NUS-ISS
Intelligent Sensing and Sense Making

Module 1 - Introduction to intelligent sensing system

by Nicholas Ho

About Nicholas Ho

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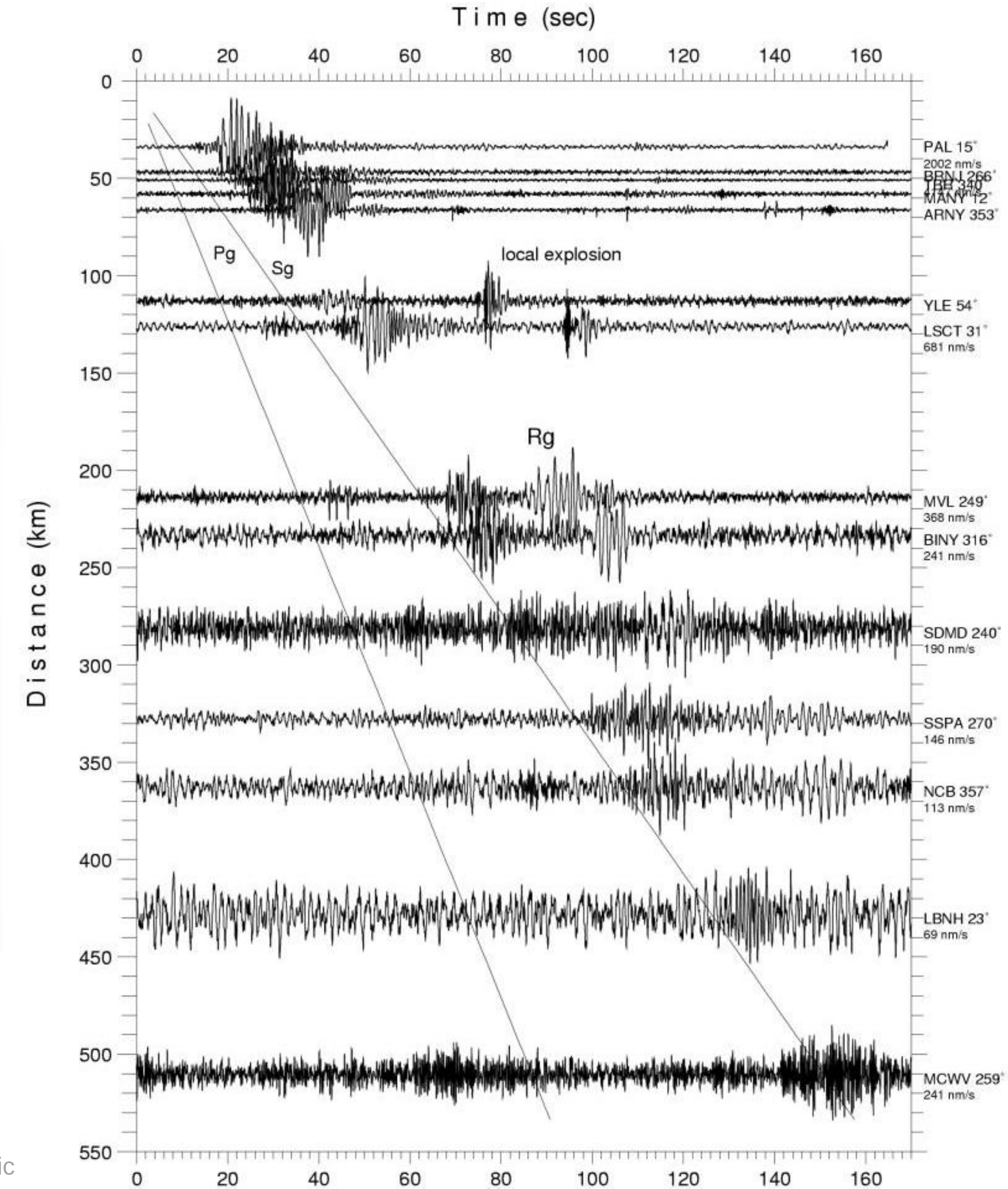
- Lecturer at NUS ISS; Courses covered include:
  - Problem Solving using Pattern Recognition
  - Autonomous Robots and Vehicles
  - Human Robot System Engineering
- BEng and PhD degree from School of Mechanical Engineering, NUS
- Specialized in architecture, design & development
  - Artificial Intelligence
  - Augmented/Virtual Reality
  - Internet-of-Things (IoT) & Cyber-Physical System (CPS)

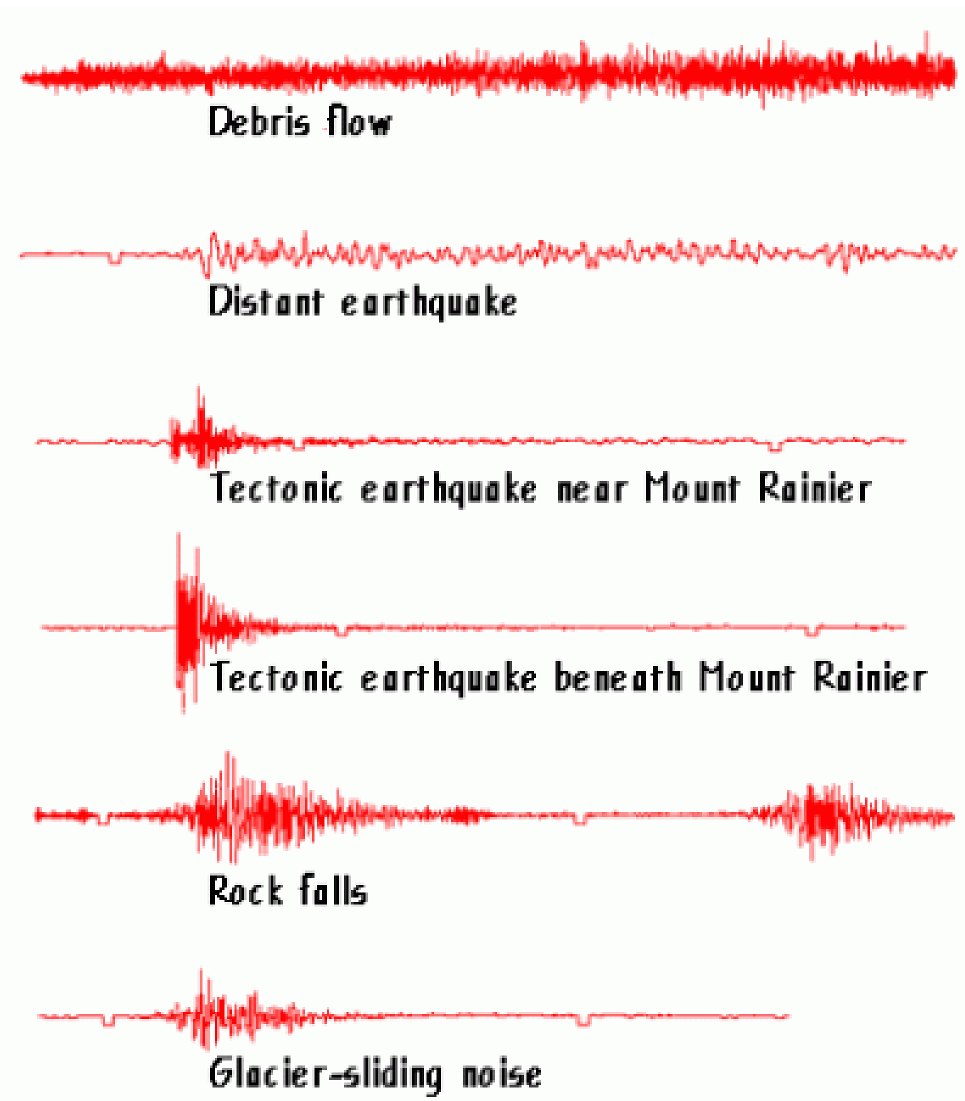
Let’s take at a look at some signals

Signals



Source:
http://911research.wtc7.net/mirrors/guardian2/wtc/seismic/WTC_PENT_KIM.htm

What is signal?

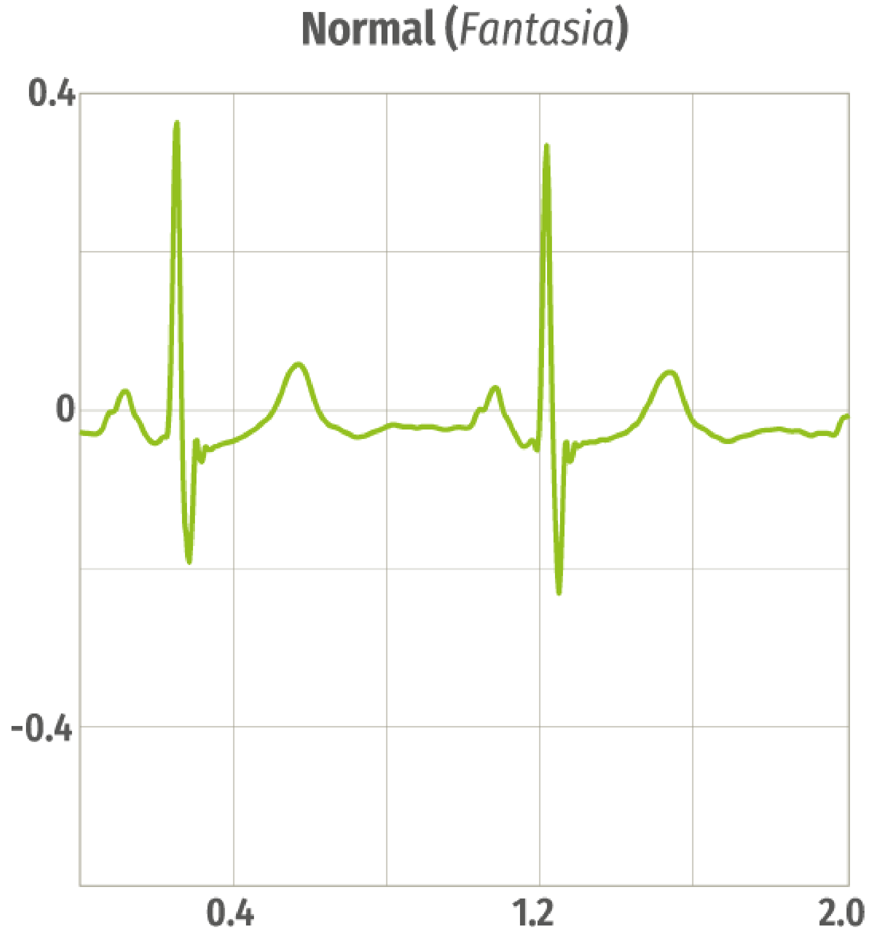


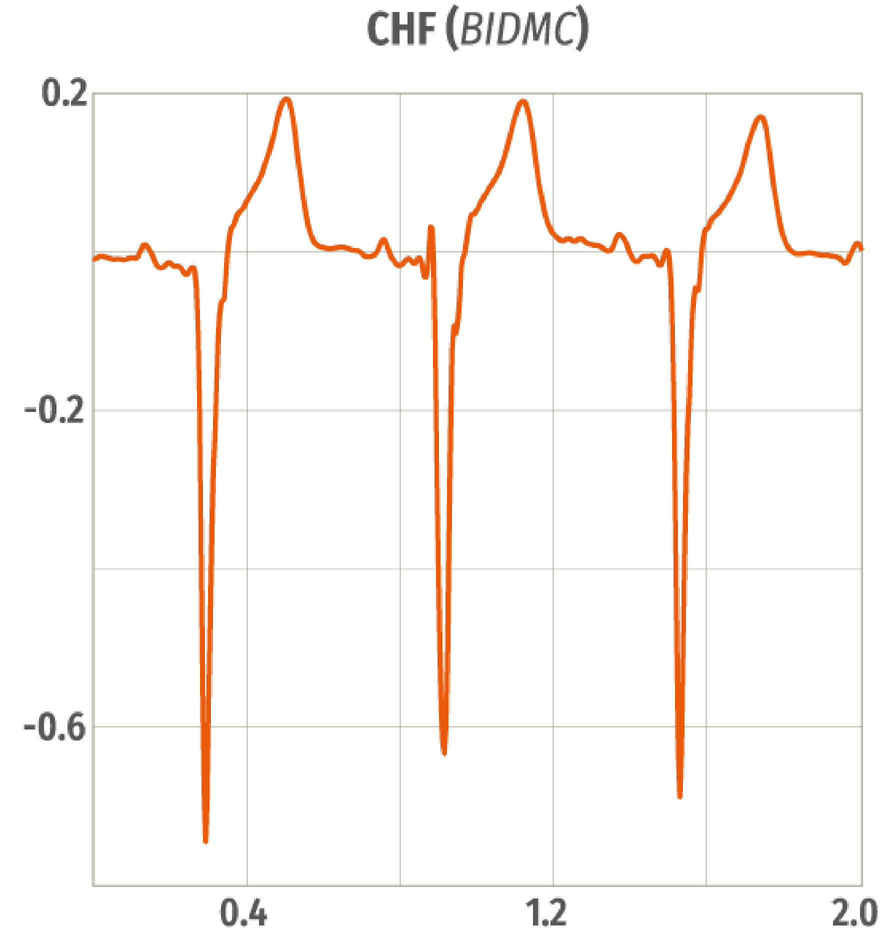
Source:
https://volcanoes.usgs.gov/vhp/seismic_signals.html

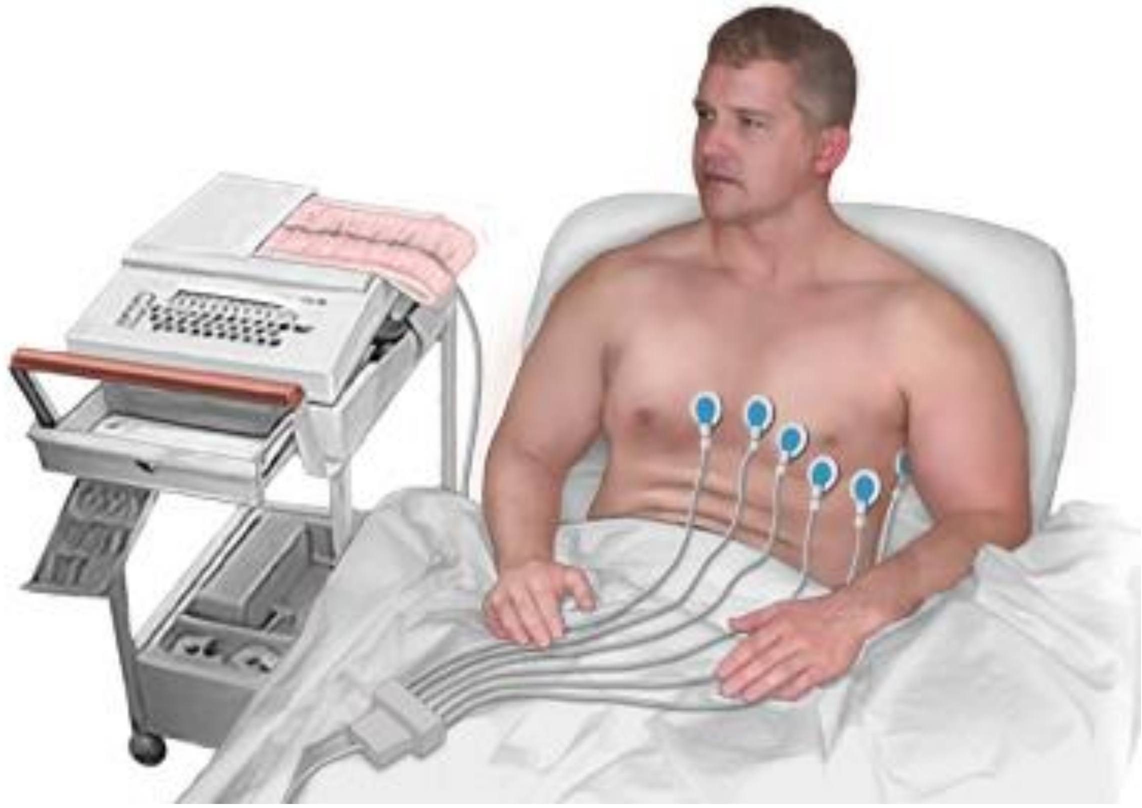
- In signal processing, signal is a function that conveys information about a phenomenon
- A signal can also be defined as an observable change in a quantity (property)
- Any physical quantity that exhibits variation in space or time can be a signal

Signals
Example: ECG

For Heart!



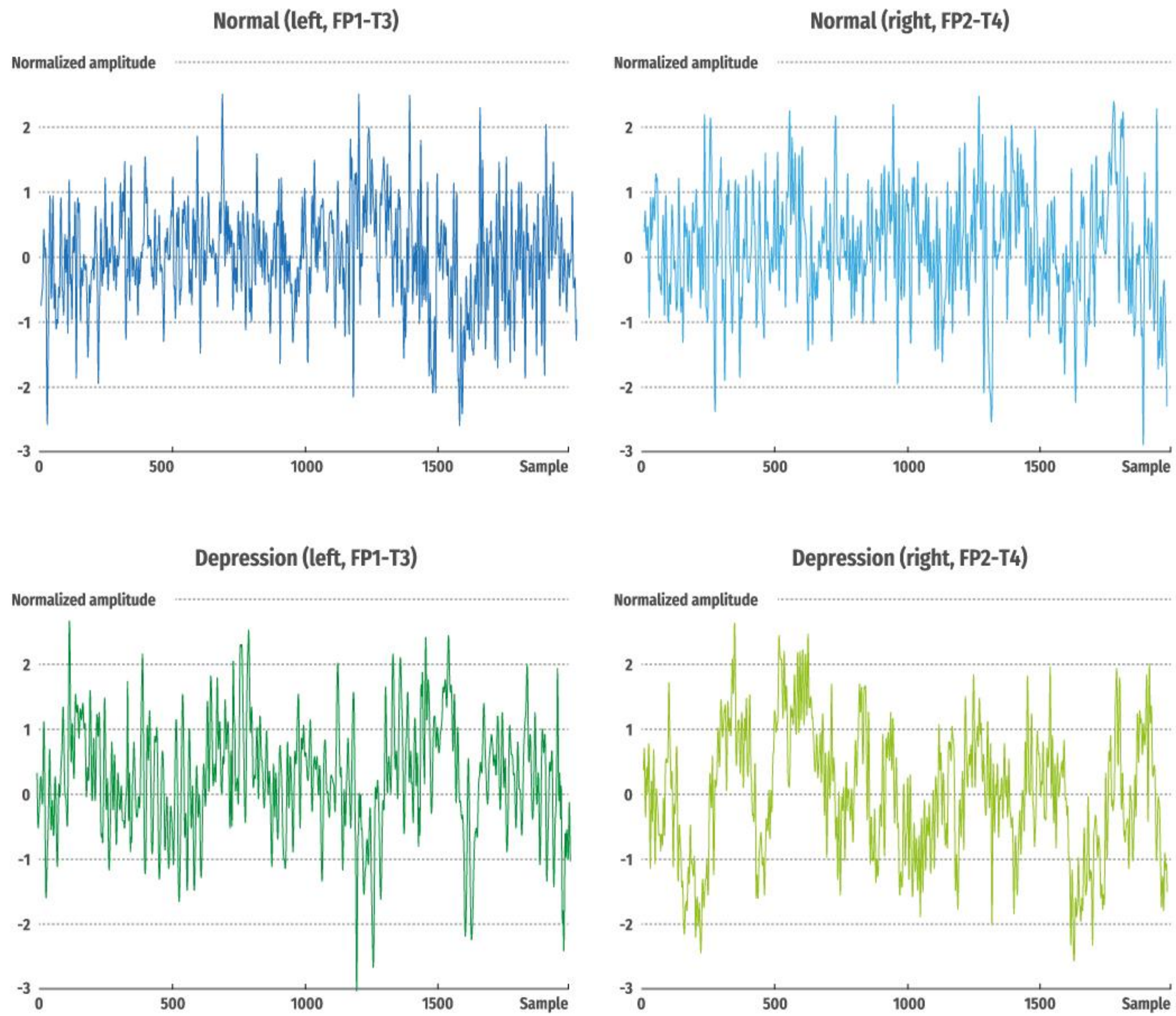


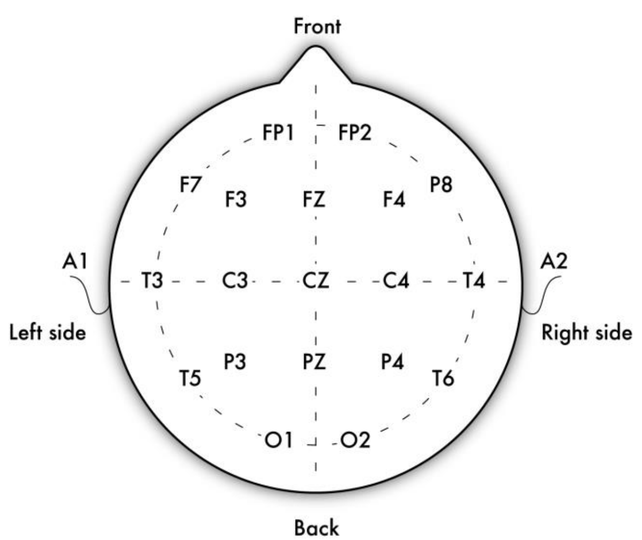


Signals

Example: EEG

For Brain!





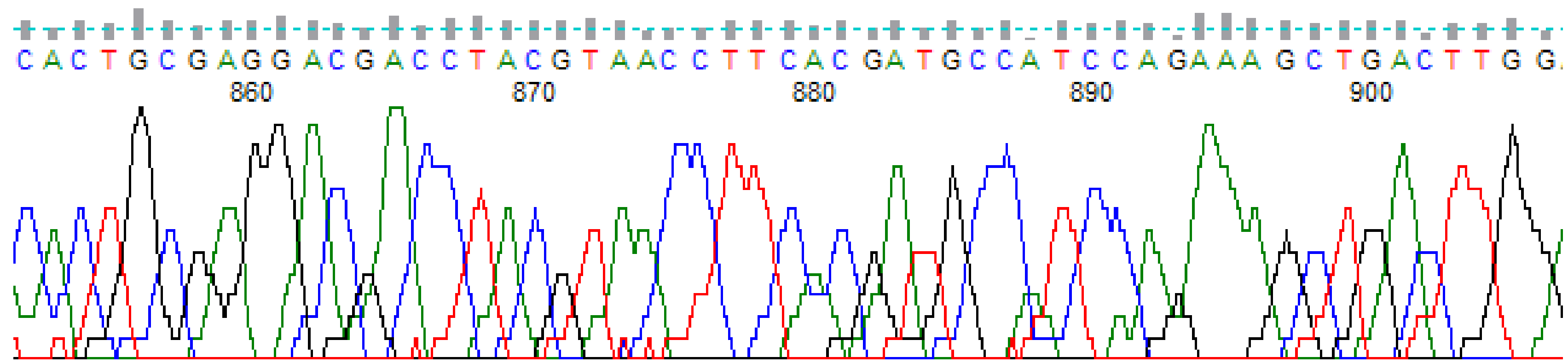
Using Brain Signals via EEG to Control Robot by MIT CSAIL
(Computer Science & Artificial Intelligence Laboratory)

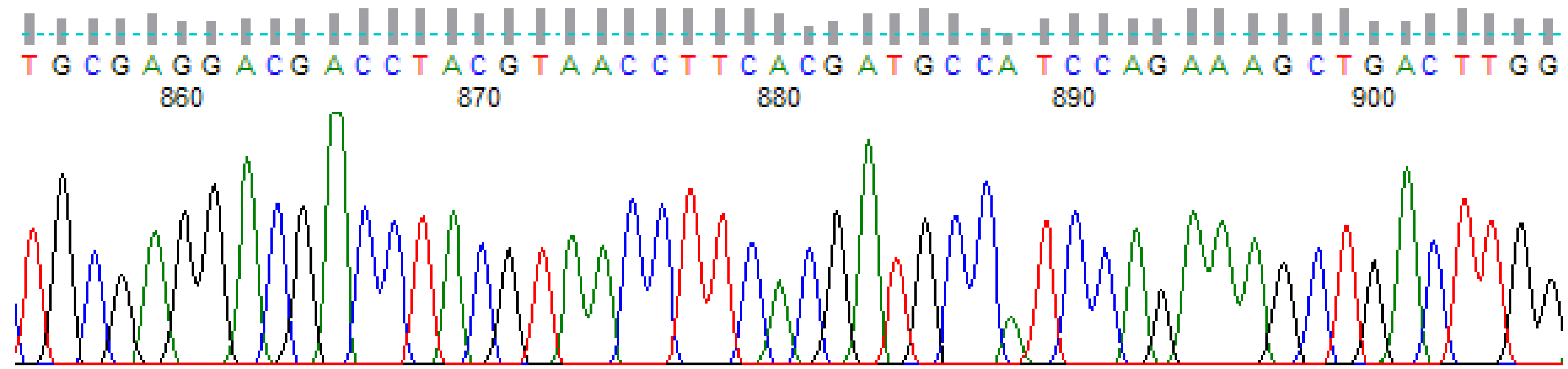
Source: https://www.youtube.com/watch?v=Zd9WhJPa2Ok

Signals

Example:
Electropherogram

For DNA!

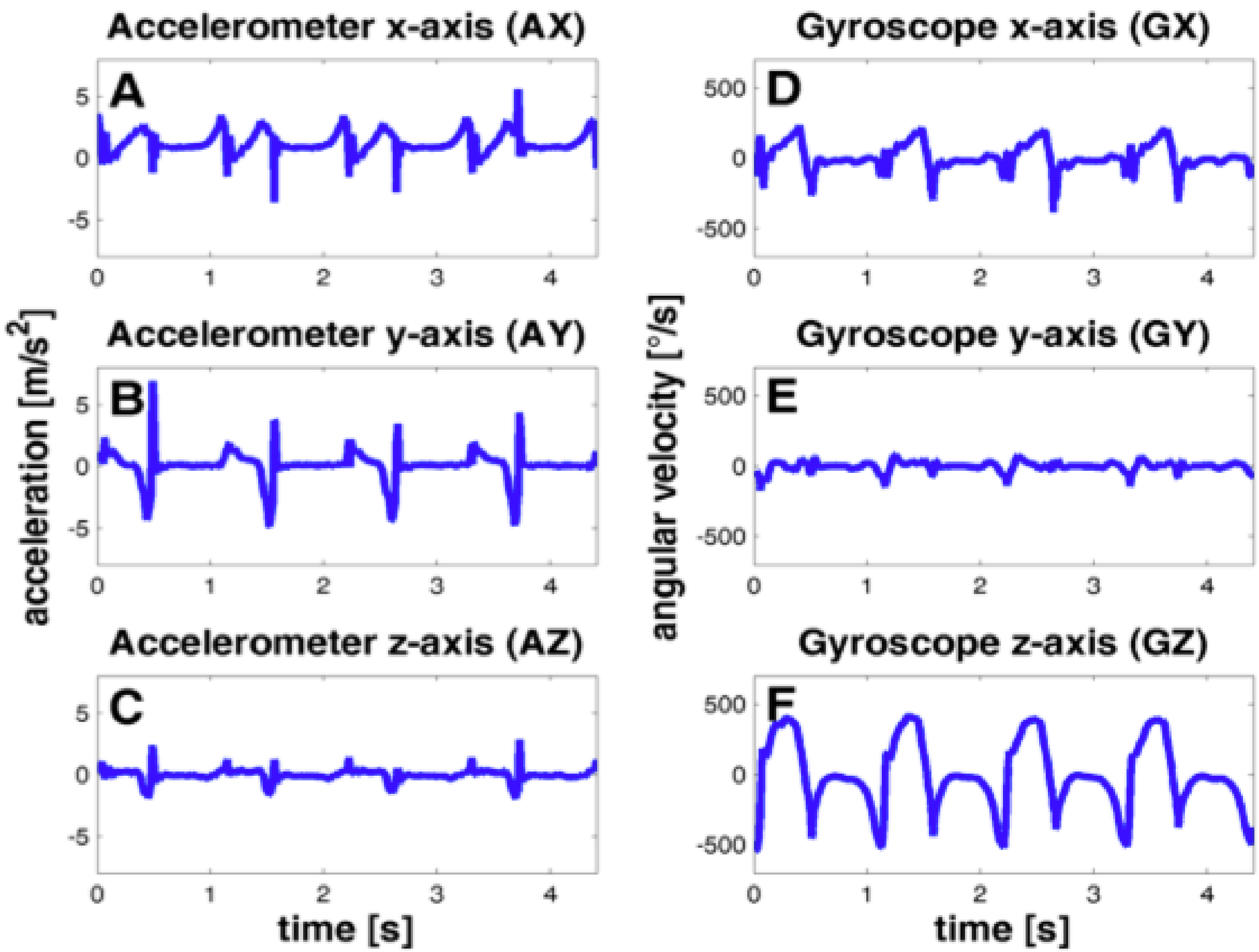




Source: https://www.nucleics.com/peaktrace/peaktrace-box-overview.html

Signals

Example: 4 walking strides from an elderly



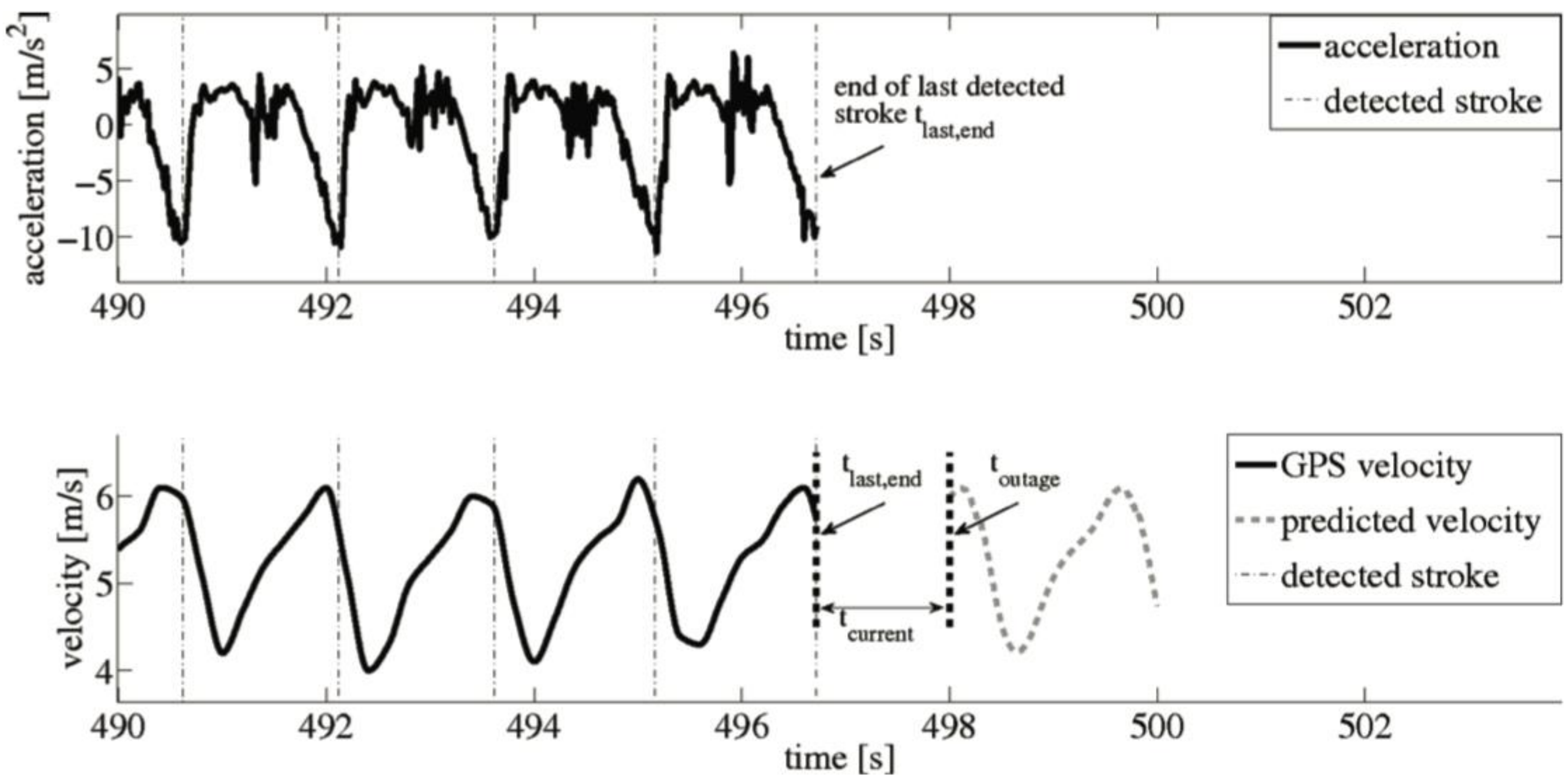
Visually unable to decipher anything. But with algorithms, we may be able to make sense out of these signals!

Source: doi:10.3390/s150306419

Signals

Example: Acceleration and velocity in rowing

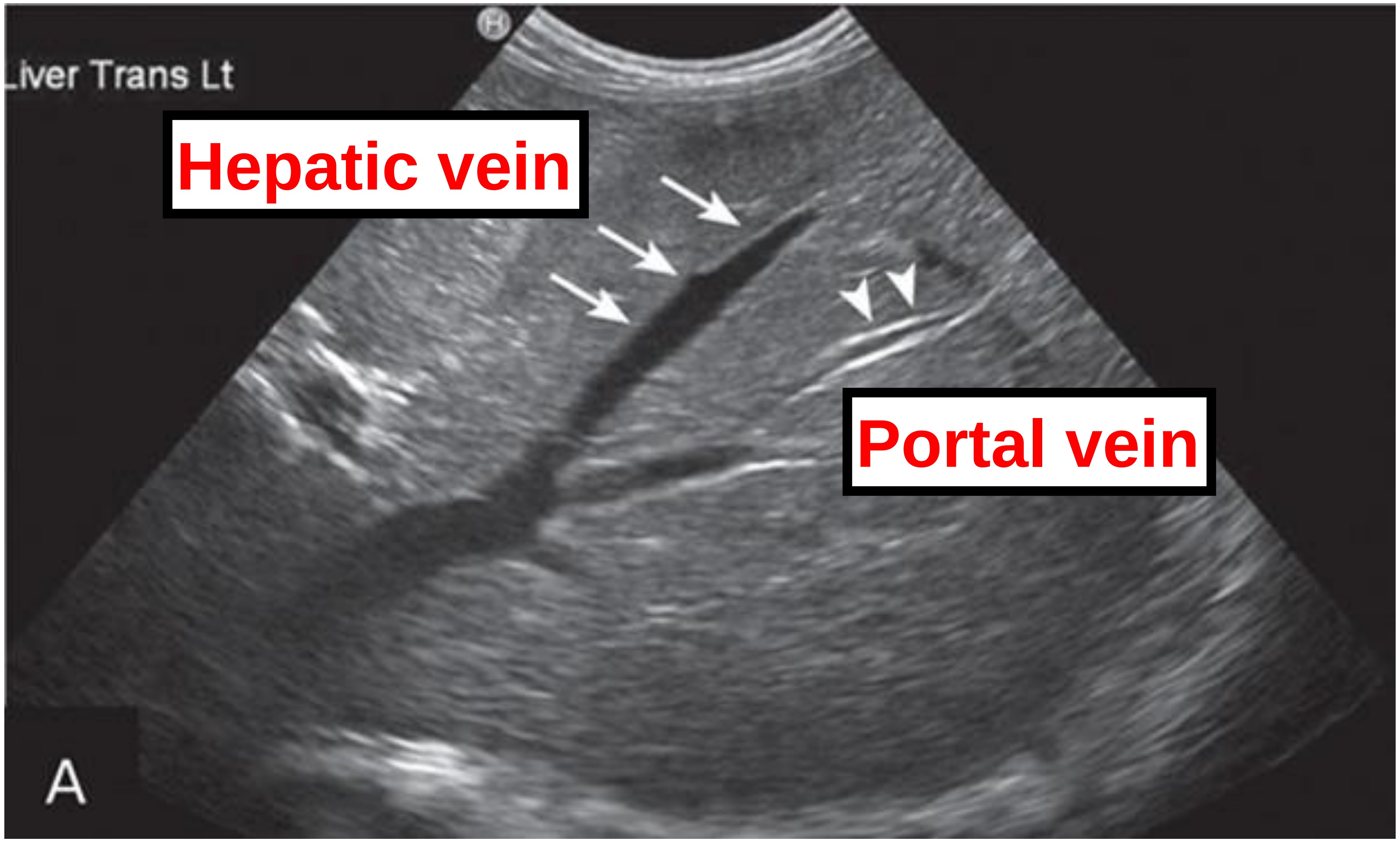
Time Series Prediction!



Source: DOI: 10.1109/ISSNIP.2014.6827684

Signals

Example: Ultrasound image



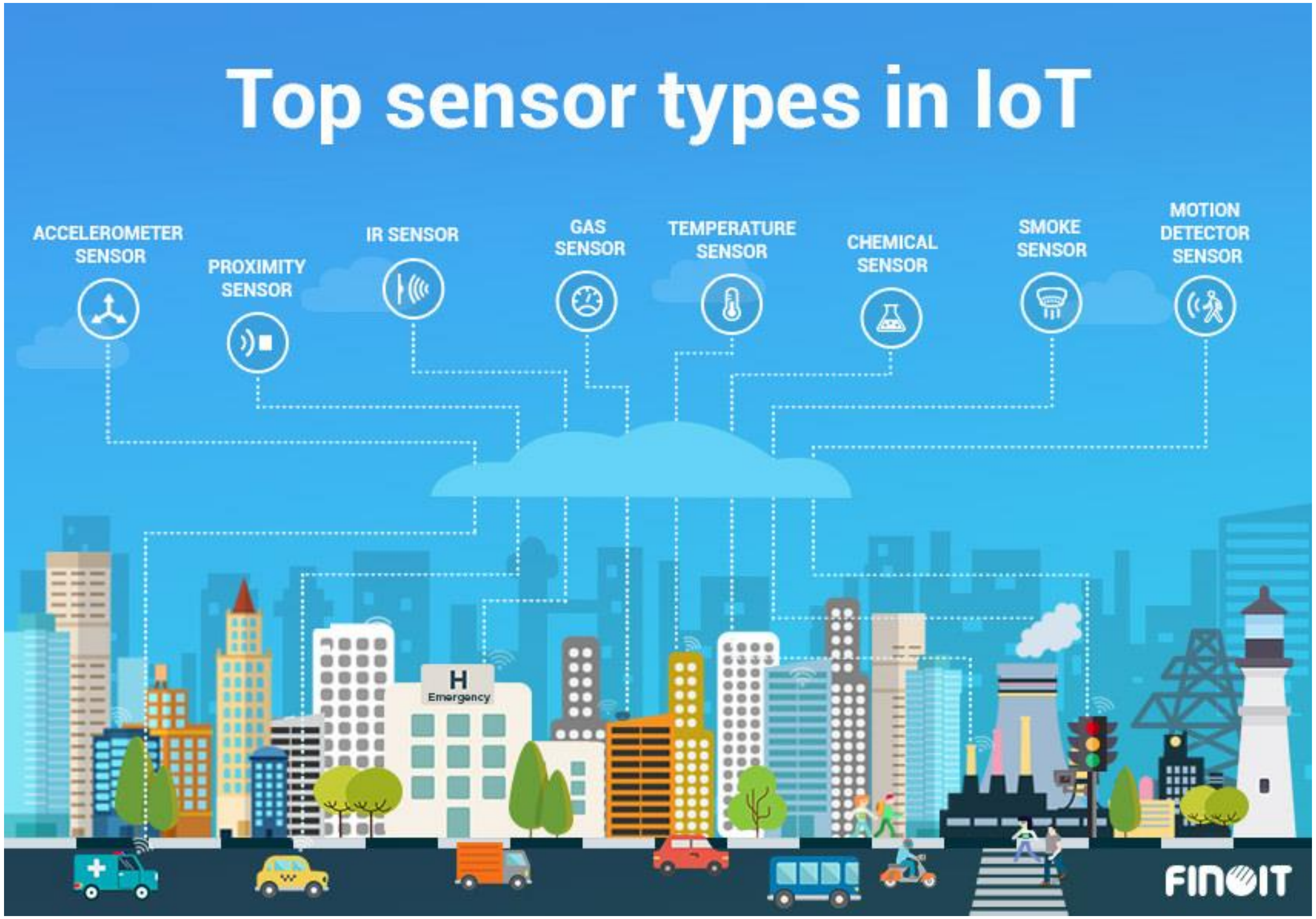
Source: https://www.cliniciansbrief.com/article/liver-ultrasound-guided-fine-needle-aspiration

Sensors that produce signals

Signals

Sensors are getting more and more important to make the world 'smart'

"One way to think of IoT is second phase of internet", by The Economist

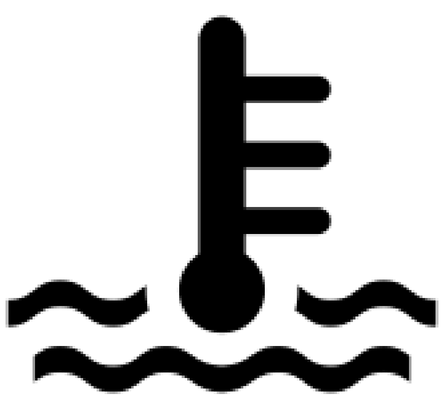


Need IoT technologies to help manage, transfer, store the data; making sense of data make the city smart!

Source: https://www.finoit.com/blog/top-15-sensor-types-used-iot/

Sensors

Temperature sensors



- Function: measure amount of heat energy that allows to detect a physical change in temperature from a particular source

- In early days mostly used in Aircon, refrigerators

- Now, Manufacturing: as some machines require specific environment temperature, need monitoring

- Now, agriculture: soil temperature is crucial for crop growth; helps with plants production, maximizing output

Source: https://icon-library.net/icon/temperature-sensor-icon-19.html

Source: https://www.finoit.com/blog/top-15-sensor-types-used-iot/

Sensors

Proximity sensors

- Function: detects the presence or absence of a nearby object, or properties of that object without getting in contact with them.
- Used in vehicles a lot, also for parking availability
- In retail industry, detect motion and the correlation between customer and the product they are interested in
- Some sensors specifically detect metallic objects

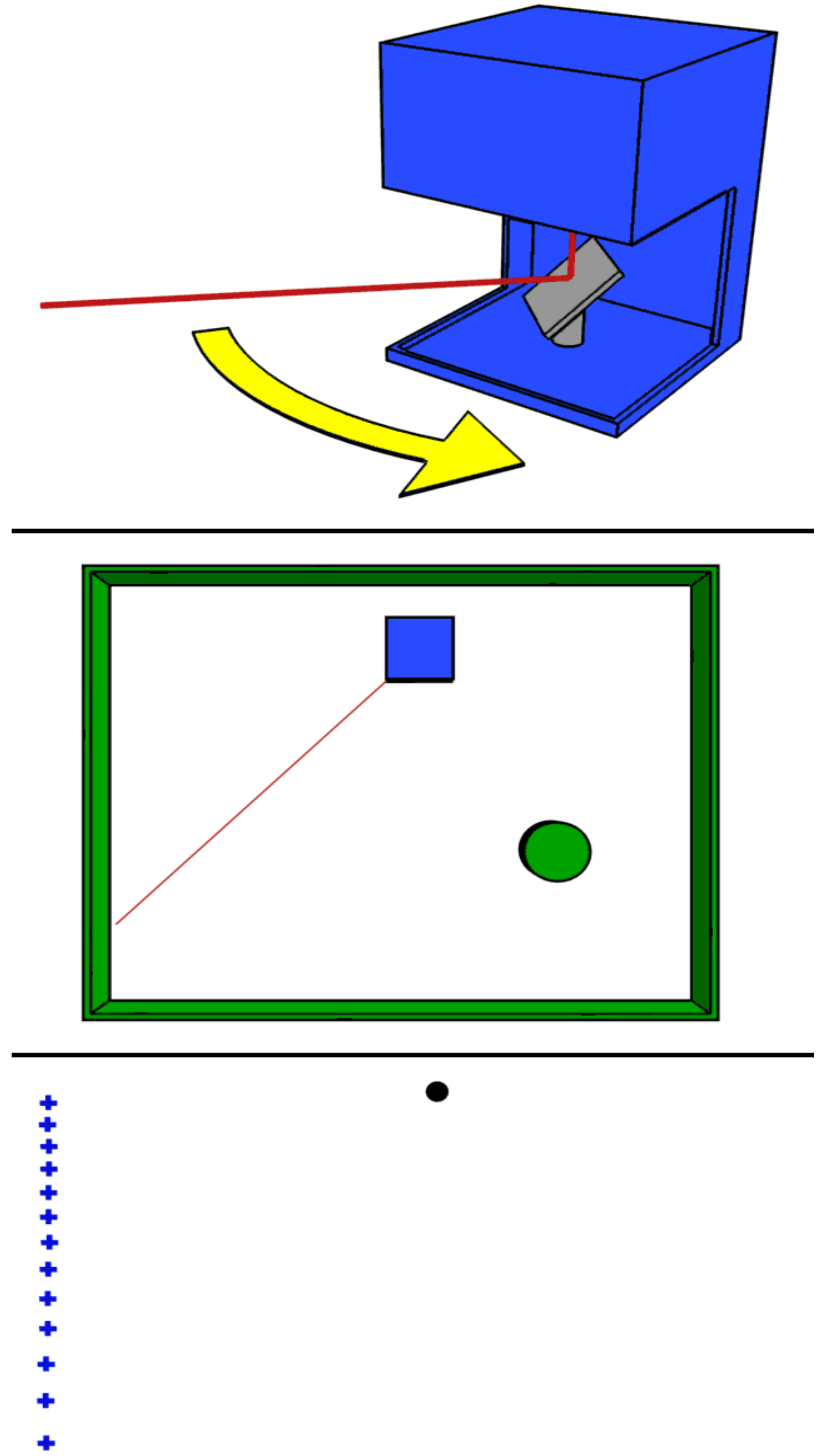
Source: https://icon-library.net/icon/proximity-icon-6.html

Source: https://www.finoit.com/blog/top-15-sensor-types-used-iot/

Sensors

Distance sensors:

E.g. LiDAR Sensors



LiDAR = Light Detection and Ranging

Sensors

Pressure sensors

Source: https://www.123rf.com/profile_vectori1

- Function: sense pressure and converts it into electric signal
- Often used to check if pressure deviates from standard range
- Useful in manufacturing
- Useful in maintenance / monitoring of whole water systems and healting systems, as it is easy to detect any fluctuation or drops in pressure

Source: https://www.finoit.com/blog/top-15-sensor-types-used-iot/

Sensors

Water quality sensors

WATER QUALITY SENSOR

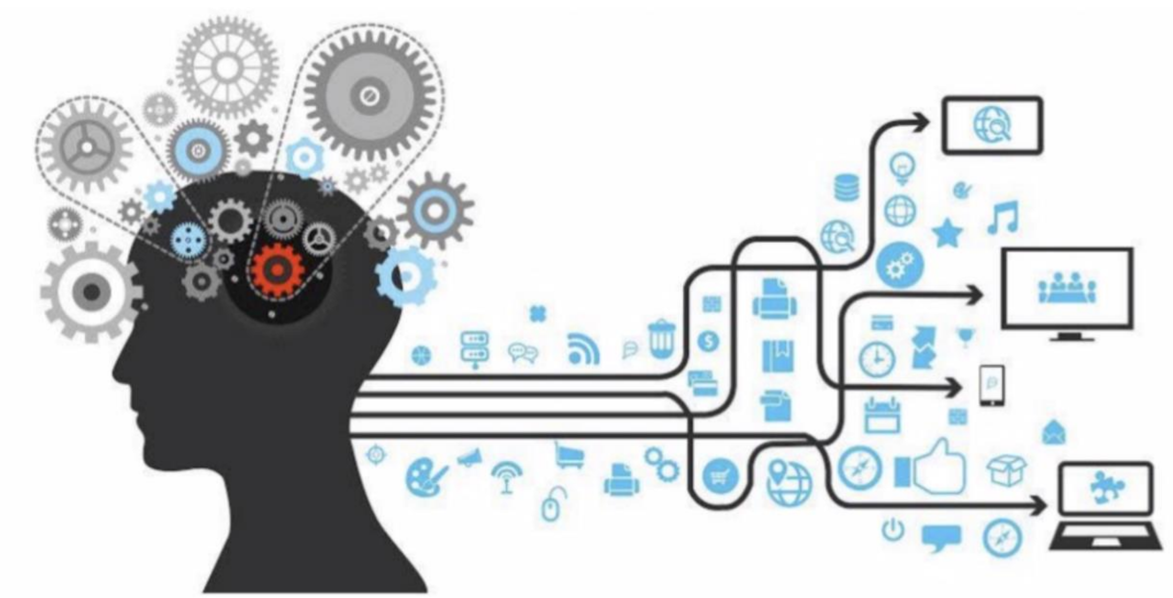
Source: https://stock.adobe.com/sg/contributor/207708434/anton-shaparenko

- Function: monitor water quality and ion
- Chlorine residual sensor: measure chlorine residual
- Total organic carbon sensor: measure organic element in water
- Turbidity sensor: measure suspended solids in water, typically used in river
- pH sensor: measure pH level in water

Source: https://www.finoit.com/blog/top-15-sensor-types-used-iot/

More than data

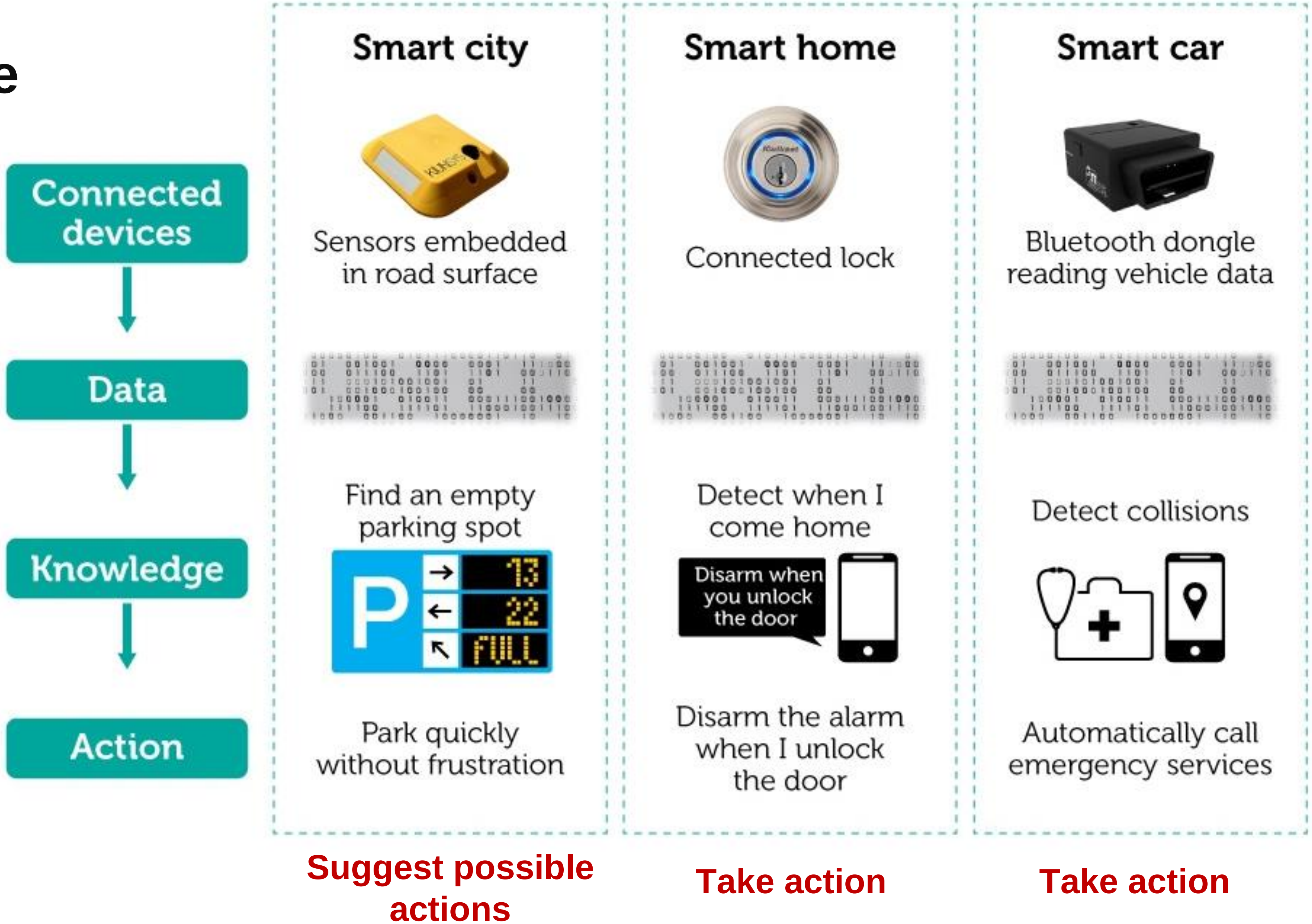
Intelligent sense making



Source: https://www.slideshare.net/muralidhar9s/data-analytics-for-iot

- Signals are just ….. numbers
- Need to extract useful information from signal - making sense out of the signal
- Understand the underlying events that produce the signals, then make **prediction, or take action, or suggest possible actions**
- Create values for user and customer

Value is created by making sense of data



Source: vmob.me/IoT

Apple watch leading to actionable insights

Source: https://www.youtube.com/watch?v=b_96eFGwrOk

Individual exercise (15~20 mins)
Suggest an example on intelligent sense making.
Avoid re-use any examples given in the lecture notes.
Refer to the given "use case exercise" template with some examples in it.

You are to describe clearly:
(a) how the sensor(s) is used/deployed and what is the acquired signal,
(b) what are the findings you are looking for from the signal
(c) what are the possible actions after the finding

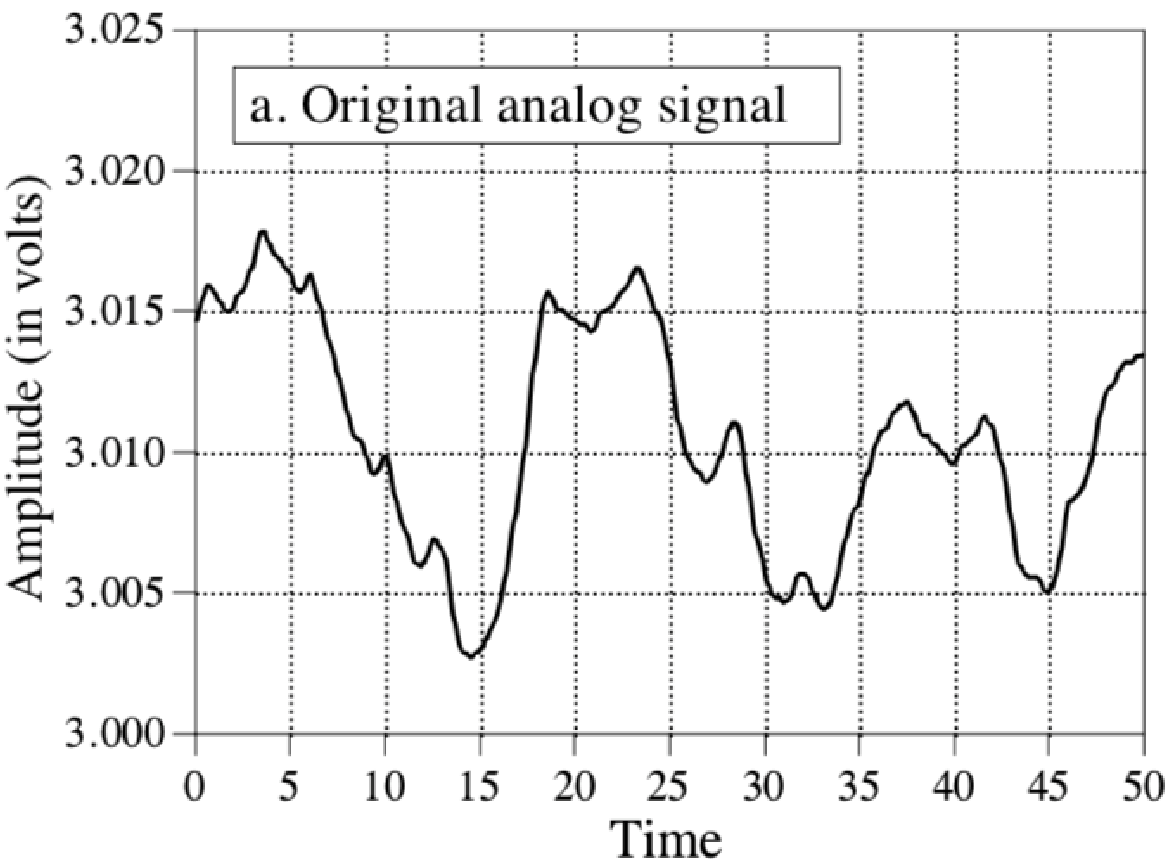
Fundamentals of signals

Signal as function

Real - Real

- Continuous function of real indepedent variables
- 1 dimensional: $z = f(x)$
- 2 dimensional: $z = f(x, y)$

$$z, x, y \in R$$



Limitation in detecting the signals in real-time in the actual situation!

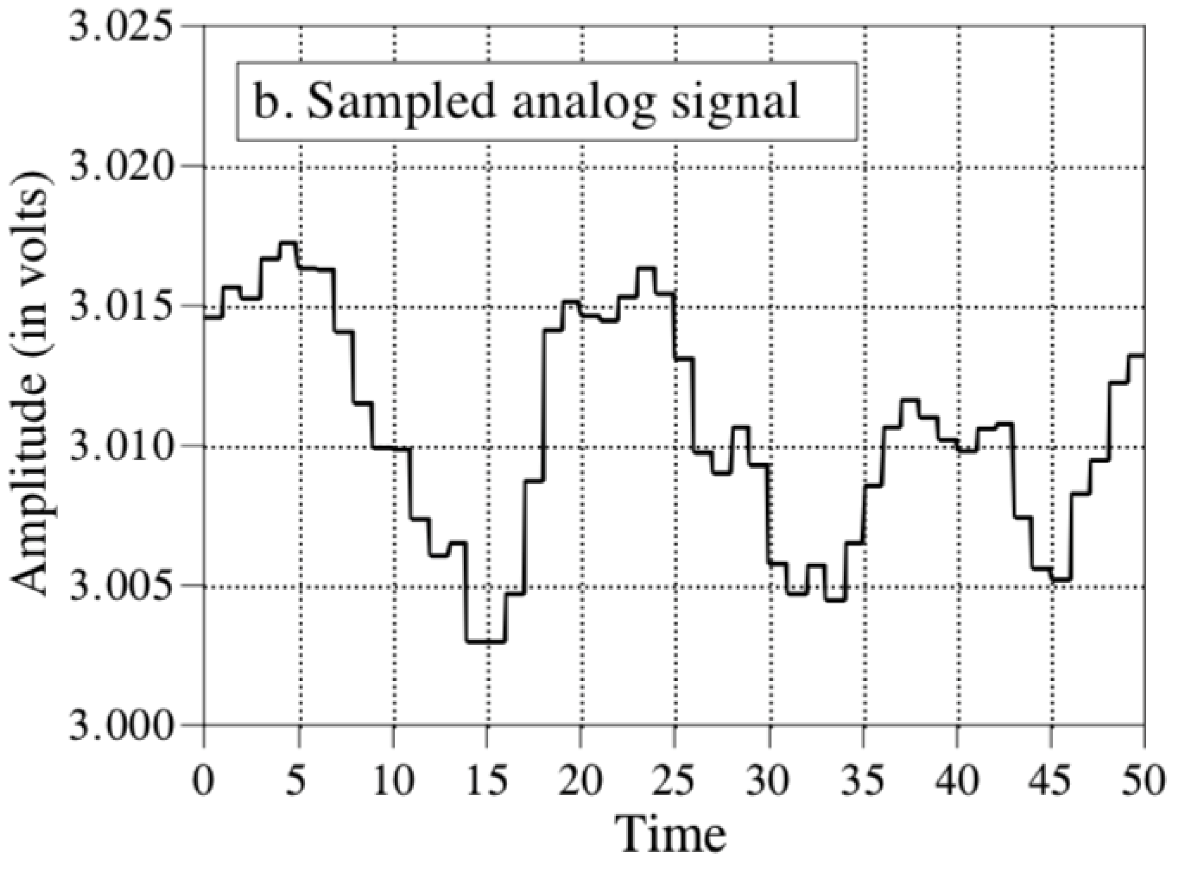
Source: "The scientist and engineer's guide to digital signal processing", by Steven W. Smith

Signal as function

Real - Discrete

- Continuous function of real indepedent variables
- 1 dimensional: $z = f[i]$
- 2 dimensional: $z = f[i, j]$

$$z \in R \qquad i, j \in Z^+$$

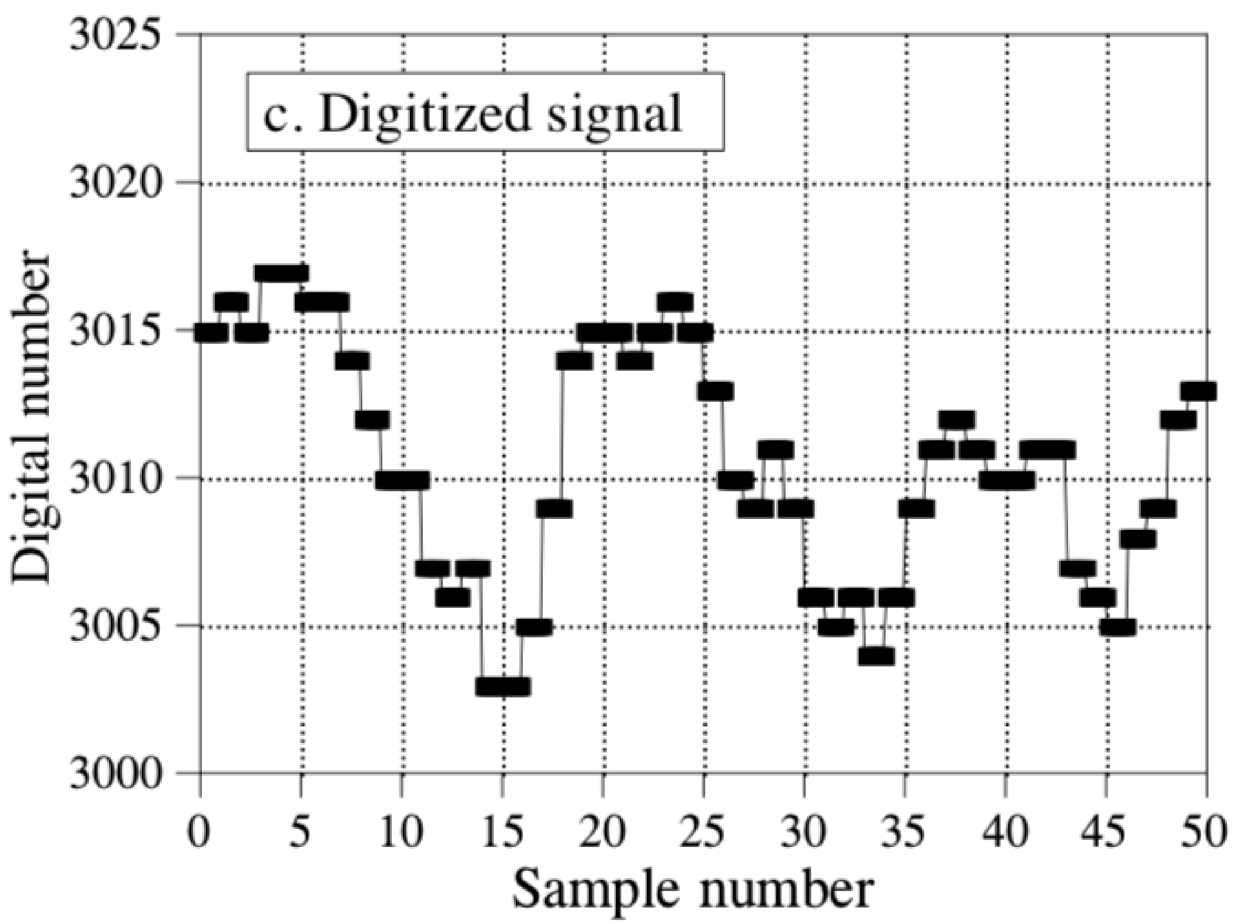


Practical situation: Collecting the signals in specific time intervals

Source: "The scientist and engineer's guide to digital signal processing", by Steven W. Smith

Signal as function
Discrete - Discrete

Sampled analog readings is relatable and can be converted to digital signals



Source: "The scientist and engineer's guide to digital signal processing", by Steven W. Smith

- Continuous function of real indepedent variables
- 1 dimensional: $z = f[i]$
- 2 dimensional: $z = f[i, j]$

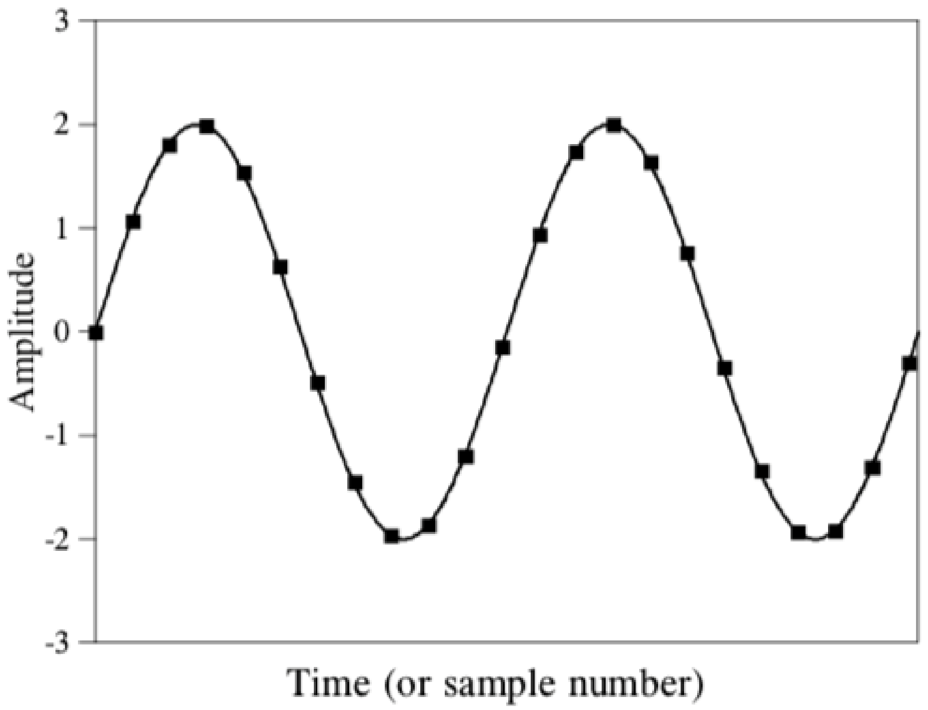
$$z \in Z \qquad i, j \in Z^{+}$$

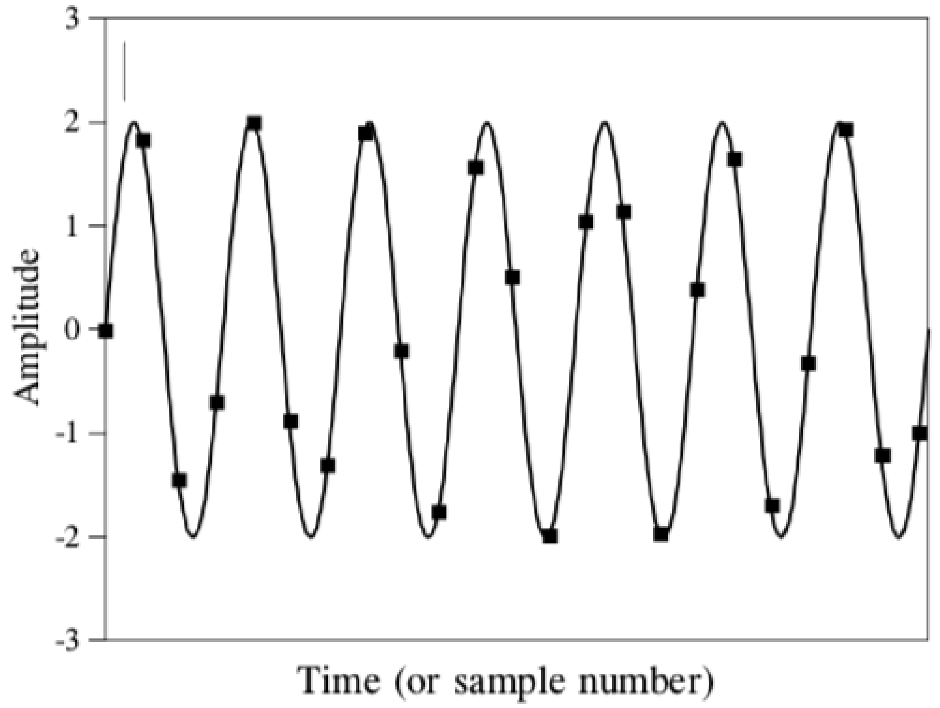
Signals from real world supposed to be continuous and smooth, but limitations of sensor devices can only enable us to collect data at certain time intervals

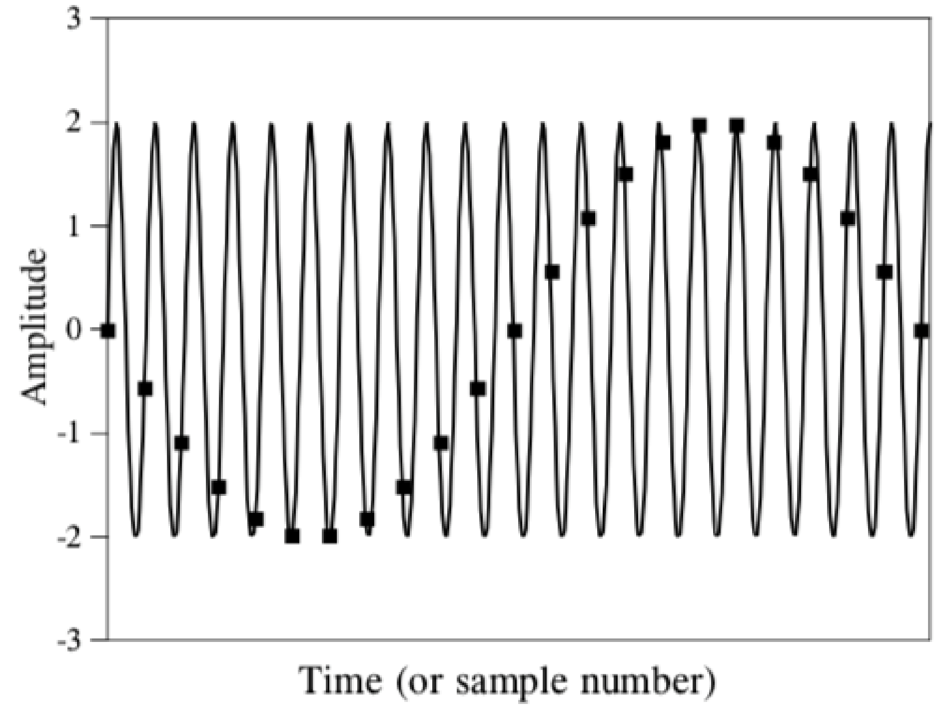
Sampling

Sampling rate is same for all graphs!

Highlights importance of choosing the correct sampling rate. How to ensure original signals are retained??

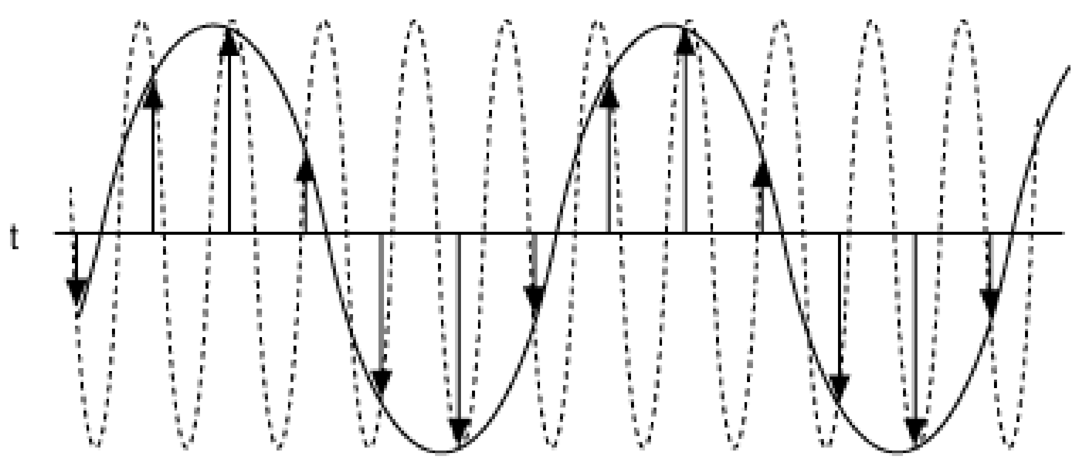






Source: "The scientist and engineer's guide to digital signal processing", by Steven W. Smith

Nyquist-Shannon theorem



- Suppose the highest frequency component, in hertz, for a given analog signal is f_{max}.

- According to the Nyquist-Shannon theorem, the sampling rate must be **at least $2f_{max}$, or twice the highest analog frequency component.**

- If the sampling rate is less than $2f_{max}$, some of the ***highest frequency components*** in the analog input signal will not be correctly represented in the digitized output

Source: http://www.writeopinions.com/nyquist-ndash-shannon-sampling-theorem

Source: https://whatis.techtarget.com/definition/Nyquist-Theorem

Sampling

Under Sampling Example

Source: https://www.howitworksdaily.com/question-of-the-day-why-do-car-wheels-look-like-they-are-spinning-backwards-at-high-speed/

- Wheel of a forward-moving car is seemed rotating backward when by right it should rotate forward
- Can be explained by under-sampling. If movie is filmed at 20 frames per second, but wheel rotates more than 12 times per second, under-sampling likely creates the impression of backward rotation

Question

- A telephone company digitize voice by assuming a maximum frequency of 4000 Hz
- What should be the sampling rate?

Question

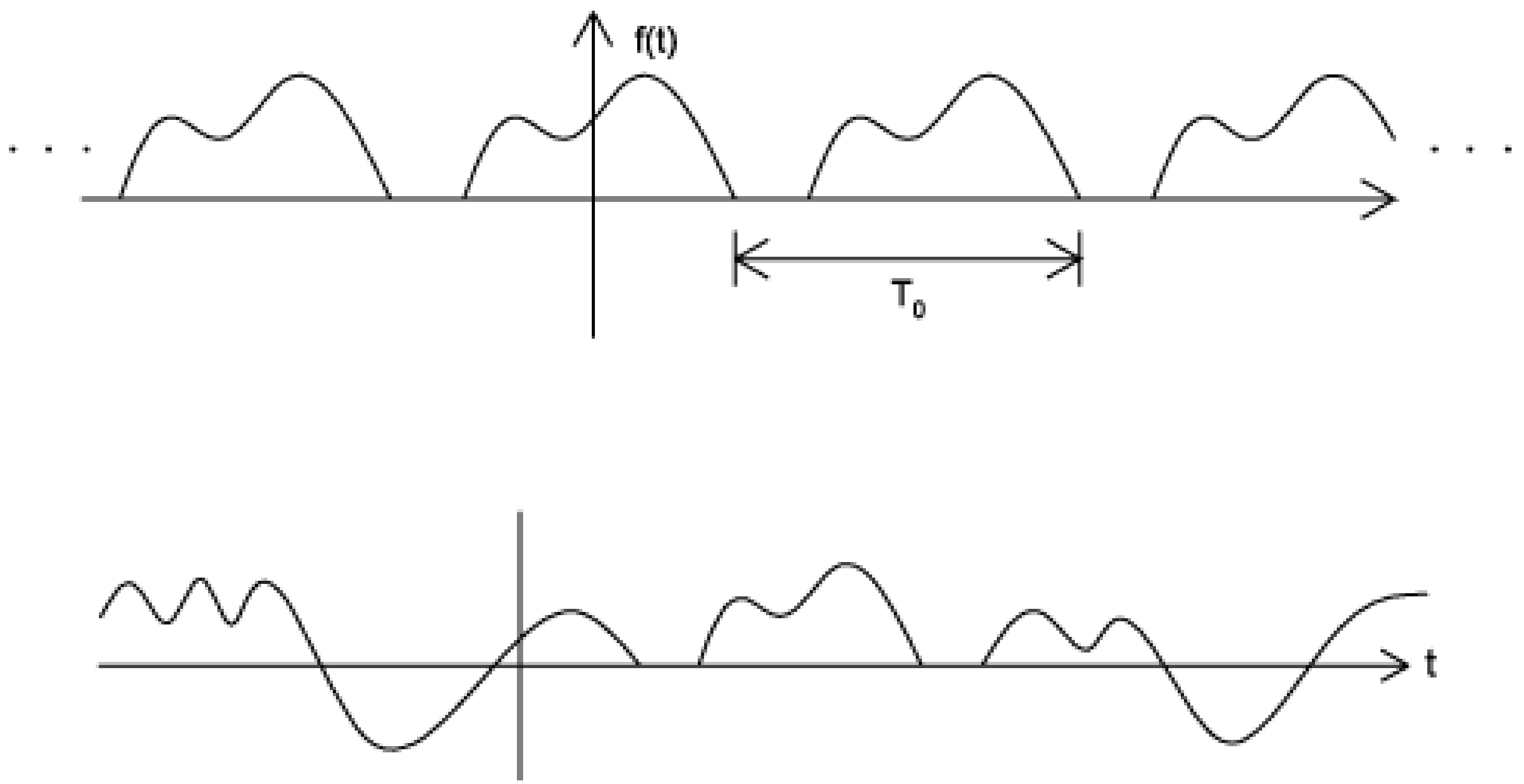
- A complex signal has a bandwidth of 200 kHz.
- What is the minimum sampling rate for this signal?

Signal types

Periodic | Aperiodic

- A signal is periodic if there exists a positive constant T_0 such that

$$f(t + T_0) = f(t) \quad \forall t$$

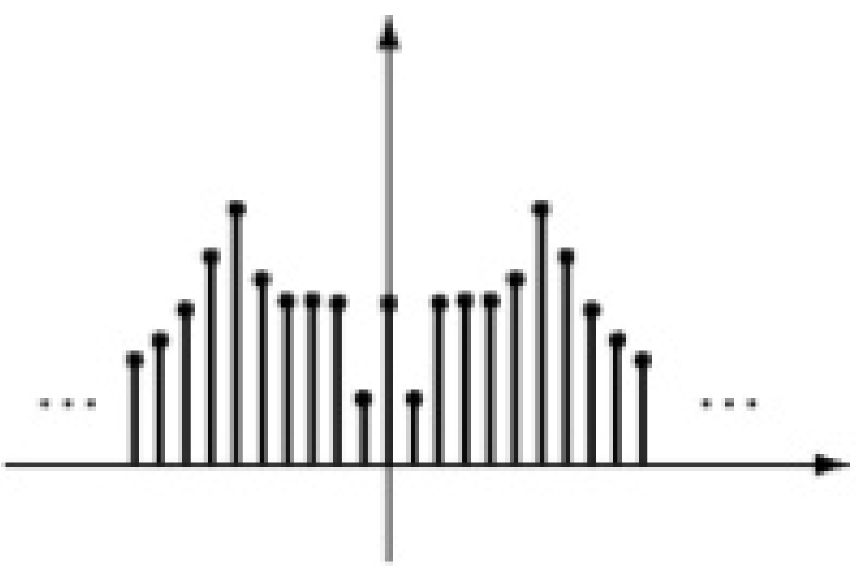


Source: http://pilot.cnxproject.org/content/collection/col10064/latest/module/m10057/latest

Signal types
Even | Odd

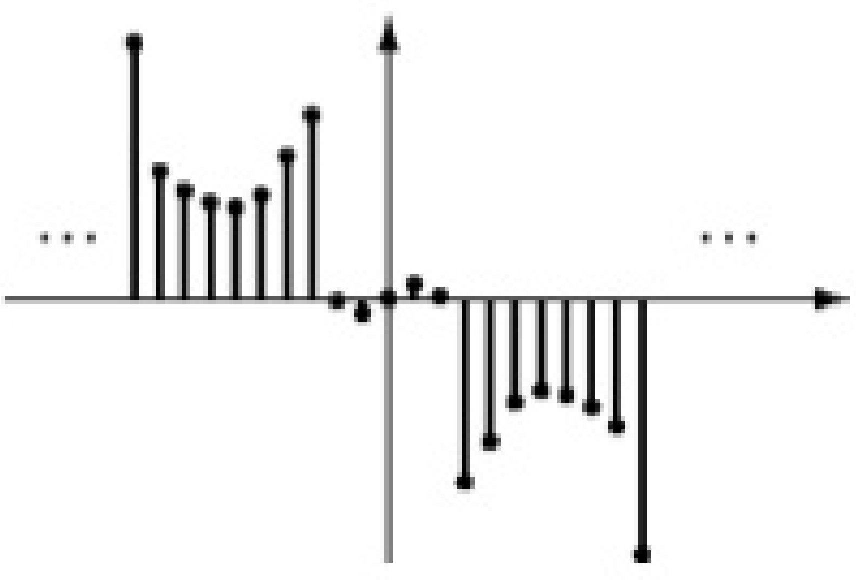
- Even signals can be easily spotted as they are symmetric around vertical axis

$$f(t) = f(-t)$$



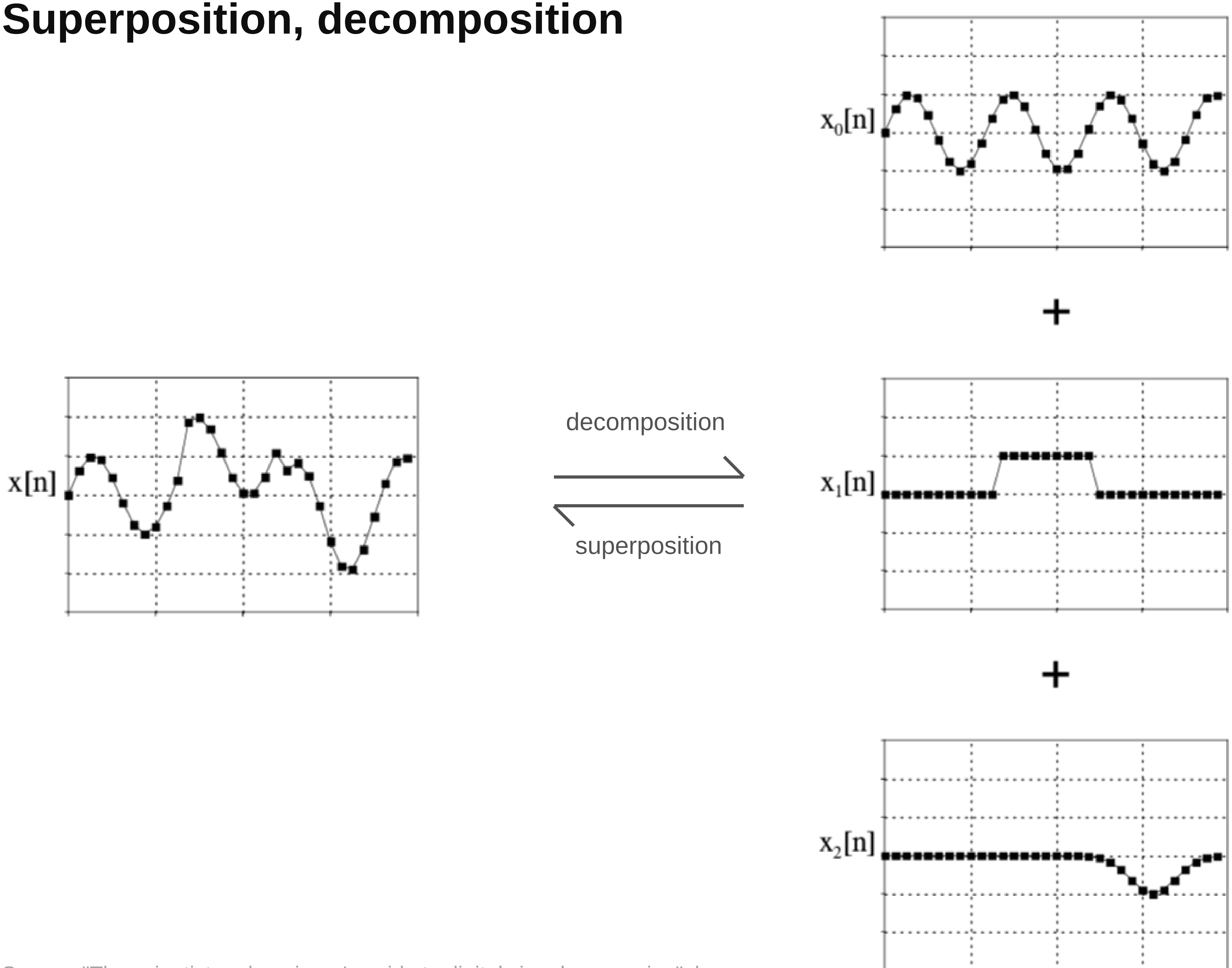
- An odd signal is a signal such that

$$f(t) = -f(-t)$$



Source: https://www.slideshare.net/mihirkjain/ch1-46505880

Superposition, decomposition



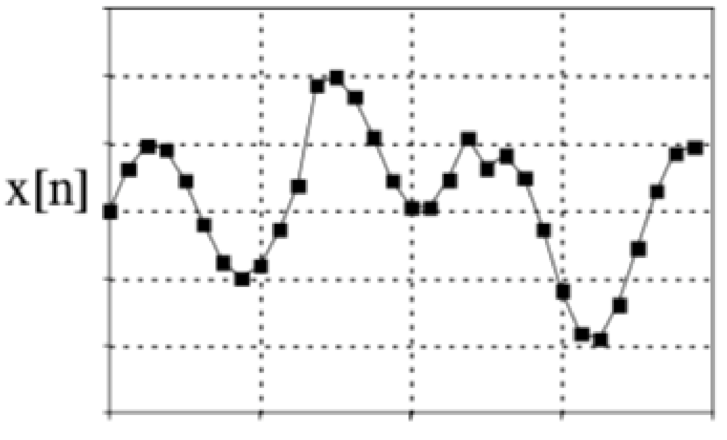
Source: "The scientist and engineer's guide to digital signal processing", by Steven W. Smith

Superposition, decomposition

- When dealing with linear systems, signals can only be combined by scaling and adding, no signal-signal multiplication

- Synthesis: The process of combining signals through scaling and addition

- The beauty of decomposition: Instead of trying to understand how complicated signals behave as a whole, we study the individual components, which are simpler signals



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