series of lectures

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This excerpt by Shoumen Palit Austin Datta is a supplement to

INDUCTION OF IMMUNITY FROM INTRUDERS? "VACCINE" STRATEGY AS A

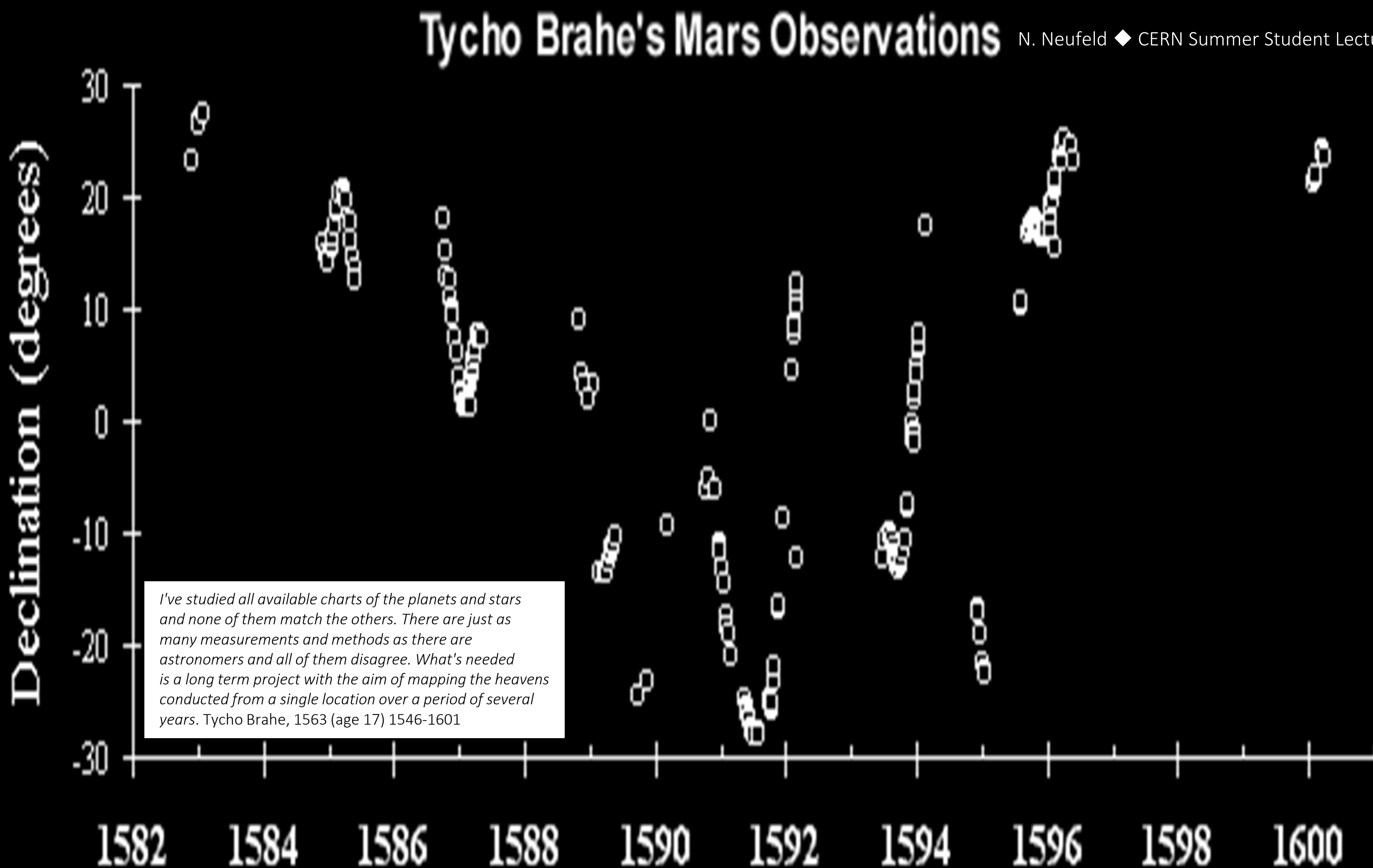
BIOLOGICAL METAPHOR FOR DEVICE-AGNOSTIC CYBERSECURITY

# DATA

Because the plural of anecdote is not evidence.

# The first 'systematic' data acquisition?

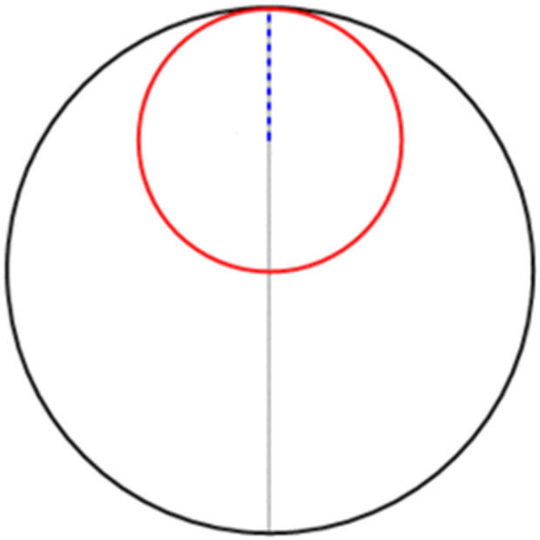
N. Neufeld ◆ CERN Summer Student Lectures, 2009




*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

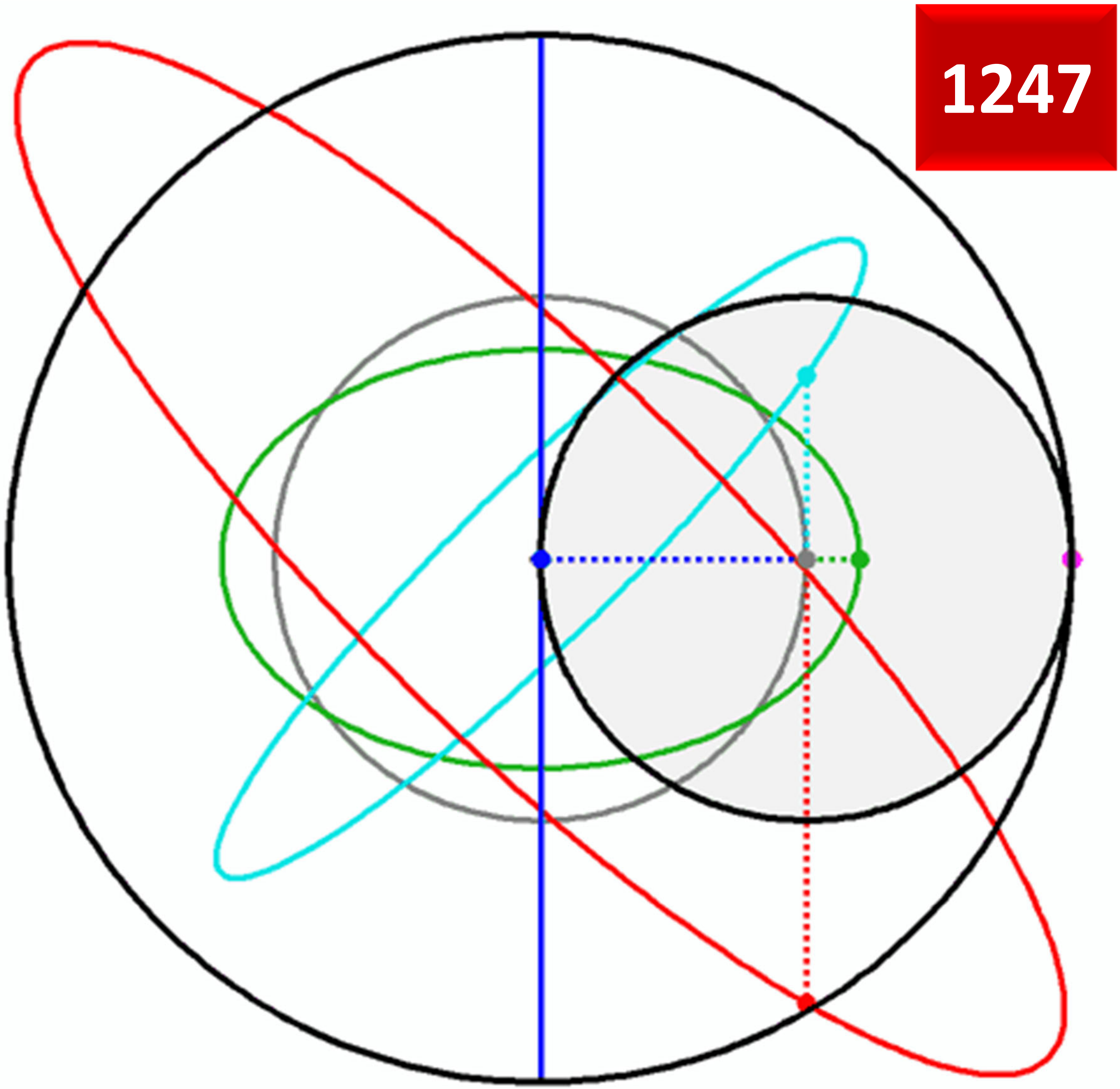
Monthly data over 18 yrs. Measurements lasted ~1 hour (naked eye)

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



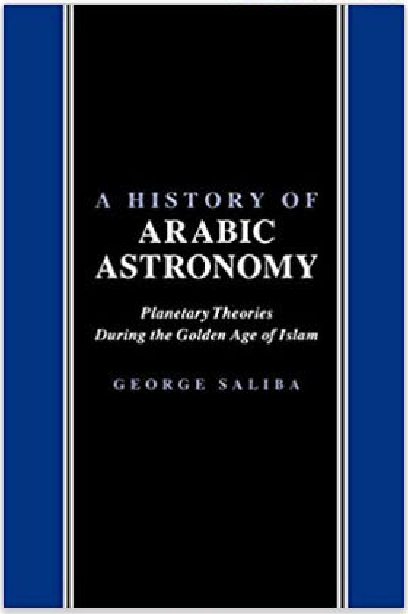
Tusi couple is a mathematical device in which a small circle rotates inside a larger circle twice the diameter of the smaller circle. Rotations of the circles cause a point on the circumference of the smaller circle to oscillate back and forth in linear motion along a diameter of larger circle. Tusi 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.

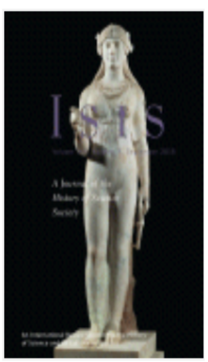
Some of the techniques and mathematical theorems developed during this period were identical to those which were employed by Copernicus in developing his own non-Ptolemaic astronomy. Significantly, this volume will shed much-needed light on the conditions under which such theories were developed in medieval 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

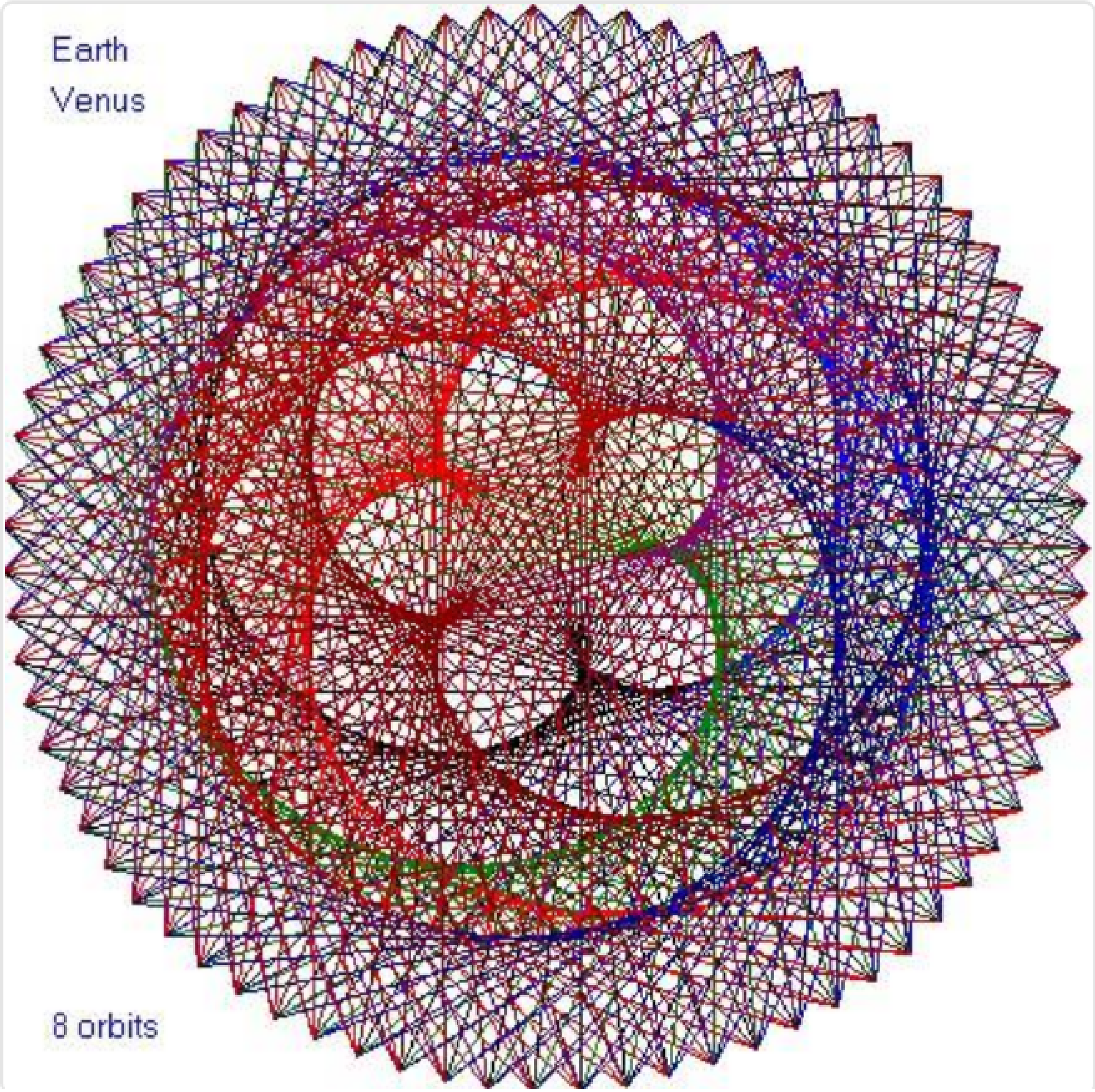


*Isis*
Vol. 57, No. 3 (Autumn, 1966), pp. 365-378 (14 pages)

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

What is the value of

Data

**WITHOUT UNDERSTANDING ?**

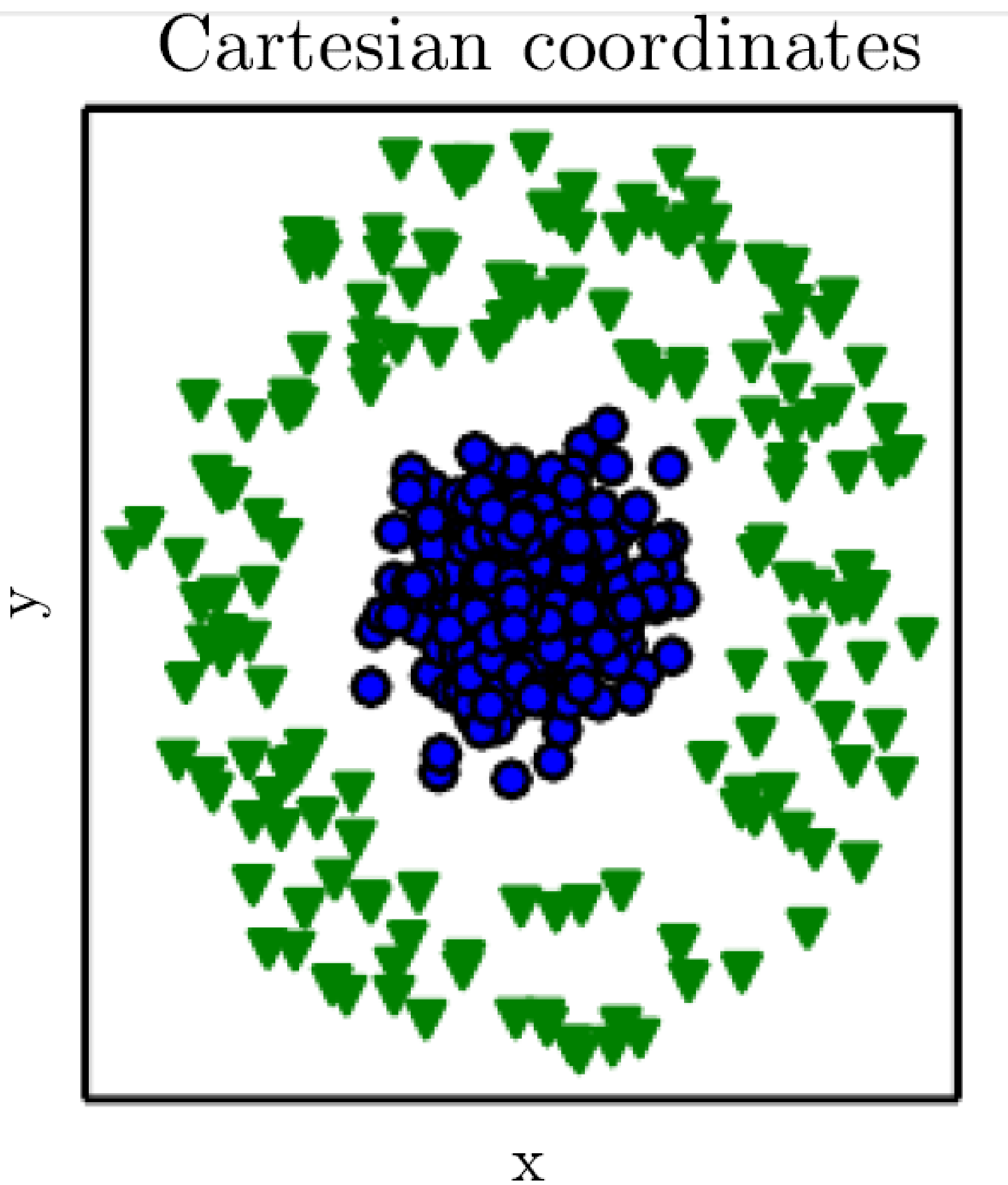



Figure 1.1: Example of different representations: suppose we want to separate two categories of data by drawing a line between them in a scatterplot. In the plot on the left, we represent some data using Cartesian coordinates, and the task is impossible.

From Ian Goodfellow in *Deep Learning*, MIT Press

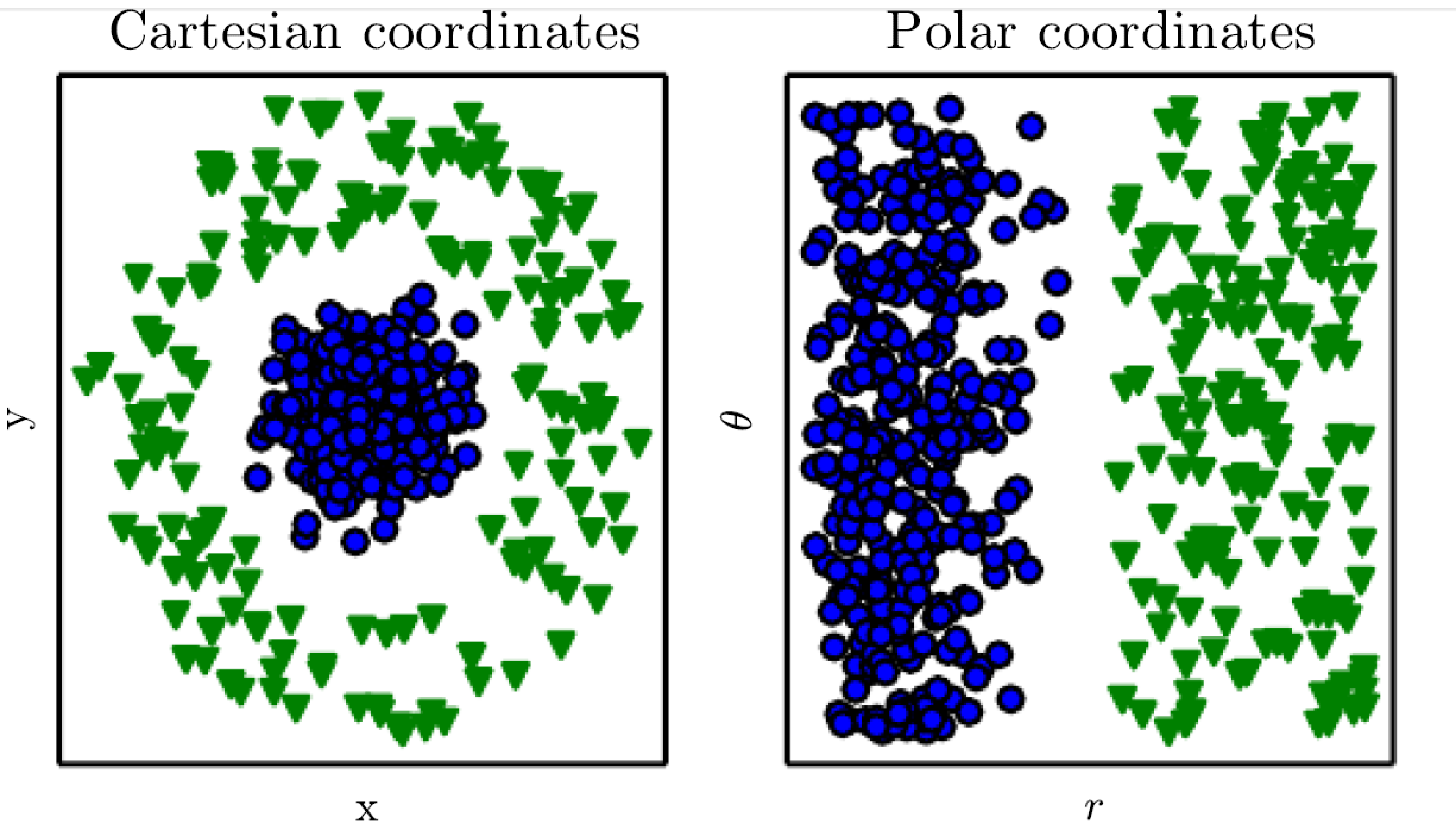



Figure 1.1: Example of different representations: suppose we want to separate two categories of data by drawing a line between them in a scatterplot. In the plot on the left, we represent some data using Cartesian coordinates, and the task is impossible. In the plot on the right, we represent the data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

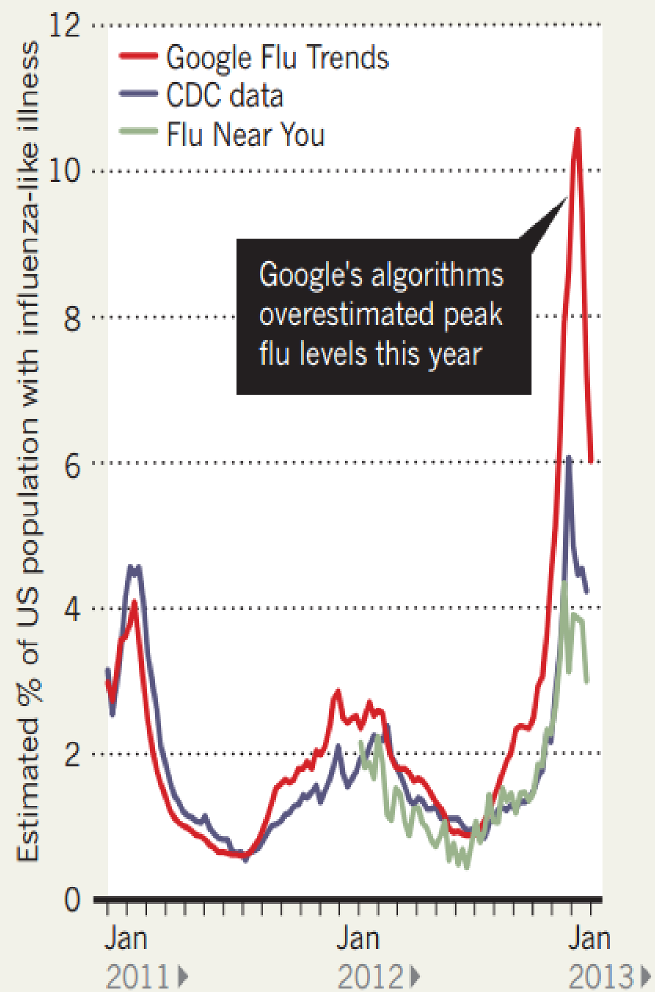
"It is hard to think today that one can provide disease surveillance without existing systems," says Alain-Jacques Valleron, an epidemiologist at the Pierre and Marie Curie University in Paris, and founder of France's Sentinelles monitoring network. "The new systems depend too much on old existing ones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

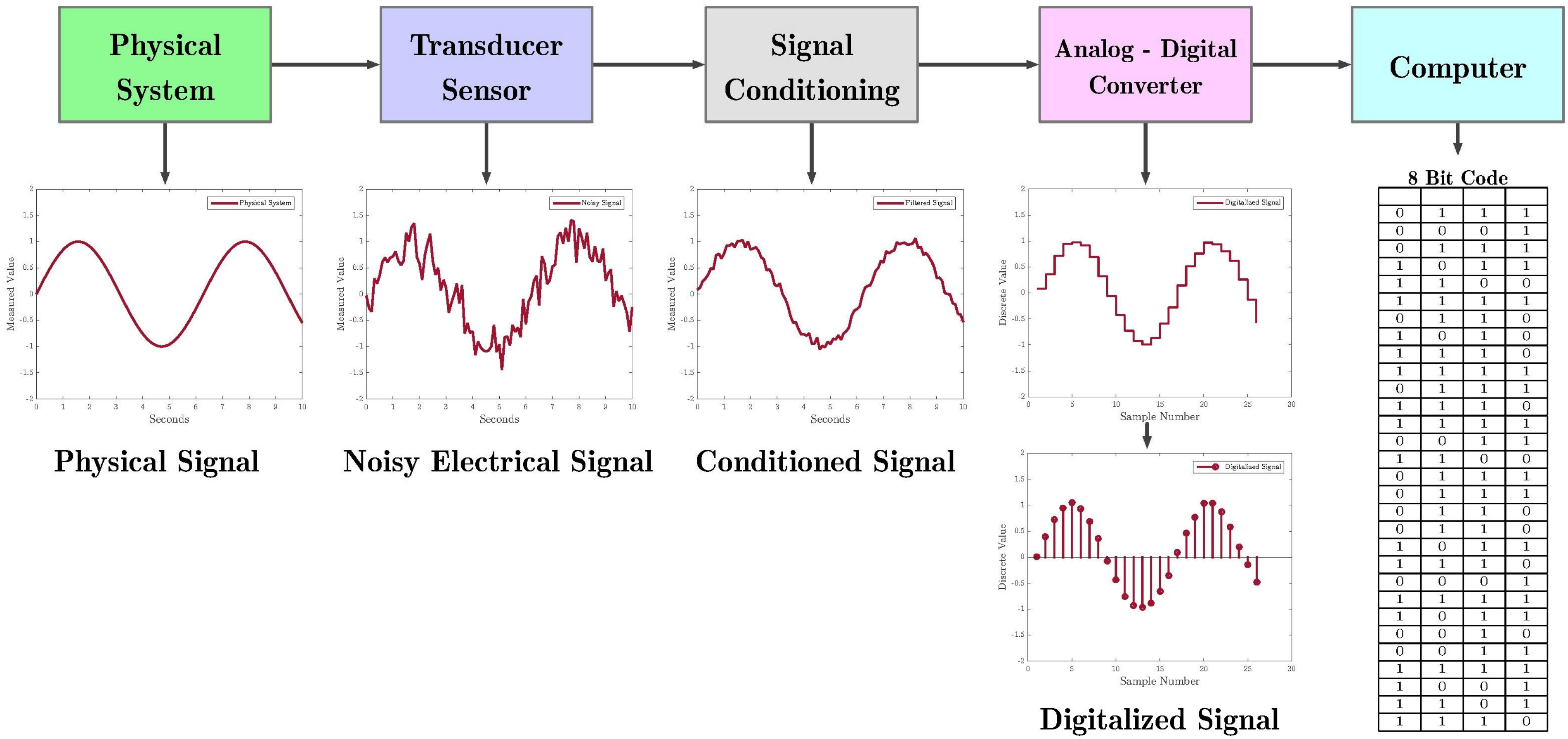


# Without context, syntax is oblivious of semantics



1997

# Digital Data Acquisition System

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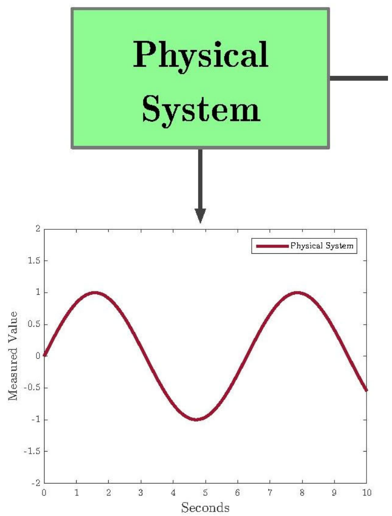
Analog signals are continuous.
Digital signals are discrete.

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

# 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.

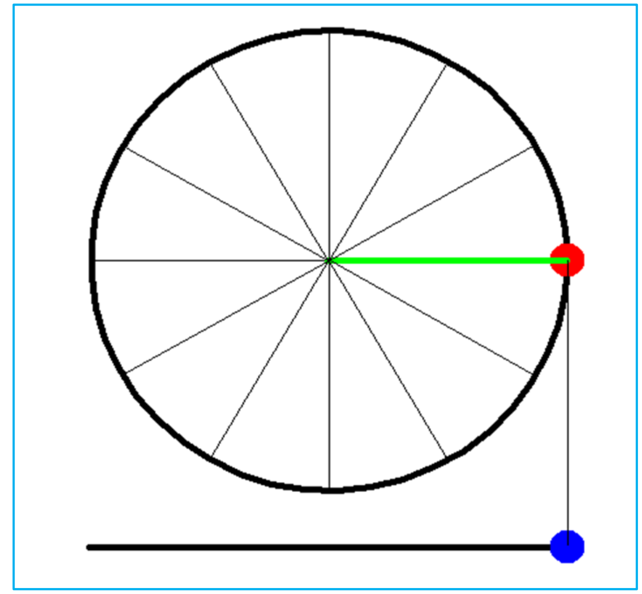
Representation of a signal as a plot of amplitude vs time constitutes the

# waveform

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

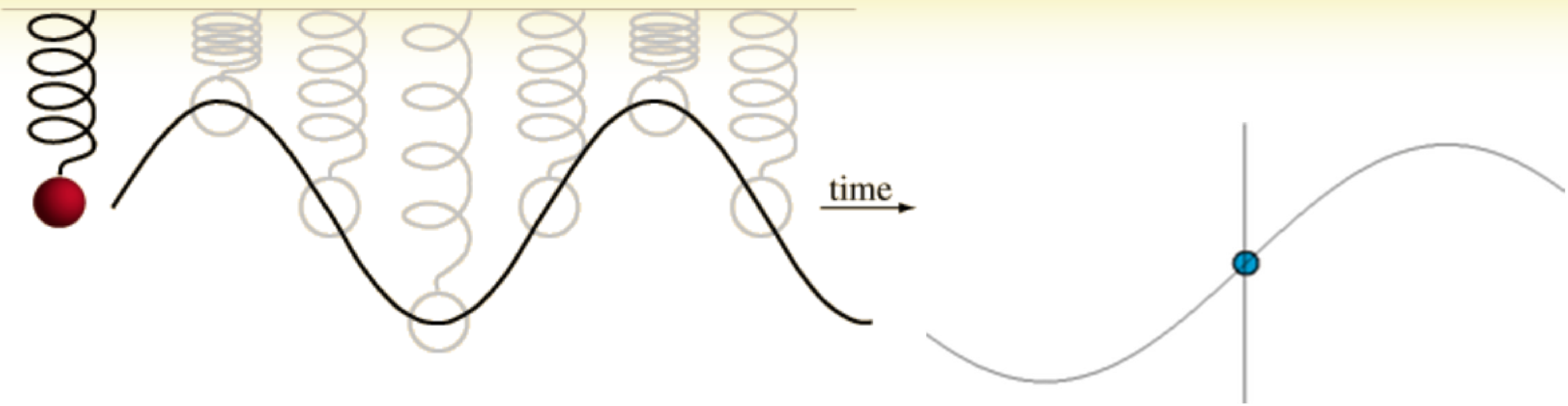
Uniform Circular Motion
(radius A, angular velocity ω)

Simple Harmonic Motion
(amplitude A, angular frequency ω)

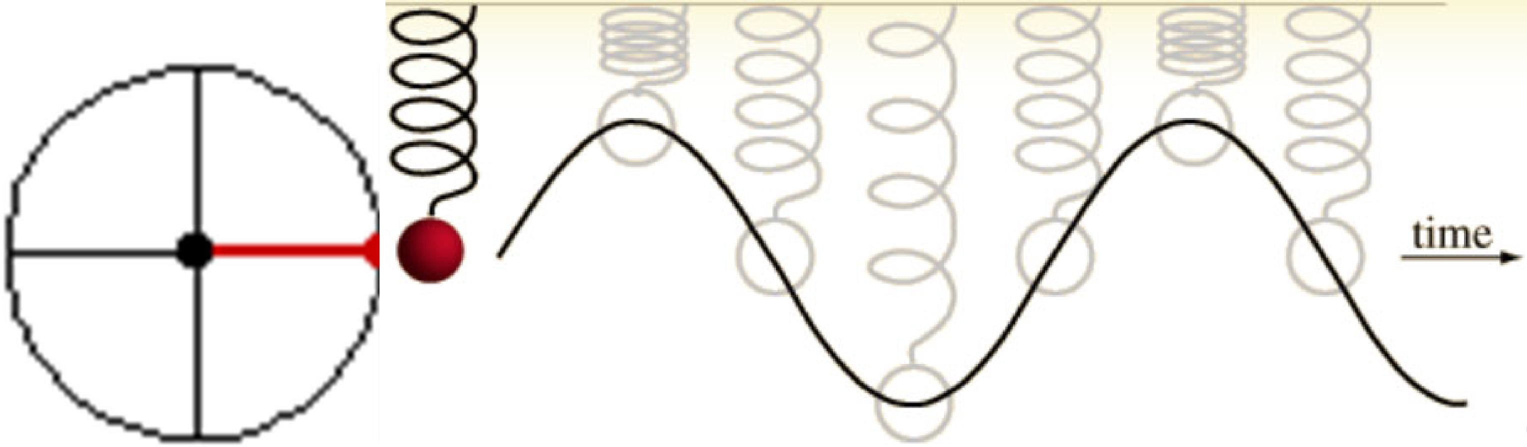


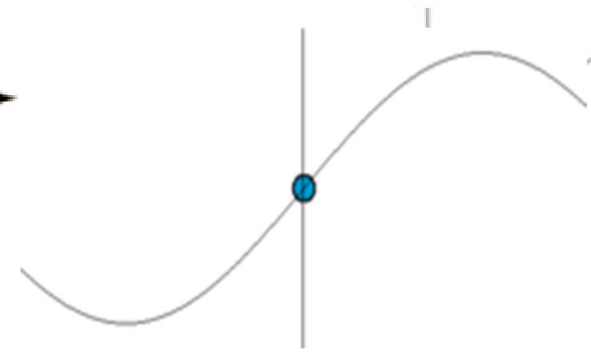
labman.phys.utk.edu/phys221core/modules/m11/harmonic_motion.html

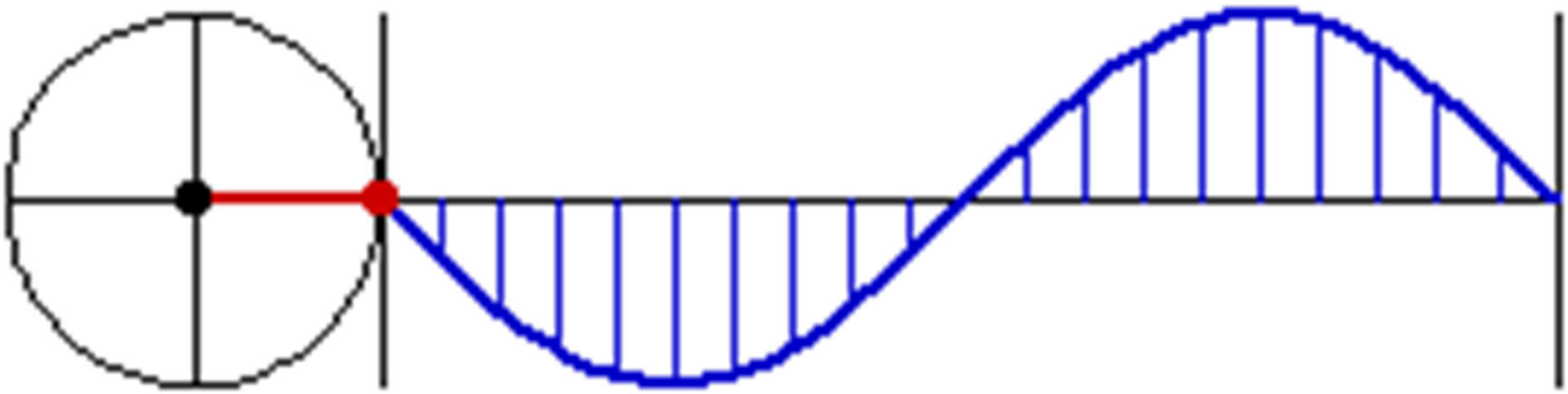
## Harmonic motion



# 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]**

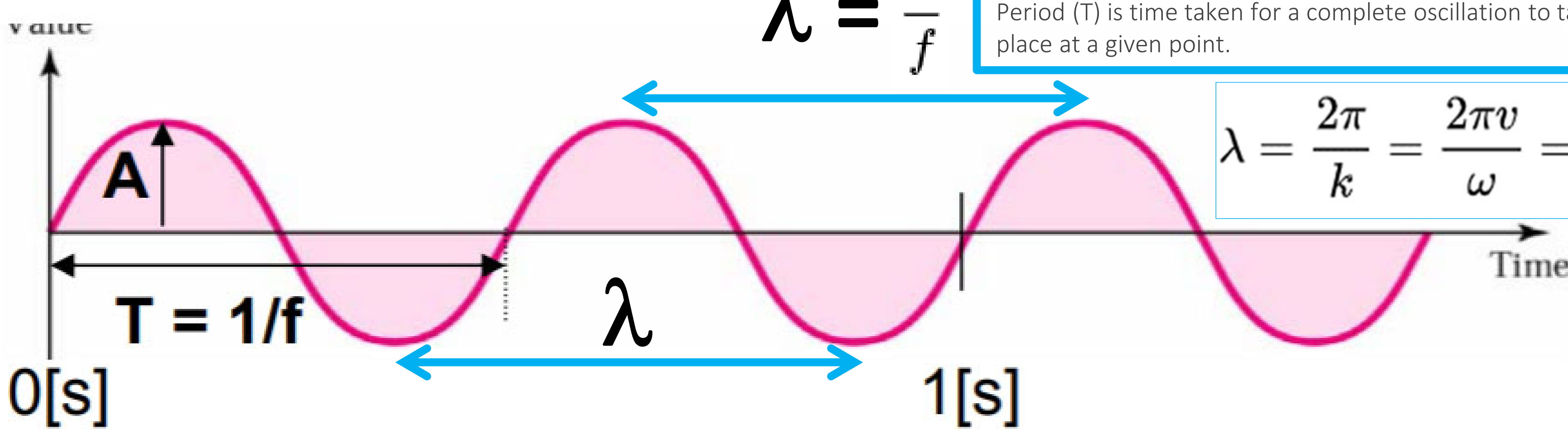
**(1.2)** **frequency** **(f) – number of periods in one second – unit: hertz [Hz] = [1/s] – inverse of period (T)!**

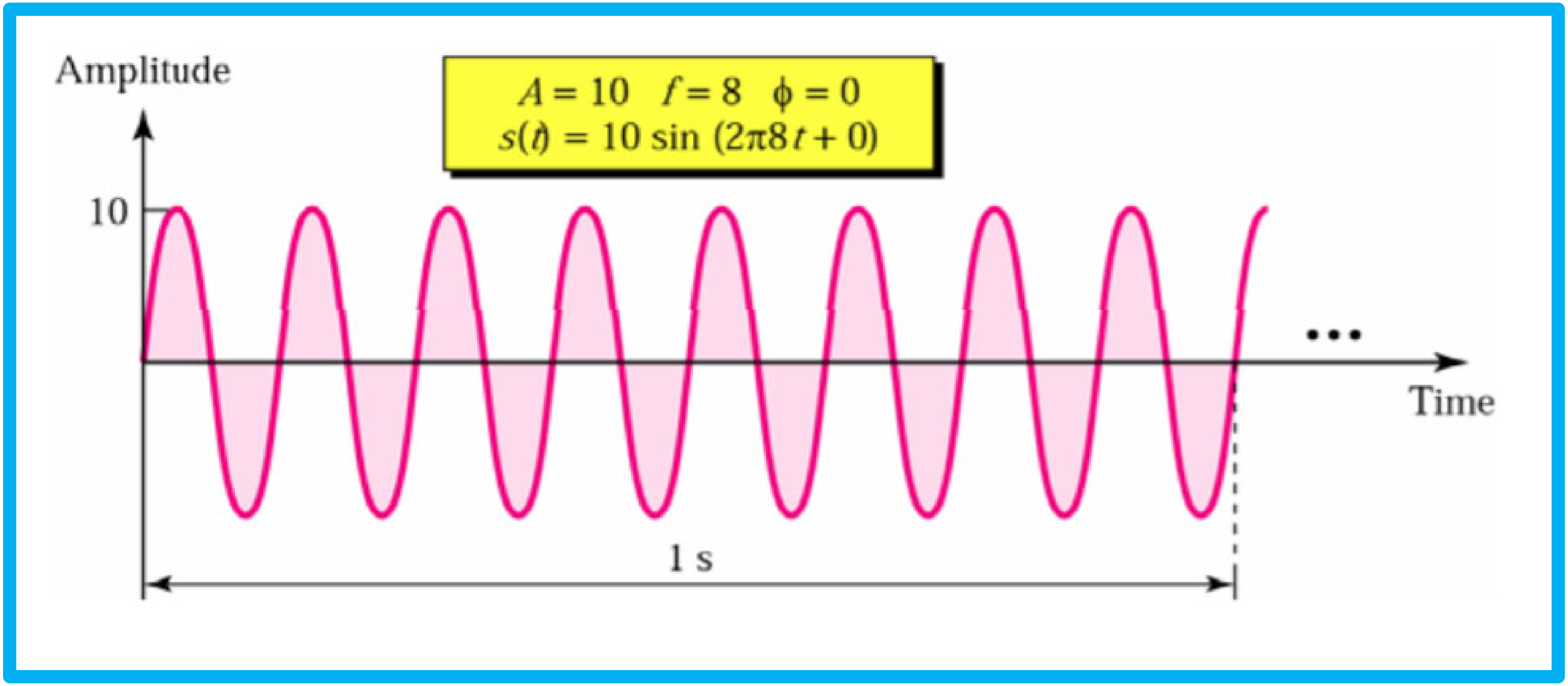
**(1.3)** **phase** **($\varphi$) – absolute position of the waveform relative to an arbitrary origin – unit: degrees [º] or radians [rad]**

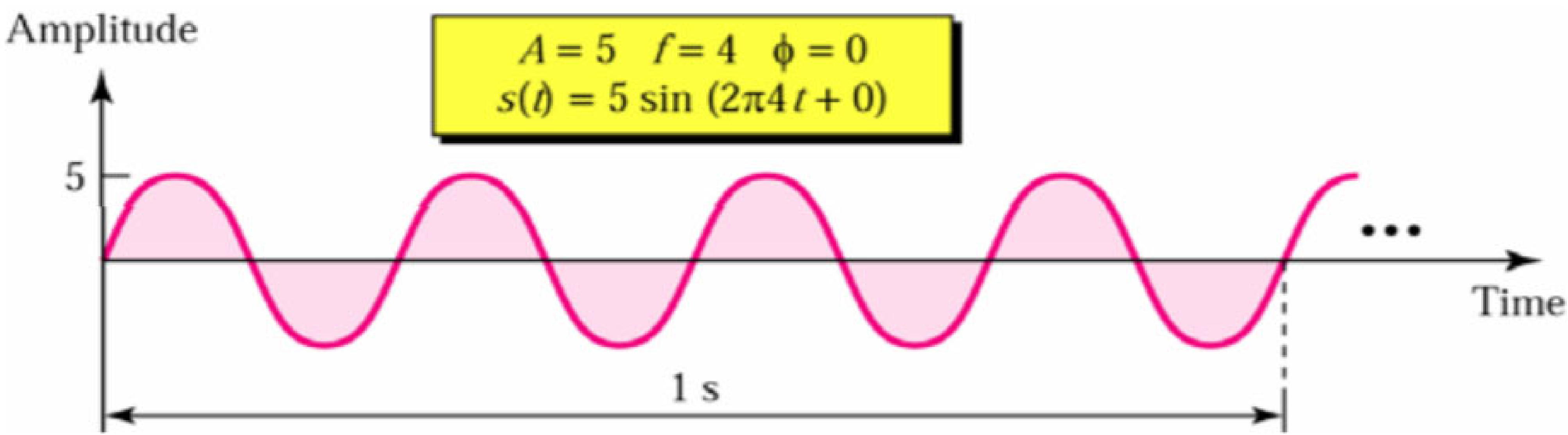
$$\lambda = \frac{v}{f}$$

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

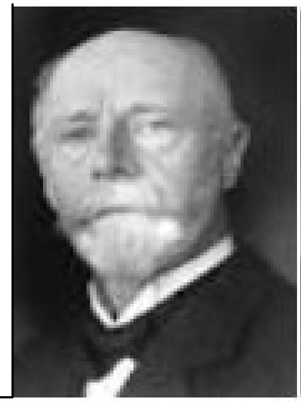

Amplitude
A = 5 f = 4 ϕ = 0
s(t) = 5 sin (2π4t + 0)
5
Time
1 s

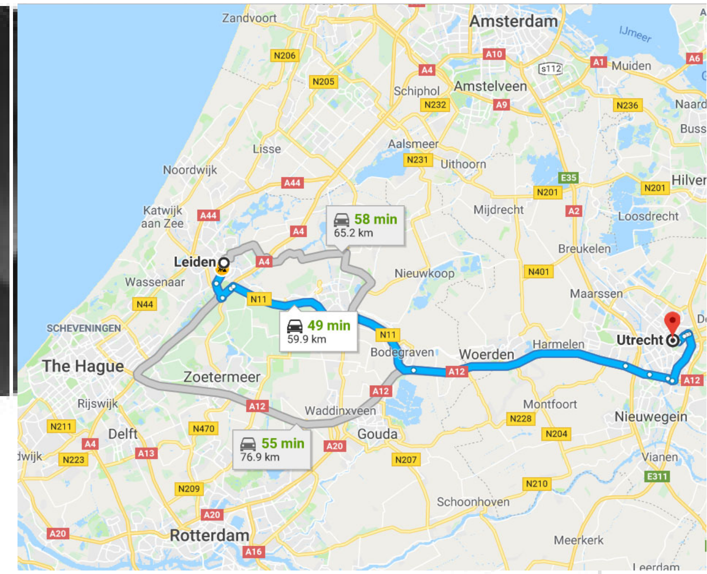
# Waveform data acquisition and understanding the information in data

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

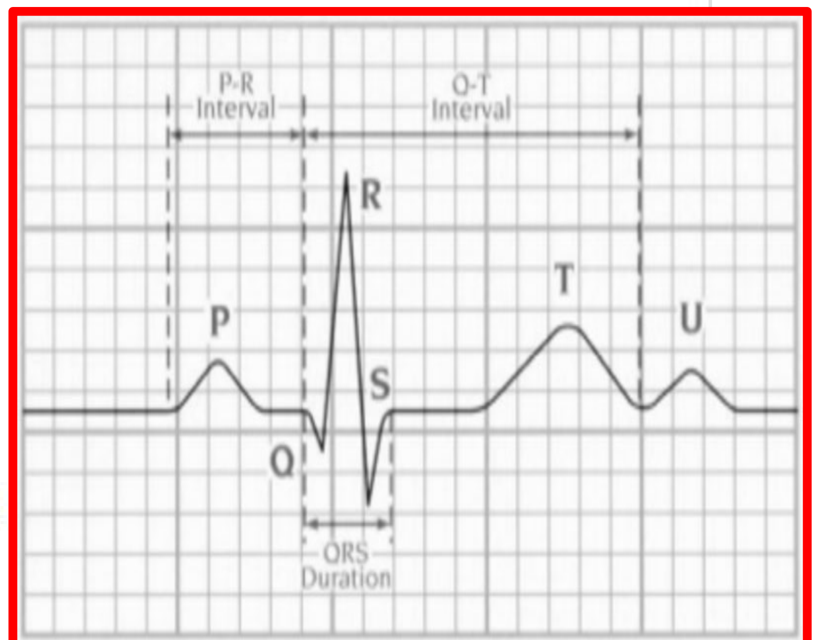
**Died:** September 29, 1927, Leiden, Netherlands

**Known for:** Electrocardiography

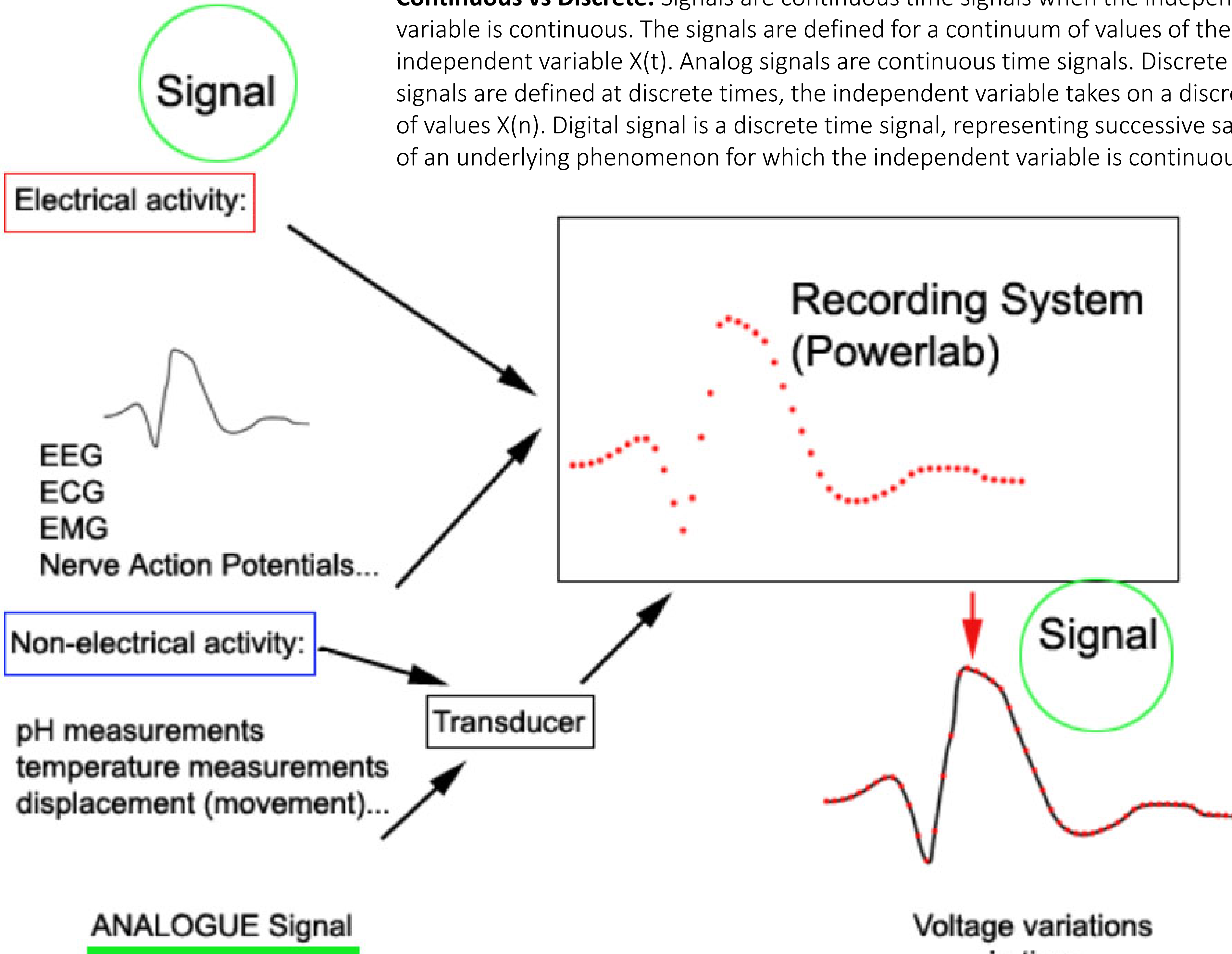
**Education:** Utrecht University

**Parents:** Jacob Einthoven, Louise Marie Mathilde

**Awards:** Nobel Prize in Physiology or Medicine



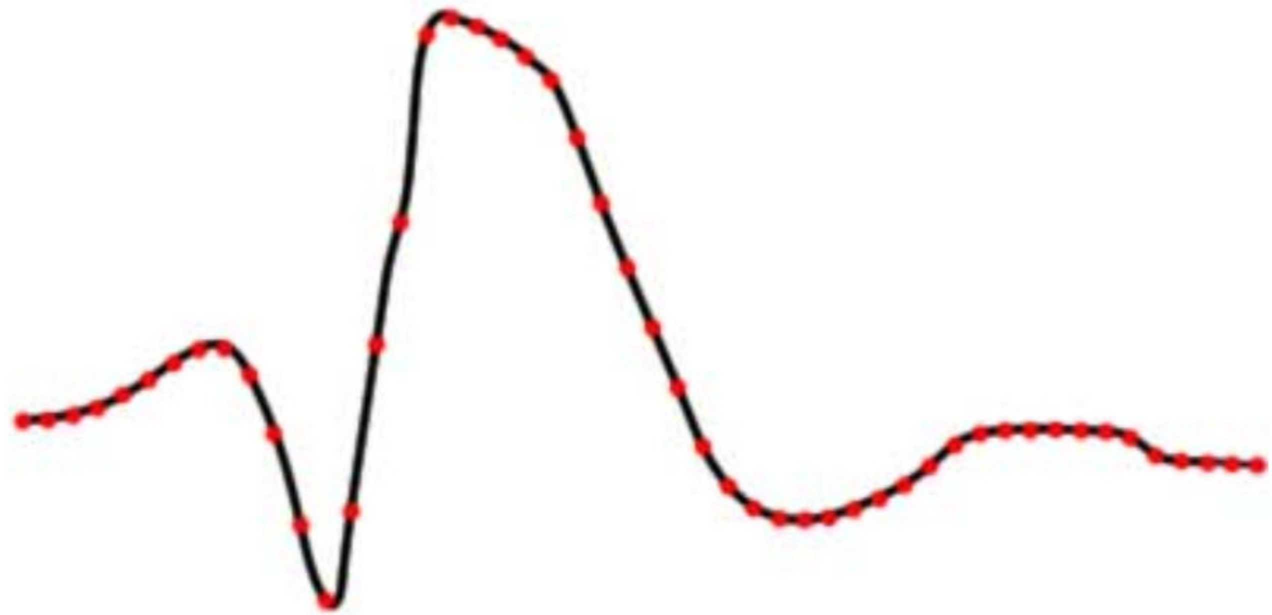
**Continuous vs Discrete:** Signals are continuous time signals when the independent variable is continuous. The signals are defined for a continuum of values of the independent variable X(t). Analog signals are continuous time signals. Discrete time signals are defined at discrete times, the independent 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.

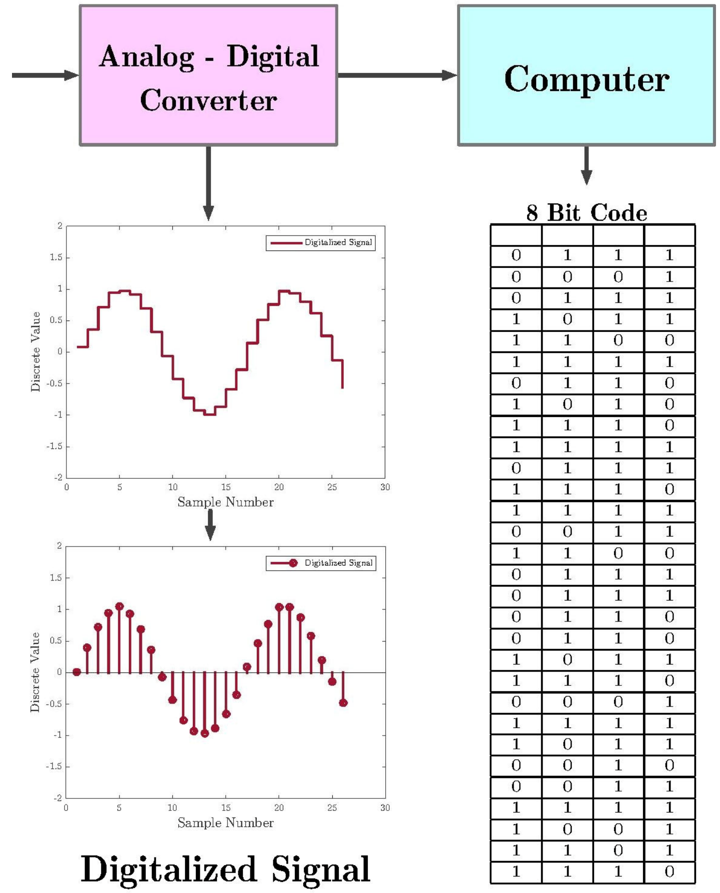


The electronic circuit that carries out the process of sampling the signal and A/D conversion is called an analogue-to-digital converter (ADC). Being an electronic device, it requires an electrical signal at its input. Thus the first step in the process of A/D conversion is to convert the analogue (non-voltage) 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 |
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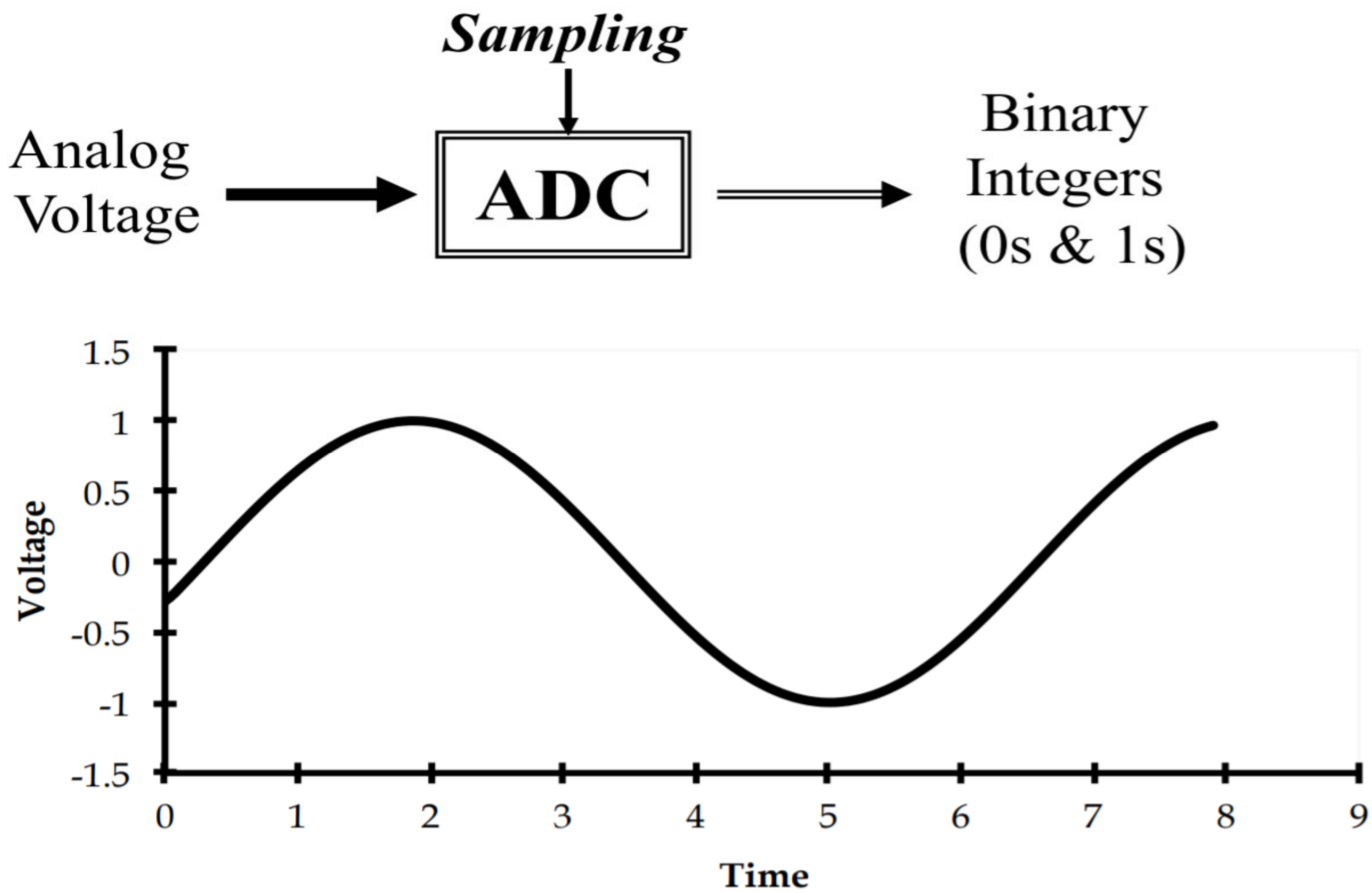
Analog signals are continuous.
Digital signals are discrete.

# ADC

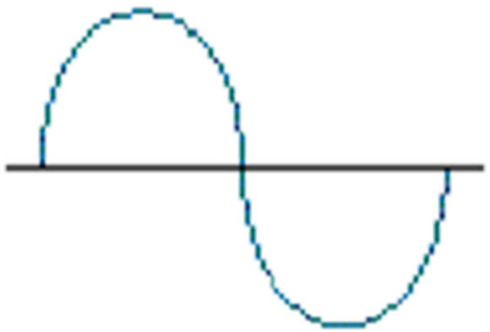
converts analog voltages to binary



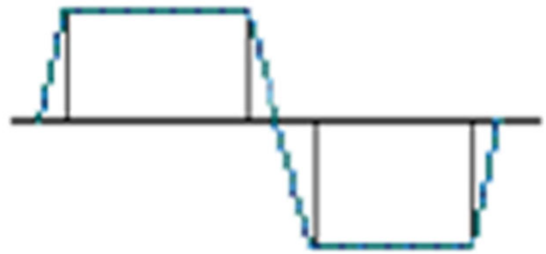

https://link-springer-com.libproxy.mit.edu/content/pdf/10.1007%2F978-3-319-44971-5.pdf

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.

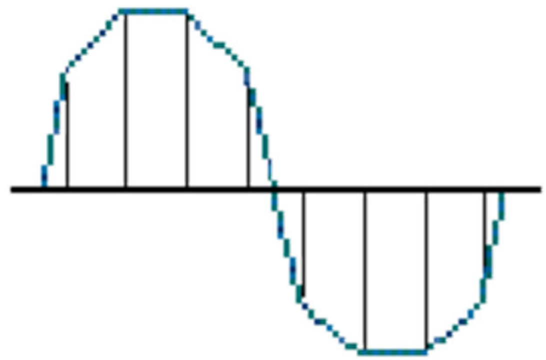
# A/D Converter ◆ Sampling Rate



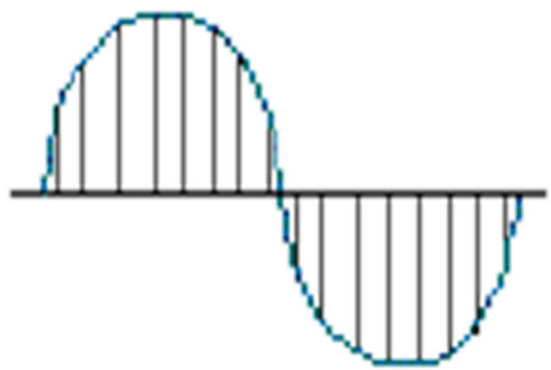
Analog Input



4 samples/cycle



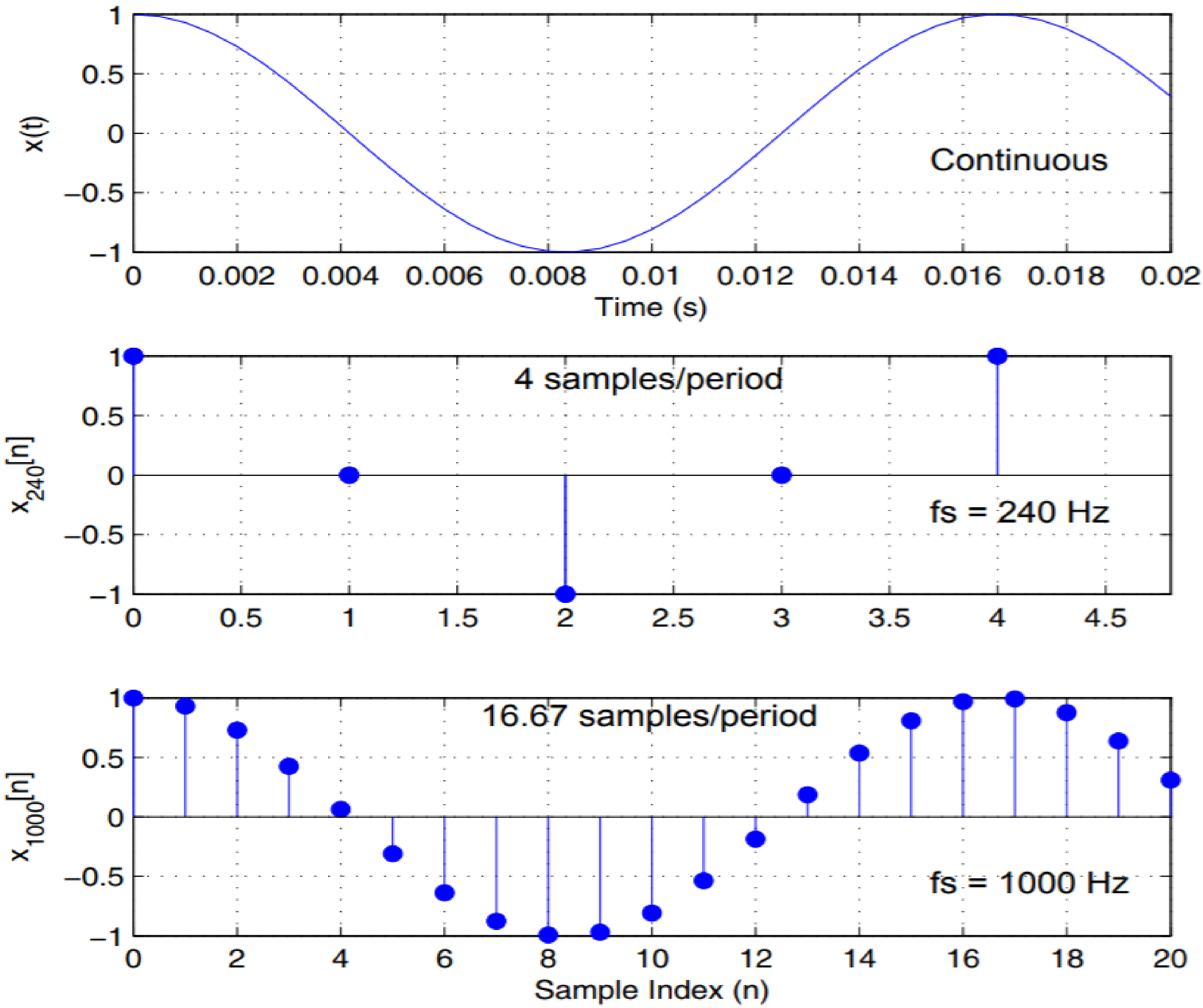
8 samples/cycle



16 samples/cycle

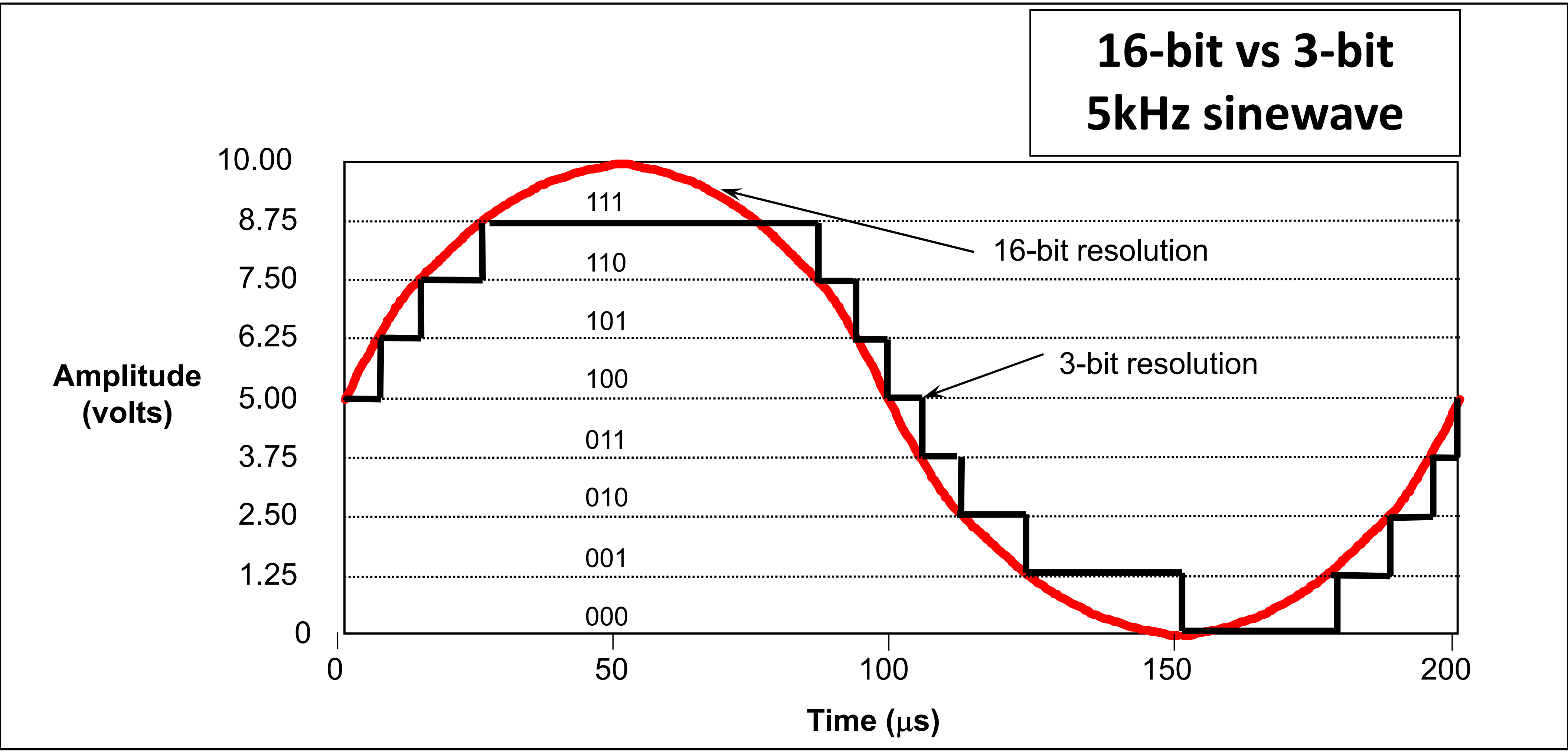
Sampling rate: the speed at which ADC converts the input signal to digital values. Digitizer samples signal after attenuation, gain, and/or filtering has been applied by analog input path, and converts resulting waveform to digital. The sampling rate is based on the sample clock that controls when the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

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



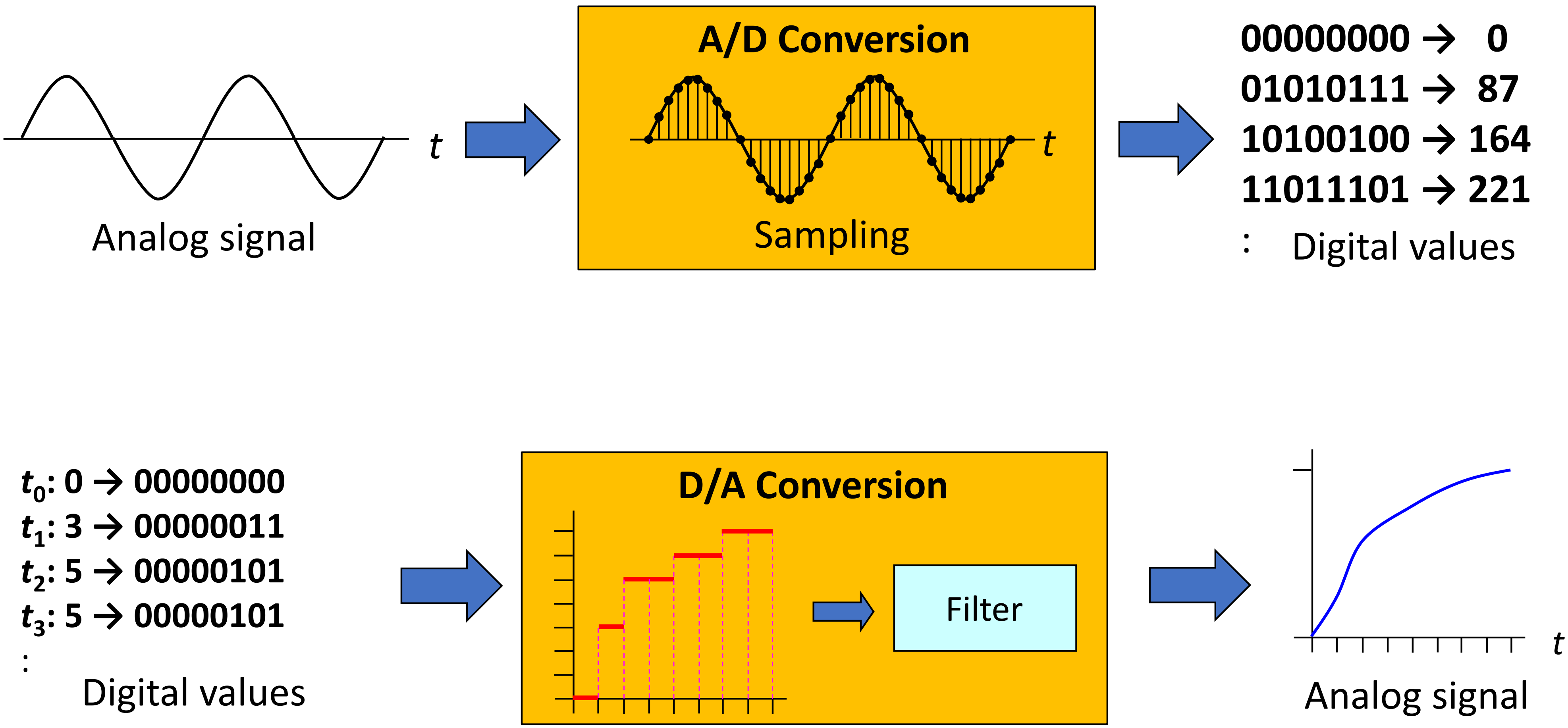
x(t)
1
0.5
0
−0.5
−1
0
0.002
0.004
0.006
0.008
0.01
0.012
0.014
0.016
0.018
0.02
Time (s)
Continuous
x240[n]
4 samples/period
fs = 240 Hz
0.5
1
1.5
2
2.5
3
3.5
4
4.5
x1000[n]
16.67 samples/period
fs = 1000 Hz
2
4
6
8
10
12
14
16
18
20
Sample Index (n)

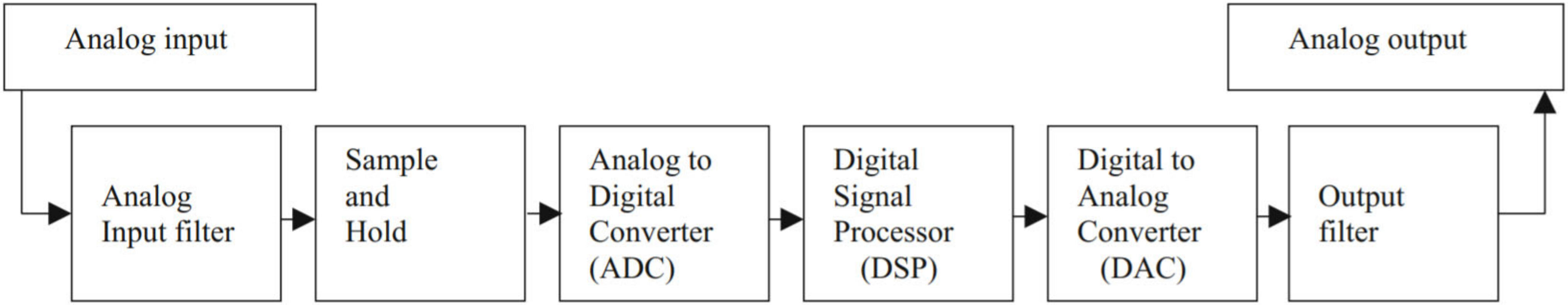
# RESOLUTION

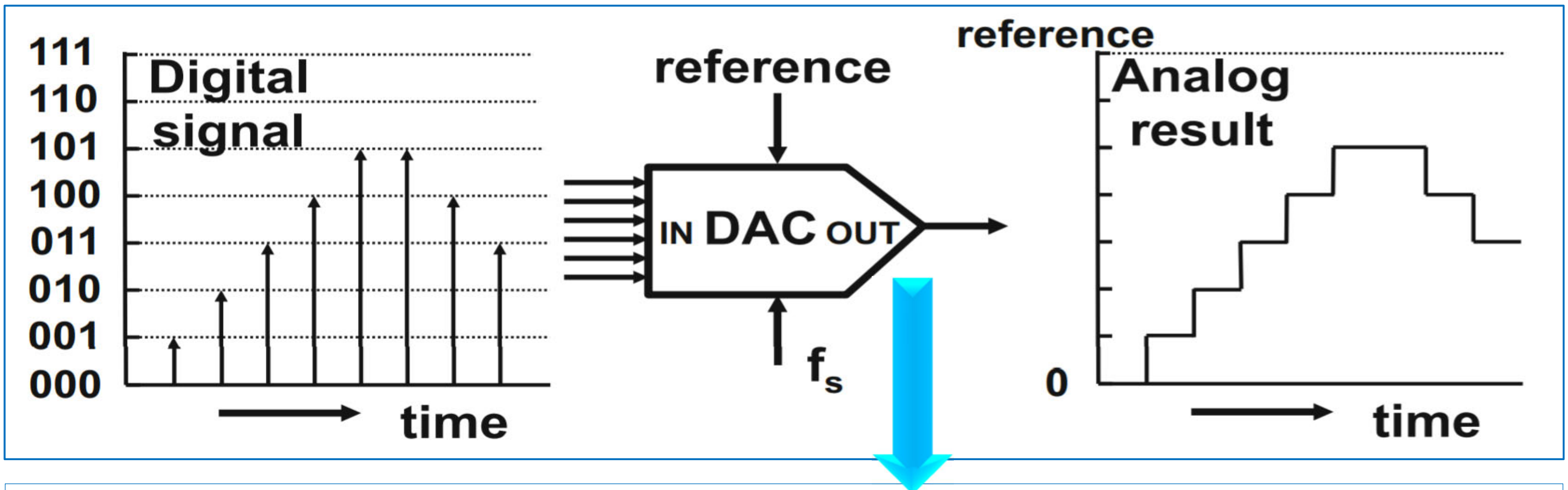


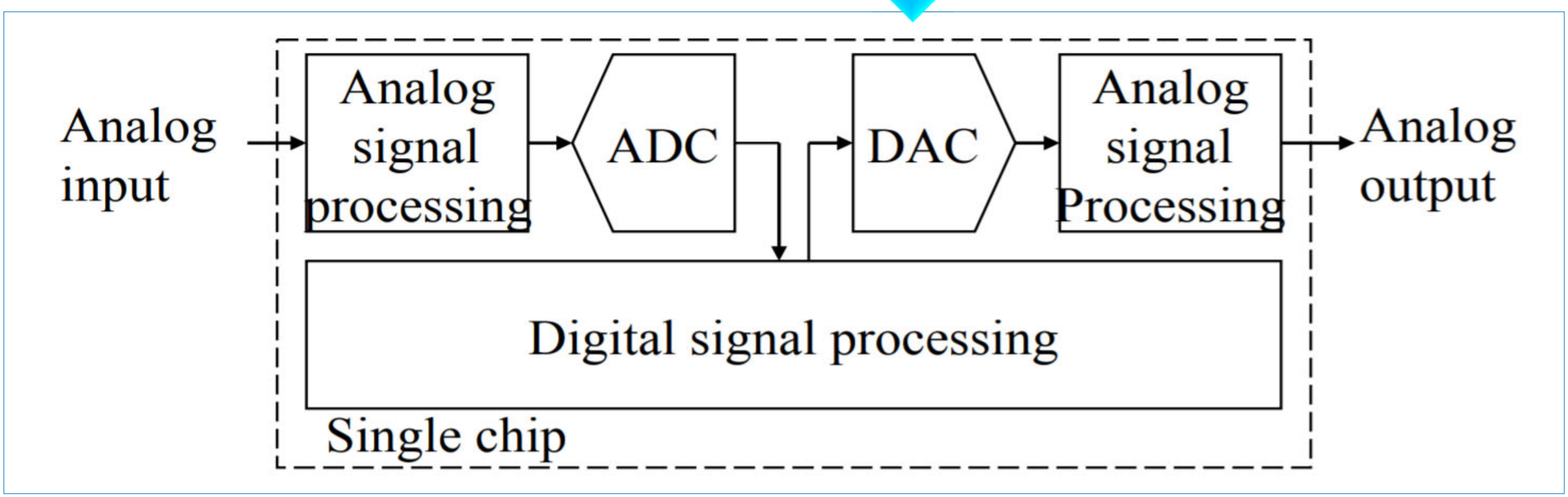

3-bit ADC can represent $2^3$=8 and 16-bit ADC can represent $2^{16}$=65,536 discrete voltage levels. 3-bit resolution looks like a step function. Resolution is a fixed quantity of an ADC. DAQ devices generally have 8-bit, 12-bit or 16-bit resolution.

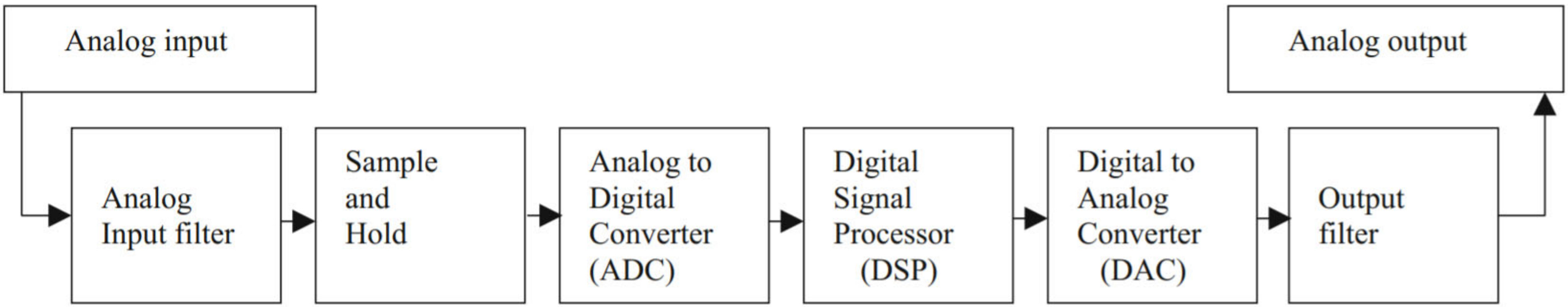
# Digital Signal Processing



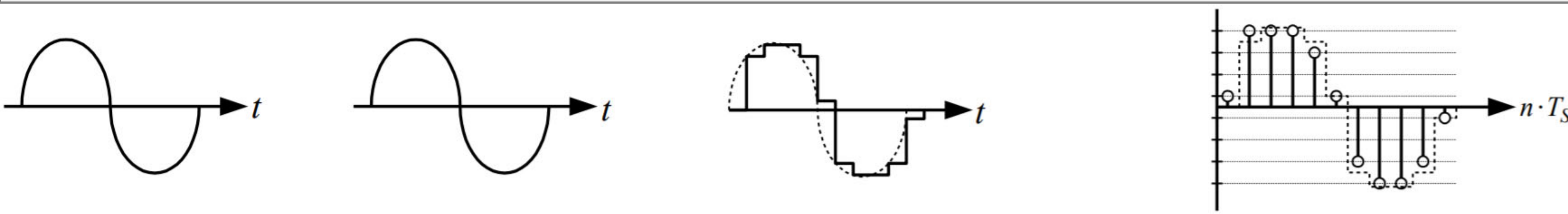

Analog input
Analog output
Analog
Input filter
Sample
and
Hold
Analog to
Digital
Converter
(ADC)
Digital
Signal
Processor
(DSP)
Digital to
Analog
Converter
(DAC)
Output
filter

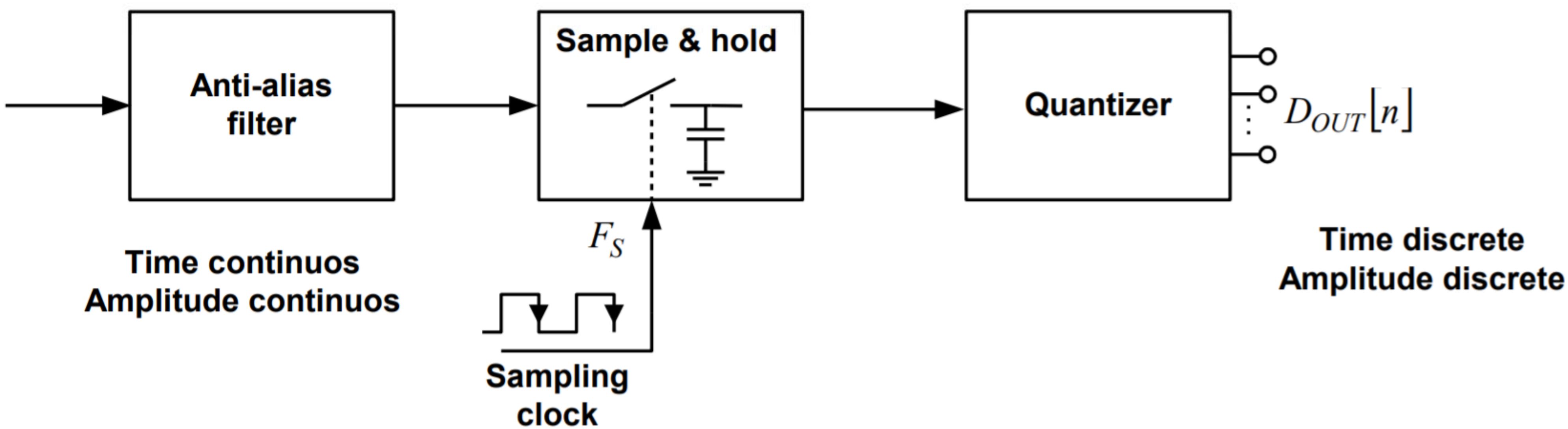

111
110
101
100
011
010
001
000
Digital
signal
time
reference
IN DAC OUT
fs
reference
Analog
result
0
time


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.*

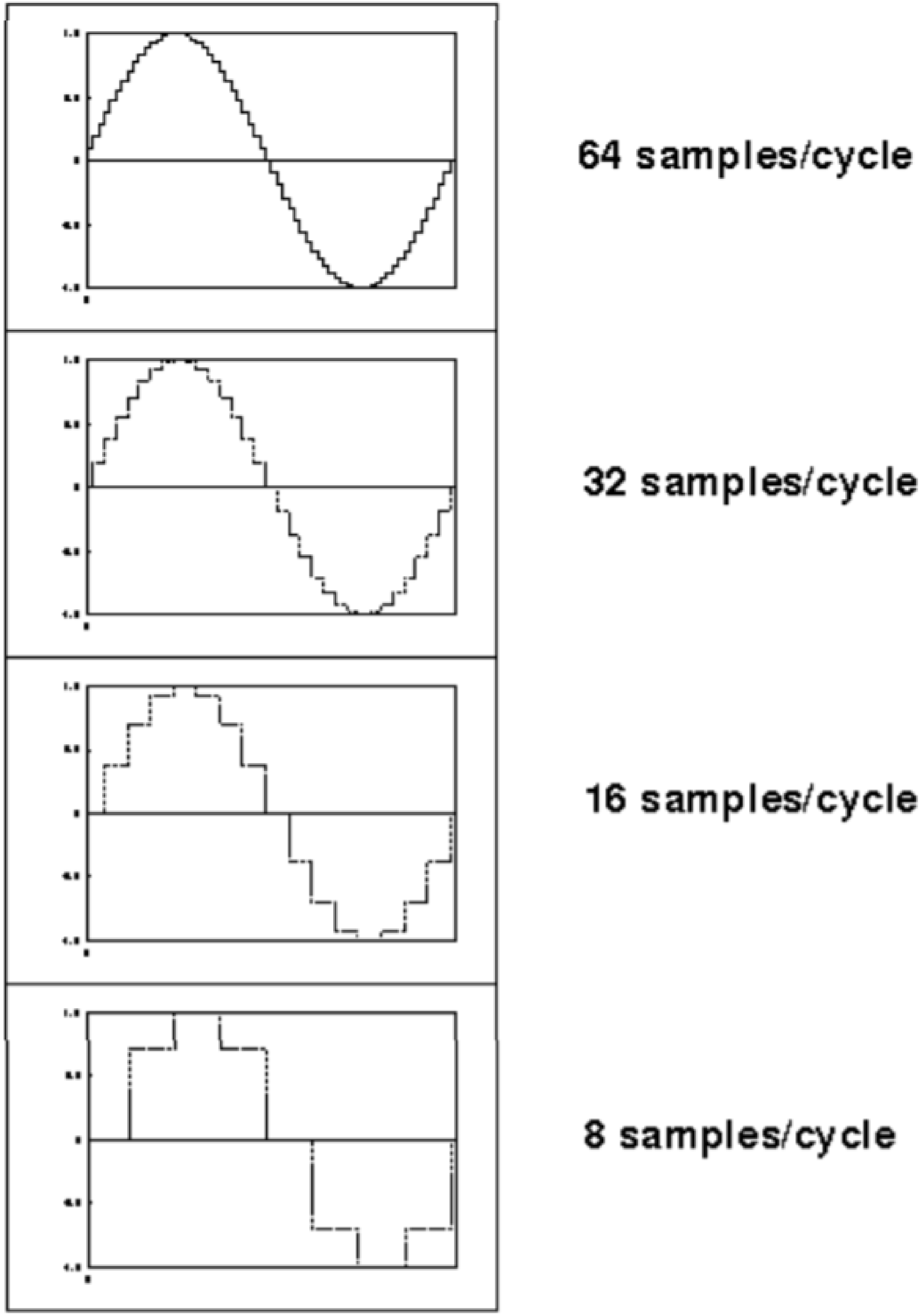
*A discussion is given of the minimum frequency range required for transmission at a given speed of signaling. In the case of carrier telegraphy, this discussion includes a comparison of single-sideband and double-sideband transmission. A number of incidental topics is also discussed.*

* * * * *

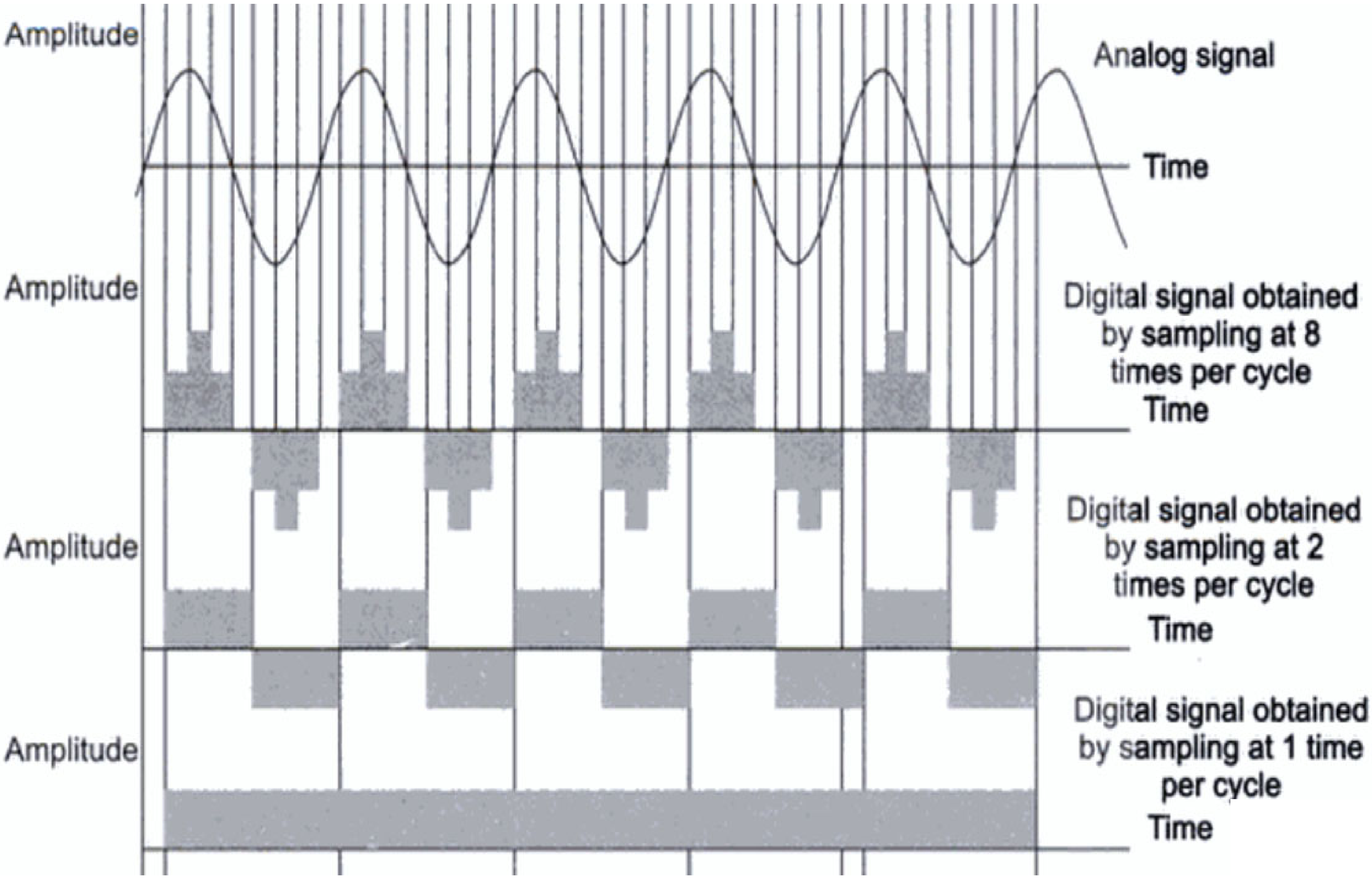
NYQUIST THEOREM – 1928 - NYQUIST PLOT

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



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

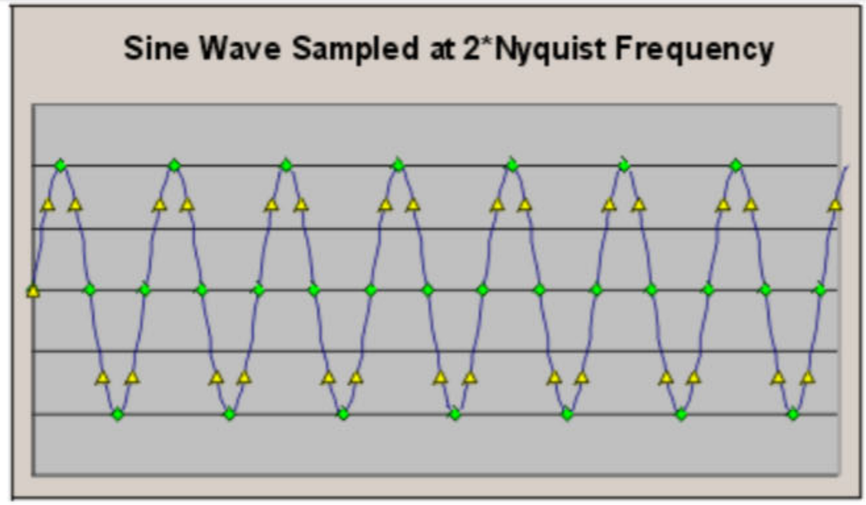
# Communication in the Presence of Noise*

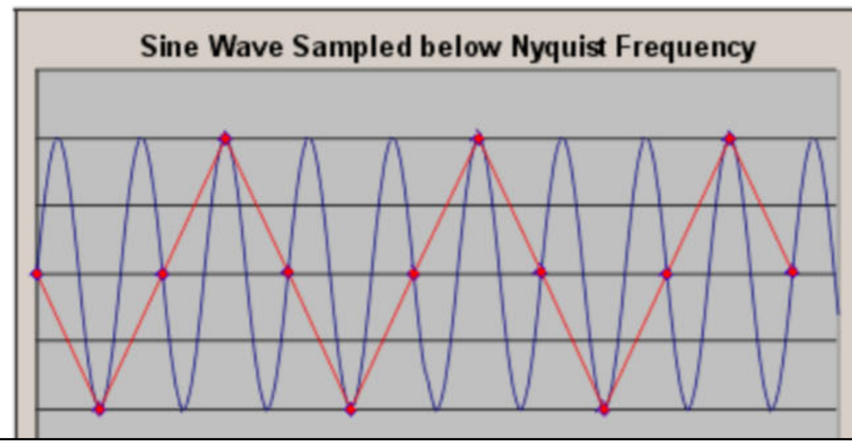
CLAUDE E. SHANNON†, MEMBER, IRE

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

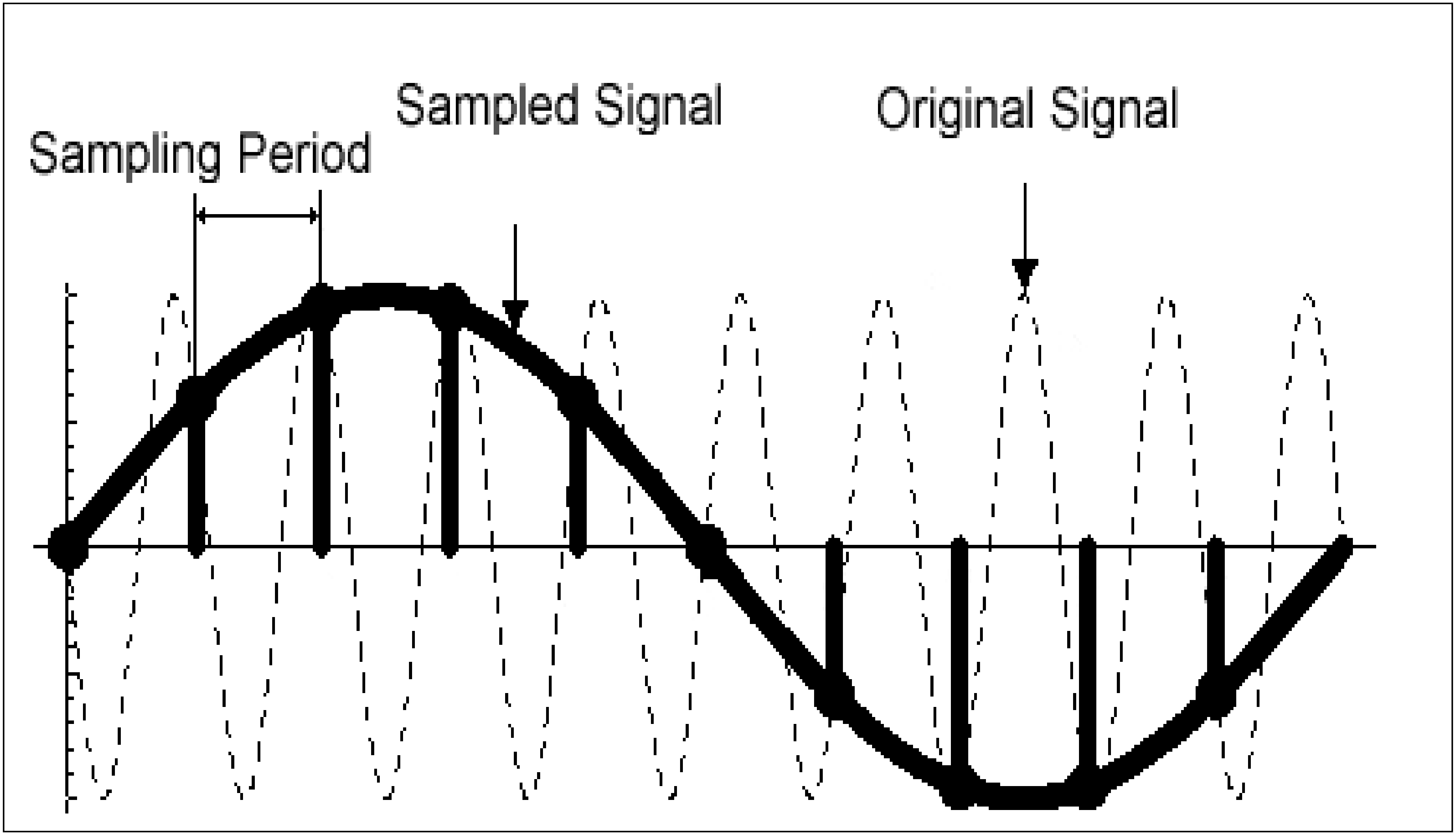



# THE SHANNON SAMPLING THEOREM (1940)

- Aliasing

  Signal distortion due to sampling rate



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

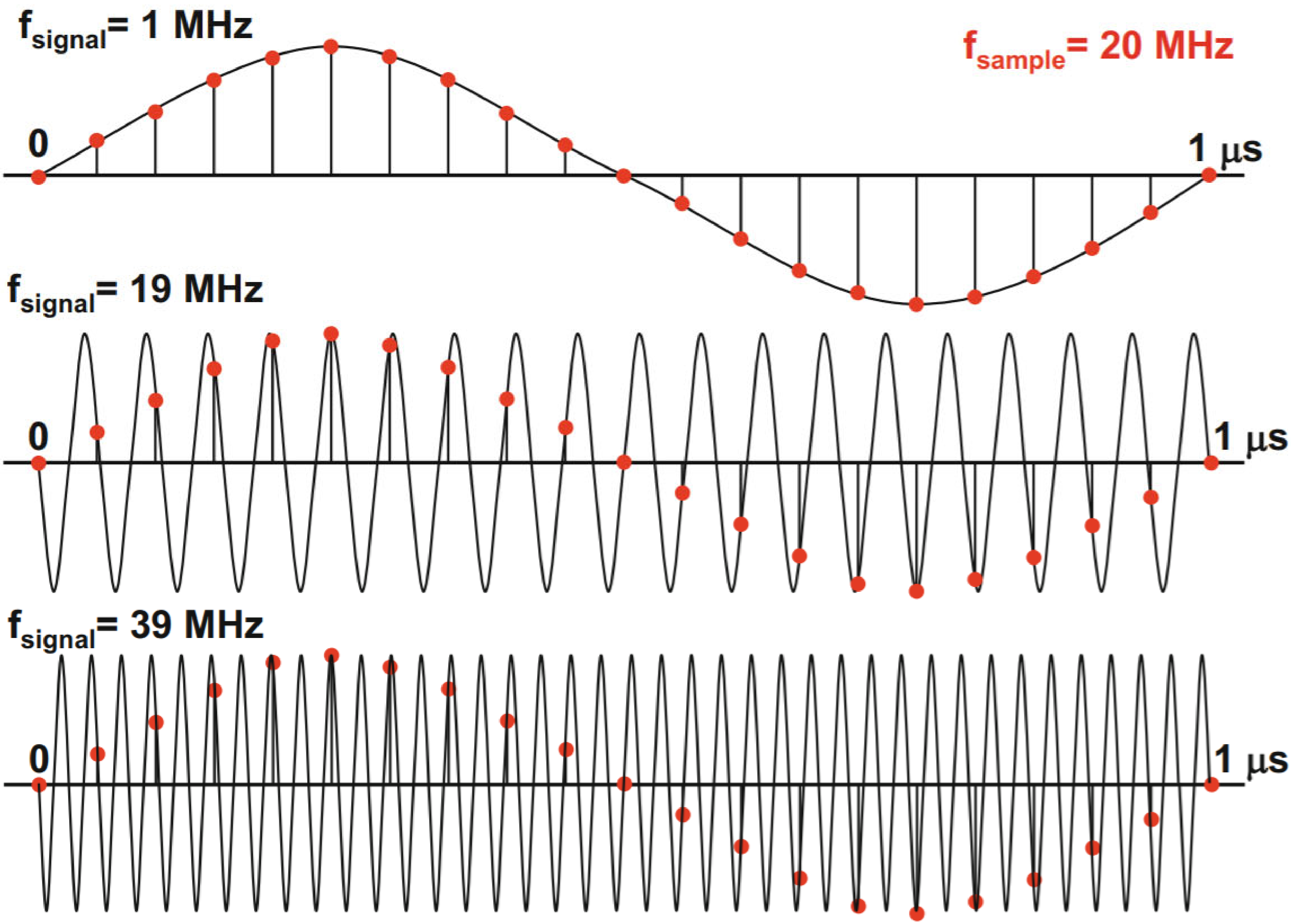
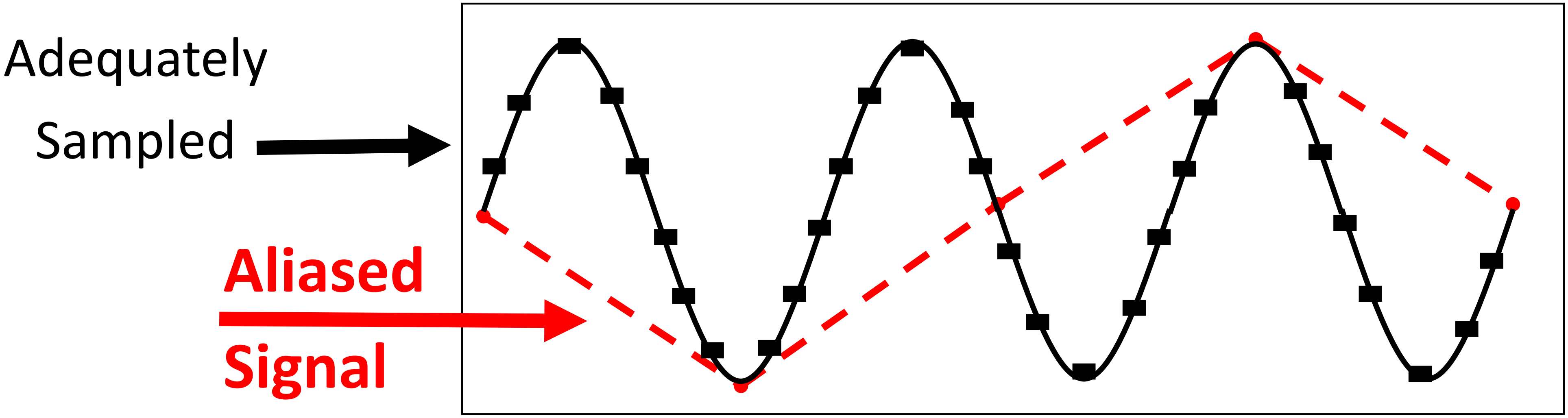
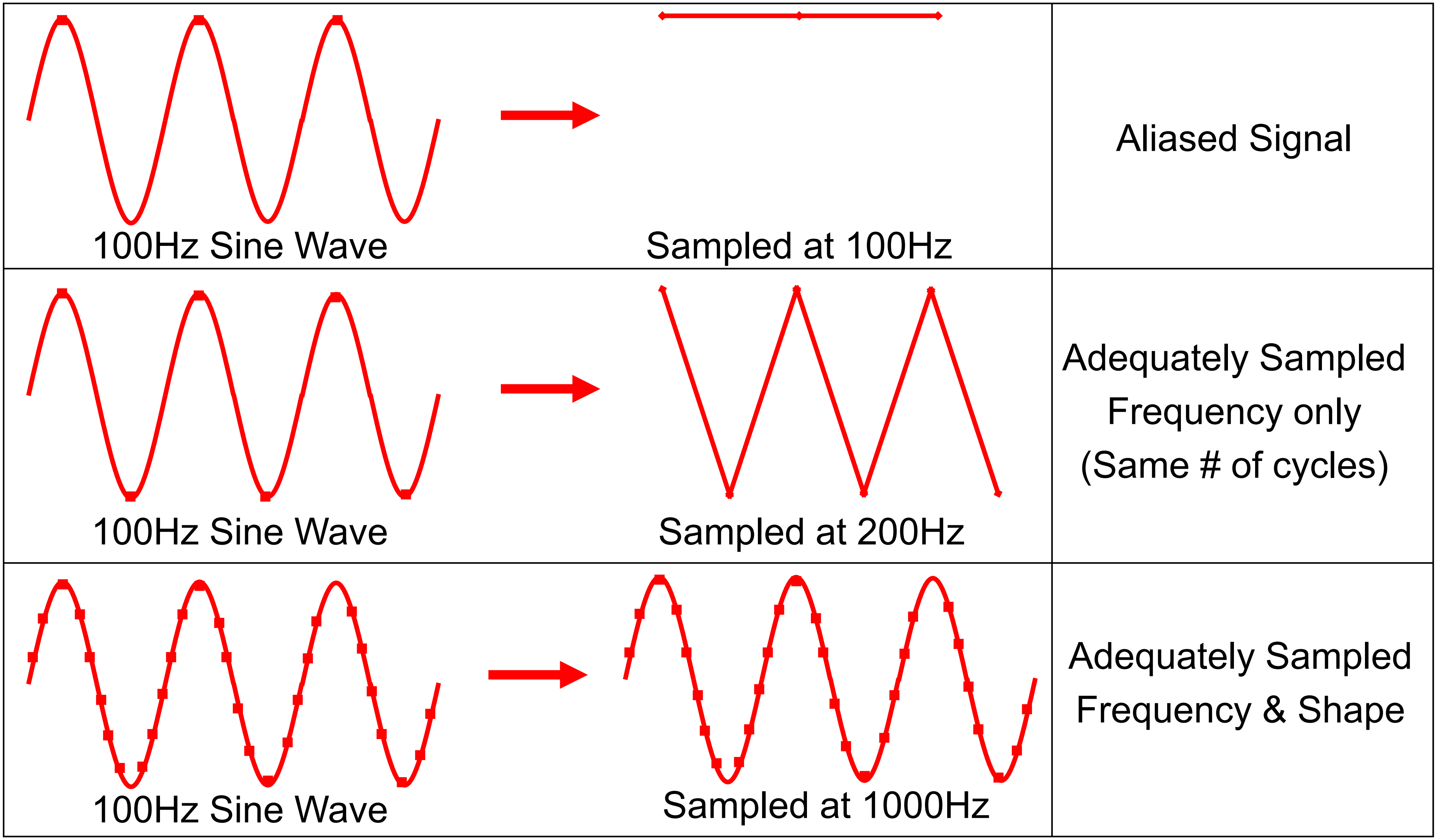



**Fig. 2.2** Sampling three time-continuous signals: 1, 19, and 39 MHz sine waves result after sampling with 20 Ms/s in the same sampled data sequence (*dots*) https://link-springer-com.libproxy.mit.edu/content/pdf/10.1007%2F978-3-319-44971-5.pdf

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**).

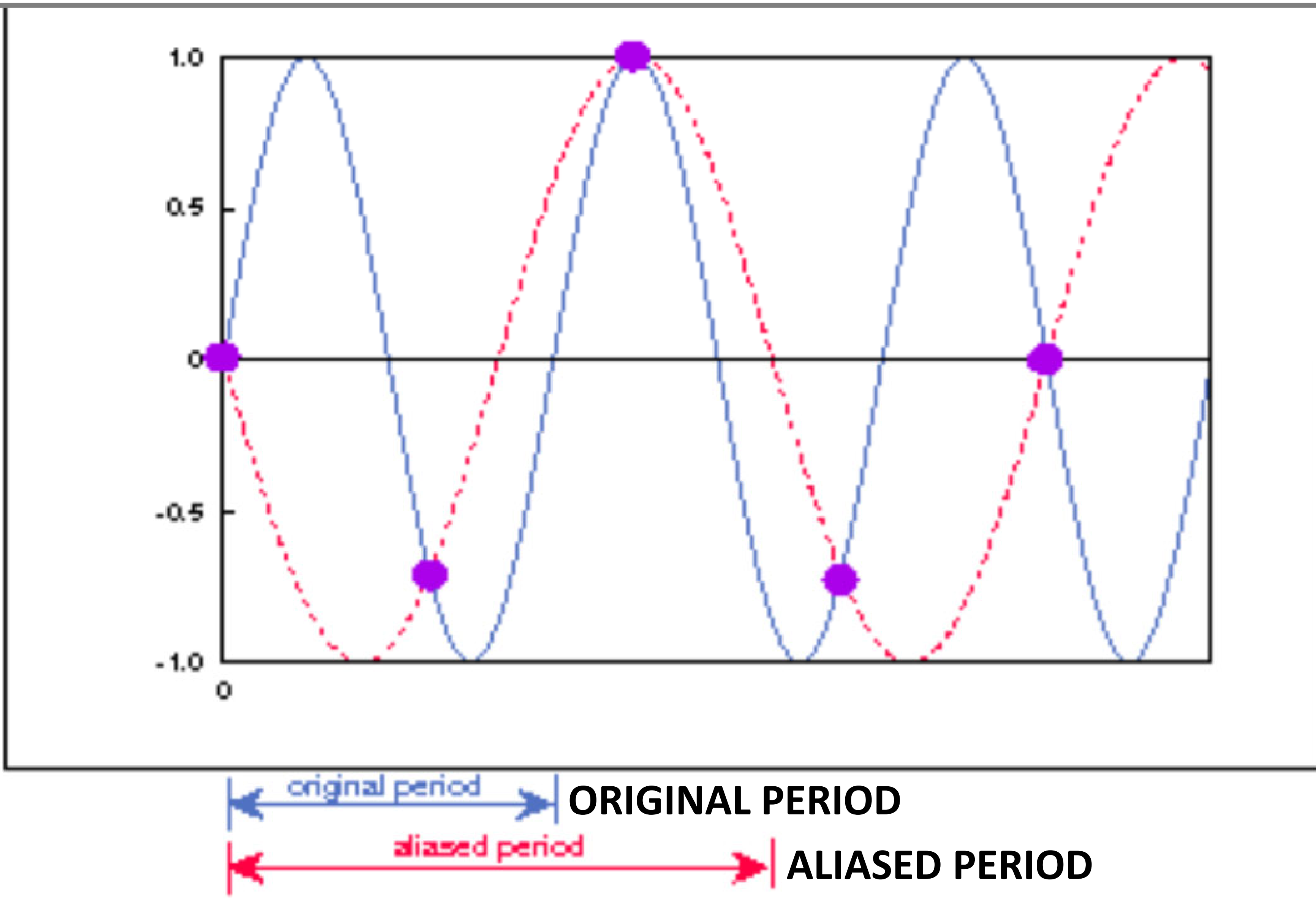



Sample >2 times max frequency of signal to represent FREQUENCY of signal (NYQUIST). Sample >5-10 times max frequency of signal to represent SHAPE of signal.

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

# NYQUIST THEOREM & ALIASING

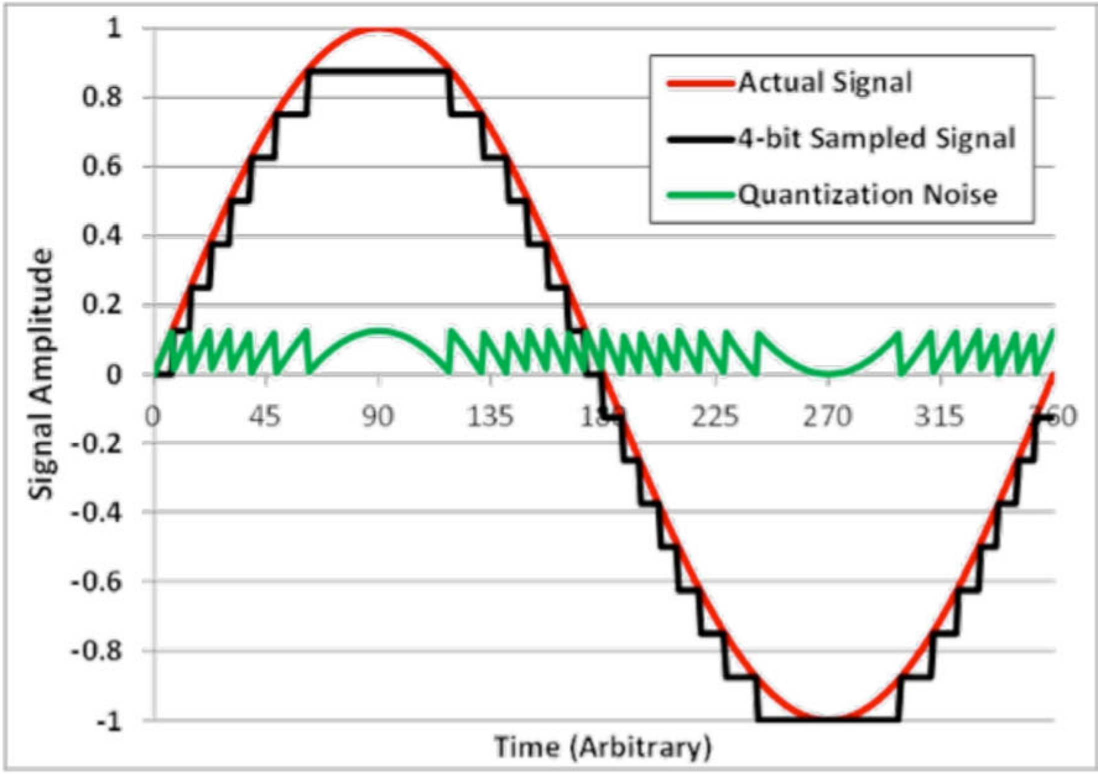
## Fitting a sine wave to sampled points gives an aliased waveform




**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



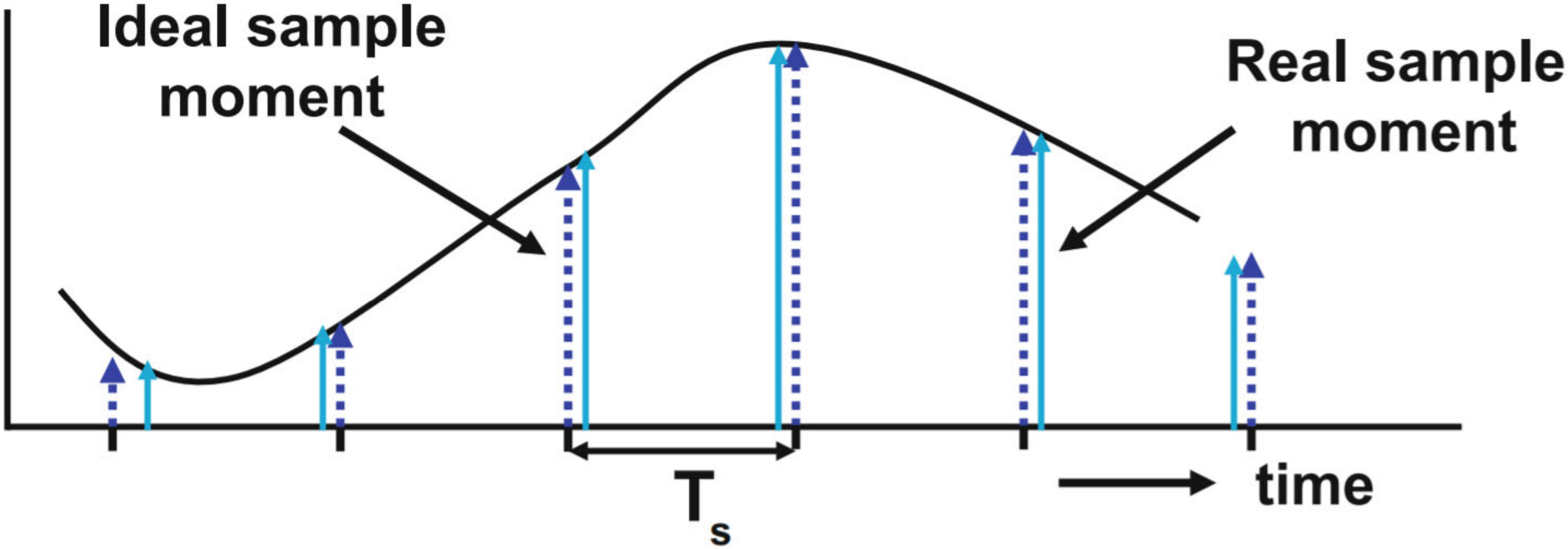


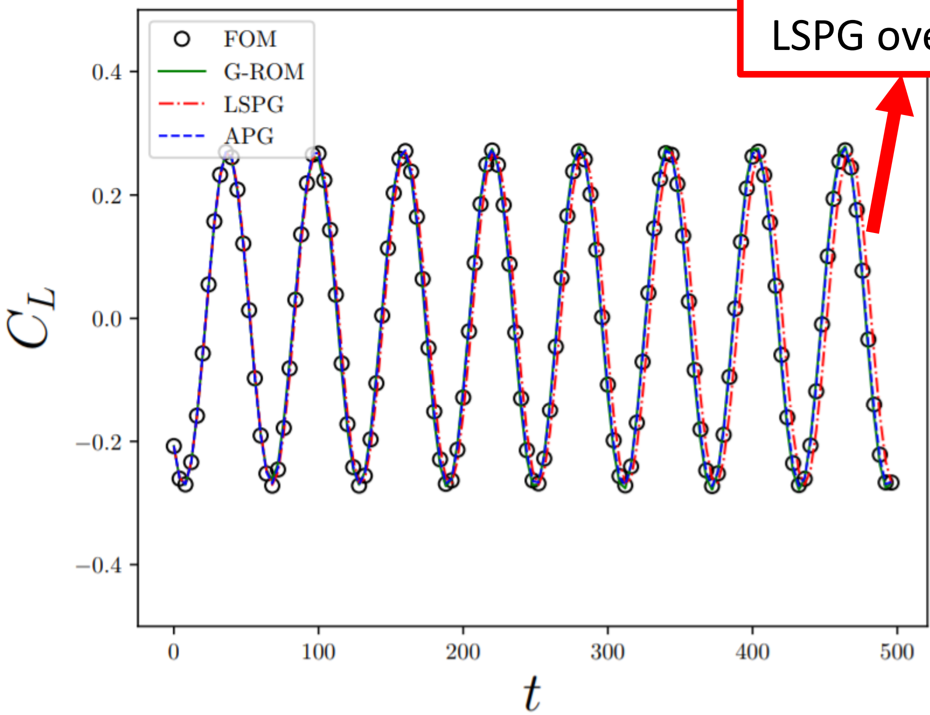

**Fig. 2.25** The ideal sampling moments (*dashed*) shift in an arbitrary fashion in time if the sample clock is disturbed by jitter

JITTER

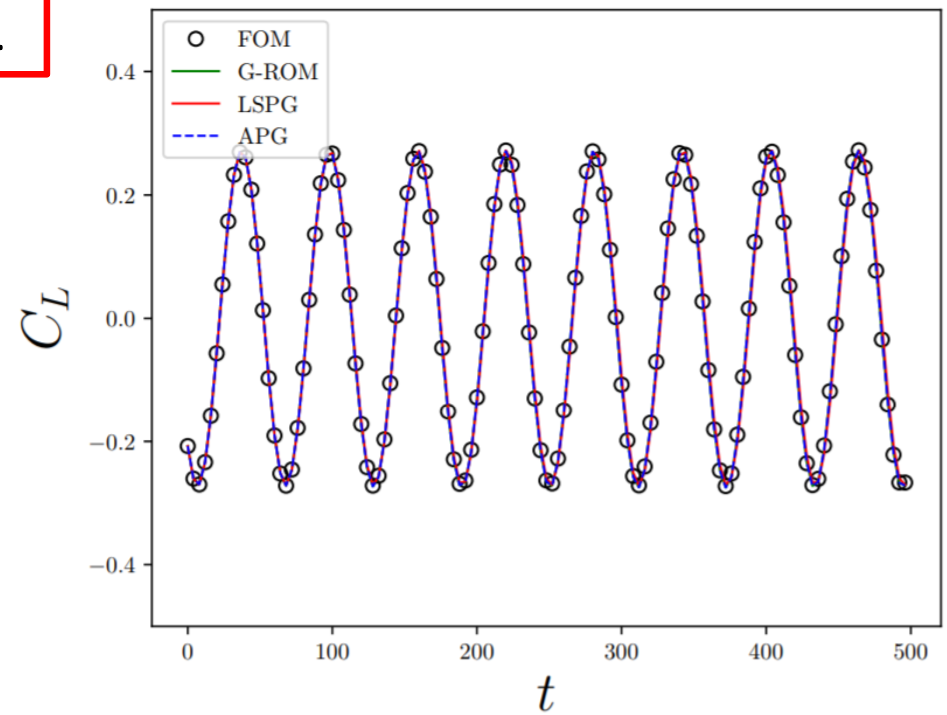
If noise changes the switching level of a buffer, the outgoing edge will have a varying delay with respect to the incoming edge. This effect is called: jitter. Jitter causes sample moments to shift from their position, and consequently the sampling circuit will sample the signal at another time moment. 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

Decreasing fit for LSPG over time.




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



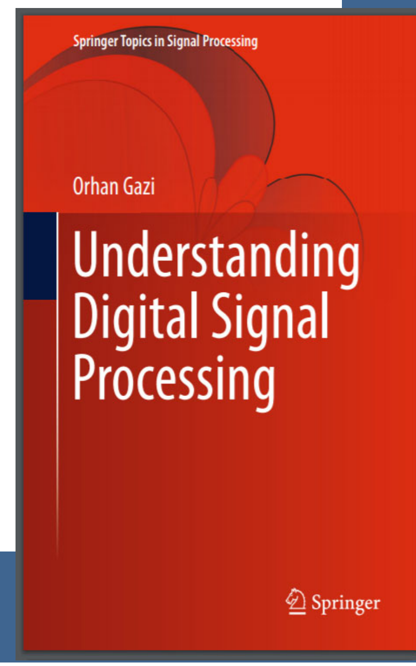

**(d)** Lift coefficient as a function of time for Basis # 6.

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

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

Patient Safety

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*

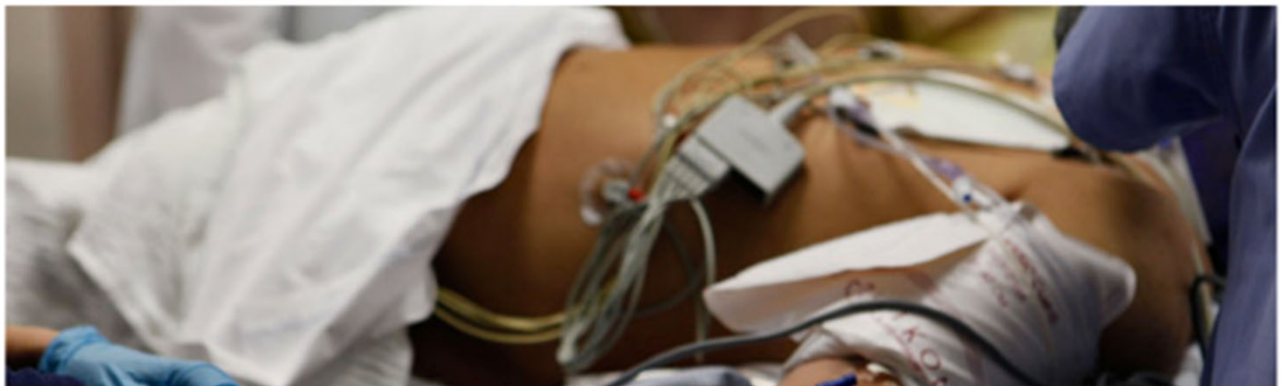
# These infusion pumps used on ONE patient. Who makes these pumps?

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 <u>180,000</u> patients in Medicare alone in a year

**Patient Safety 2013**
**Exploring Quality of Care in the U.S.**

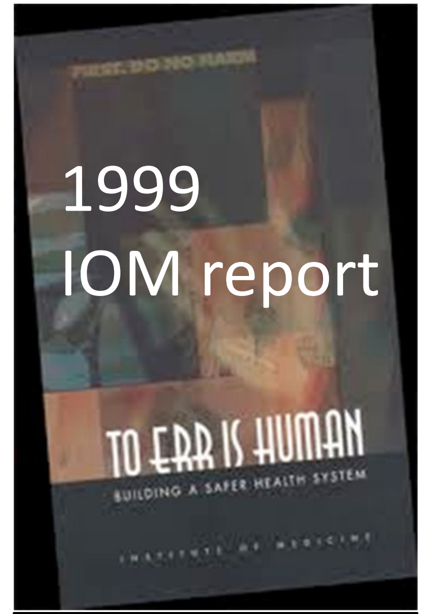
# How Many Die From Medical Mistakes in U.S. Hospitals?



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

Vital Signs Monitor

Simulator connected to vital signs monitor

Fluke ProSim 8 connected to intelligent monitor

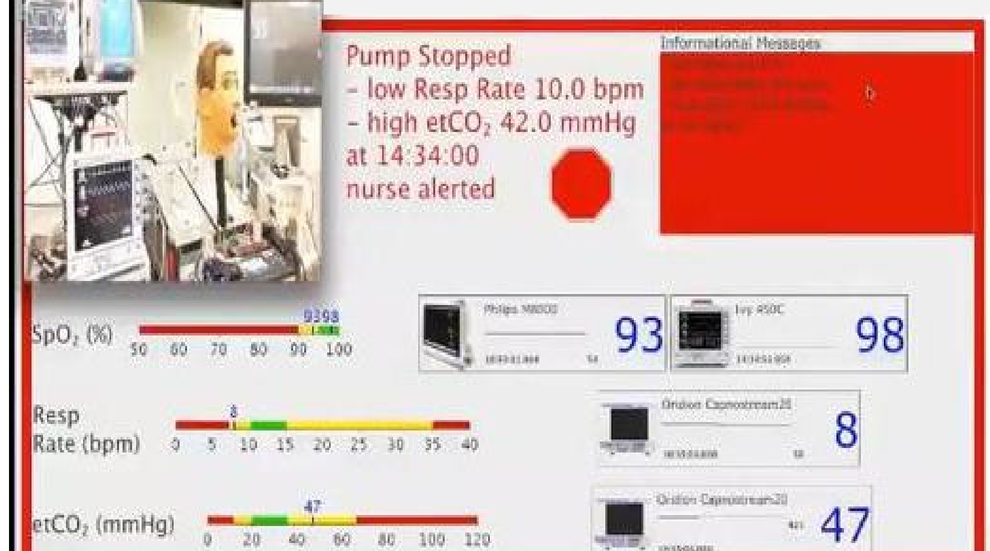
$O_2$ Saturation

Respiratory Rate

end-tidal $CO_2$

Connected Data
Collective Analysis
Automated Response

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.

# 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
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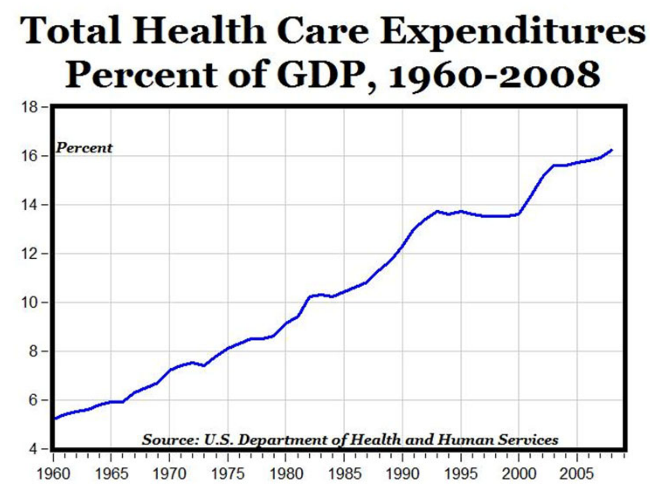



*Equivalent to at least one 747 airplane crash every day* https://www.beckershospitalreview.com/ehrs/physician-viewpoint-ehr-gag-clauses-perpetuate-patient-safety-hazards.html

# 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

# 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









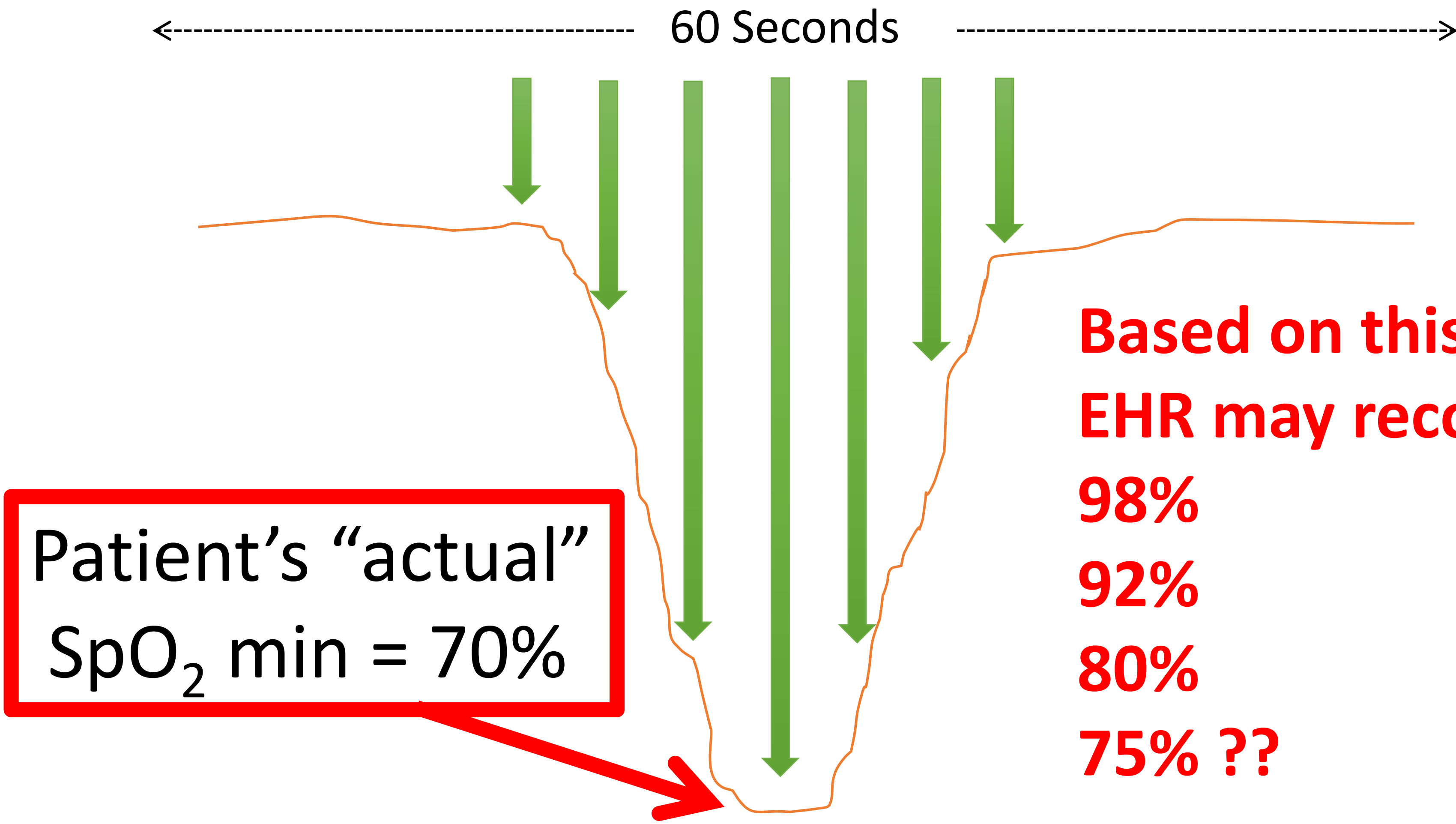


# ALL MEDICAL DEVICES
# MUST USE ANALOG TO DIGITAL CONVERTER

- 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% ??**

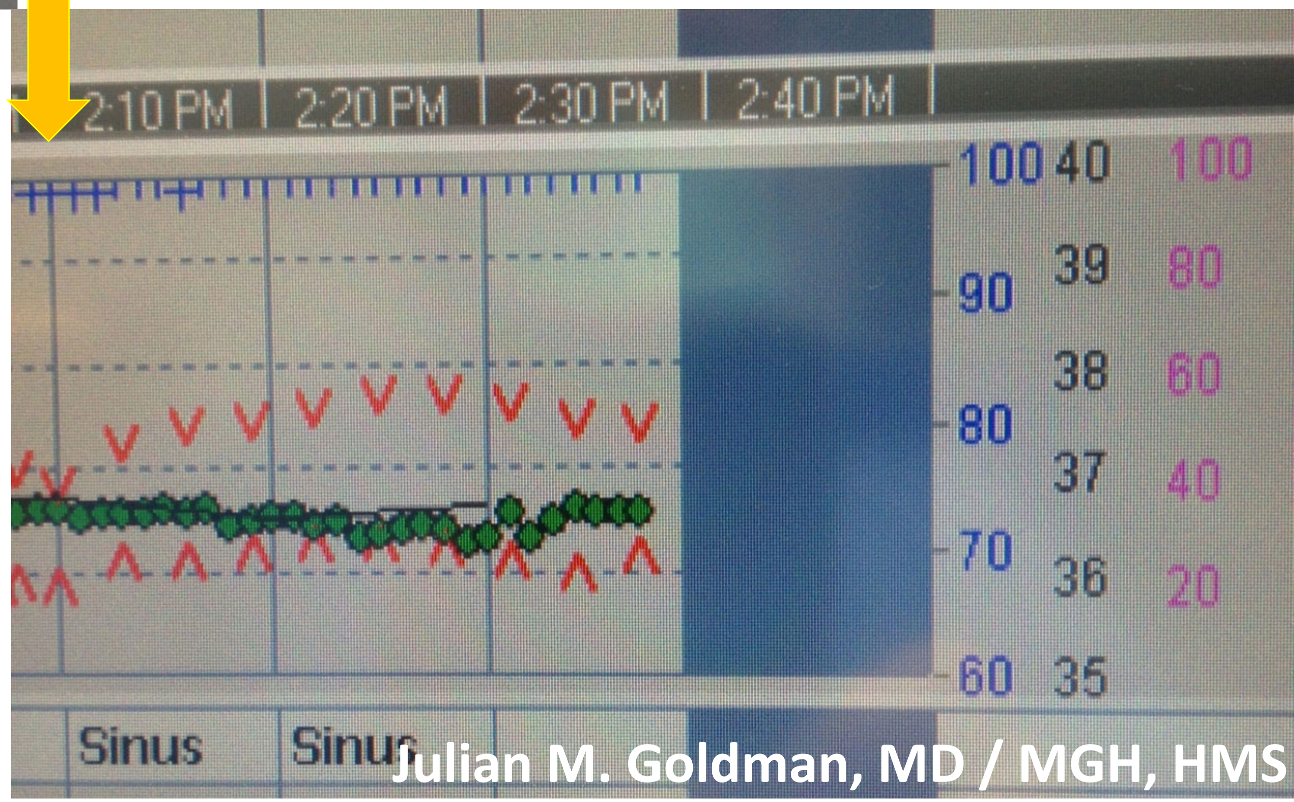
Error prone EHR documentation due to data sampling

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


No evidence of 84% $SpO_2$ in EHR

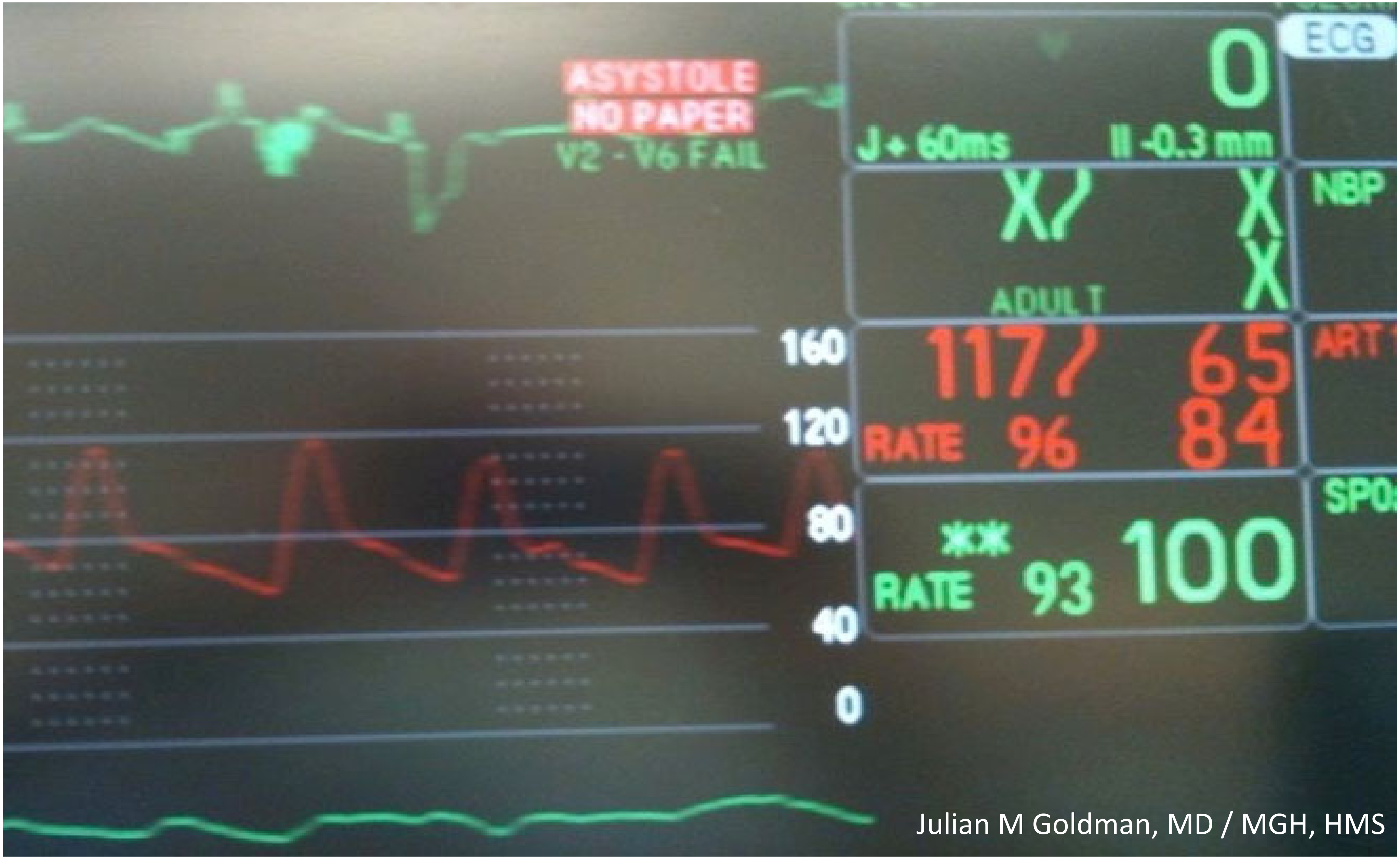
Blue marks represent $SpO_2$ values

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

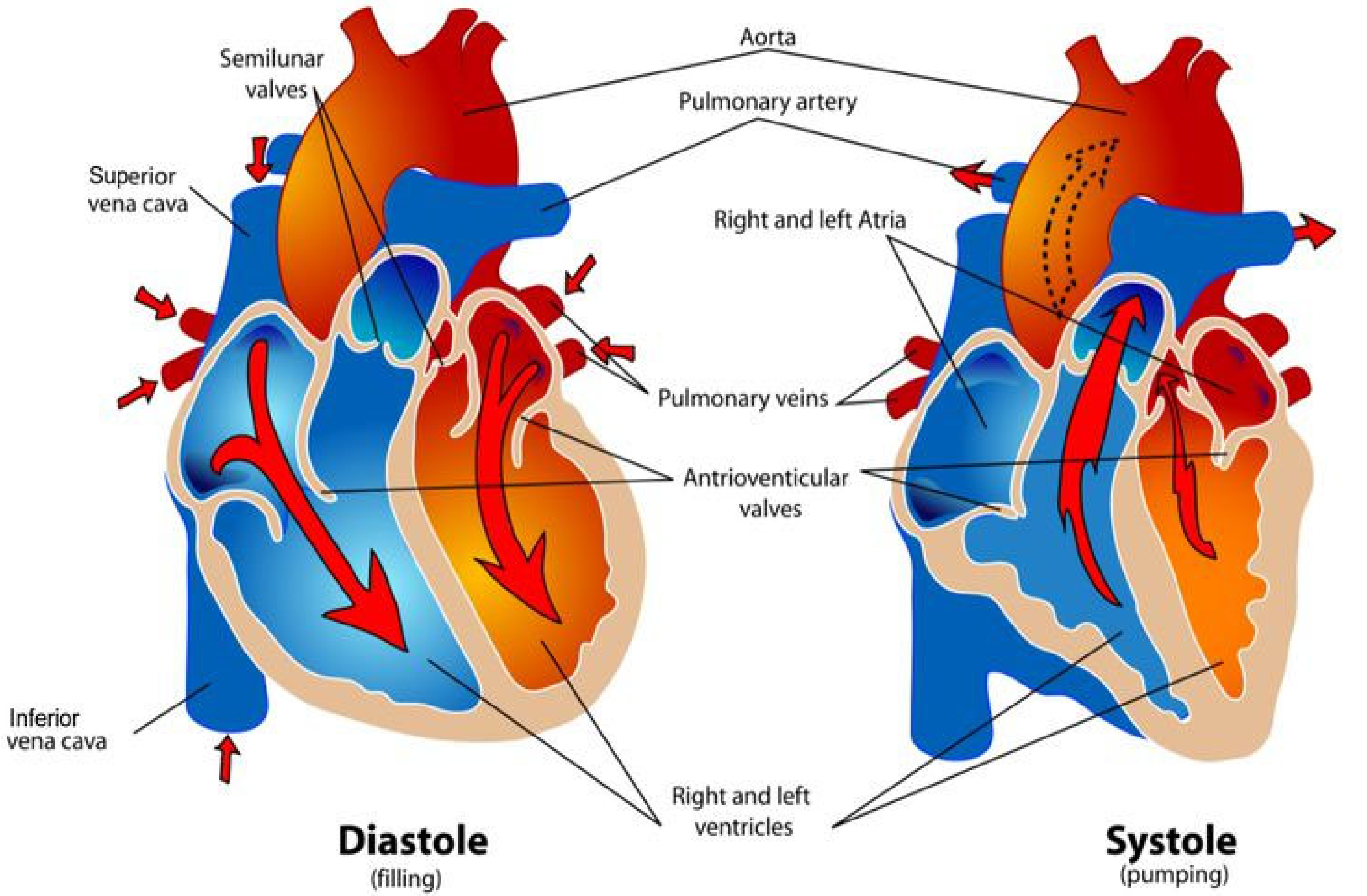



Julian M. Goldman, MD / MGH, HMS

# ASYSTOLE ??

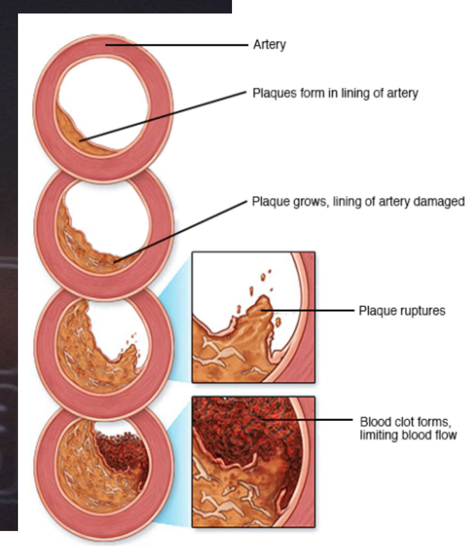



Julian M Goldman, MD / MGH, HMS




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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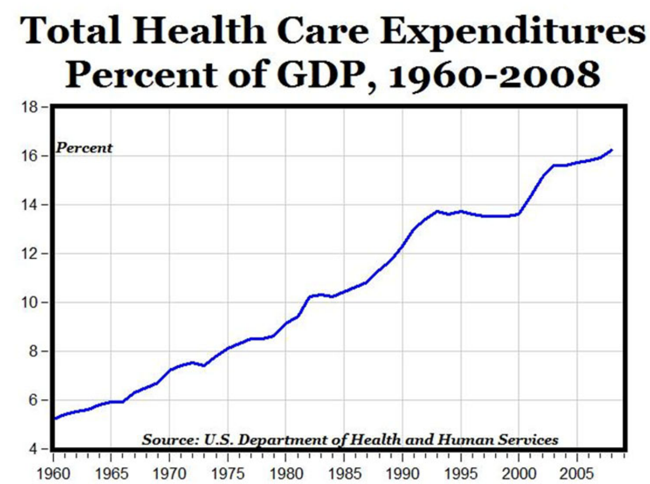
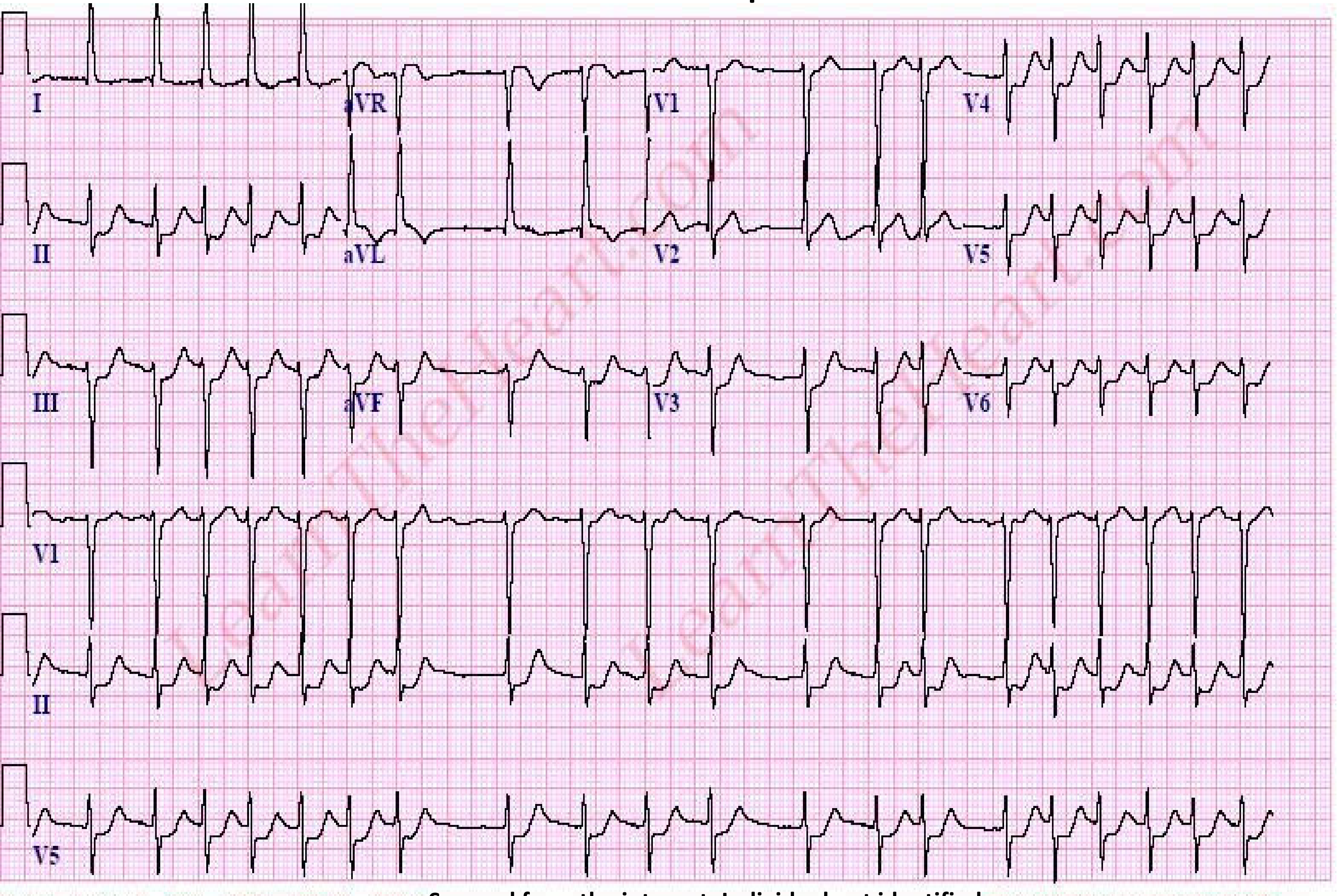
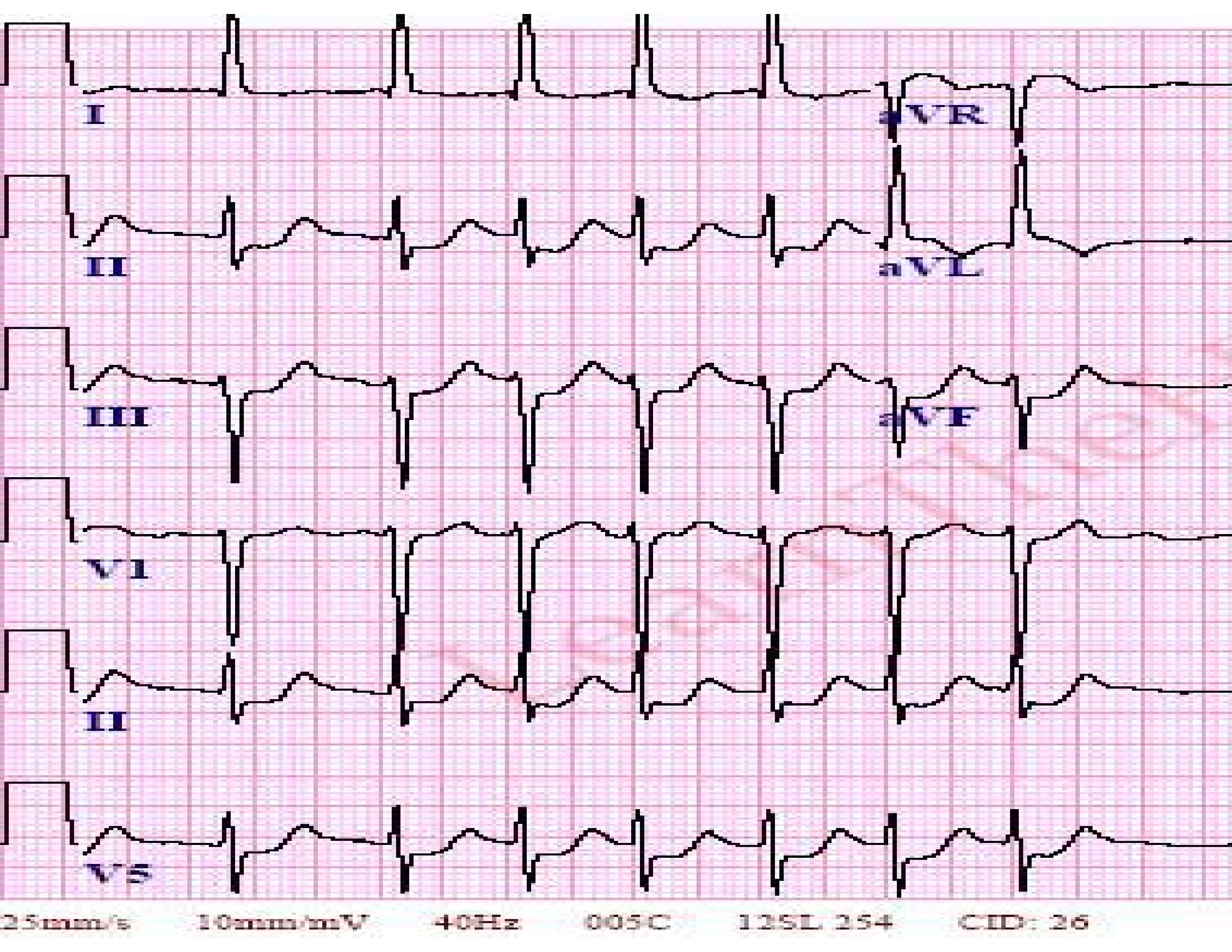



*Equivalent to at least one 747 airplane crash every day*

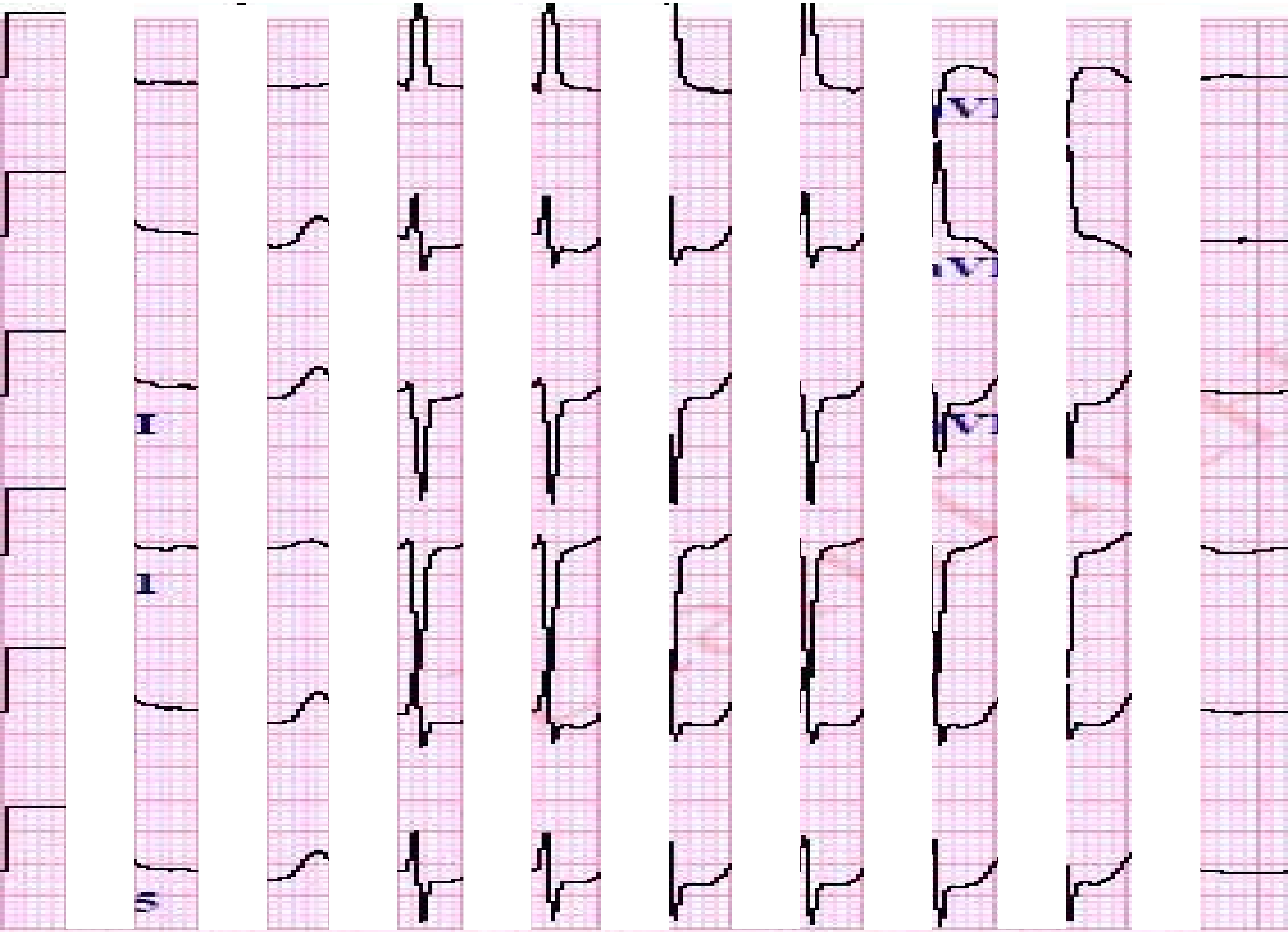
# Atrial Fibrillation with Rapid Ventricular Rate




Sourced from the internet. Individual not identified.

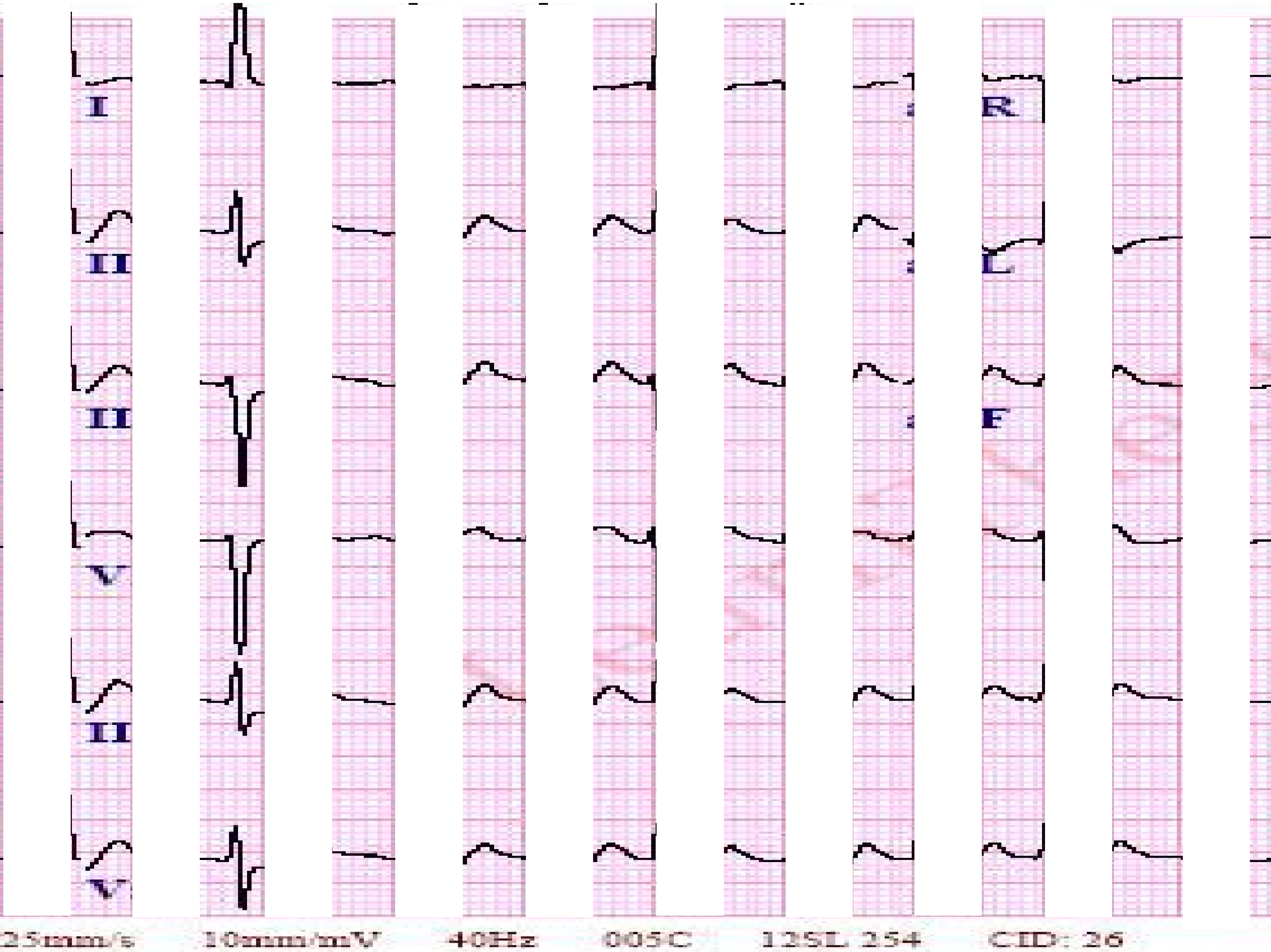

I
aVR
II
aVL
III
aVF
V1
II
V5
25mm/s 10mm/mV 40Hz 005C 12SL 254 CID: 26

# ECG SAMPLING “A”



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

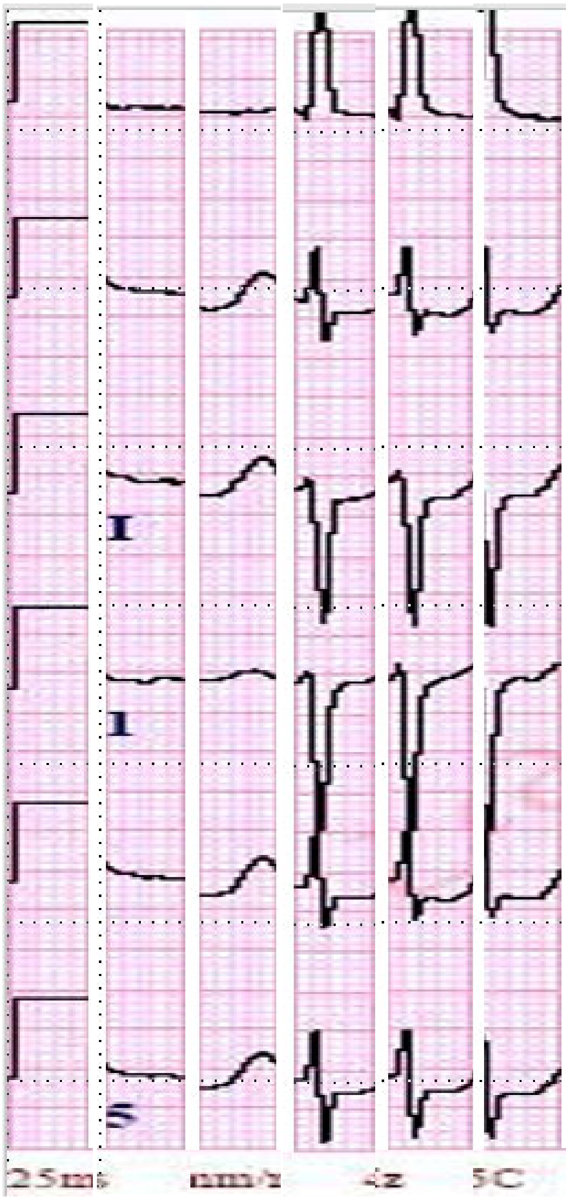
# ECG SAMPLING “B”

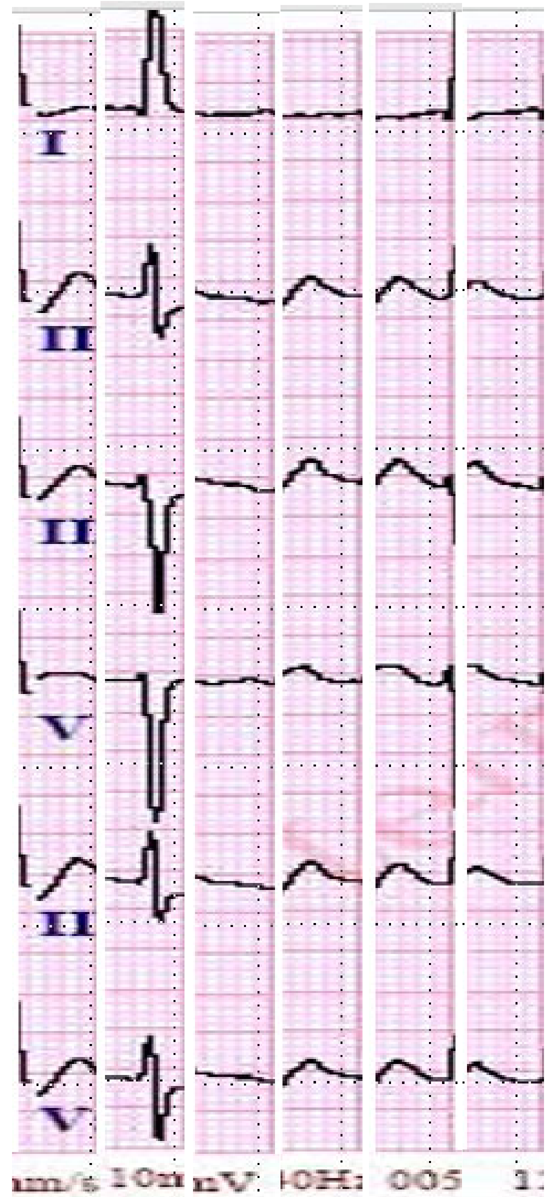

I
II
II
V
II
V
R
L
F
25mm/s
10mm/mV
40Hz
005C
12SL 254
CID: 26

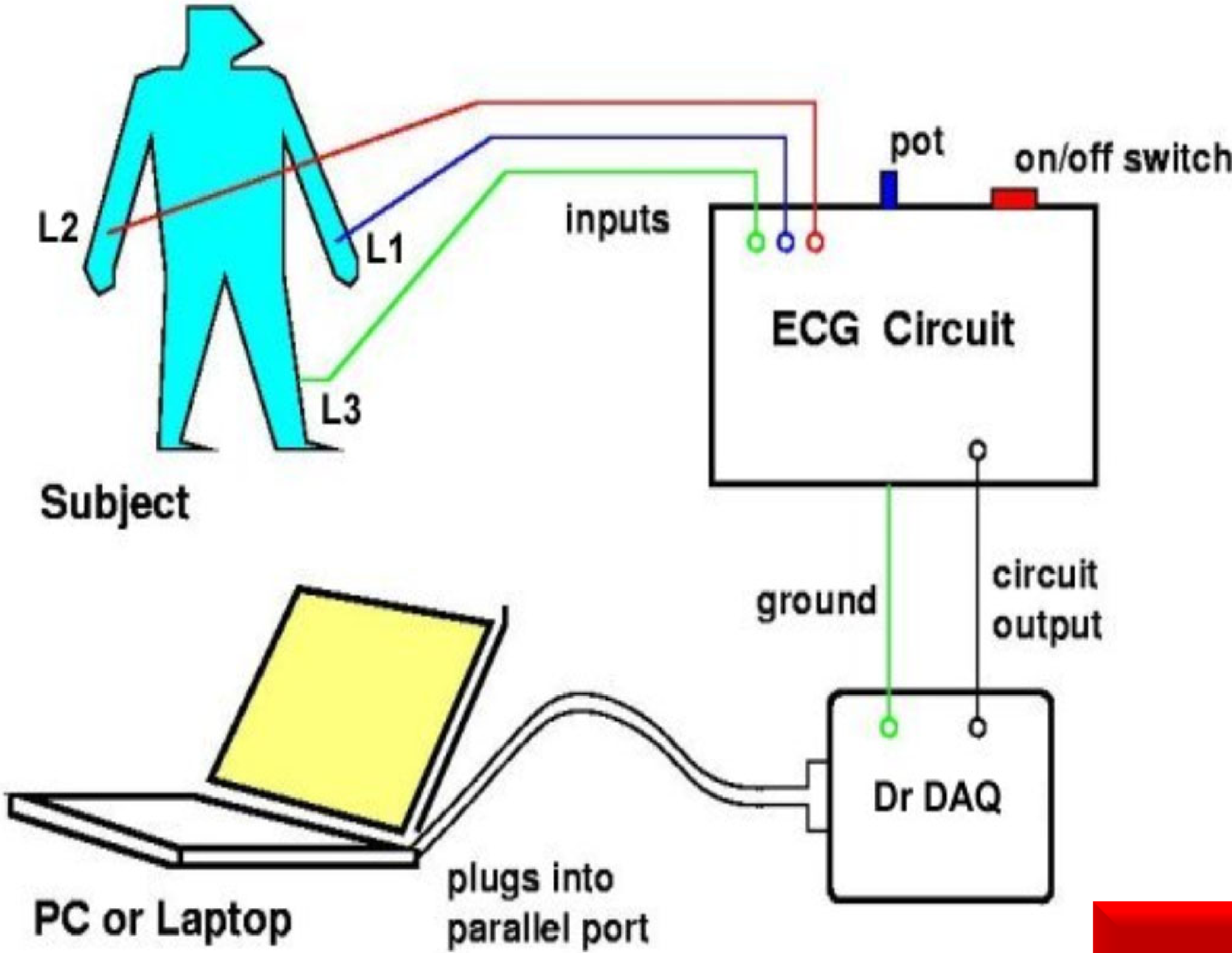
A

# Same ECG Different Sampling

B

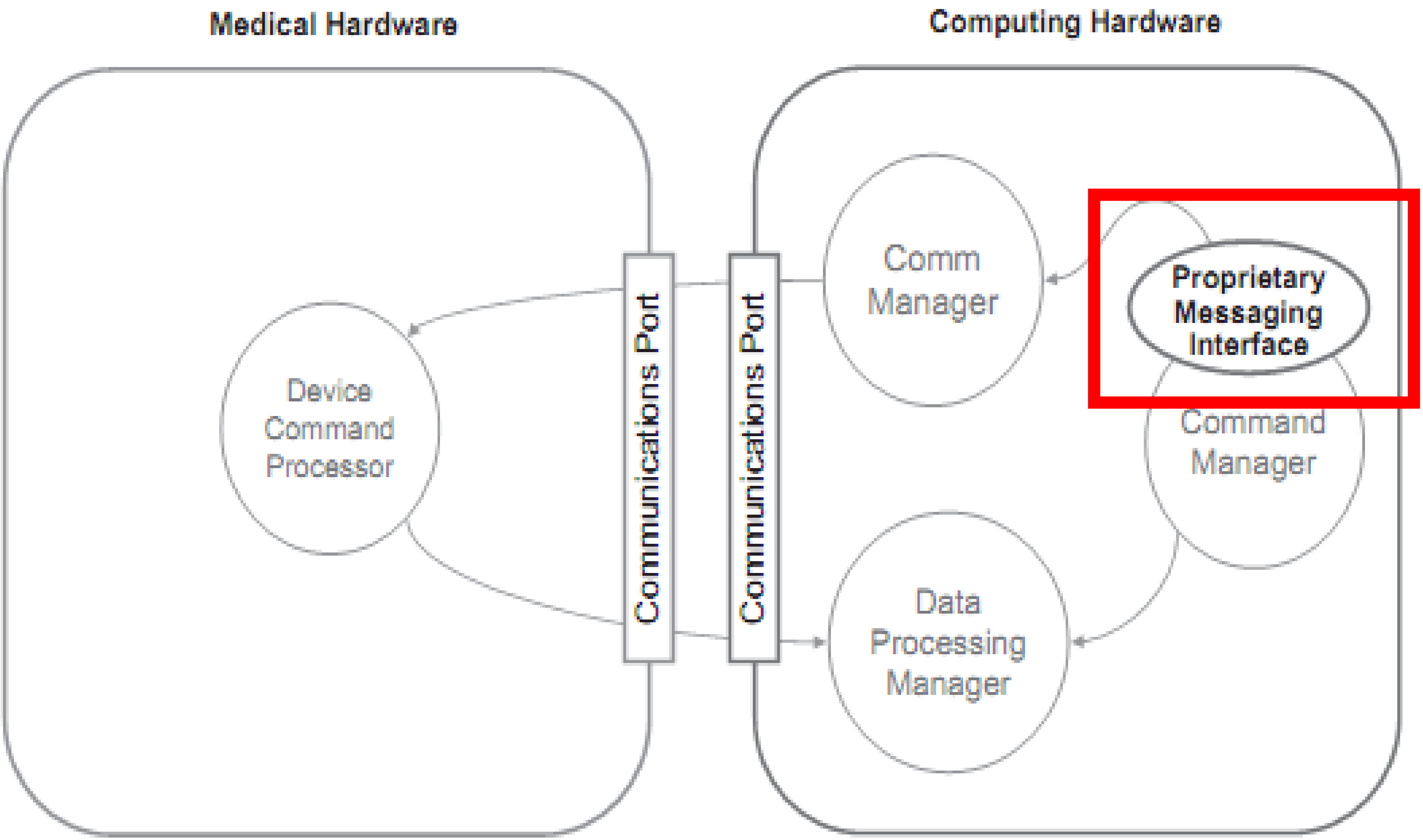







Medical professionals must access the data acquisition system to change parameters

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

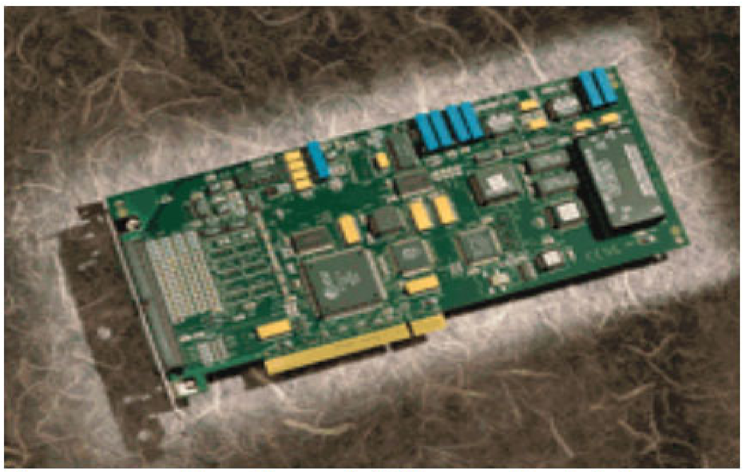



Medical hardware device connectivity when proprietary messaging interfaces are embedded into the processing functionality in the computing hardware

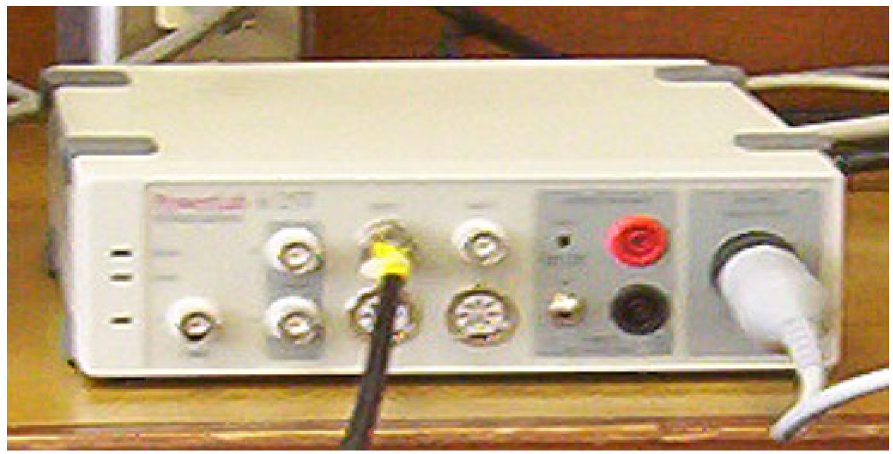
# Biomedical Signals Acquisition

**Manufacturers prohibit access to waveform data**

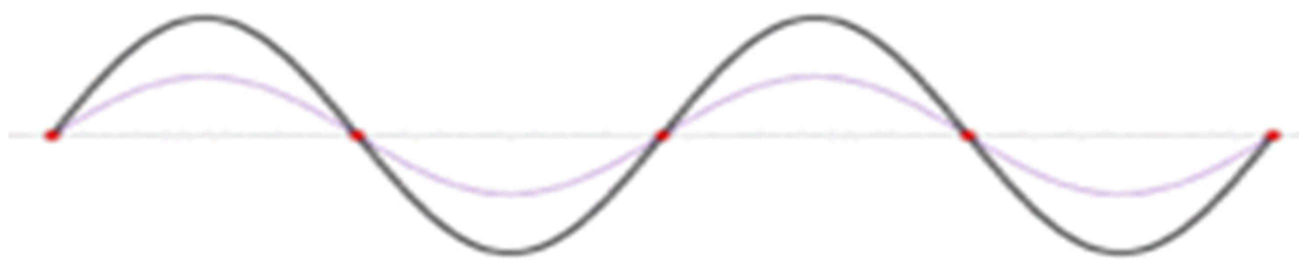
In the process of **analogue to digital conversion**, an analogue signal is converted into a digital signal which can then be stored in a computer for further processing. Analogue signals are "real world" signals - for example physiological signals such as electroencephalogram, electrocardiogram or electrooculogram.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

https://link-springer-com.libproxy.mit.edu/content/pdf/10.1007%2F978-981-10-8081-4.pdf

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

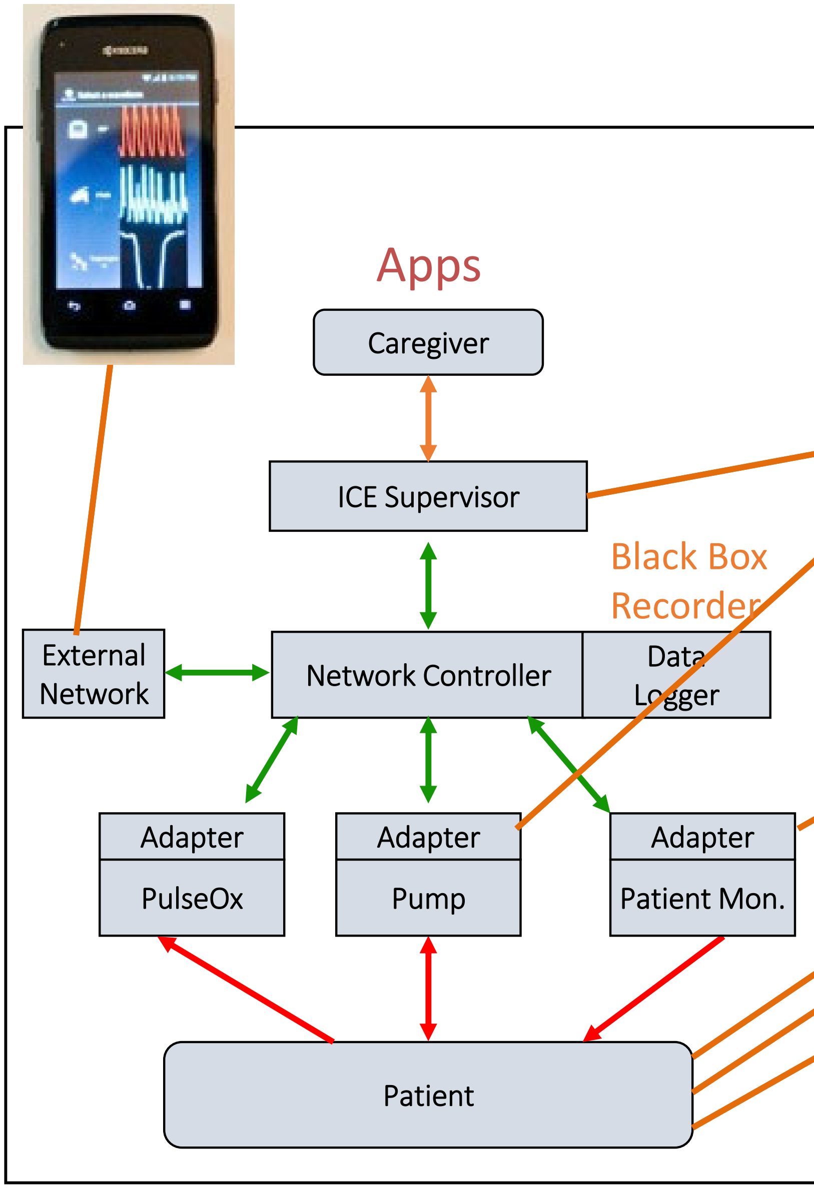
PROPRIETARY

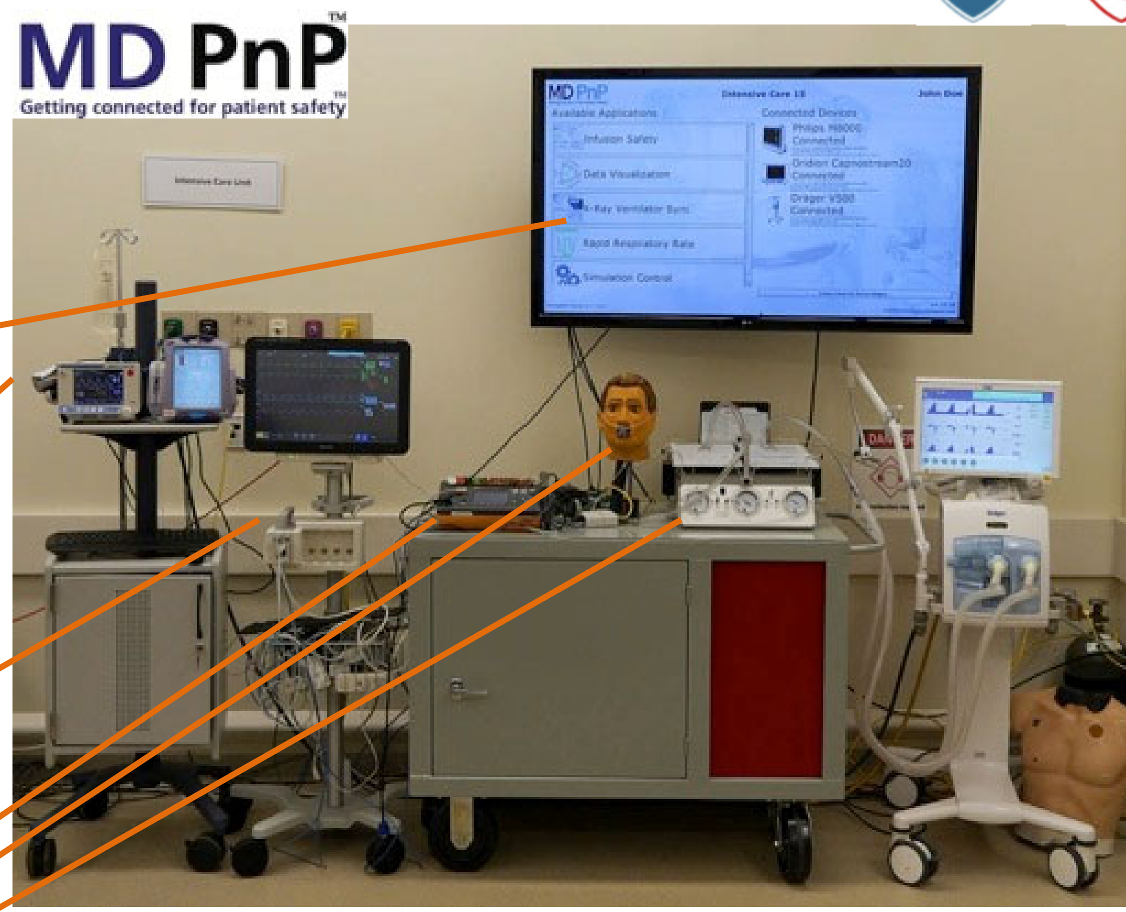
SOFTWARE

“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/

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

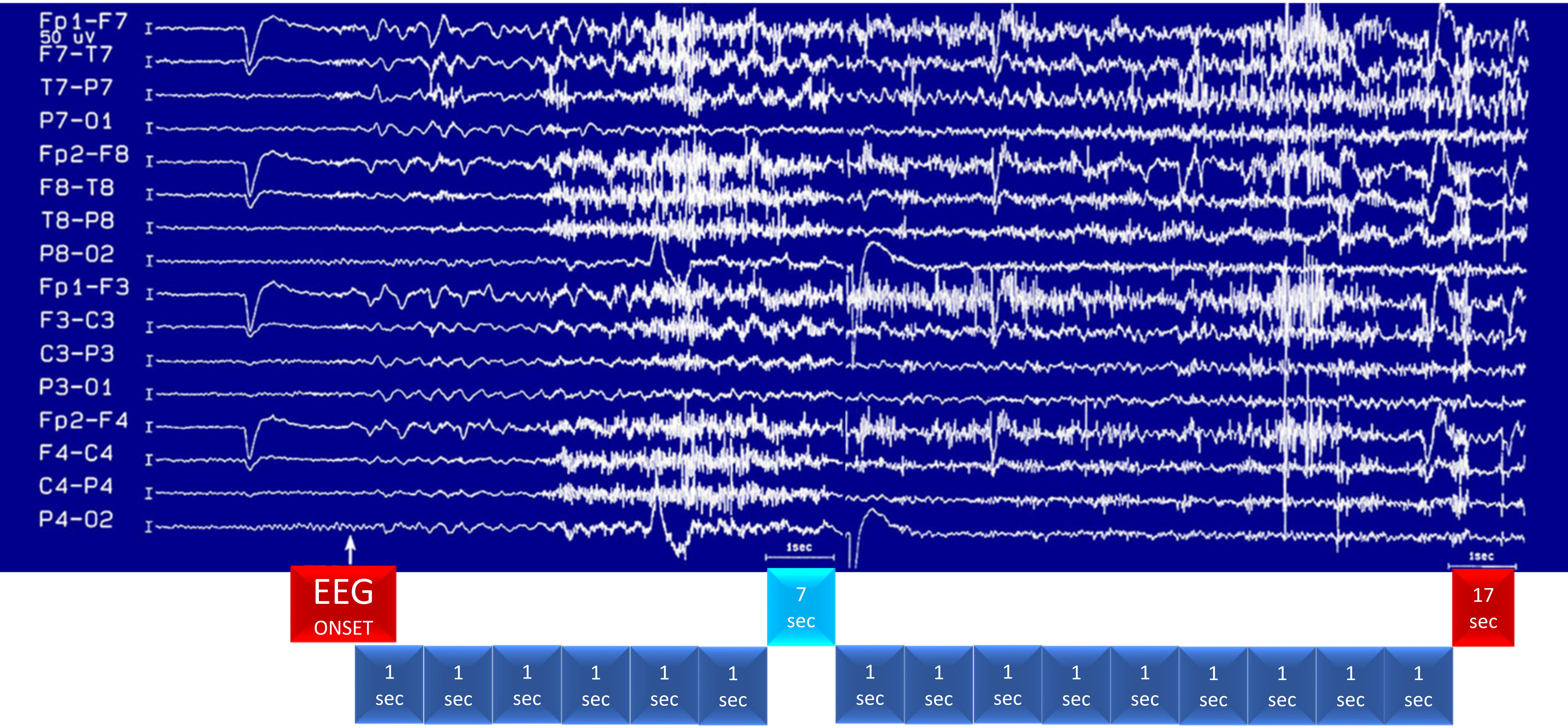



Other standards used: OMG DDS; IEEE 11073; HL7 FHIR

EEG Differentiating Sleep-Related Seizures from NREM Arousal Disorders

*Any sampling "interval" has the potential to change the semiology and electro-clinical correlation which is quintessential for medical diagnosis.*




**Storage of the raw data (i.e. original waveform) is crucial for the patient.**

EEG Source: Cleveland Clinic • https://consultqd.clevelandclinic.org/differentiating-sleep-related-seizures-from-nrem-arousal-disorders

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

## Data

*There are no short cuts*

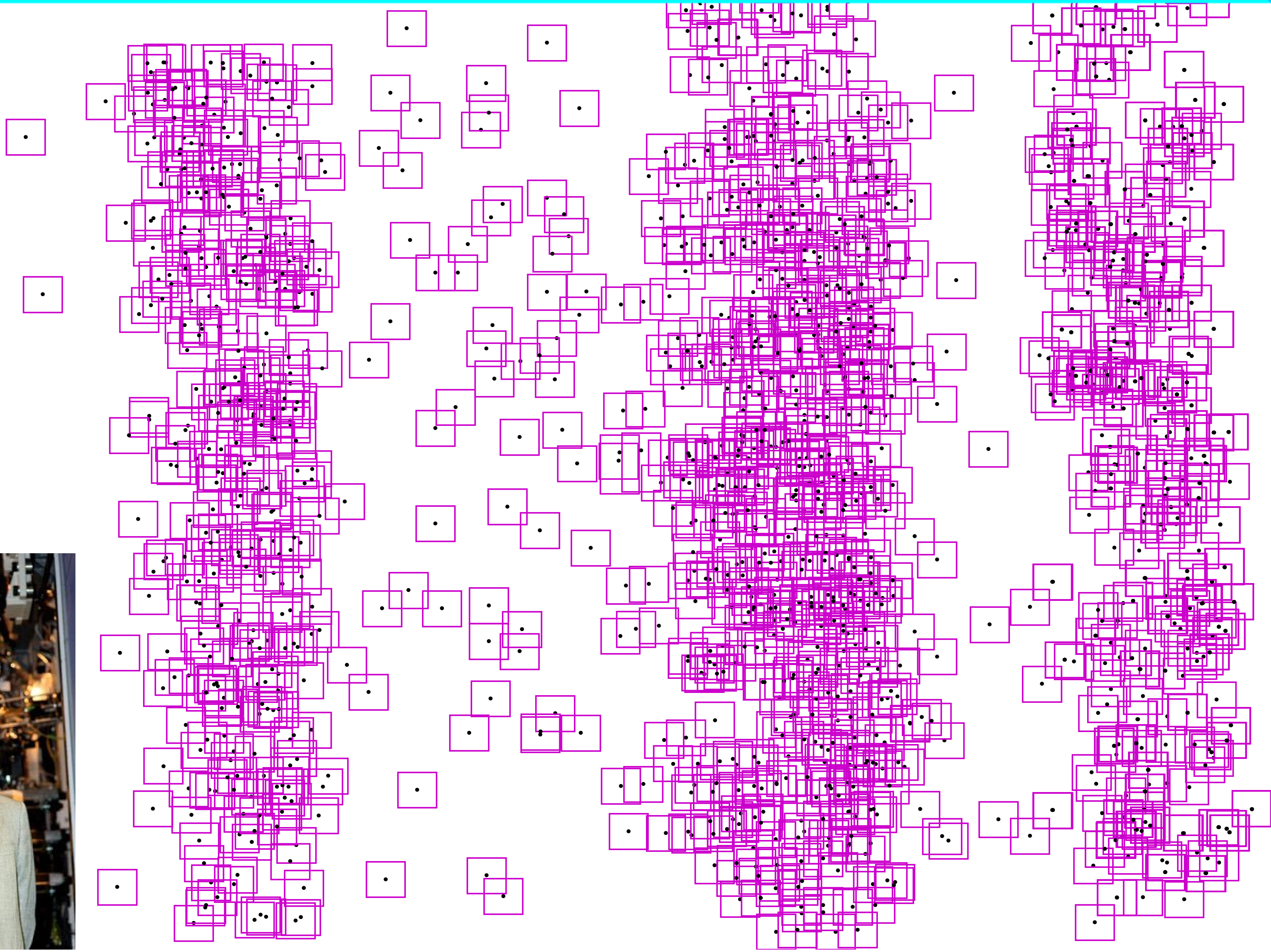
# Data ...

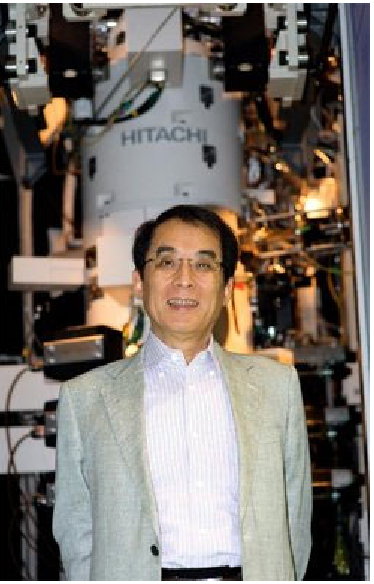

More data points ...

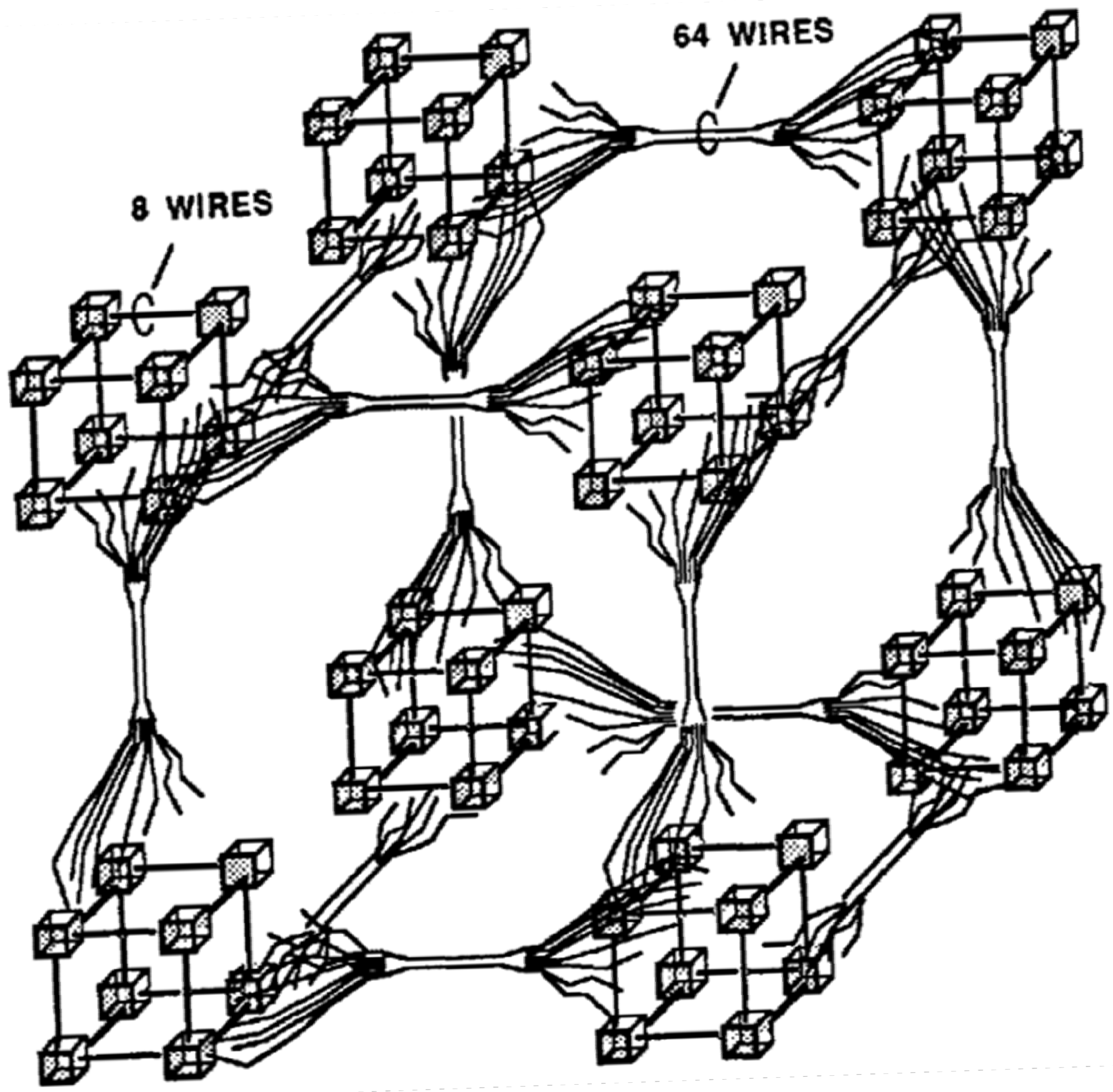

Data shows emerging pattern ...

# Young's Double Slit Experiment with Electrons

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








Here, 8 agents make a little cube, and 8 such cubes make a 64-agent supercube.

If we join 8 of these supercube: we'll have 512 agents. And if w repeat this cube-on-cube patte ten times, the resulting superc will contain a billion agents!

But if we link each agent to 30 others instead of only 6, then e agent could communicate with billion others in only 6 steps.

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

RFID 1999

IoT

Daniel W. Engels, Sanjay E. Sarma, Laxmiprasad Putta, and David Brock

# ***The Networked Physical World System***

International *Conference* WWW/Internet *2002* (ICWI): pages 104-111

https://www.researchgate.net/profile/Daniel-Engels-2/publication/220969017_The_Networked_Physical_World_System/links/0c96052aba0920de0e000000/The-Networked-Physical-World-System.pdf

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.

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

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