

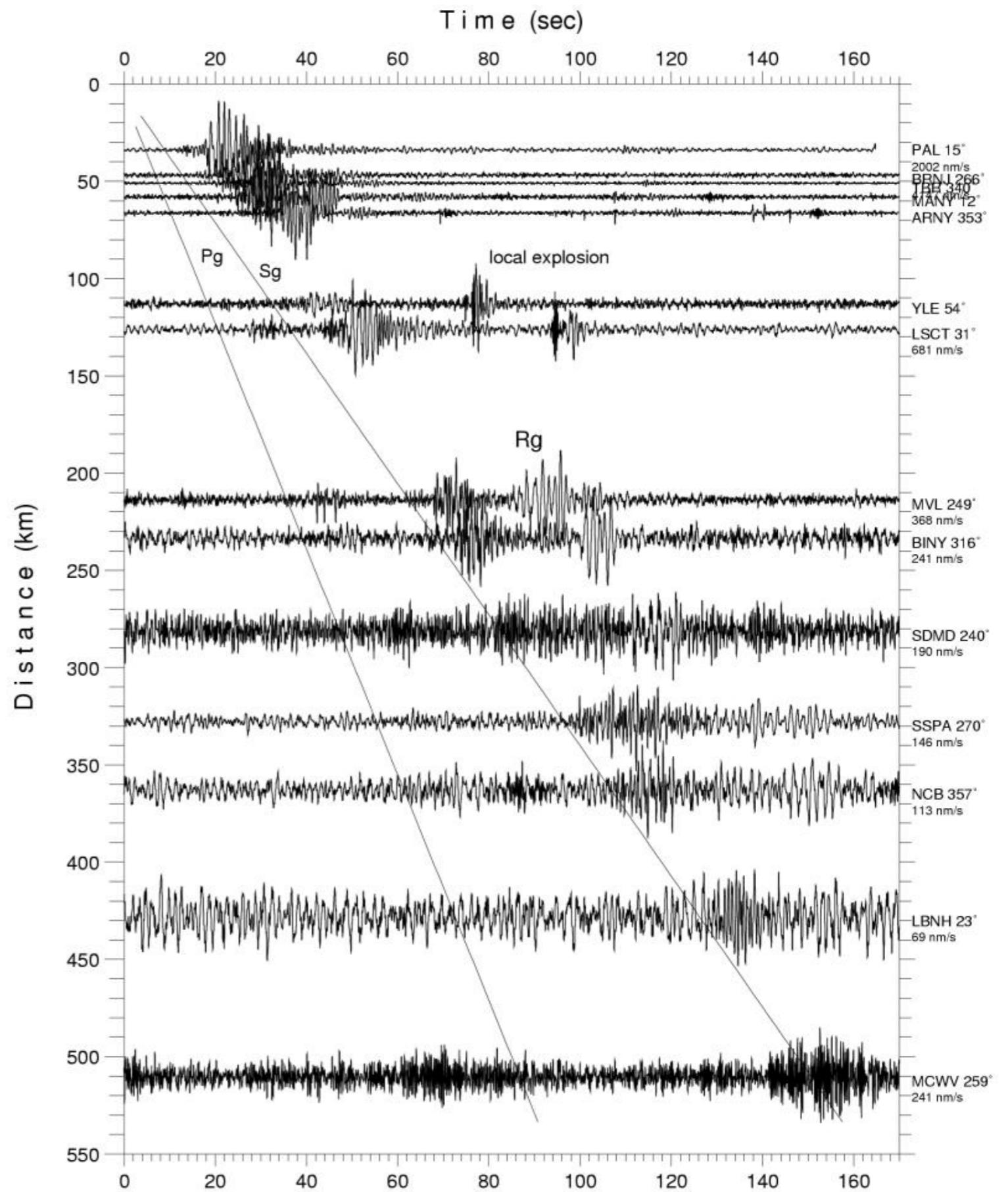
# Introduction to signals and sense making

by Dr. Tan Jen Hong

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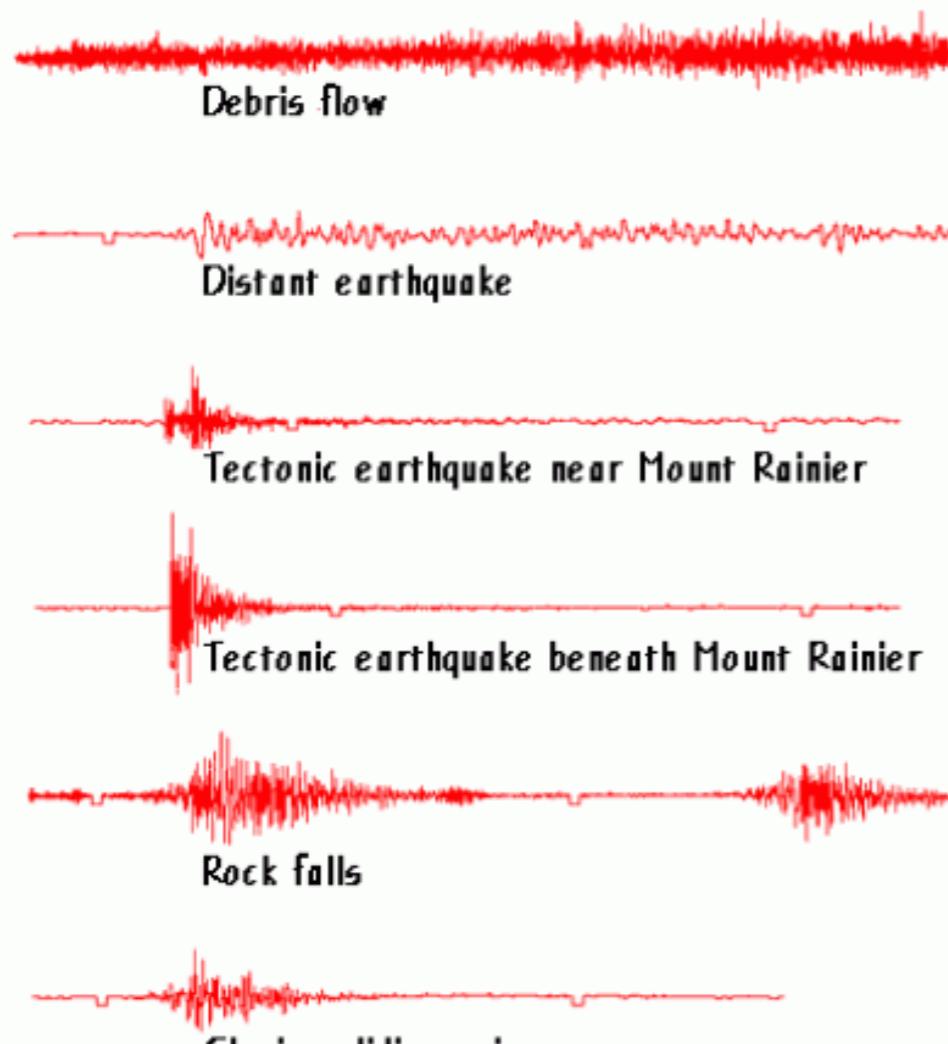
**Let's take at a look at some signals**

# Signals



Source: [http://911research.wtc7.net/mirrors/guardian2/wtc/seismic/WTC\\_PENT\\_KIM.htm](http://911research.wtc7.net/mirrors/guardian2/wtc/seismic/WTC_PENT_KIM.htm)

# What is signal?

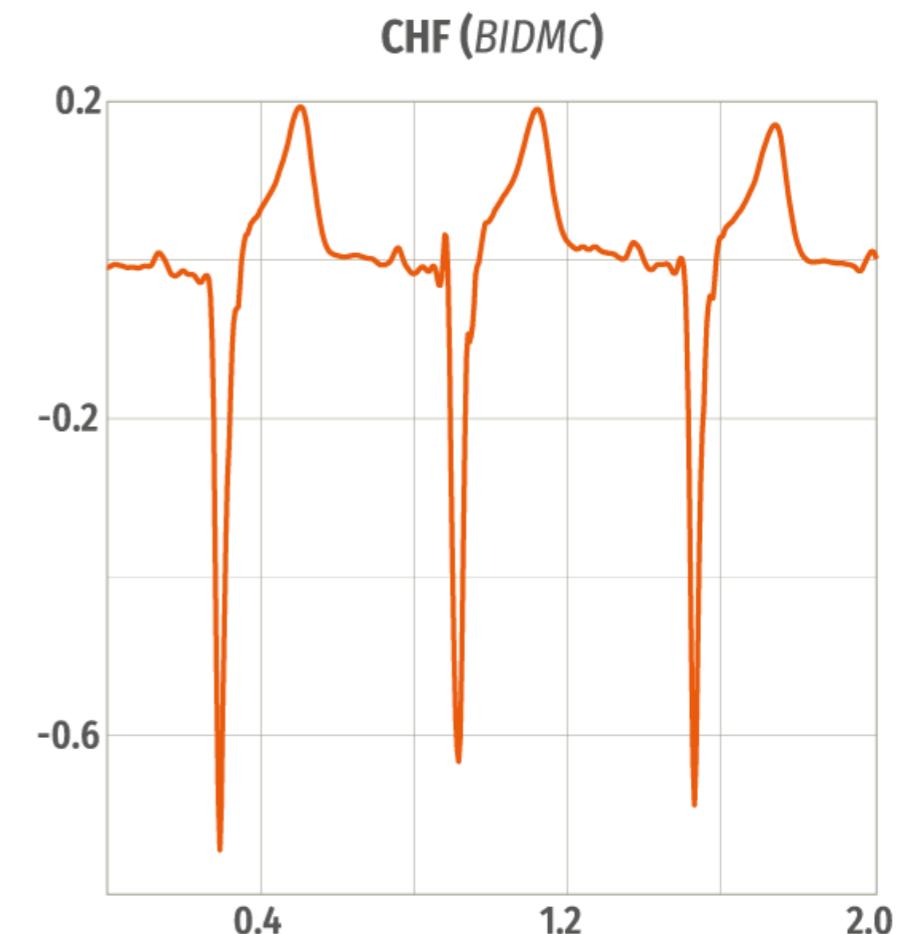
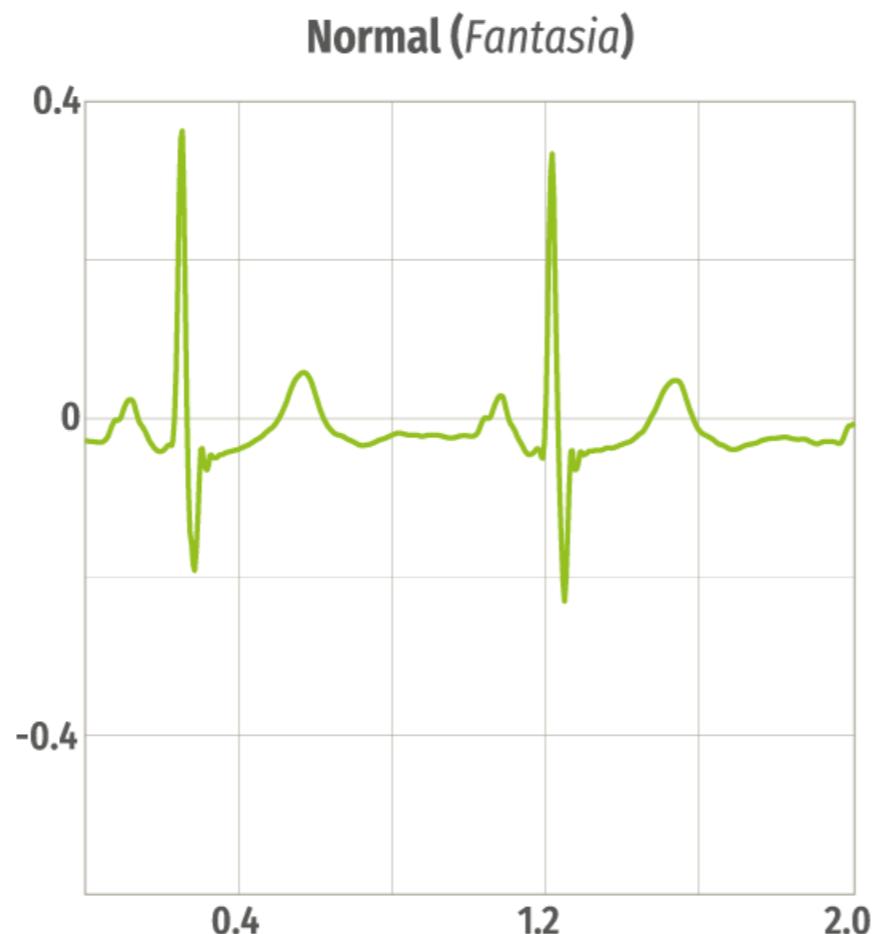


- In signal processing, signal is a function that conveys information about a phenomenon
- A signal can also be defined as an observable change in a quantity (property)
- Any physical quantity that exhibits variation in space or time can be a signal

Source: [https://volcanoes.usgs.gov/vhp/seismic\\_signals.html](https://volcanoes.usgs.gov/vhp/seismic_signals.html)

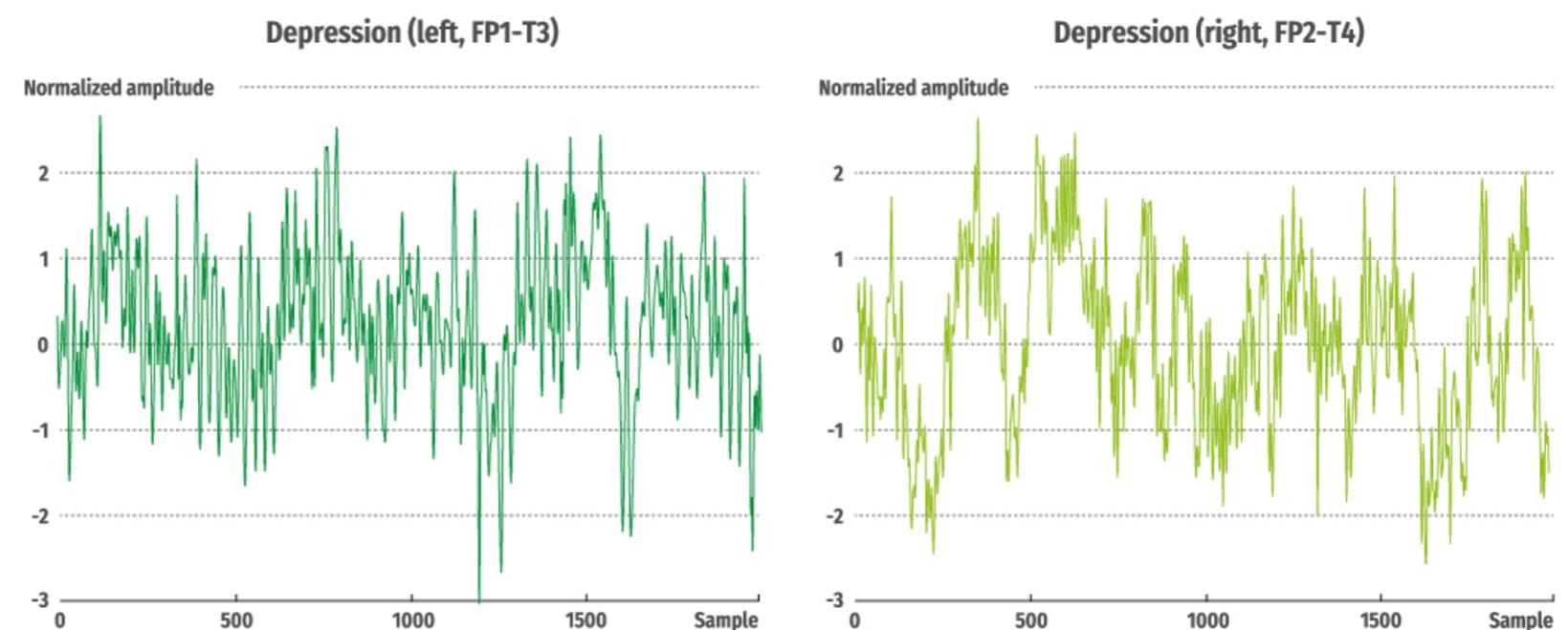
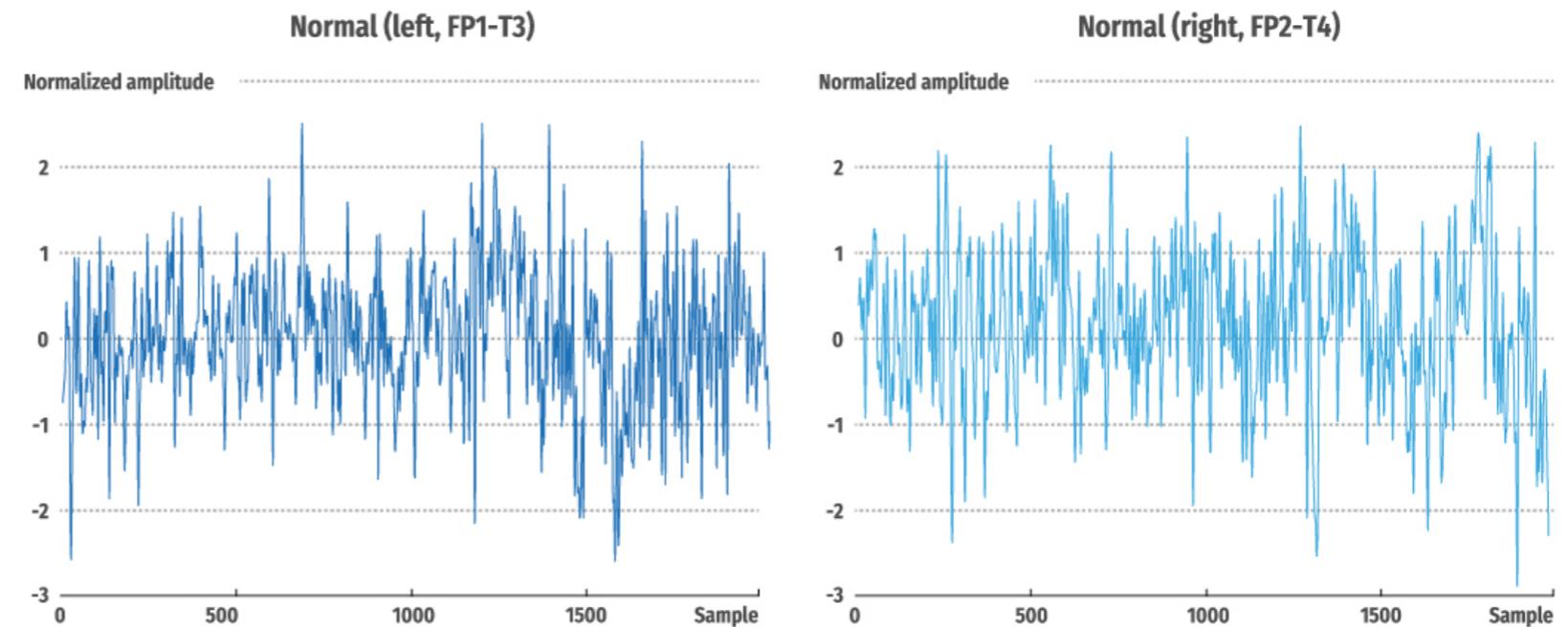
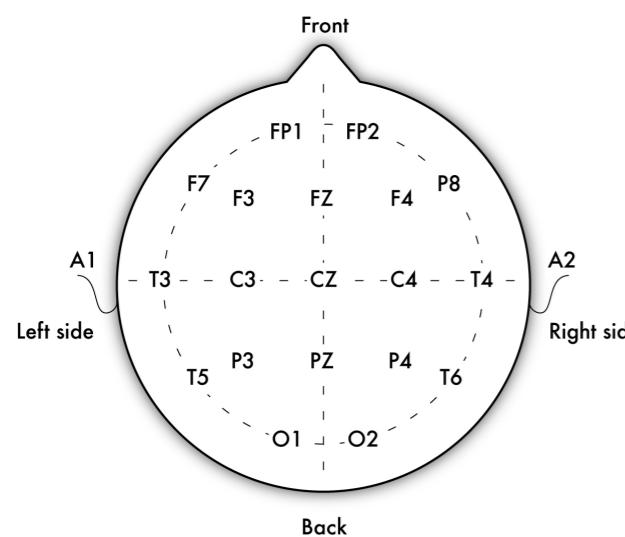
# Signals

Example: ECG



# Signals

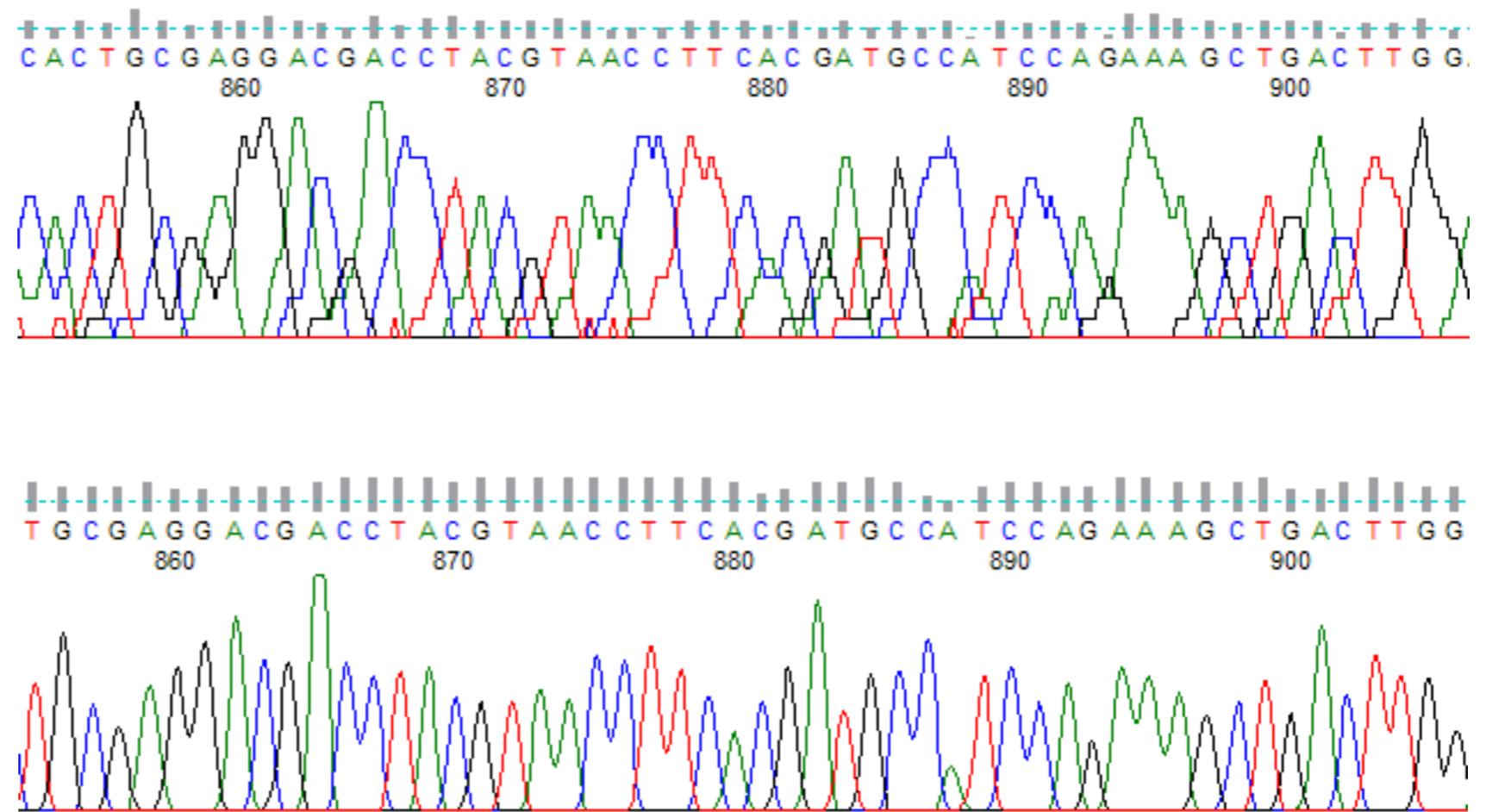
Example: EEG



# Signals

Example:

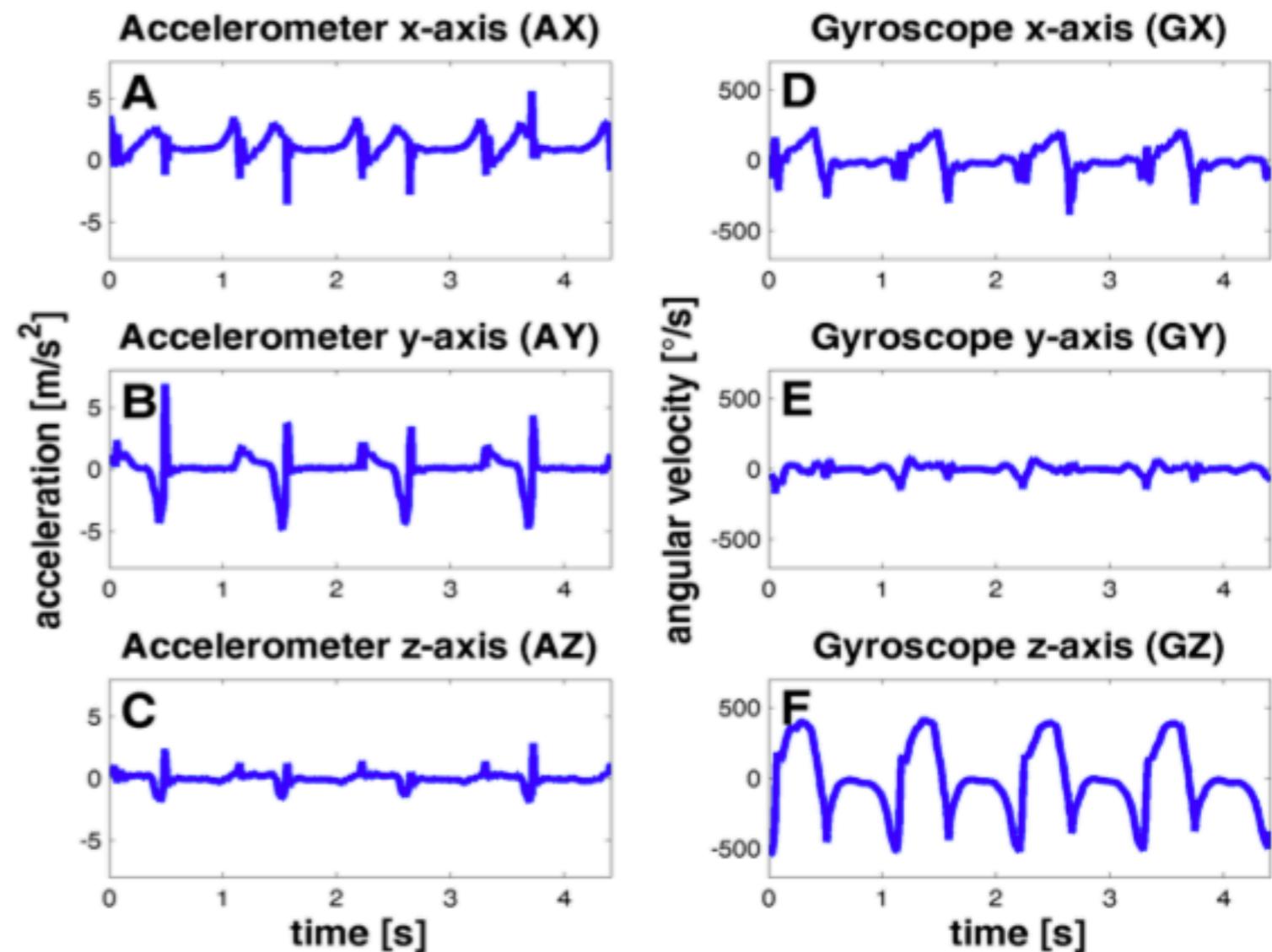
Electropherogram



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

# Signals

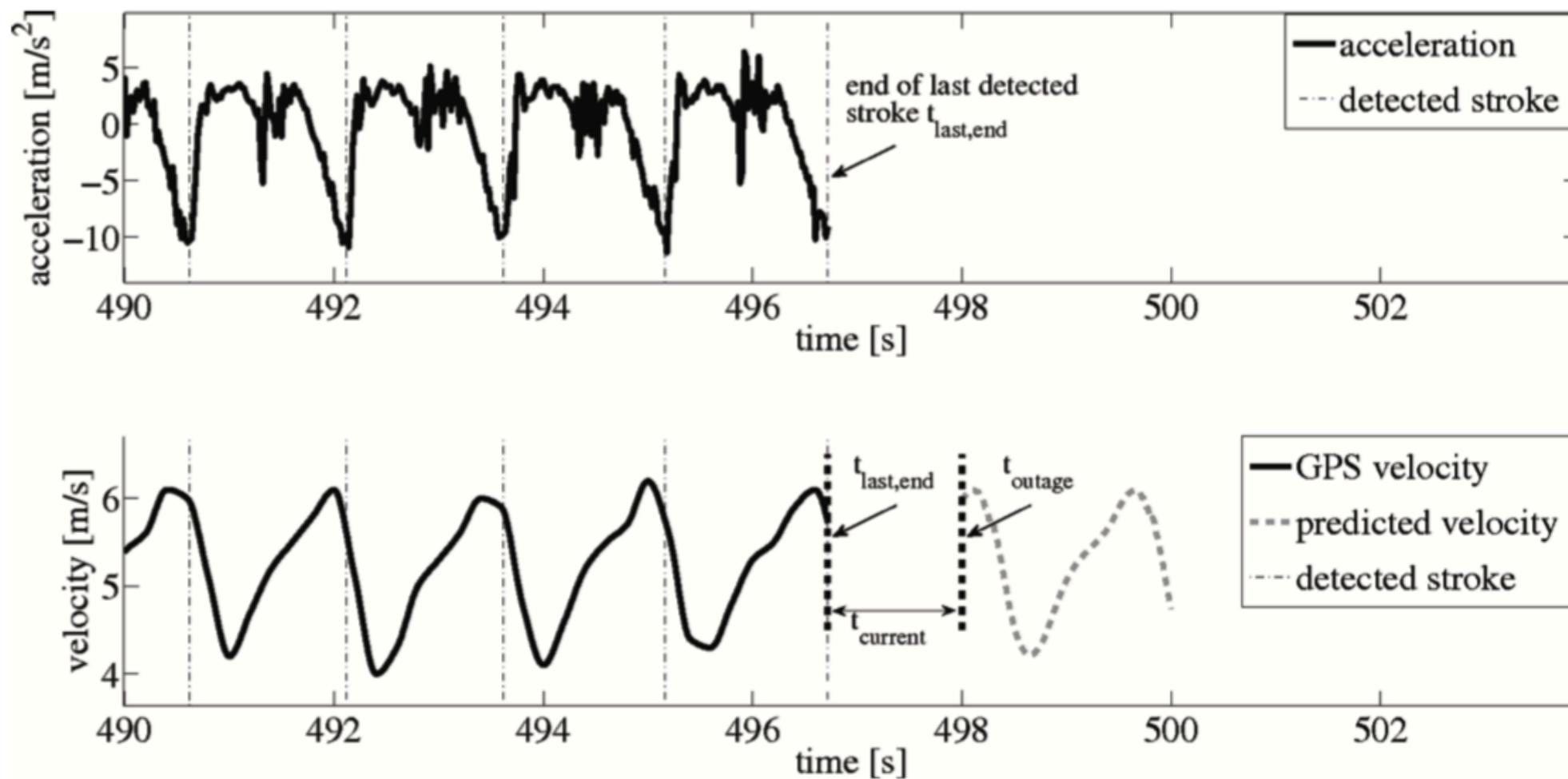
Example: 4 walking strides from an elderly



Source: doi:10.3390/s150306419

# Signals

Example: Acceleration and velocity in rowing



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’



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



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

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

# Sensors

## Pressure sensors

- 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 heating systems, as it is easy to detect any fluctuation or drops in pressure



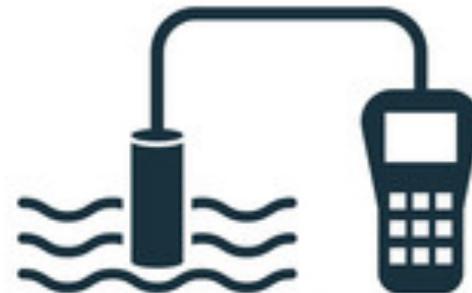
Source: [https://www.123rf.com/profile\\_vectori1](https://www.123rf.com/profile_vectori1)

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

# Sensors

## Water quality sensors

- 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



### WATER QUALITY SENSOR

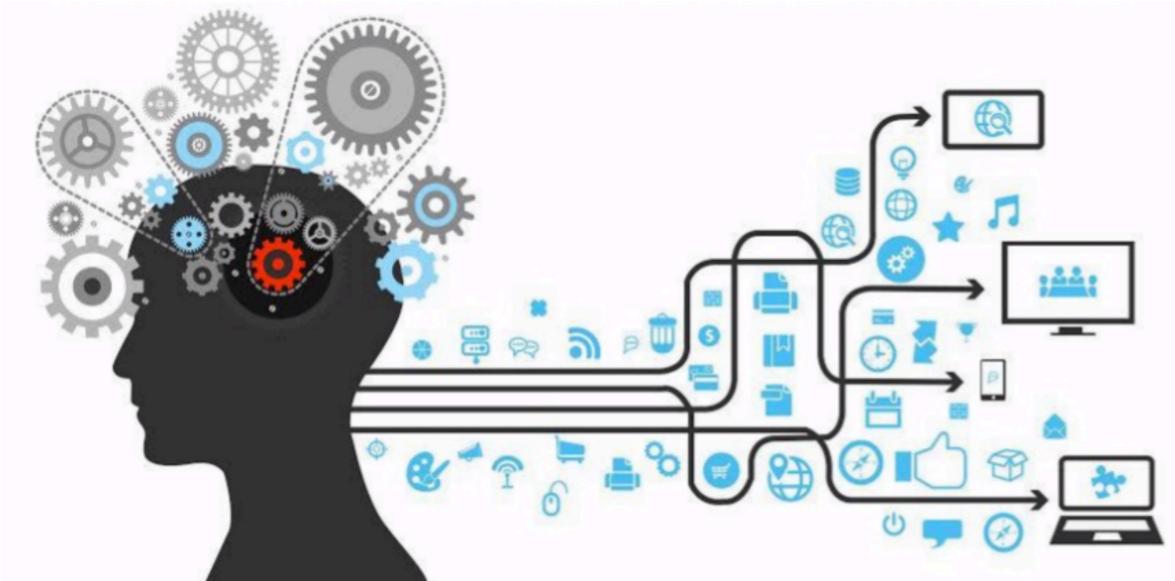
Source: <https://stock.adobe.com/sg/contributor/207708434/anton-shaparenko>

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

# More than data

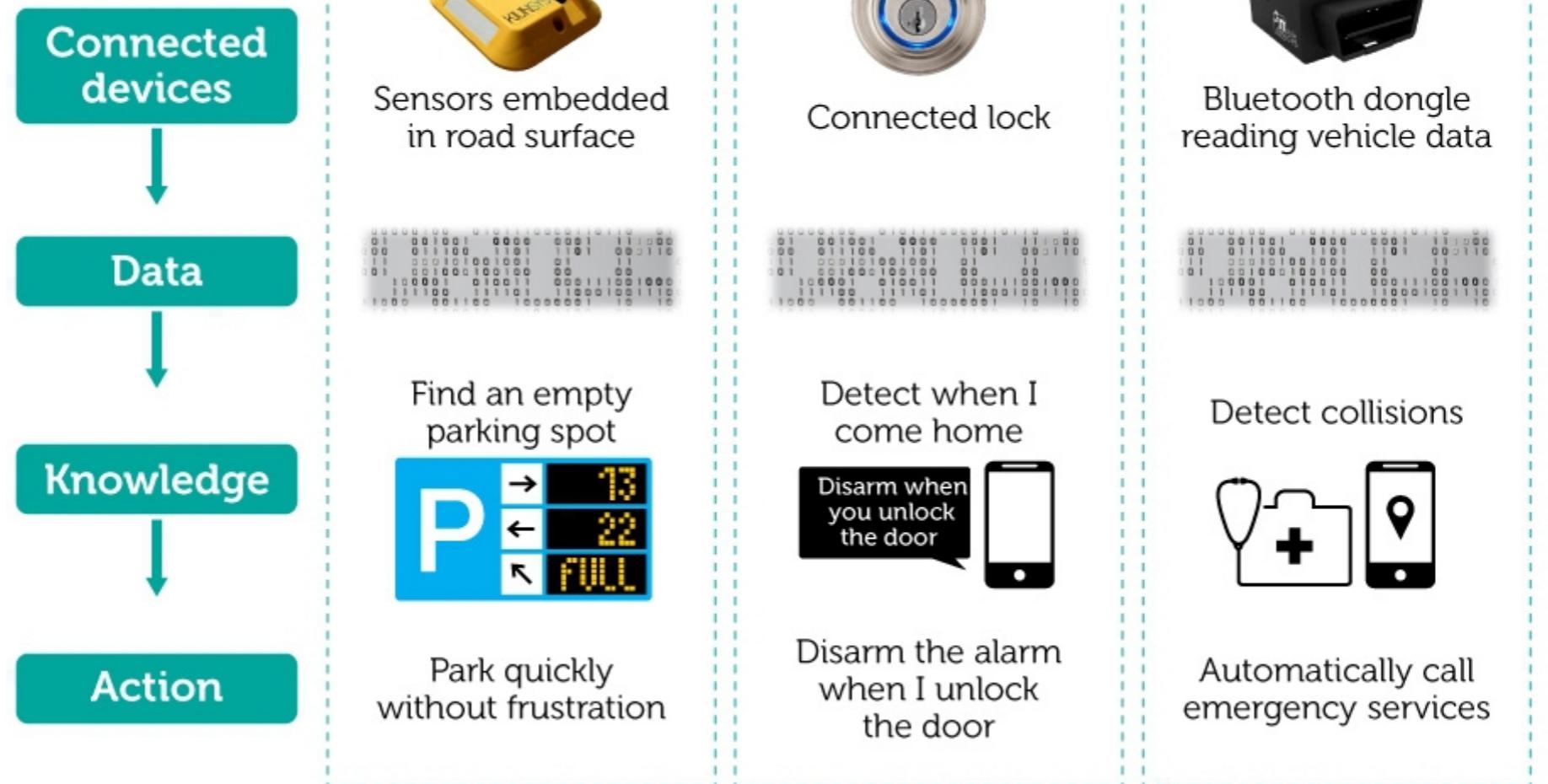
Intelligent sense  
making

- 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



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

# Value is created by making sense of data



Source: [vmob.me/IoT](http://vmob.me/IoT)

# Fundamentals of signals

# Signal as function

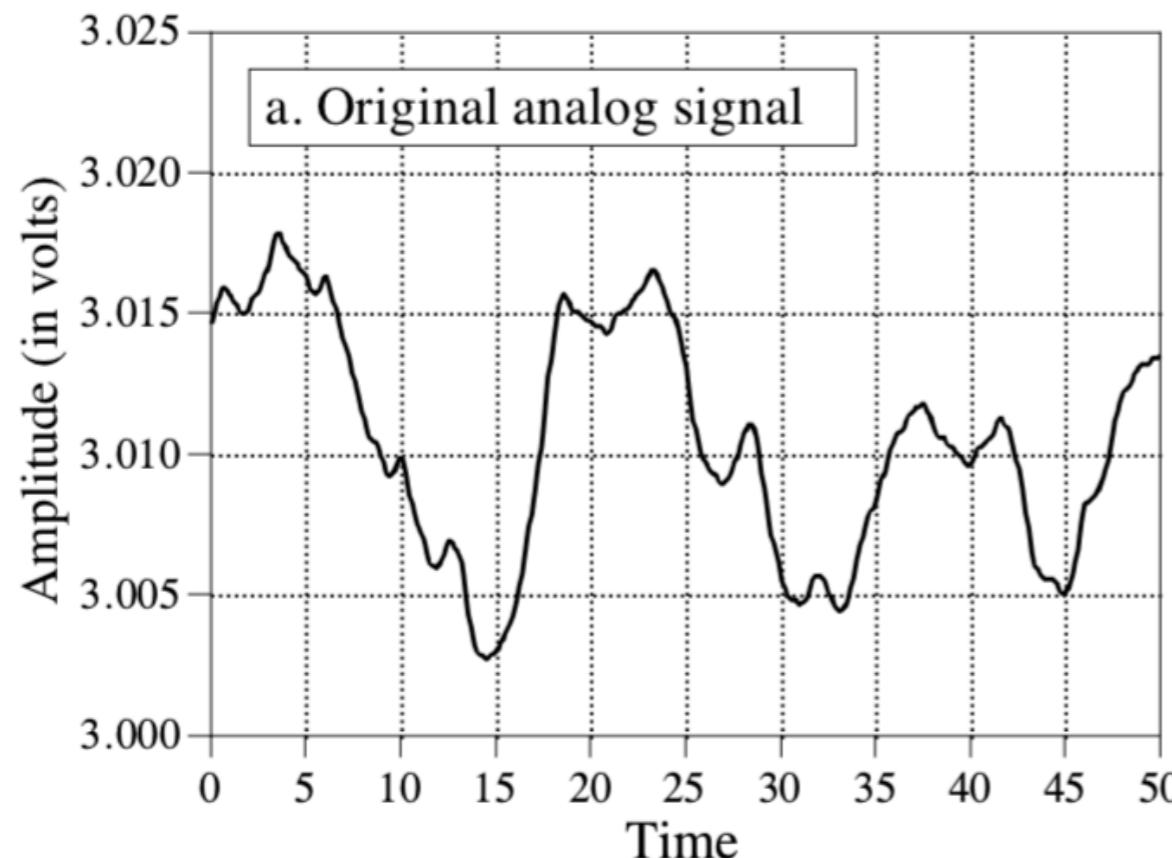
Real - Real

- Continuous function of real independent variables

- 1 dimensional:  $z = f(x)$

- 2 dimensional:  $z = f(x, y)$

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



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

# Signal as function

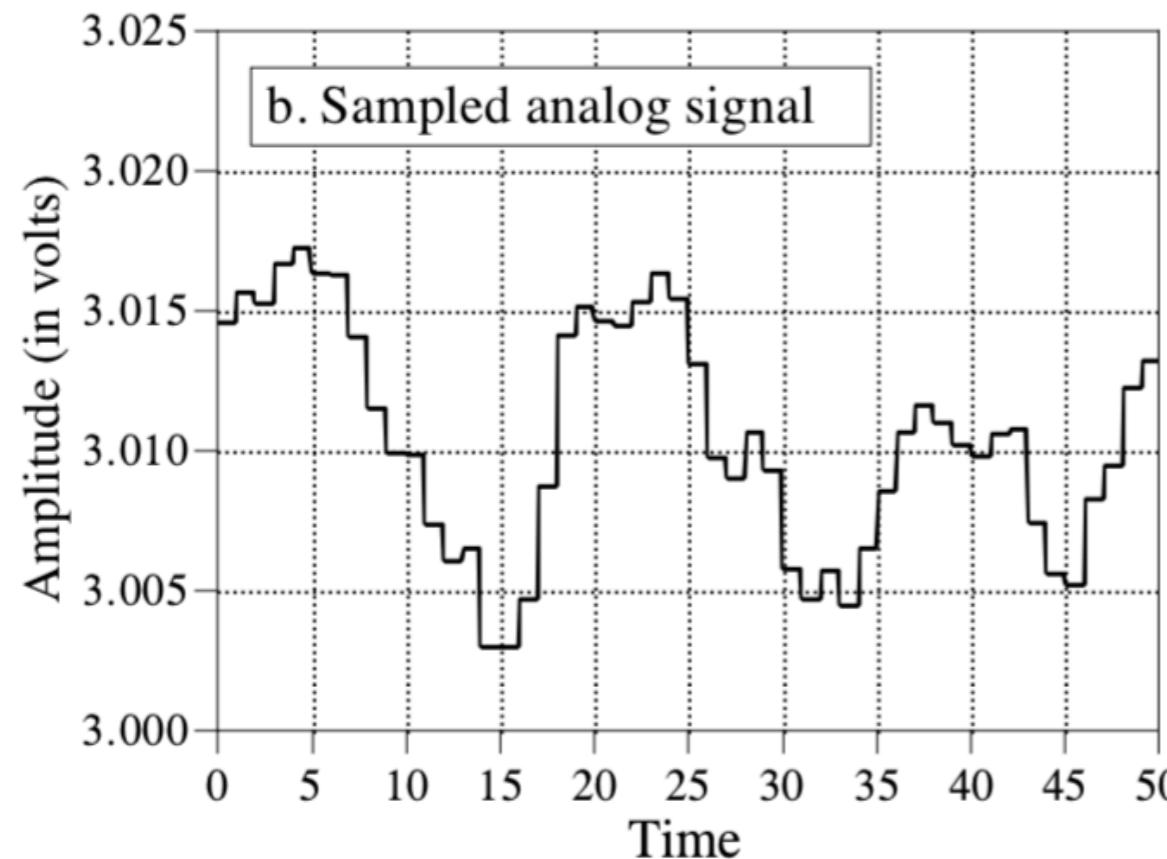
Real - Discrete

- Continuous function of real independent variables

- 1 dimensional:  $z = f[i]$

- 2 dimensional:  $z = f[i, j]$

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



Source: "The scientist and engineer's guide to digital signal processing",  
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# Signal as function

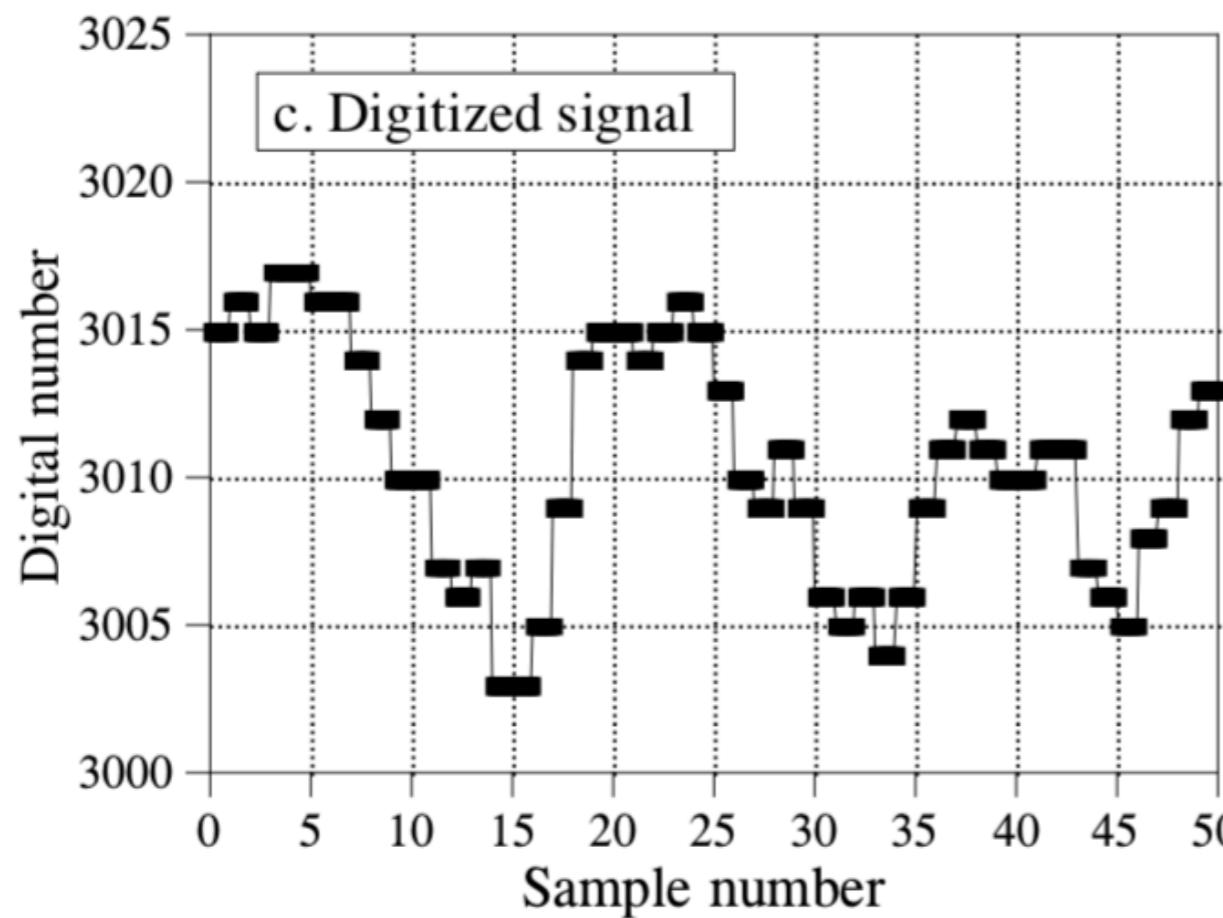
Discrete - Discrete

- Continuous function of real independent variables

- 1 dimensional:  $z = f[i]$

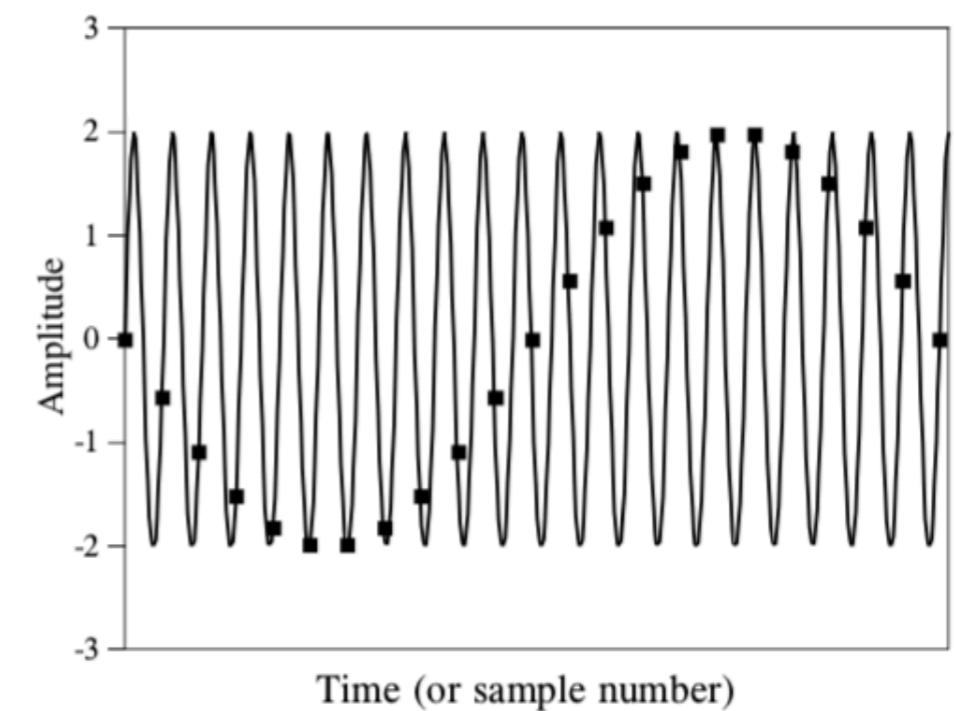
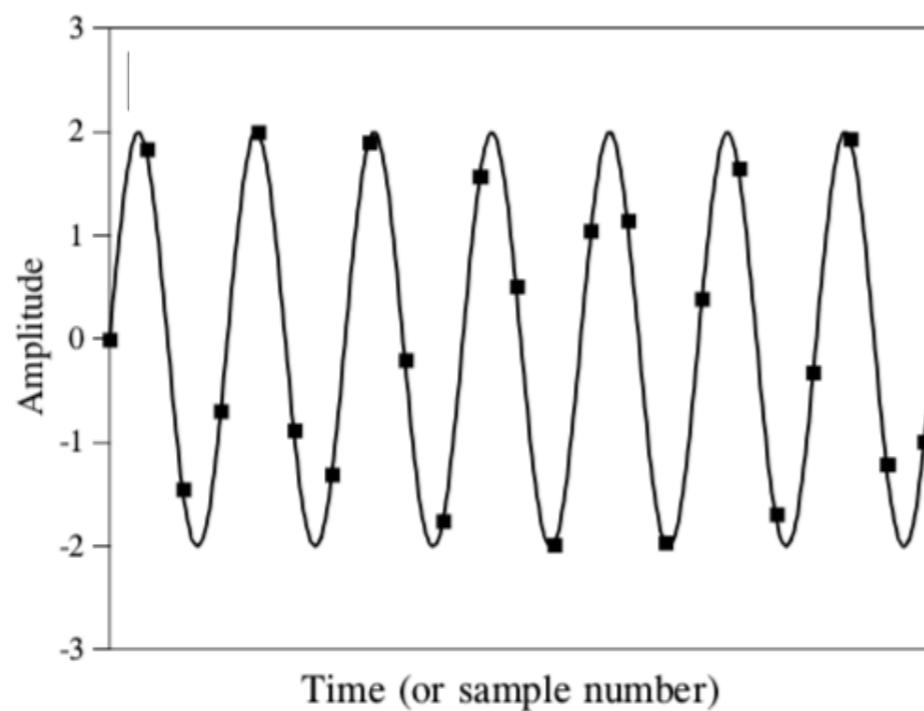
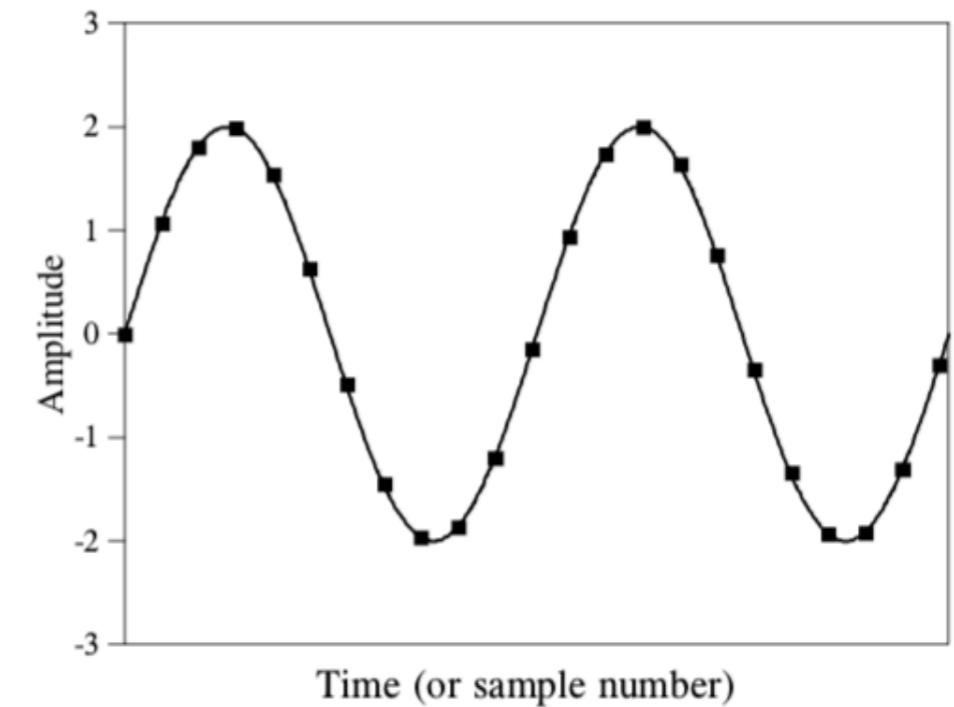
- 2 dimensional:  $z = f[i, j]$

$$z \in Z \quad i, j \in Z^+$$



Source: "The scientist and engineer's guide to digital signal processing",  
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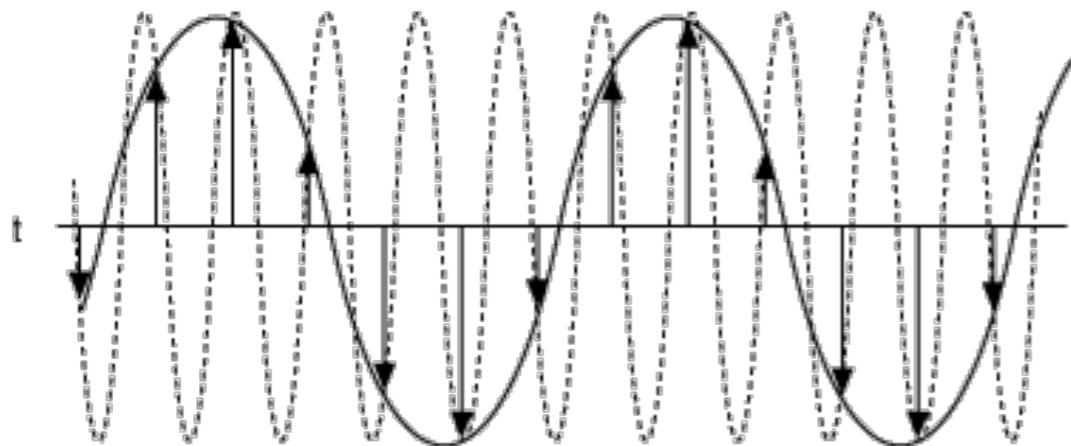
# Sampling



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

## Example

- 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 24 frames per second, but wheel rotates more than 12 times per second, under-sampling likely creates the impression of backward rotation



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

# Question

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

# Question

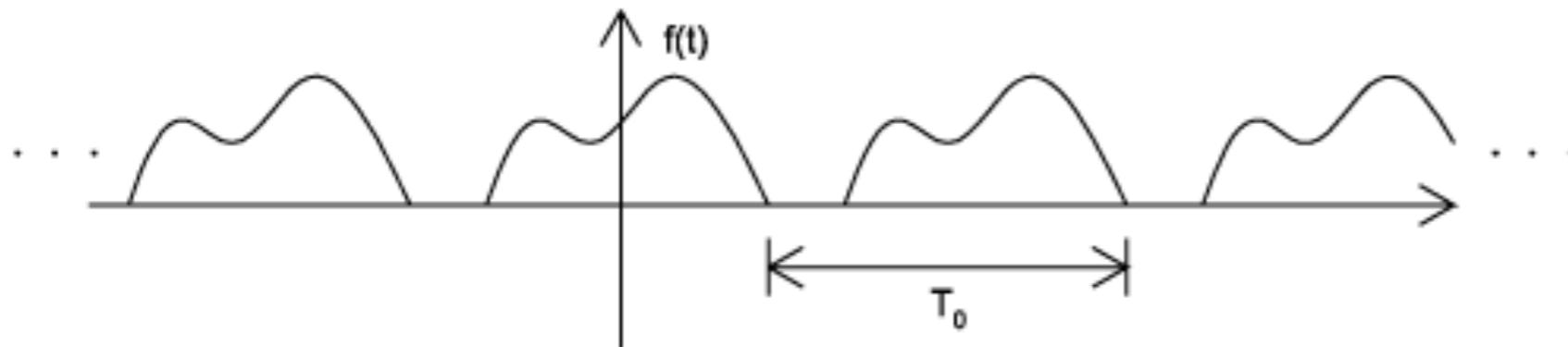
- A complex signal has a bandwidth of 200 kHz.
- What is the minimum sampling rate for this signal?

# Signal types

Periodic | Aperiodic

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

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



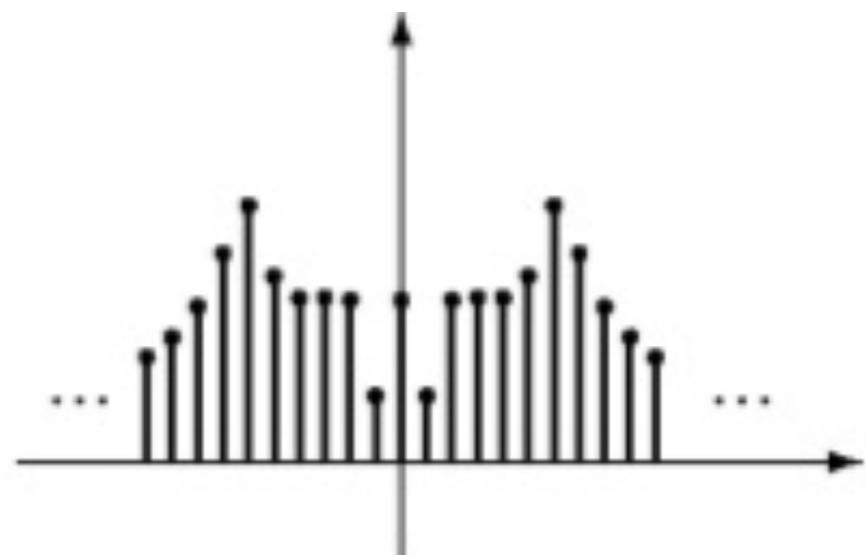
Source: <http://pilot.cnxproject.org/content/collection/col10064/latest/module/m10057/latest>

# Signal types

Even | Odd

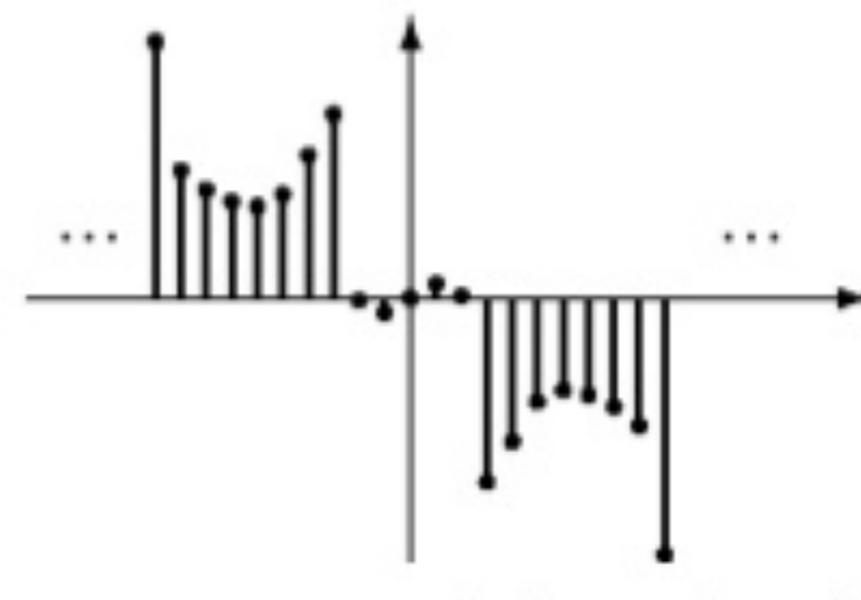
- Even signals can be easily spotted as they are symmetric around vertical axis

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



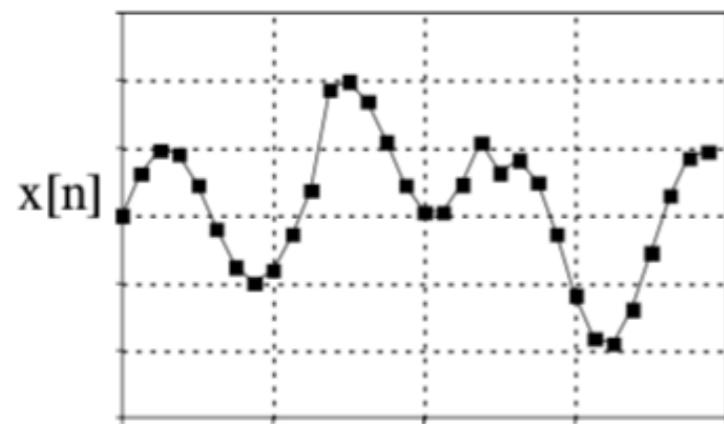
- An odd signal is a signal such that

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

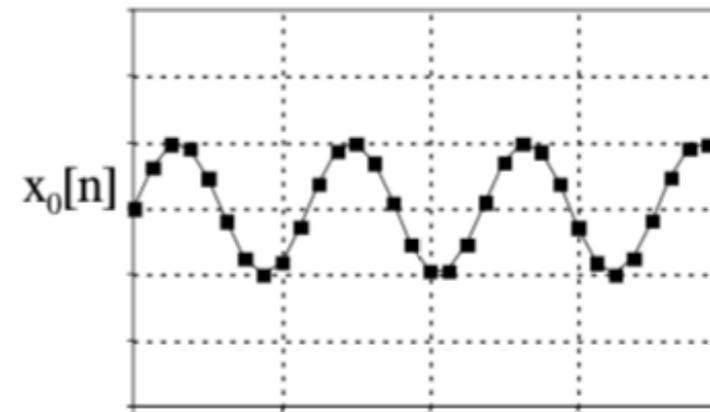


Source: <https://www.slideshare.net/mihirkjain/ch1-46505880>

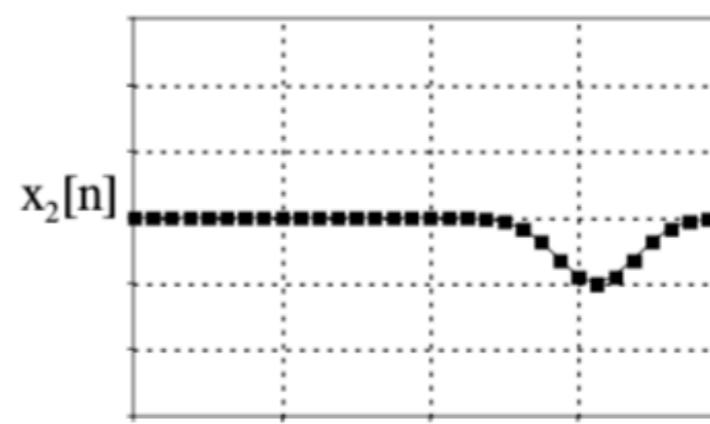
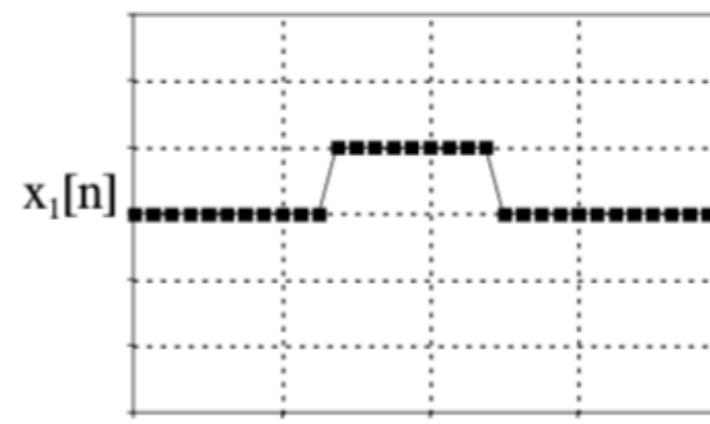
# Superposition, decomposition



decomposition  
superposition



+

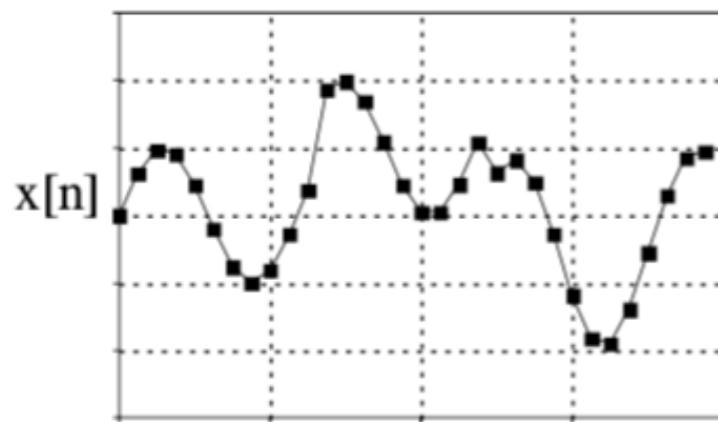


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Source: "The scientist and engineer's guide to digital signal processing",  
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# Superposition, decomposition

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



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