ELTE | FACULTY OF INFORMATICS

ANALOGY AND SIGNALS

Embodied Intelligence – Balázs Nagy, PhD

ELTE | IK
DEPARTMENT OF ARTIFICIAL INTELLIGENCE

What is embodied intelligence?

Cangelosi, A., Bongard, J., Fischer, M.H., Nolfi, S. (2015). Embodied Intelligence. In: Kacprzyk, J., Pedrycz, W. (eds) Springer Handbook of Computational Intelligence. Springer Handbooks. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-43505-2_37

What is embodied intelligence?

Embodied intelligence is the computational approach to the design and understanding of intelligent behavior in embodied and situated agents through the consideration of the strict coupling between the agent and its environment (situatedness), mediated by the constraints of the agent’s own body, perceptual and motor system, and brain (embodiment).

Cangelosi, A., Bongard, J., Fischer, M.H., Nolfi, S. (2015). Embodied Intelligence. In: Kacprzyk, J., Pedrycz, W. (eds) Springer Handbook of Computational Intelligence. Springer Handbooks. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-43505-2_37

Analogy

human

robot

Analogy

Central processing unit

human

Brain

CPU

robot

Analogy

human

Central processing unit

Brain | CPU

Sensors

Eyes	Optical sensor (cameras)
Nose	Olfactory sensors
Tongue	
Ears	Audio sensor
Skin	Equilibrium sensor
Spidey Sense	

robot

Analogy

human

Central processing unit

Brain	CPU

Sensors

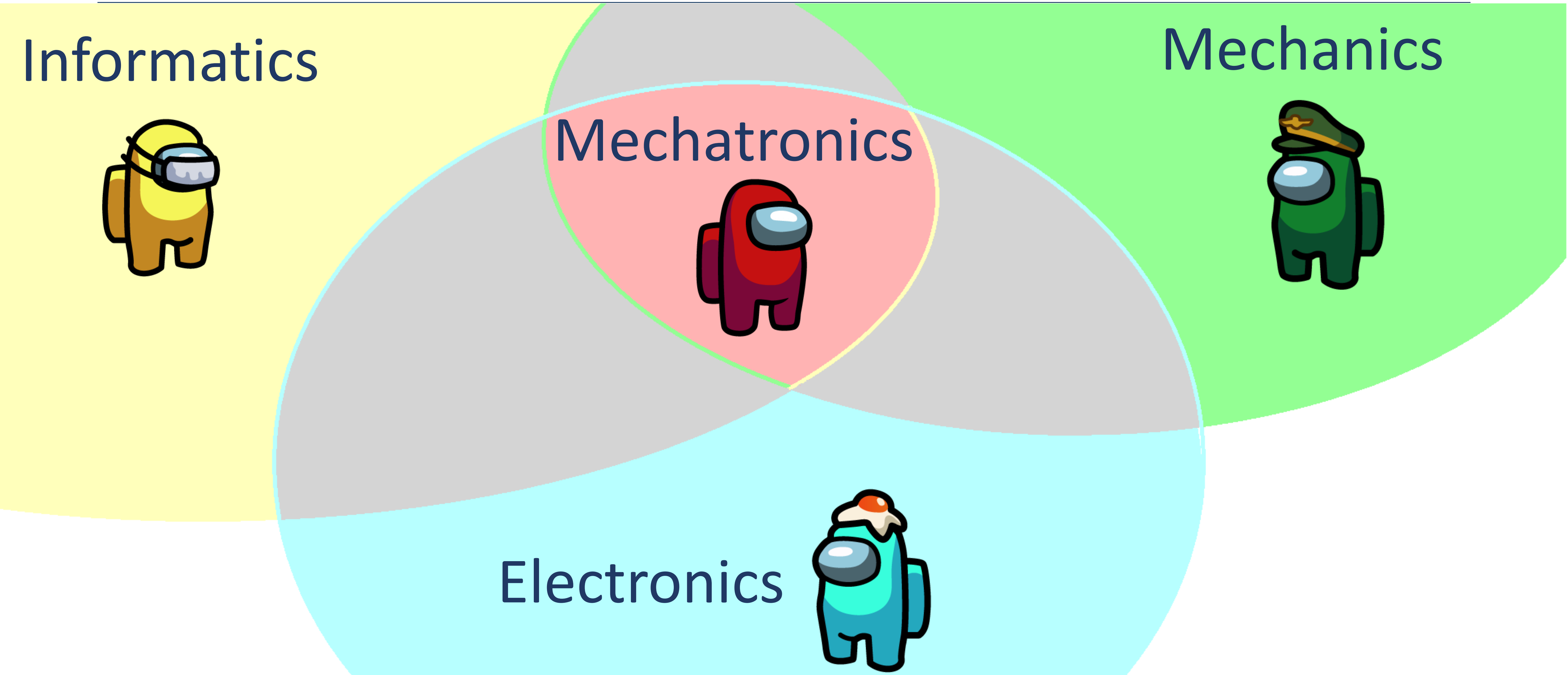
Eyes	Optical sensor (cameras)
Nose	Olfactory sensors
Tongue	
Ears	Audio sensor
Skin	Equilibrium sensor
Spidey Sense	

Actuators

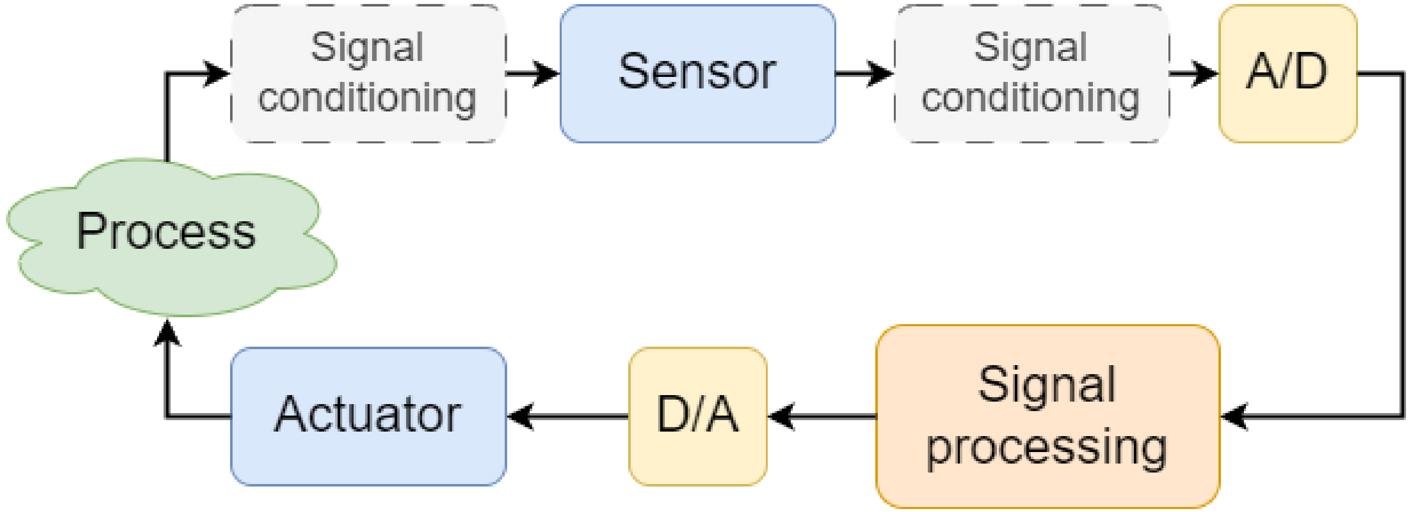
Muscles	Motors
Web shooter	Blasters

robot

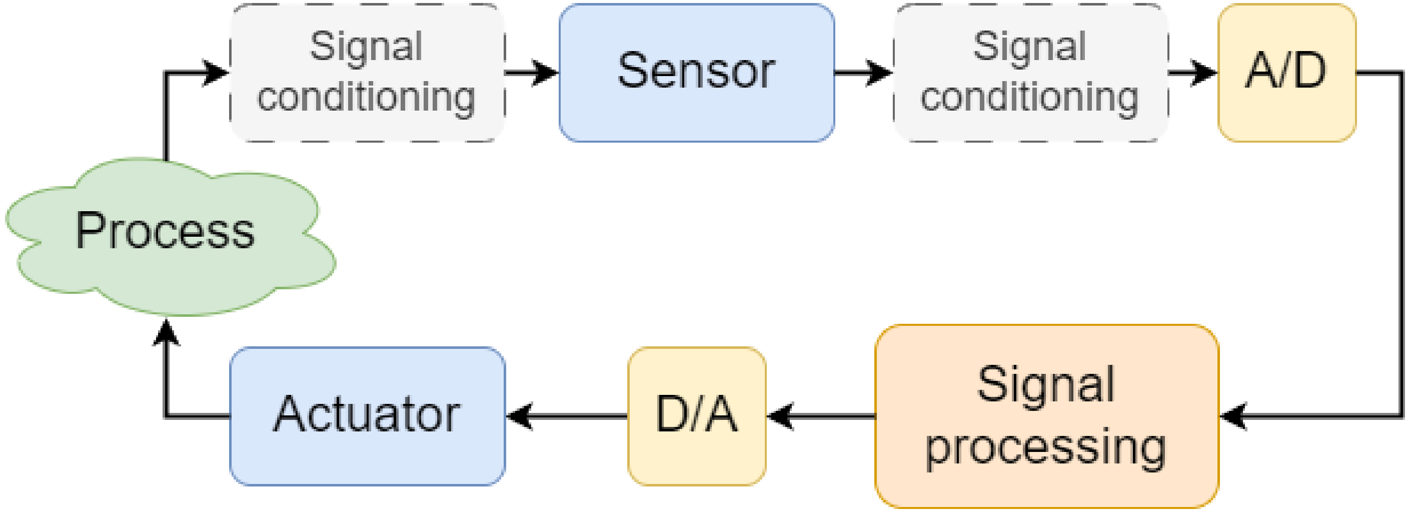
Skills needed



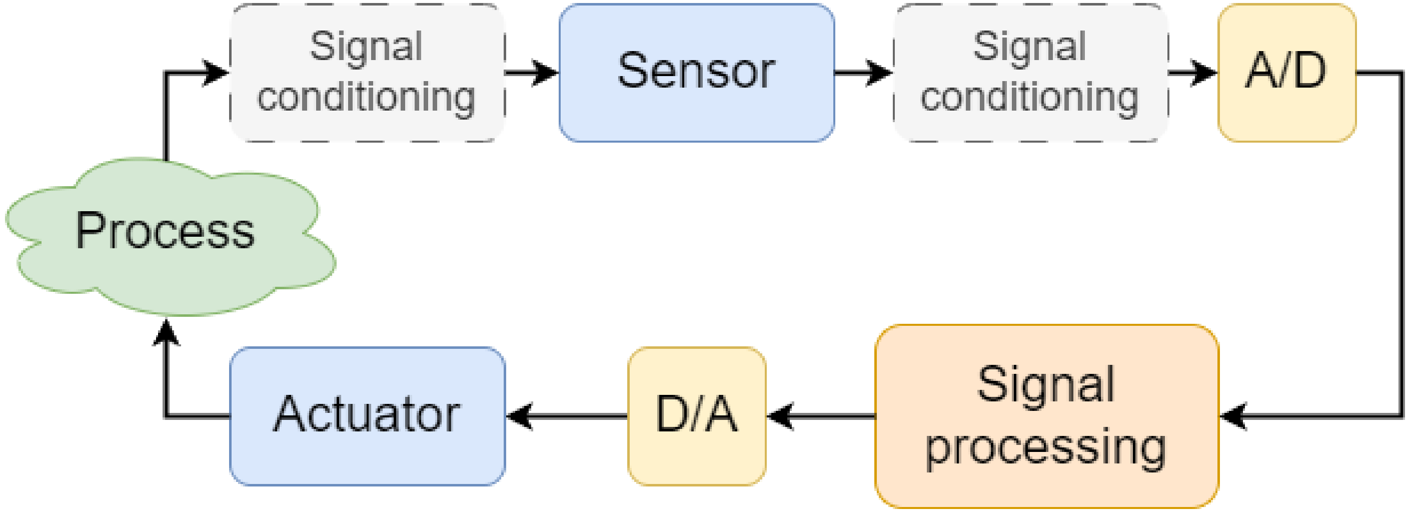
Generalized control loop



Generalized control loop



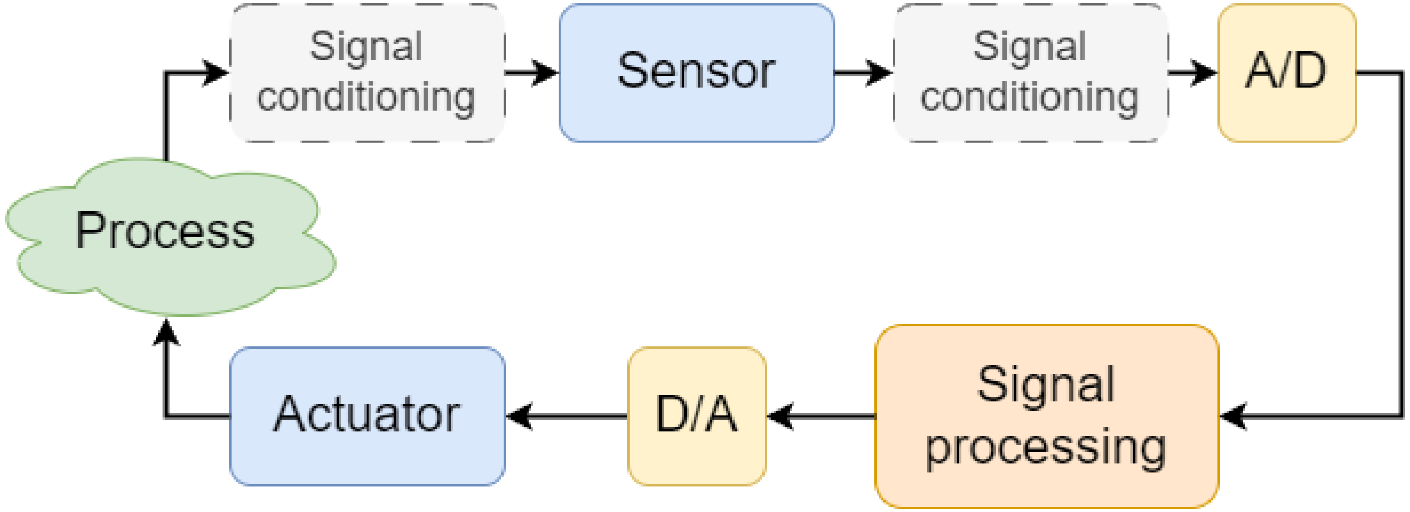
Generalized control loop



- **Signal conditioning**:
  the manipulation of an analog signal in such a way that it meets the requirements of the next stage for further processing.

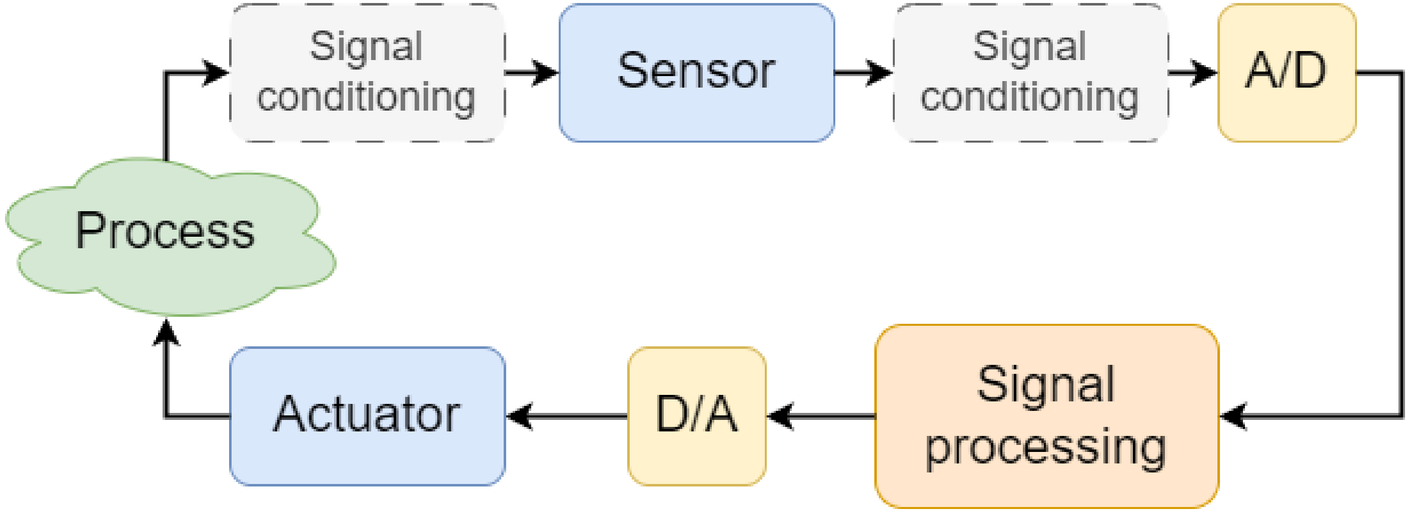
  amplification, filtering, converting, range matching, isolation

Generalized control loop



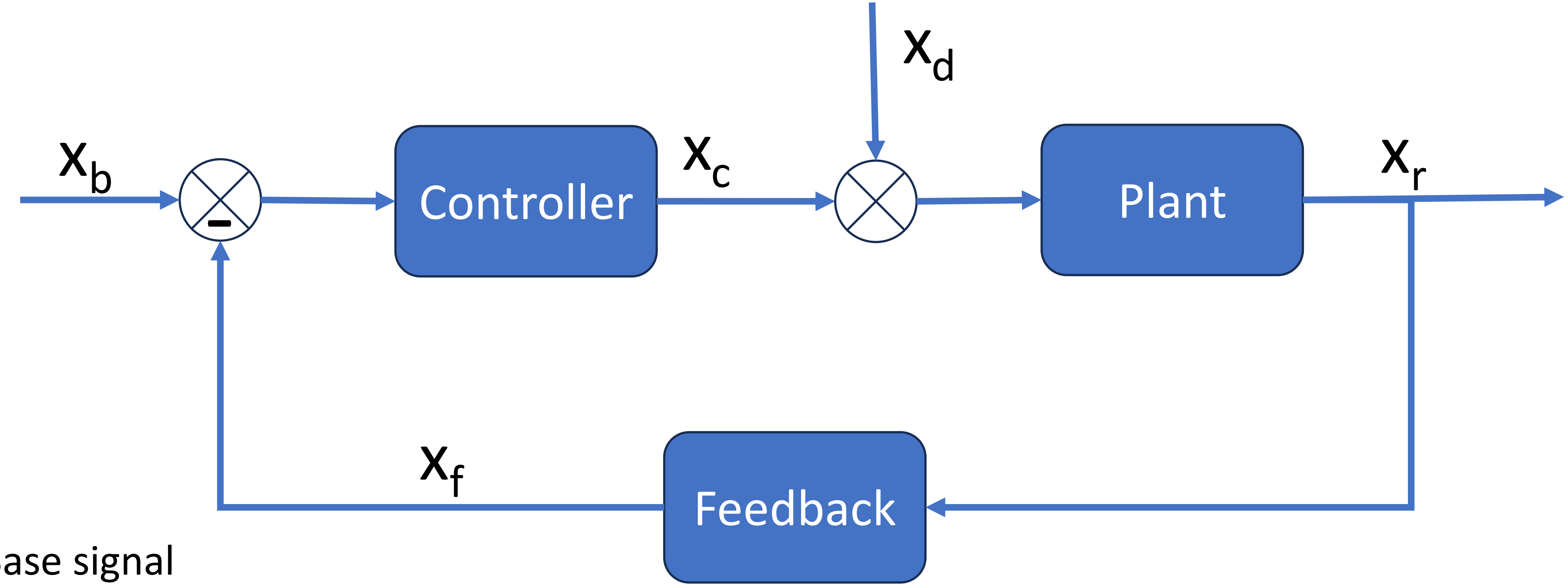
- **A/D:** Analog to digital conversion
- **D/A:** Digital to analog conversion

Generalized control loop



- **Signal processing:** the „brain”, this is were the intelligent part is implemented

Canonical control loop



x_b: Base signal
x_c: Control signal
x_r: Regulated/controlled signal
x_f: Feedback signal
x_d: Disturbance signal

<u>Transfer function</u>

= mathematical model of the plant

Garbage in garbage out (GIGO)

In computer science, garbage in, garbage out (GIGO) is the concept that flawed, or nonsense (garbage) input data produces nonsense output.

Rubbish in, rubbish out (RIRO) is an alternate wording.

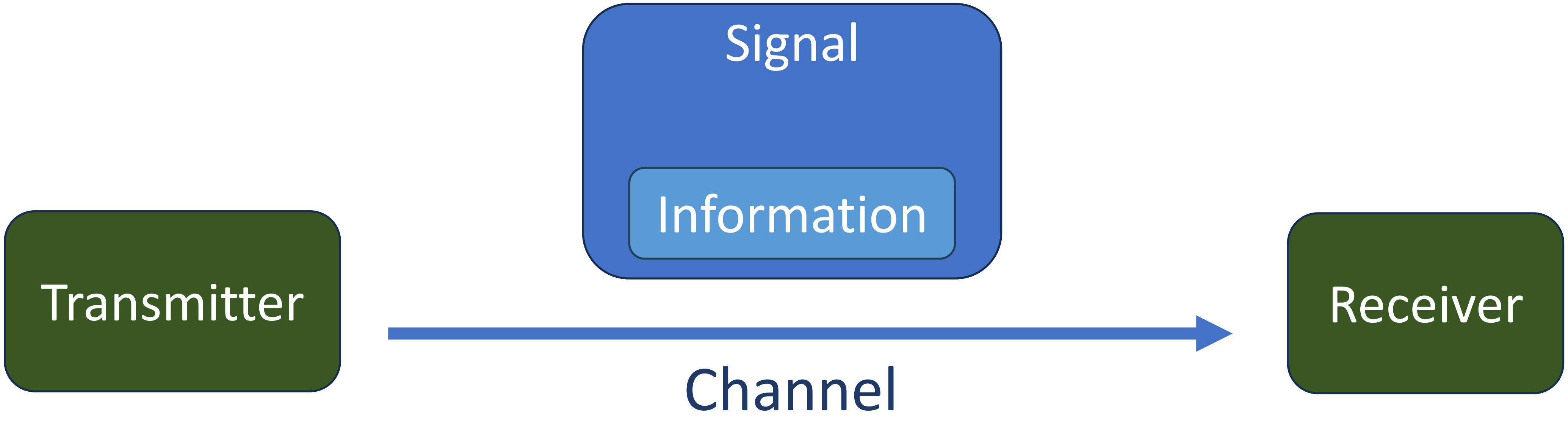
What is a signal?

- Signal can be anything
- Physical state changes during time

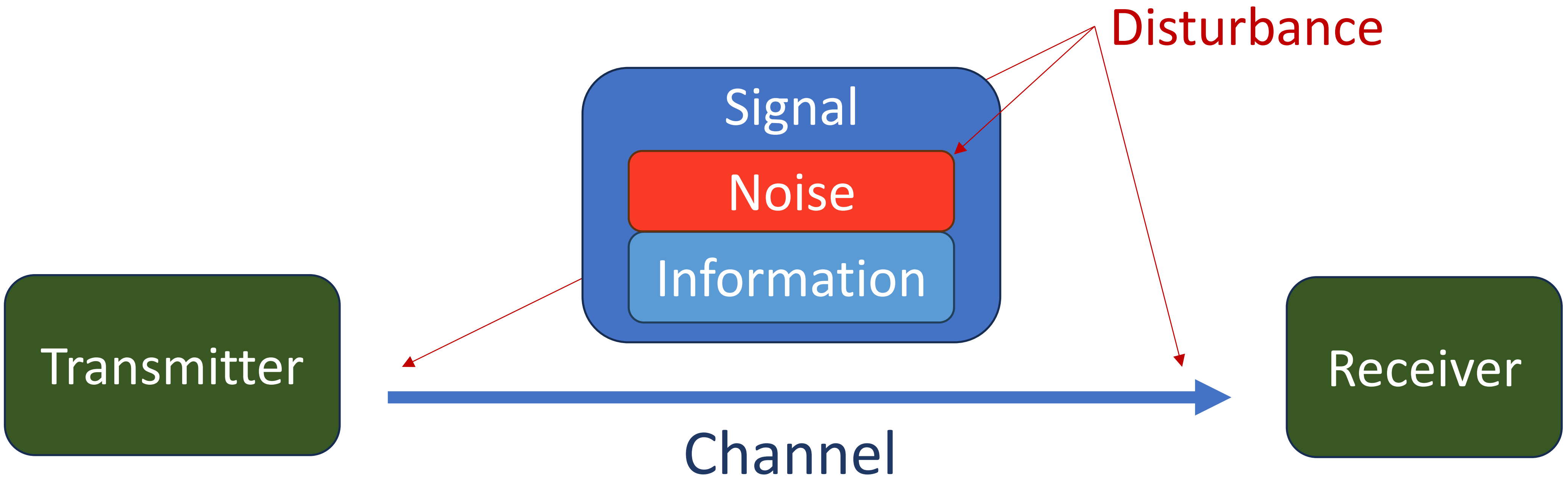
Signal = Information + Noise

- **Information**: useful part of the signal
- **Noise**: unwanted disturbance

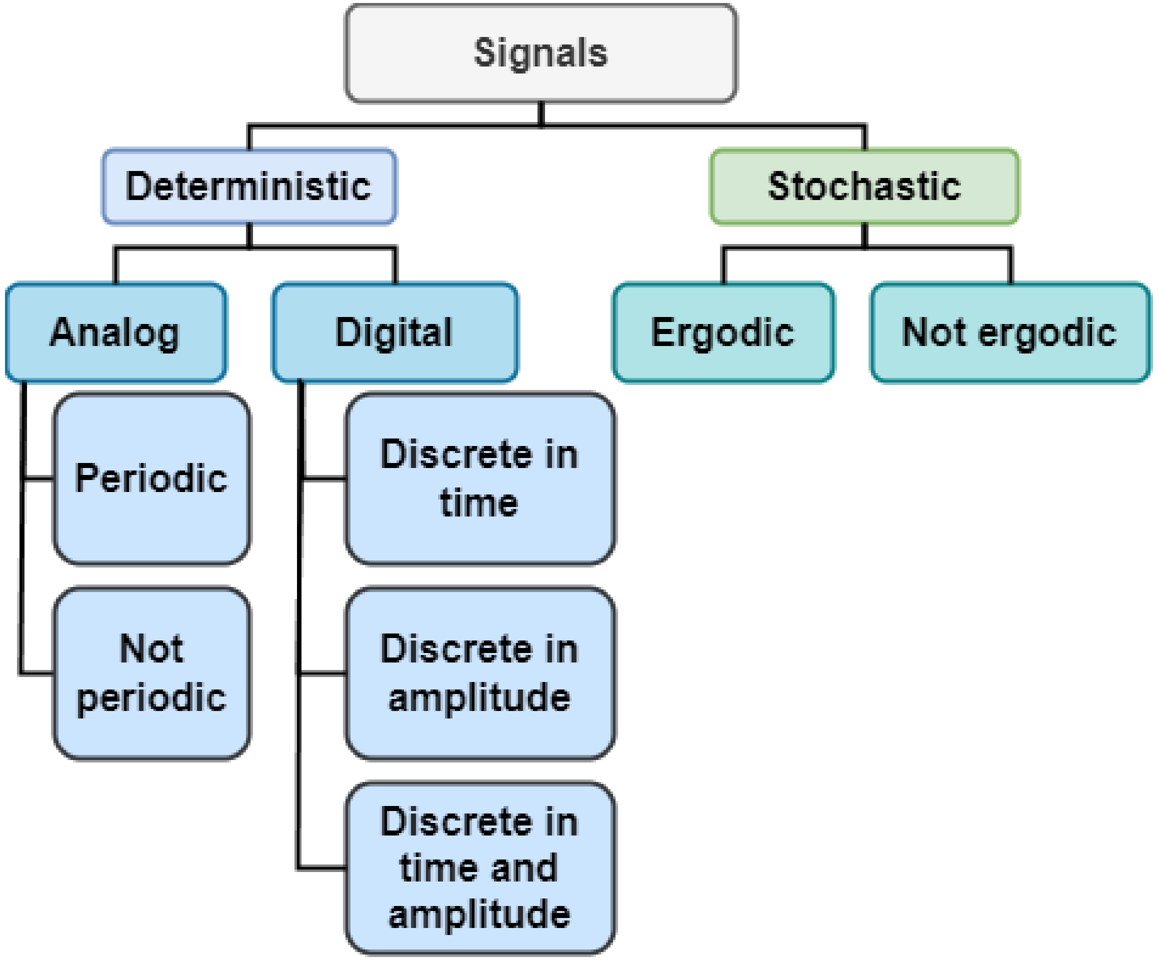
Communication model



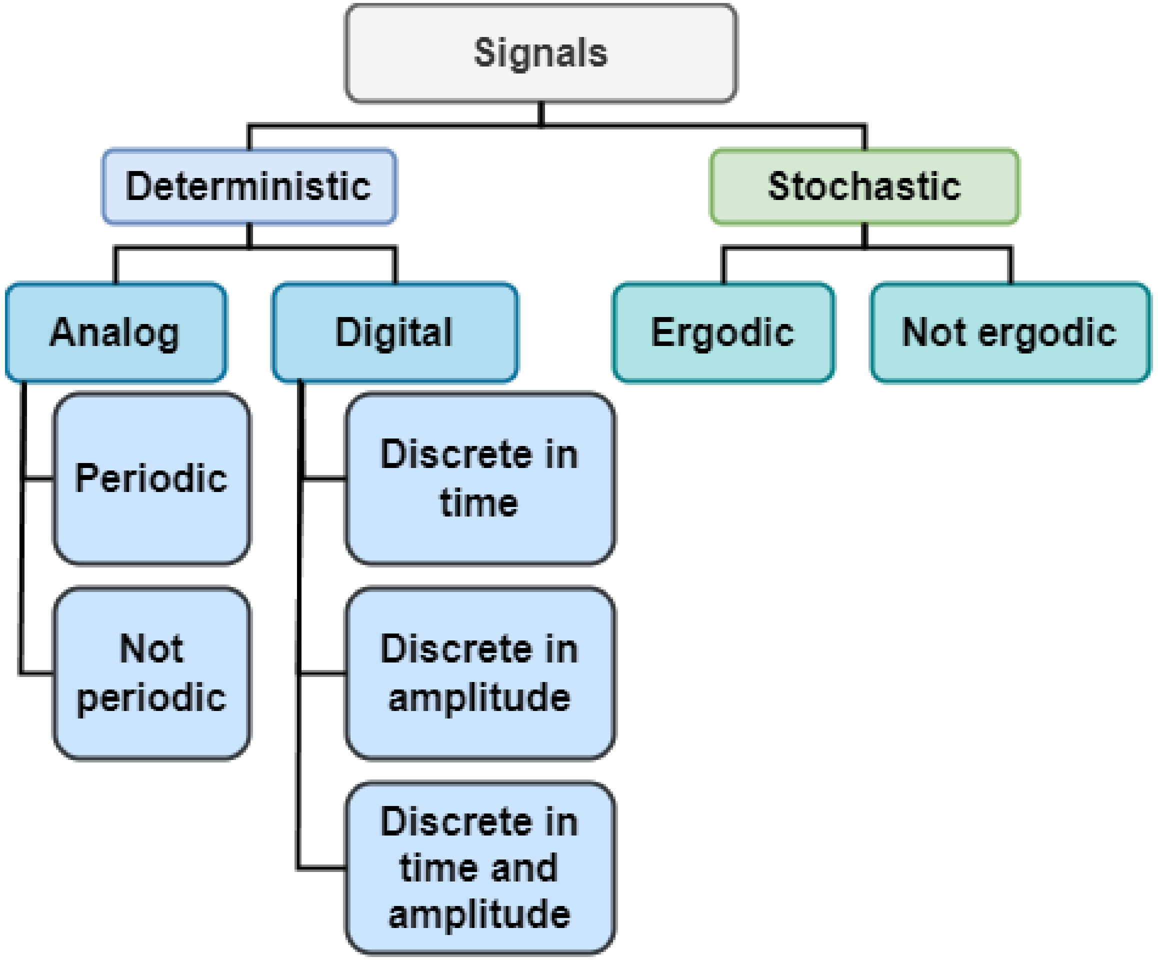
Communication model



Signal types



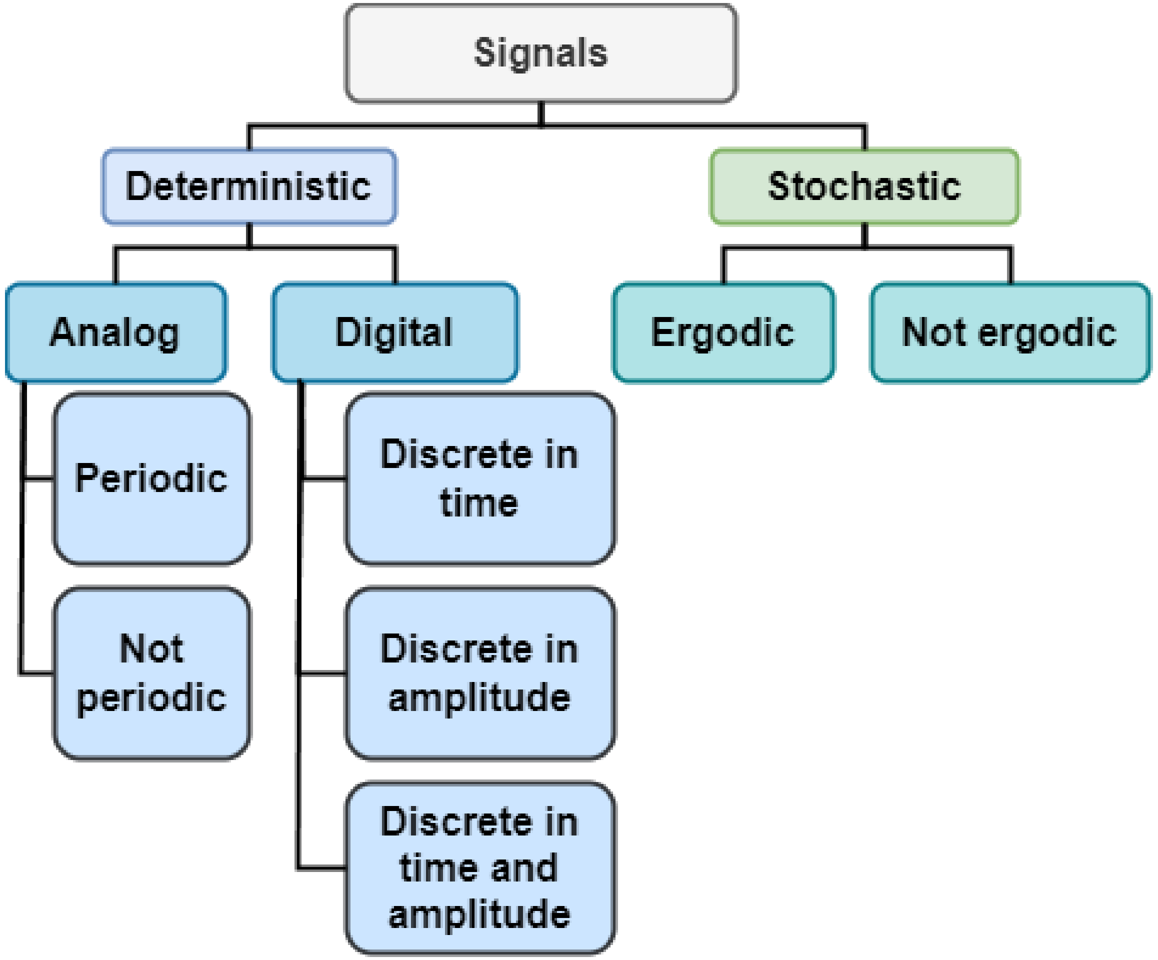
Signal types



- **Deterministic:**
  If a signal value at any point in time can be defined precisely by a mathematical equitation.

- **Stochastic** (non-deterministic):
  A signal is said to be non-deterministic if. there is uncertainty with respect to its value at some instant of time

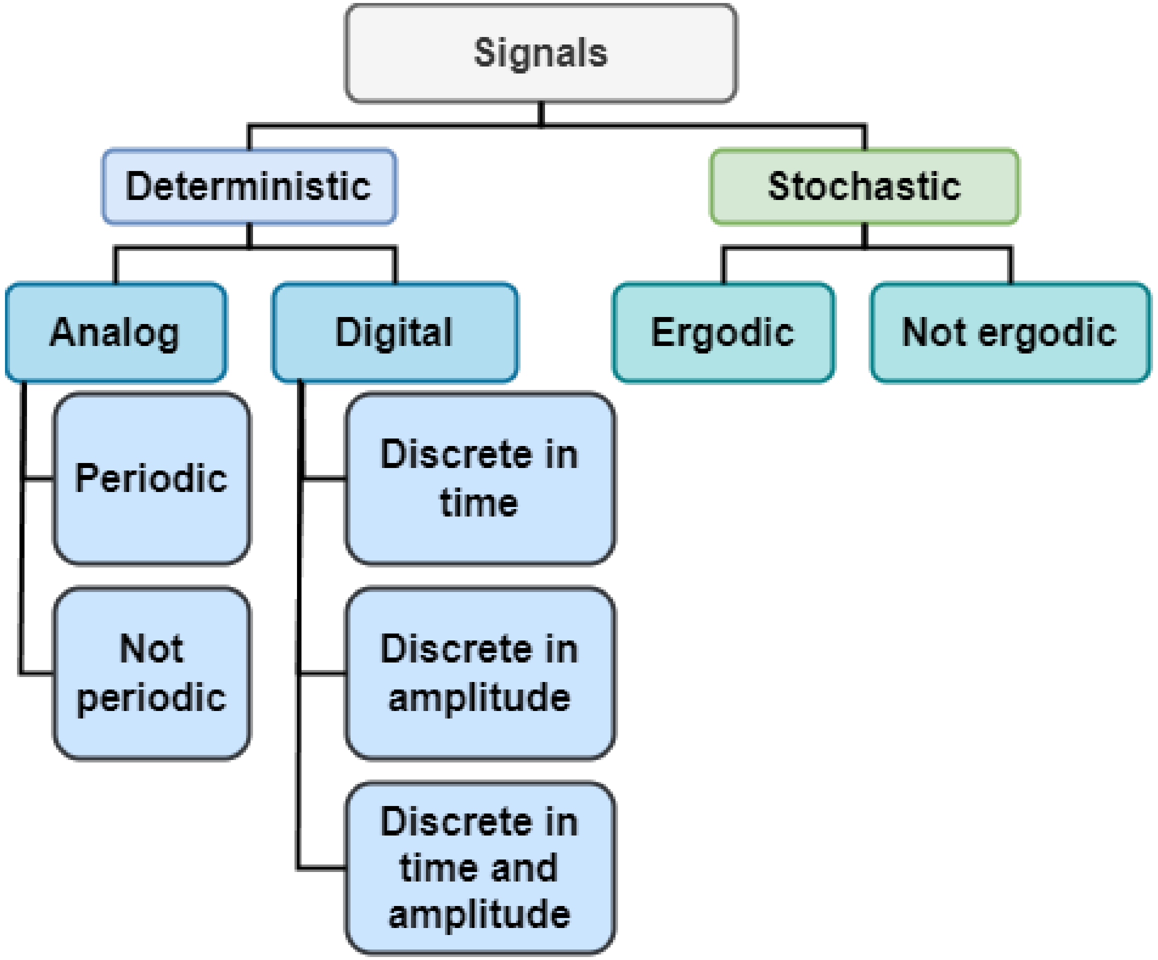
Signal types



- **Ergodic:**
  A random signal where time averages equal ensemble averages for fixed time.
  => Can be predicted with a finite statistics.
  (noise with normal distribution)

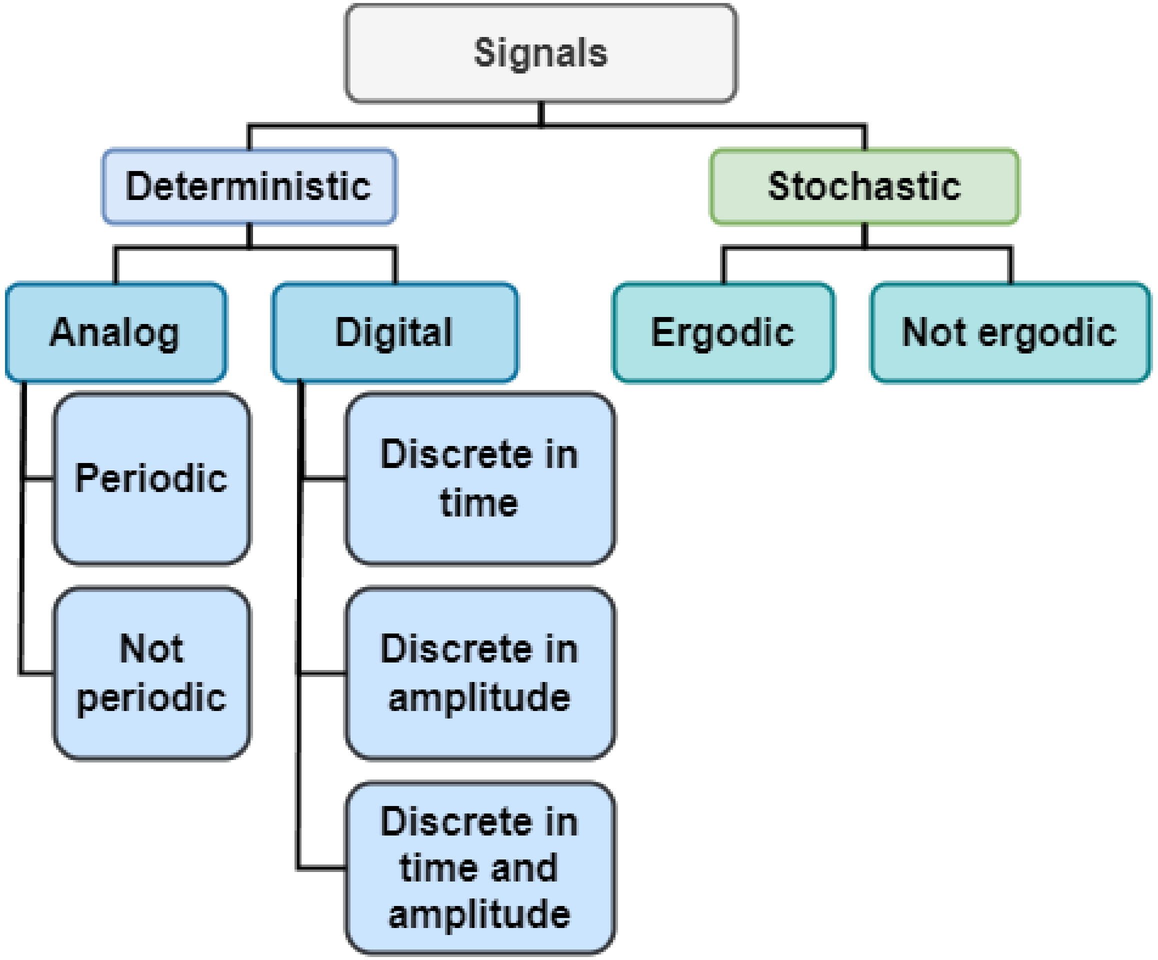
- **Not ergodic:**
  Can not be predicted.

Signal types



- **Analog:**
  A signal that continuously and infinitely varies in accordance with some time-varying parameter
- **Digital:**
  A signal that represents data as a sequence of discrete values

Signal types

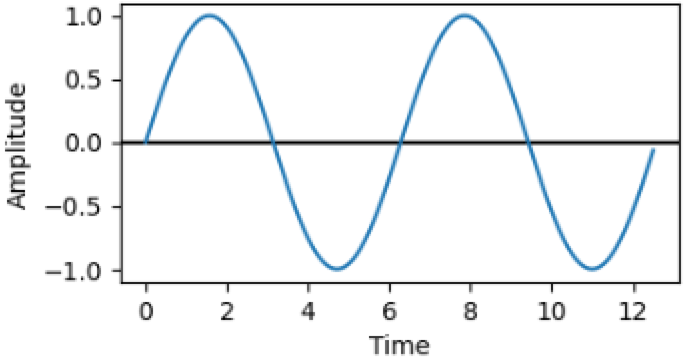


- **Periodic**
  A signal that has a definite pattern and repeats itself at a regular interval of time.
  - Sinusoid
  - General periodic
- **Not periodic (aperiodic):**
  - Quasiperiodic
  - Transient

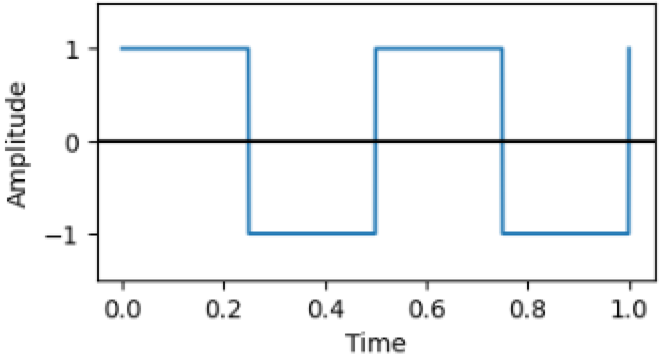
Signal types examples

Periodic

Sinusoid

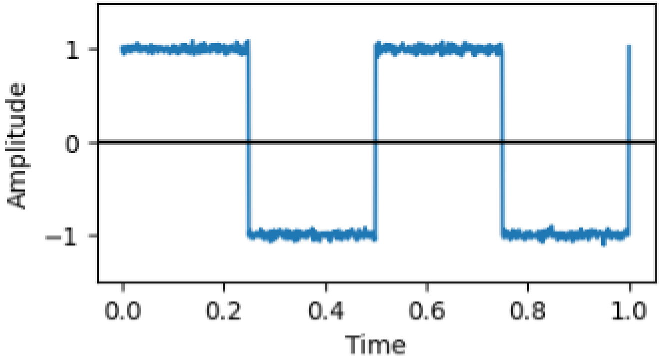


General periodic

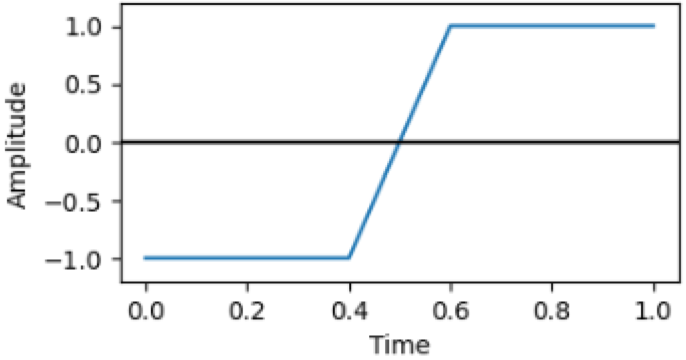


Not periodic

Quasiperiodic

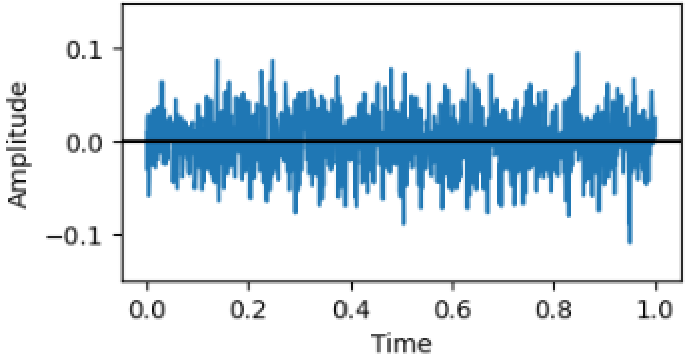


Transient



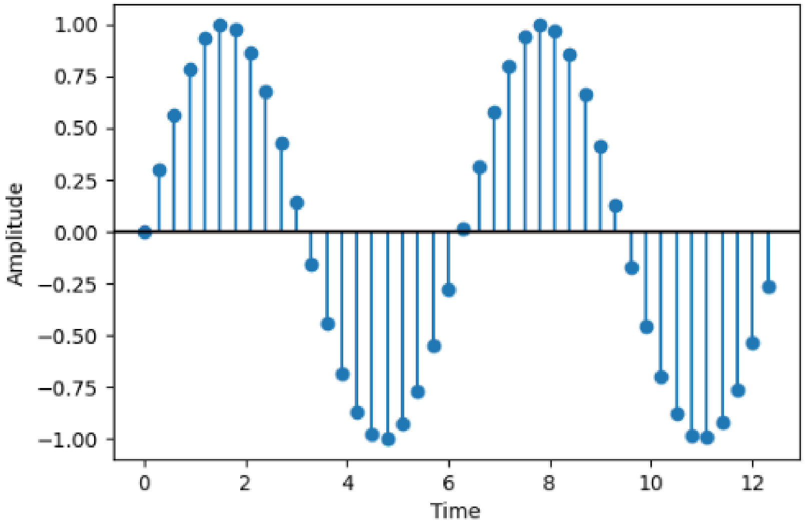
Ergodic

Noise

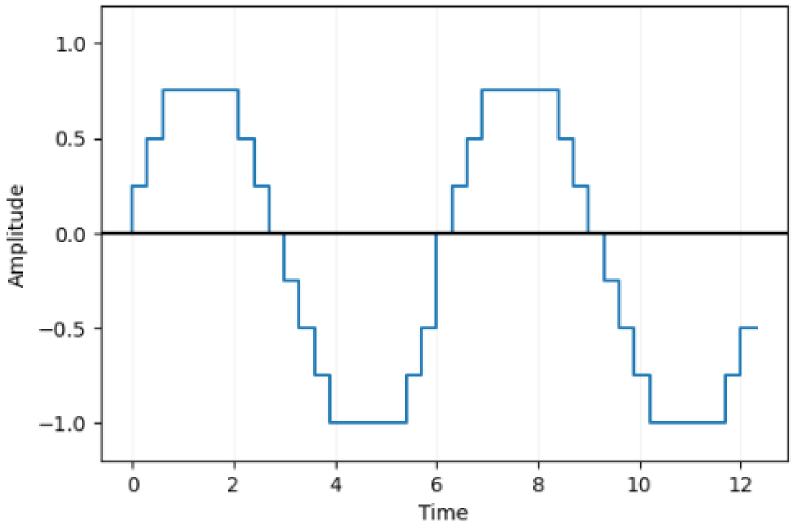


Signal types examples

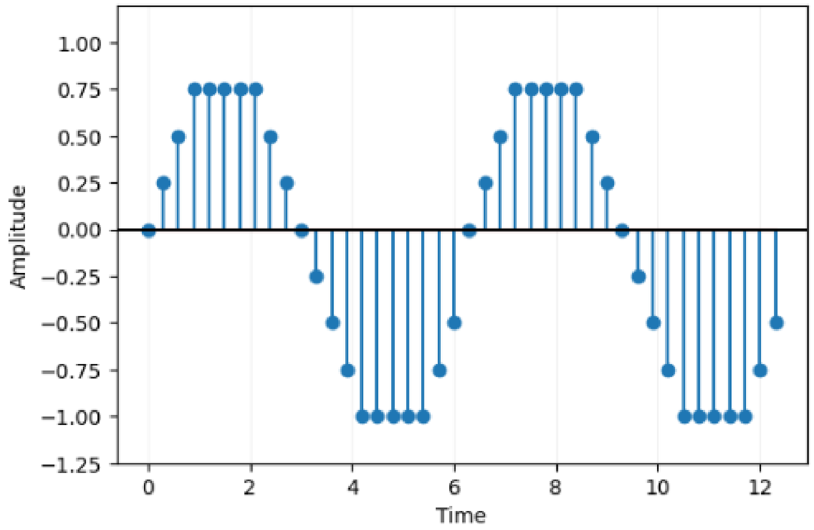
Discrete in time



Discrete in amplitude



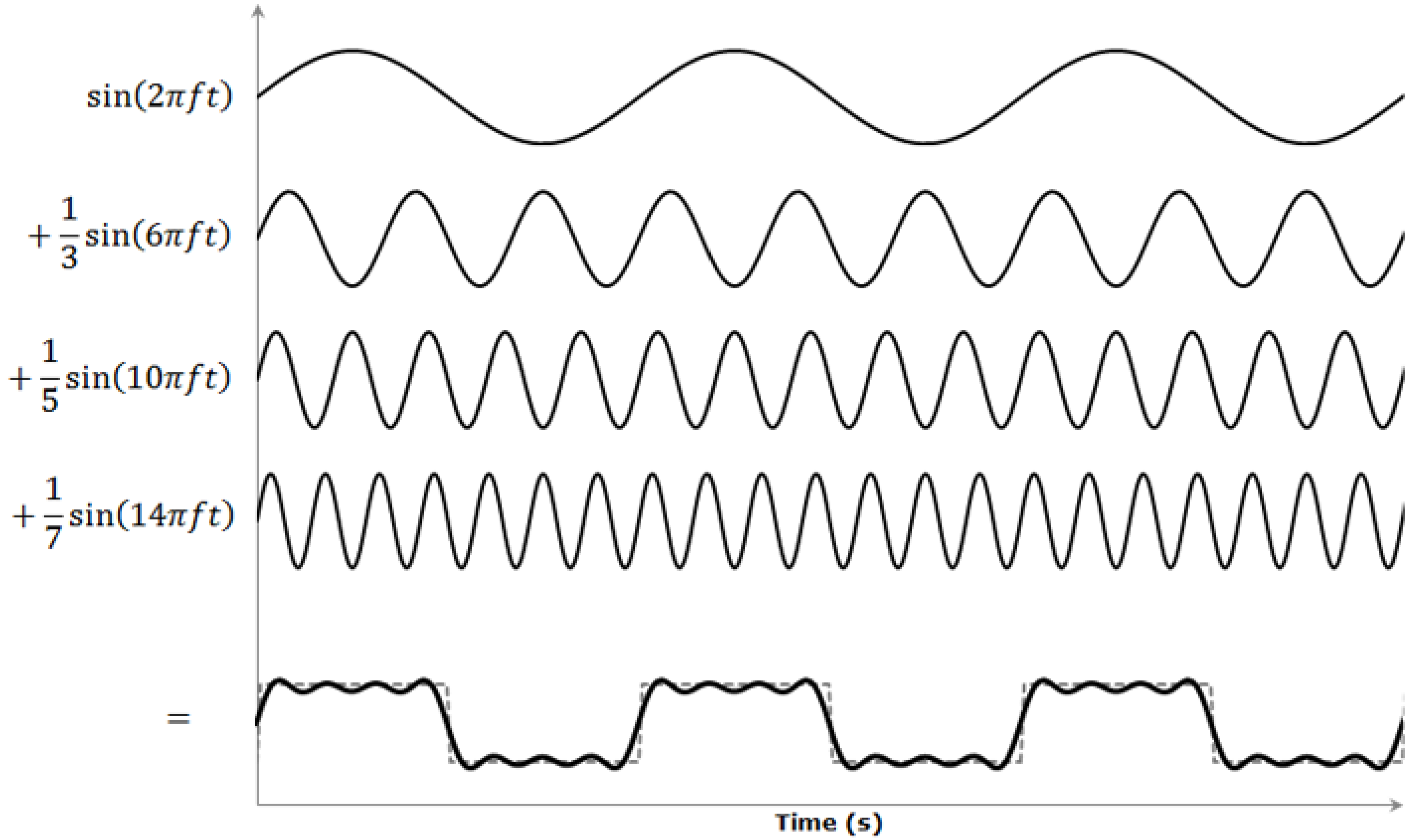
Discrete in time and amplitude



Comparison

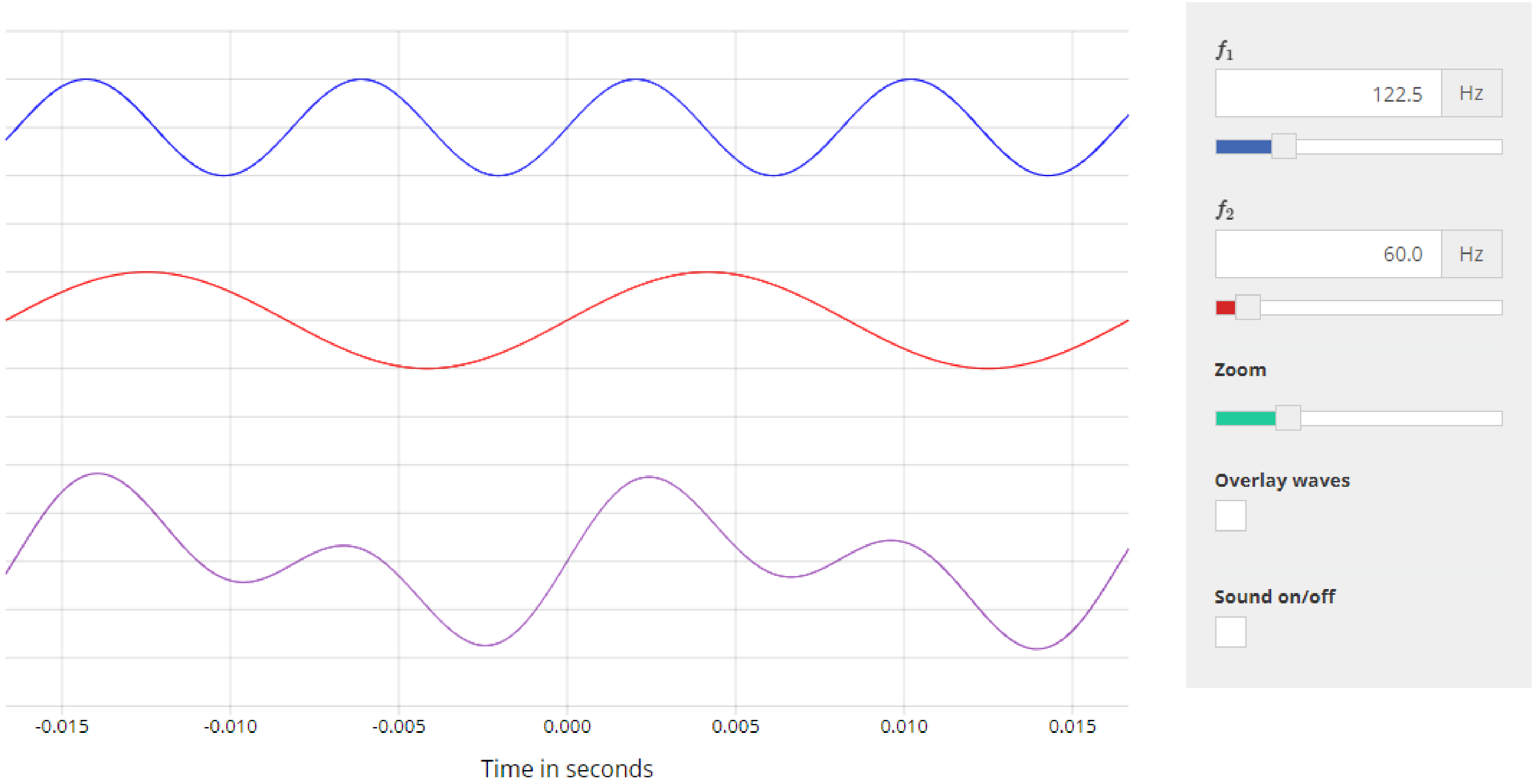
	Analog	Digital
Signal	Continuous signal	Discrete time signals
Waves	Denoted by sine waves	Denoted by square waves
Representation	Continuous range of values	Discrete or discontinuous values
Noise	More likely to get affected, subjected to deterioration by noise during transmission	Less affected since noise response, can be noise-immune without deterioration during transmission
Flexibility	Analog hardware is not flexible.	Digital hardware is flexible in implementation.
Bandwidth	Analog signal processing can be done in real time and consumes less bandwidth	There is no guarantee that digital signal processing can be done in real time and consumes more bandwidth to carry out the same information
Power	Analog instrument draws large power	Digital instrument draws only negligible power

Nature of signals



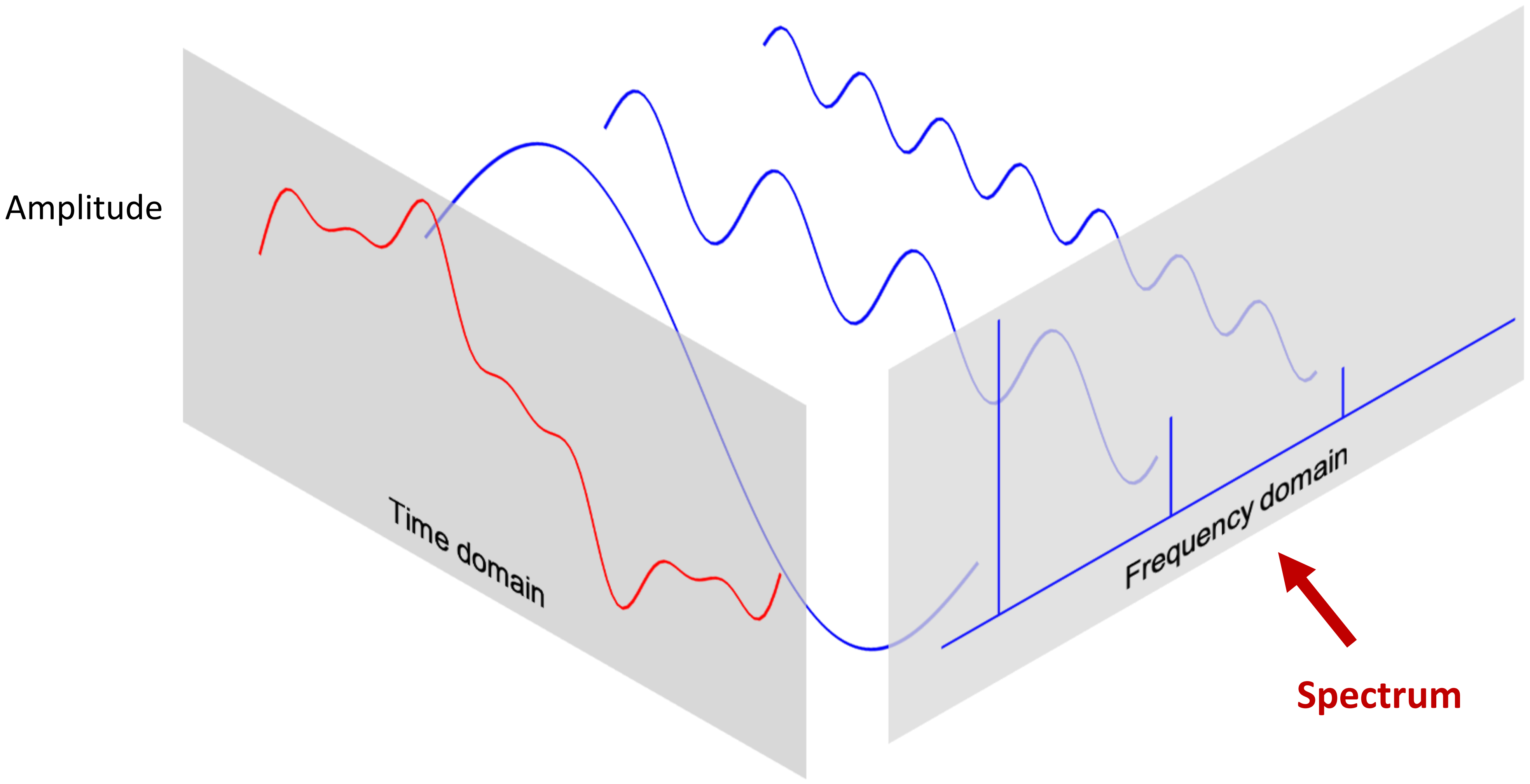
Every signal is a superposition of many sinusoid signal

Nature of signals

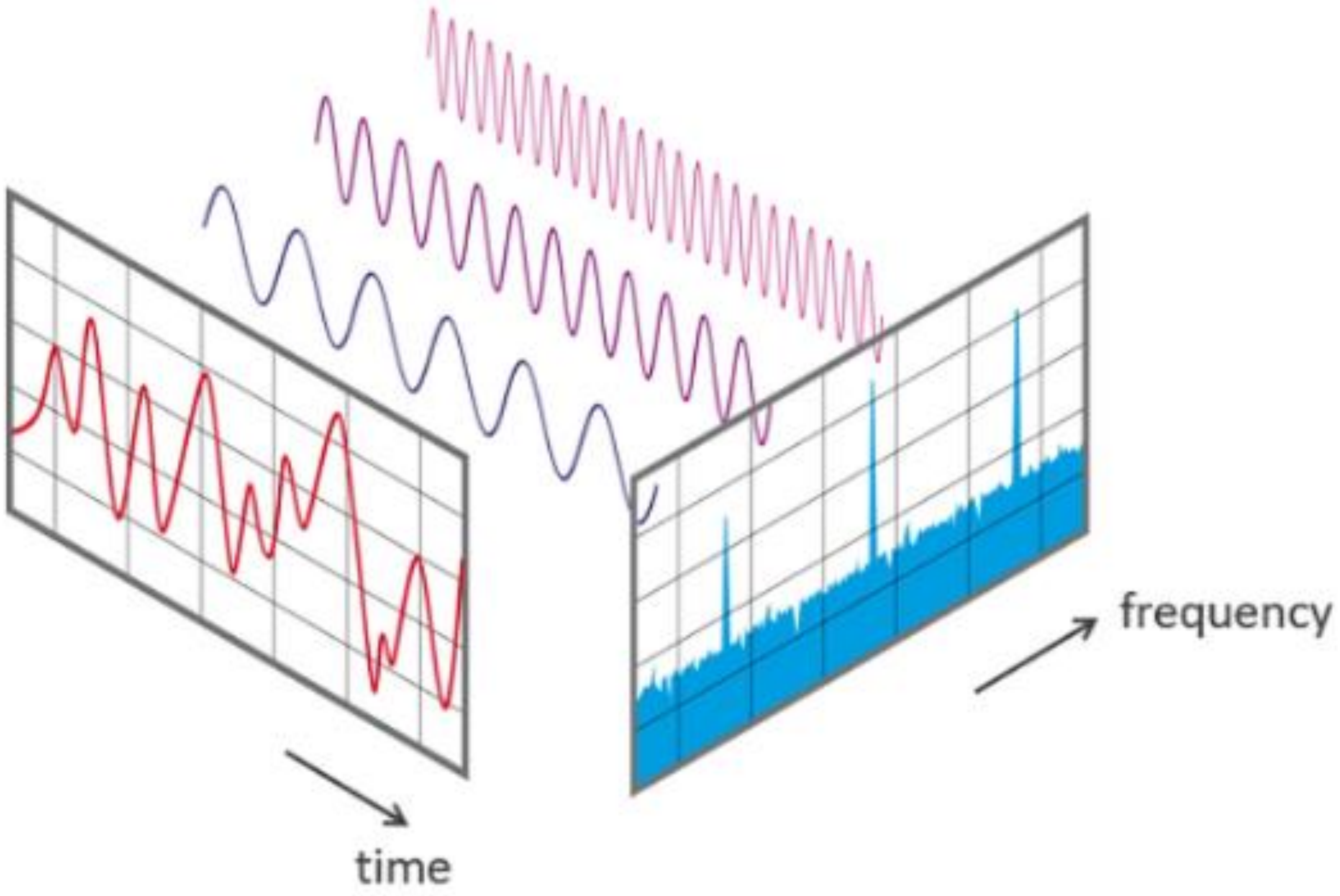


https://academo.org/demos/wave-interference-beat-frequency/

Nature of signals



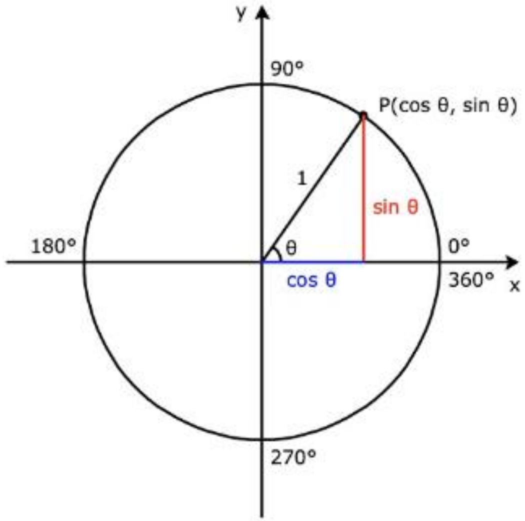
Nature of signals

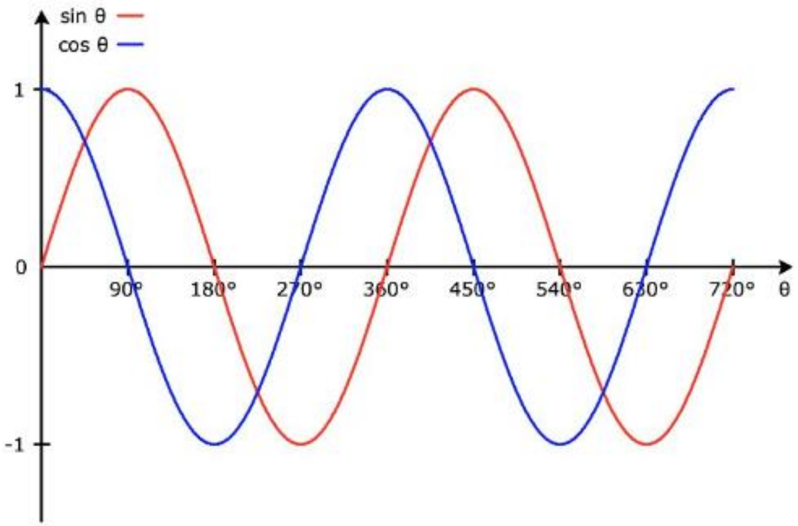


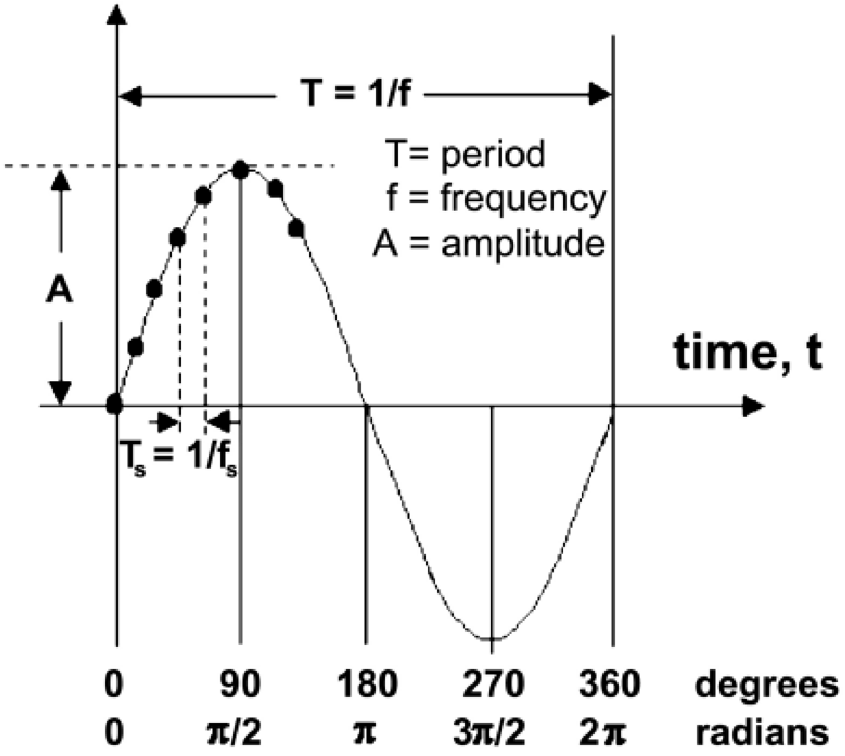
Spectrum

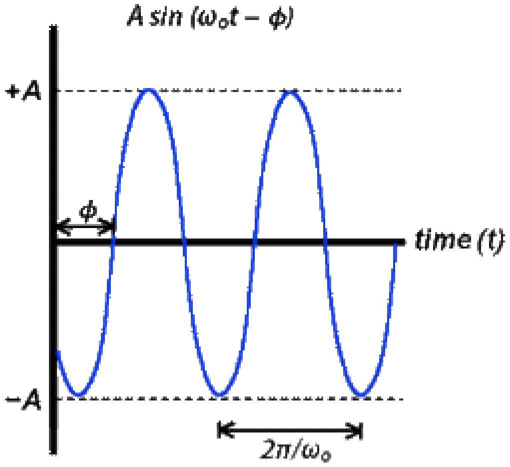
- A signal is a function of time which can be represented by a series of sinusoidal functions or sinusoidal components.
- These sinusoidal components have different frequencies, different amplitudes, and different phases.
- Therefore, the plots of frequency versus amplitude and phase for the sinusoidal components which comprise the signal are called the **Frequency Spectrum** or **Spectrum** of the signal.

Sinusoid wave composition









$$\omega = 2\pi f.$$

$$f = \frac{1}{T}$$

$$A\sin\left(\omega t\right) = A\sin\left(2\pi f t\right) = A\sin\left(\frac{2\pi}{T}t\right)$$

Decomposition of a Signal

- We can express the following representation of a function:

$$x(t) = A_o + \sum_{k=1}^{N} A_k \cos(2\pi f_k t + \theta_k)$$

$$= X_o + \Re e\{\sum_{k=1}^{N} X_k e^{j2\pi f_k t}\}$$

Where $X_o = A_o$ is a real constant (DC component) and

$X_k = A_k e^{j\theta_k}$ is the phasor for frequency f_k

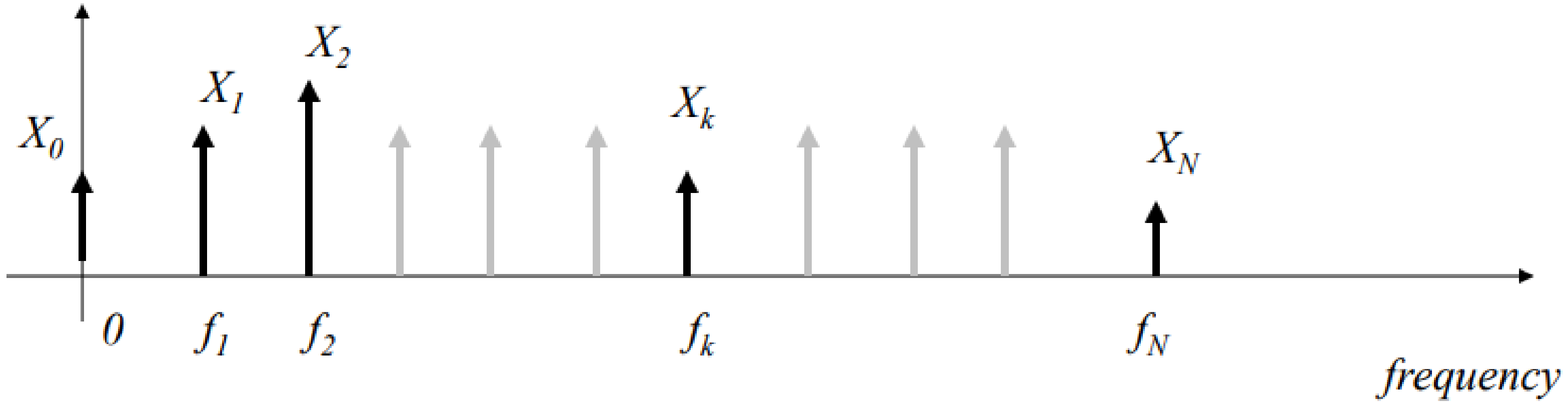
- Here we see that there are *N+1* frequency components for *x(t)*, $0 \le k \le N$ and with each frequency there is a phasor.

Decomposition of a Signal

- For example, the k[th] frequency has a phasor X_k with amplitude, A_k, and phase θ_k

$$x(t) = A_o + \sum_{k=1}^{N} A_k \cos(2\pi f_k t + \theta_k) = X_o + \Re e\{\sum_{k=1}^{N} X_k e^{j2\pi f_k t}\}$$

Where X_o = DC component and $X_k = A_k e^{j\theta_k}$ is the phasor for frequency f_k



- This is really only half of the spectrum.

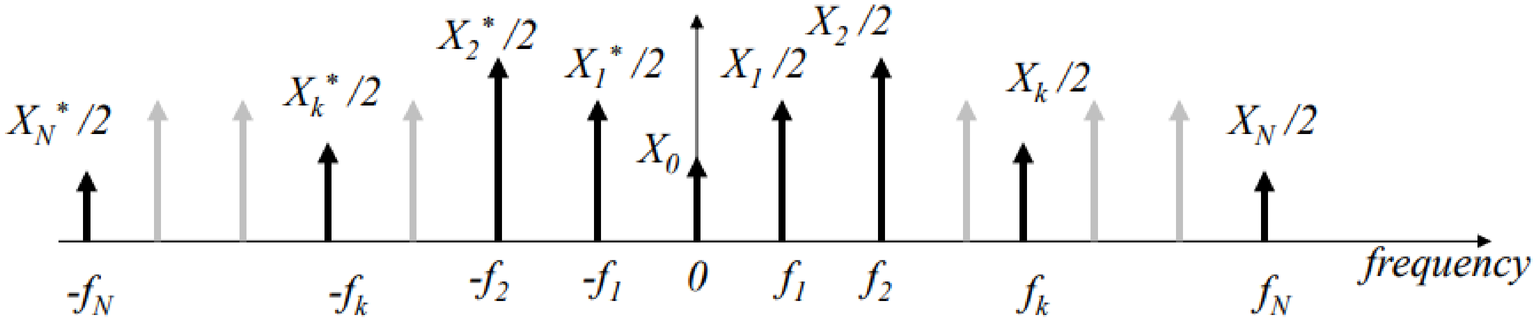
Decomposition of a Signal

- Using Euler's formula, rewrite x(t):

$$x(t) = A_o + \sum_{k=1}^{N} A_k \cos(2\pi f_k t + \theta_k) = X_o + \sum_{k=1}^{N} \{\frac{A_k}{2} e^{j\theta_k} e^{j2\pi f_k t} + \frac{A_k}{2} e^{-j\theta_k} e^{-j2\pi f_k t}\}$$

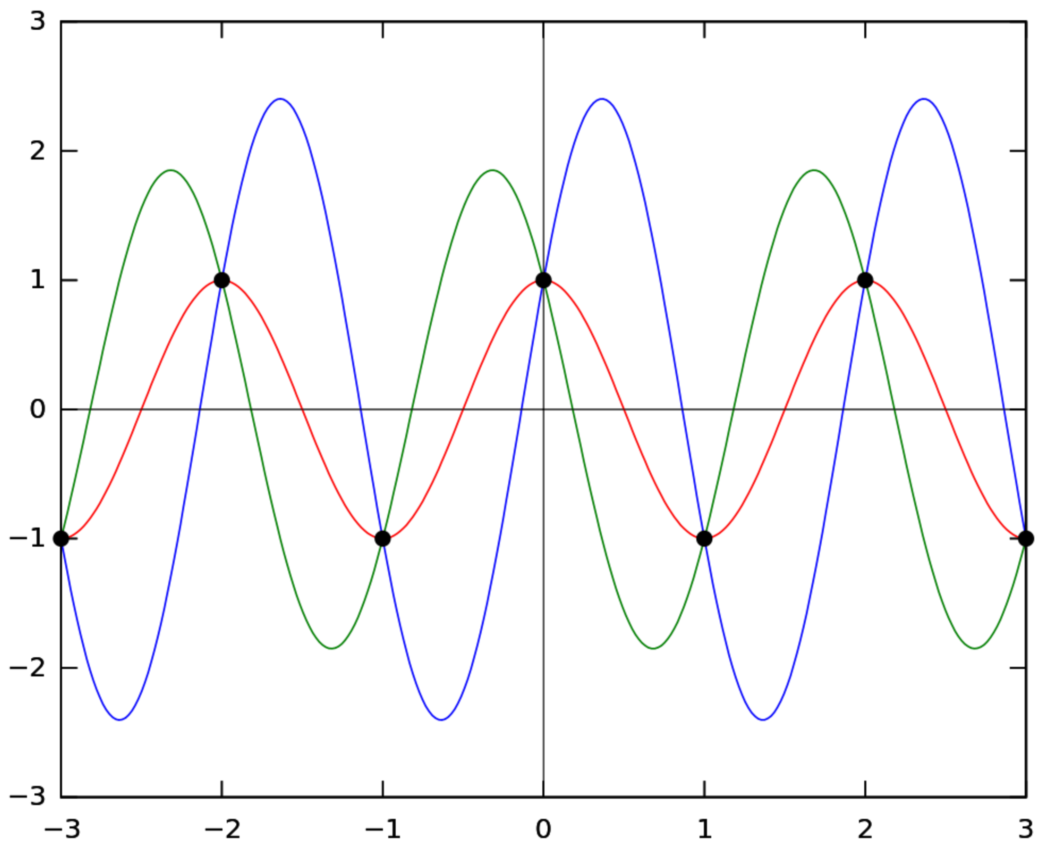
$$= X_o + \sum_{k=1}^{N} \{\frac{X_k}{2} e^{j2\pi f_k t} + \frac{X_k{}^*}{2} e^{-j2\pi f_k t}\}$$

- Using this approach, we see that there are 2N+1 frequency component
- Or we can say that for each k where $1 \le k \le N$, there is a positive frequency f_k with phasor $X_k/2$ and a negative frequency $-f_k$ with phasor $X_k^*/2$
- Therefore, we say that the spectrum is two-sided



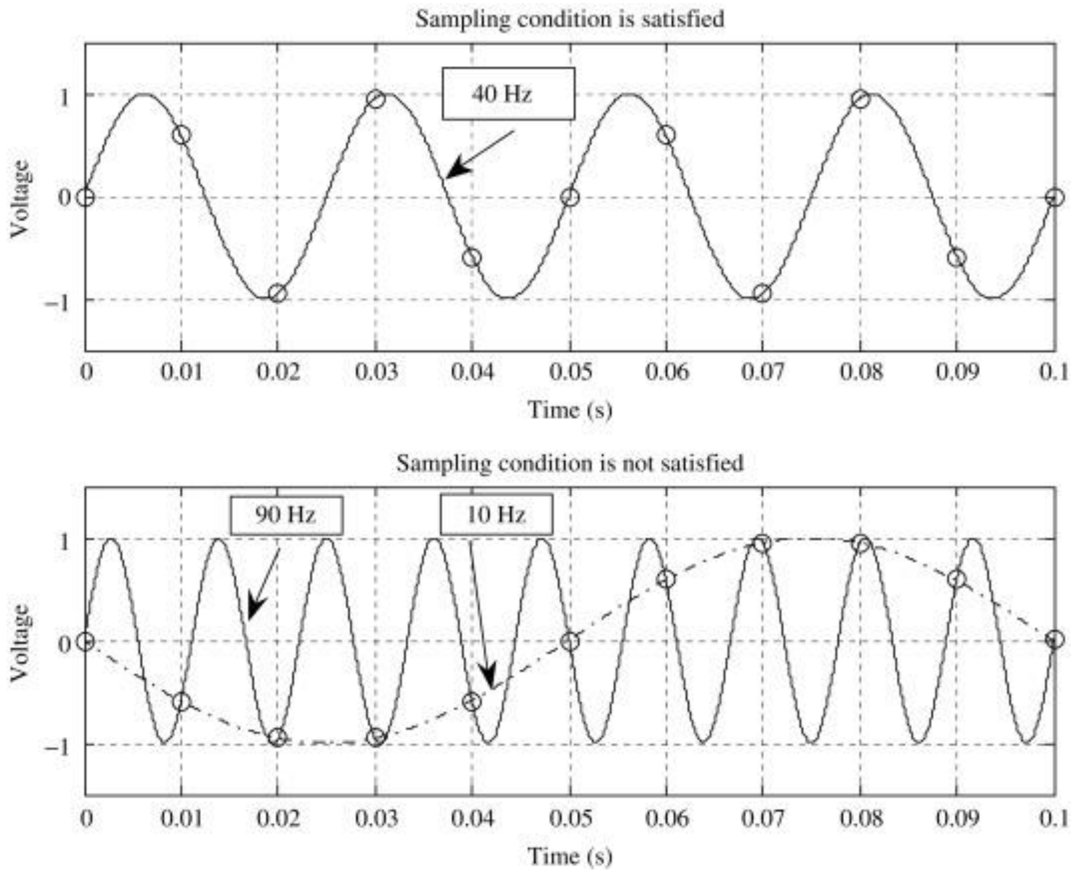
Aliasing

- A family of sinusoids at the critical frequency, all having the same sample sequences of alternating +1 and –1. That is, they all are aliases of each other



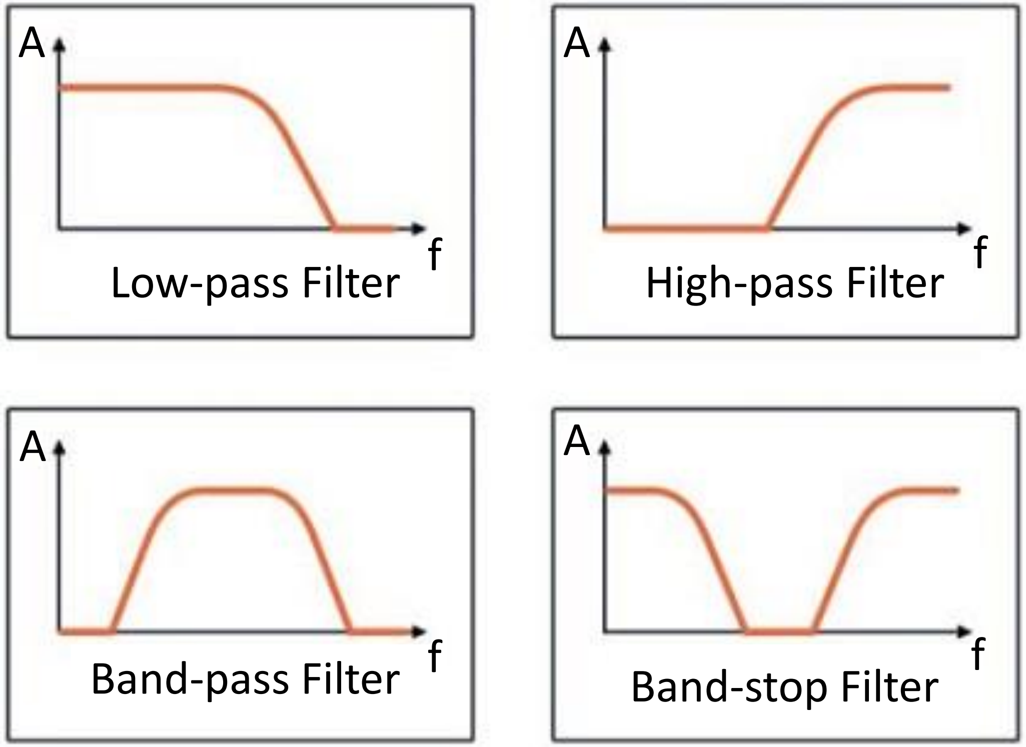
Shannon theorem

- According to the sampling theorem (Shannon, 1949), to reconstruct a one-dimensional signal from a set of samples, the sampling rate must be equal to or greater than twice the highest frequency in the signal.



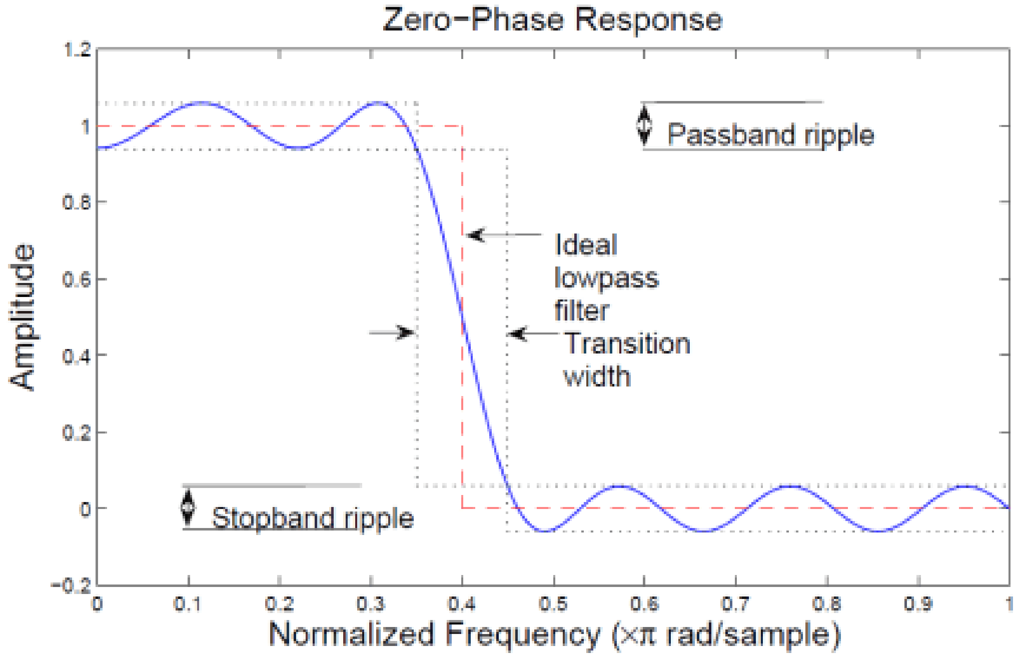
Filter types

- **Low-pass filter:**
  low frequencies are passed, high frequencies are attenuated.
- **High-pass filter:**
  high frequencies are passed, low frequencies are attenuated.
- **Band-pass filter:**
  only frequencies in a frequency band are passed.
- **Band-stop filter** (or band-reject filter):
  only frequencies in a frequency band are attenuated.



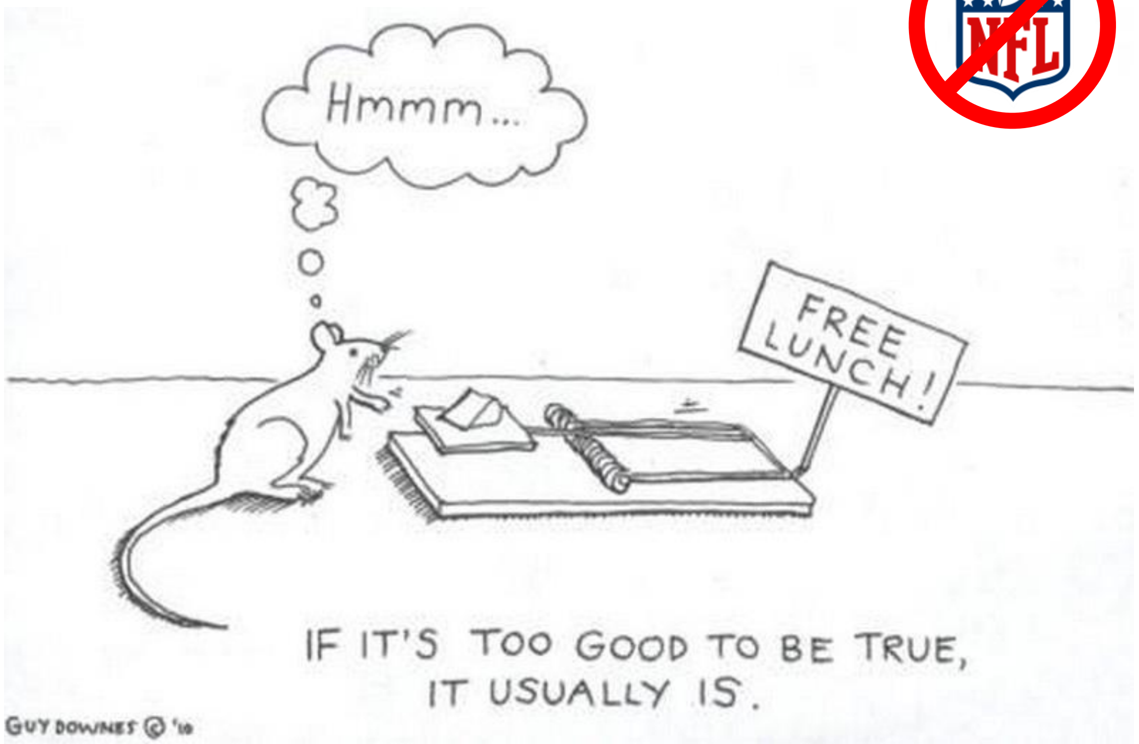
Parts of a filter

- **Ripples:**
  the fluctuations in the pass band, or stop band, of a filter's frequency magnitude response curve.
- **Transition region:**
  The region which is in between the passband and stopband



No free lunch theory (NFL)

No free lunch theory states that any two optimization algorithms are equivalent when their performance is averaged across all possible problems.



Wolpert, D.H., and Macready, W.G. (2005) "Coevolutionary free lunches", *IEEE Transactions on Evolutionary Computation*, 9(6): 721–735

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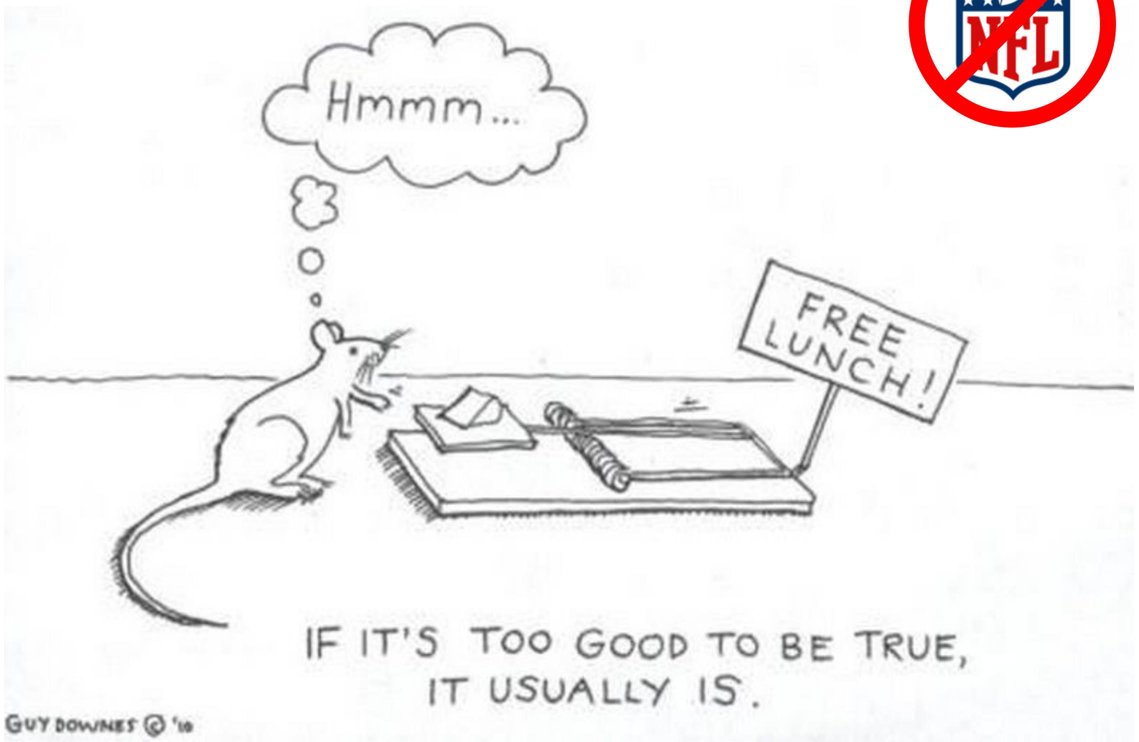
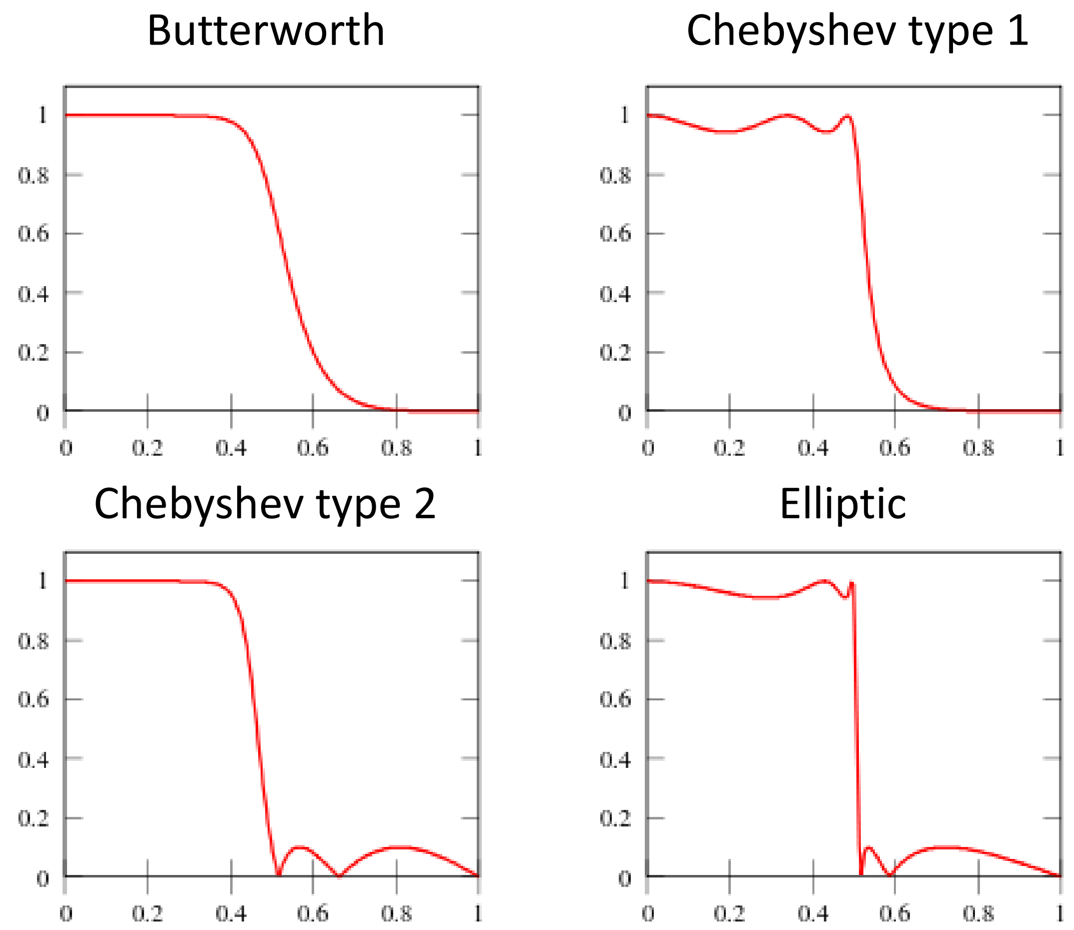


If you gain something, you will lose something. There is always an exchange.

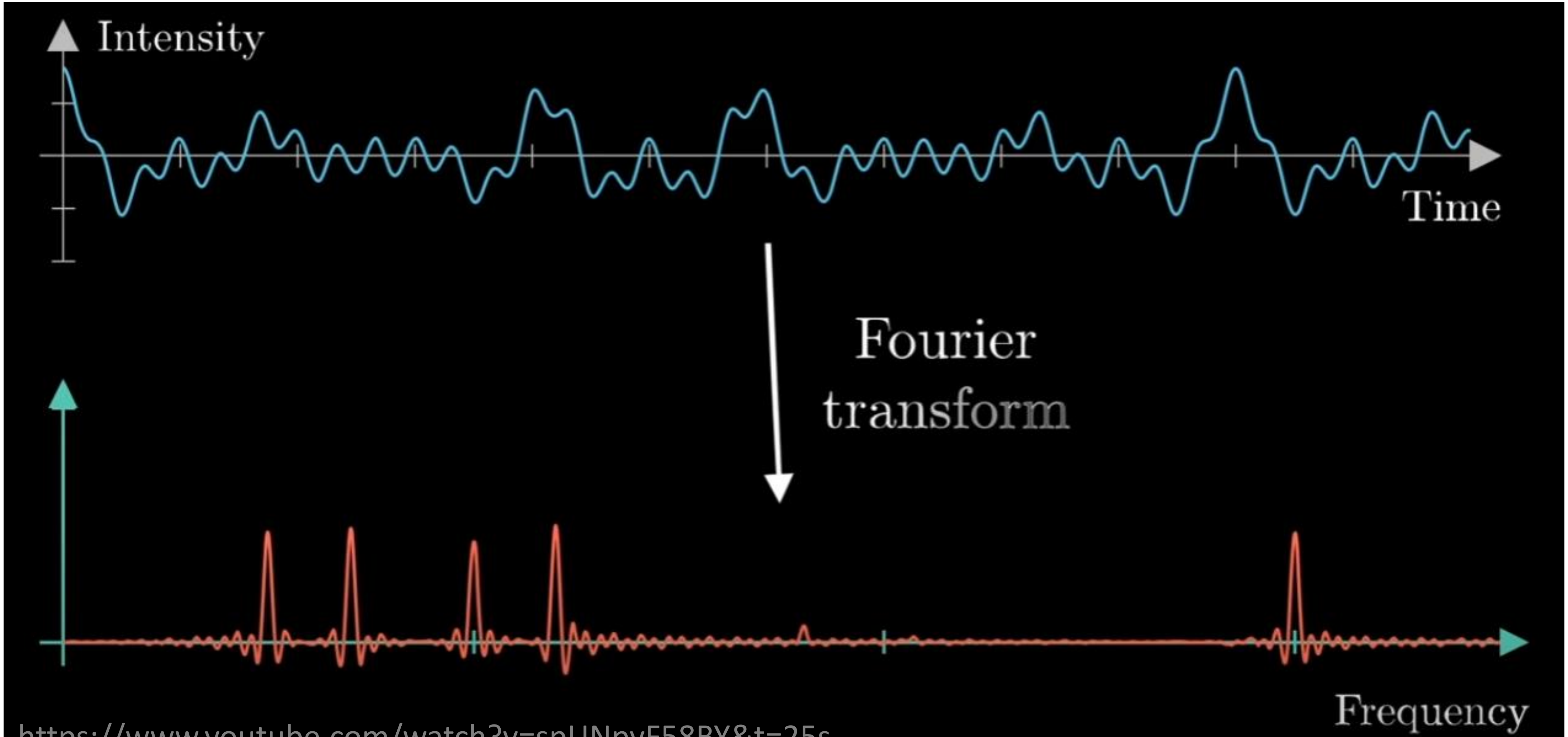
Wolpert, D.H., and Macready, W.G. (2005) "Coevolutionary free lunches", *IEEE Transactions on Evolutionary Computation*, 9(6): 721–735

Filters

- **Butterworth**
  no gain ripple in pass band and stop band, slow cutof
- **Chebyshev type 1:**
  no gain ripple in stop band, moderate cutoff
- **Chebishev type 2:**
  No gain ripple in pass band, moderate cutoff
- **Elliptic:**
  gain ripple in pass and stop band, fast cutoff

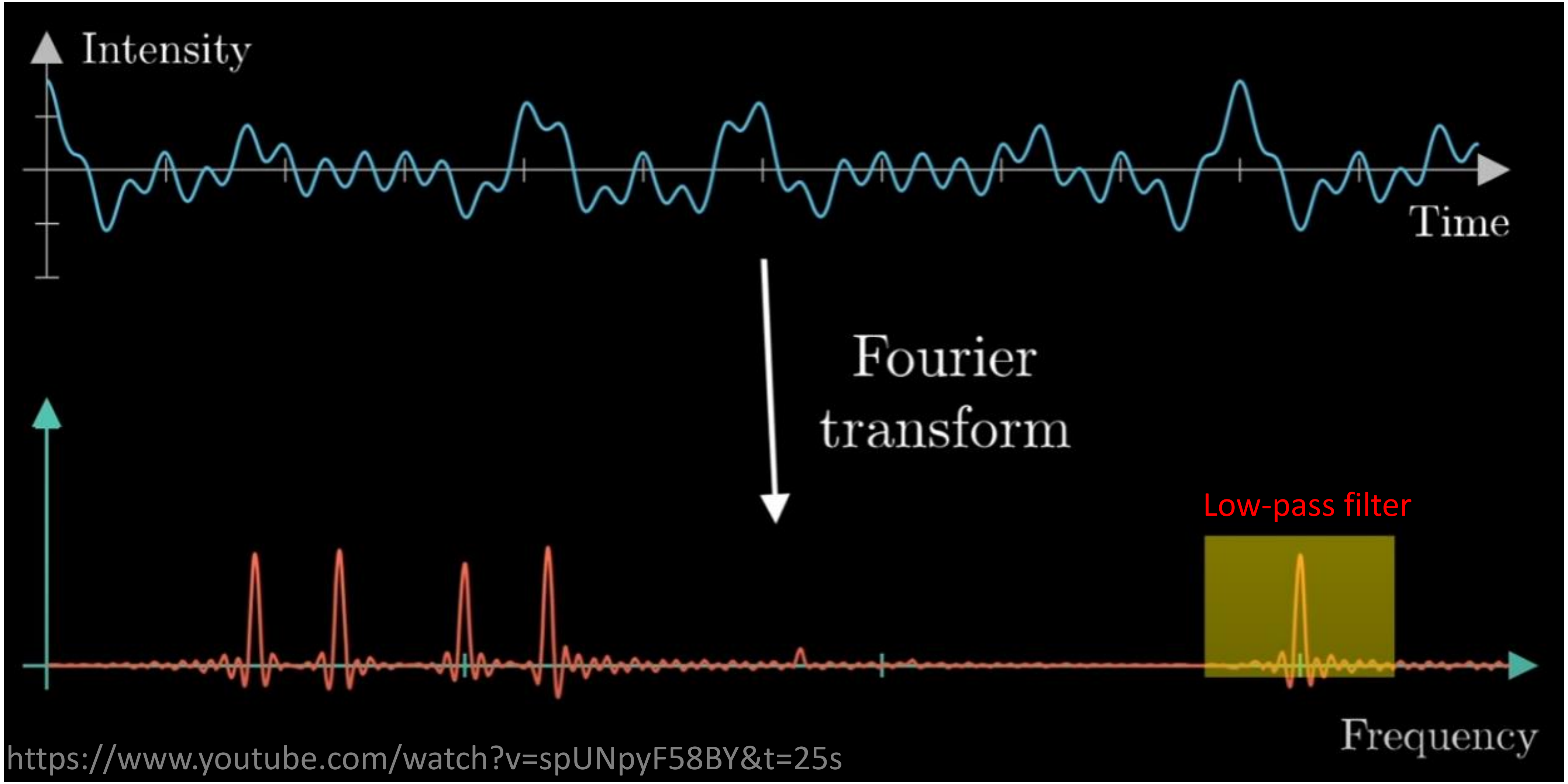


Example



https://www.youtube.com/watch?v=spUNpyF58BY&t=25s

Example


Intensity
Time
Fourier
transform
Low-pass filter
Frequency
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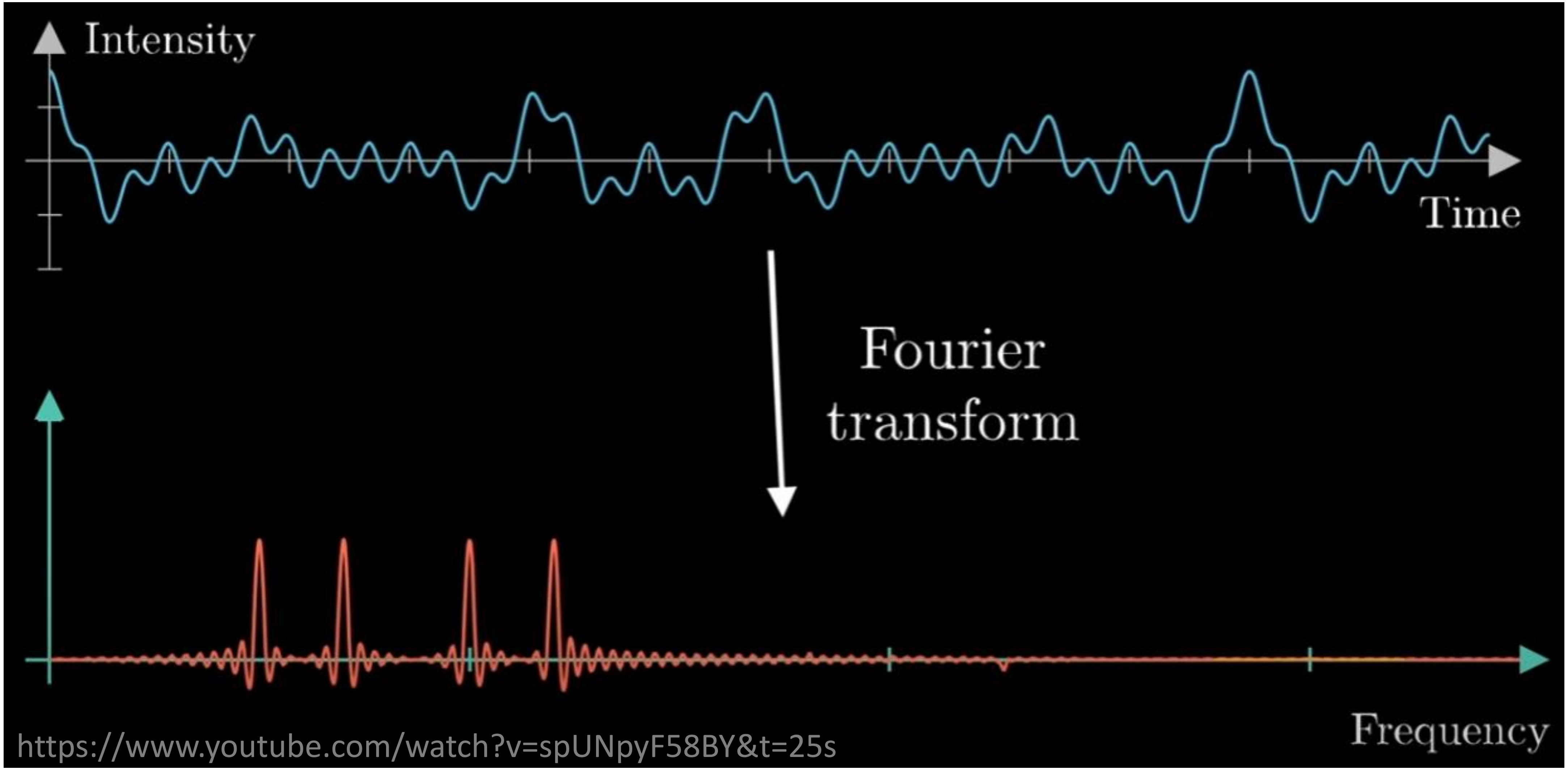
Example



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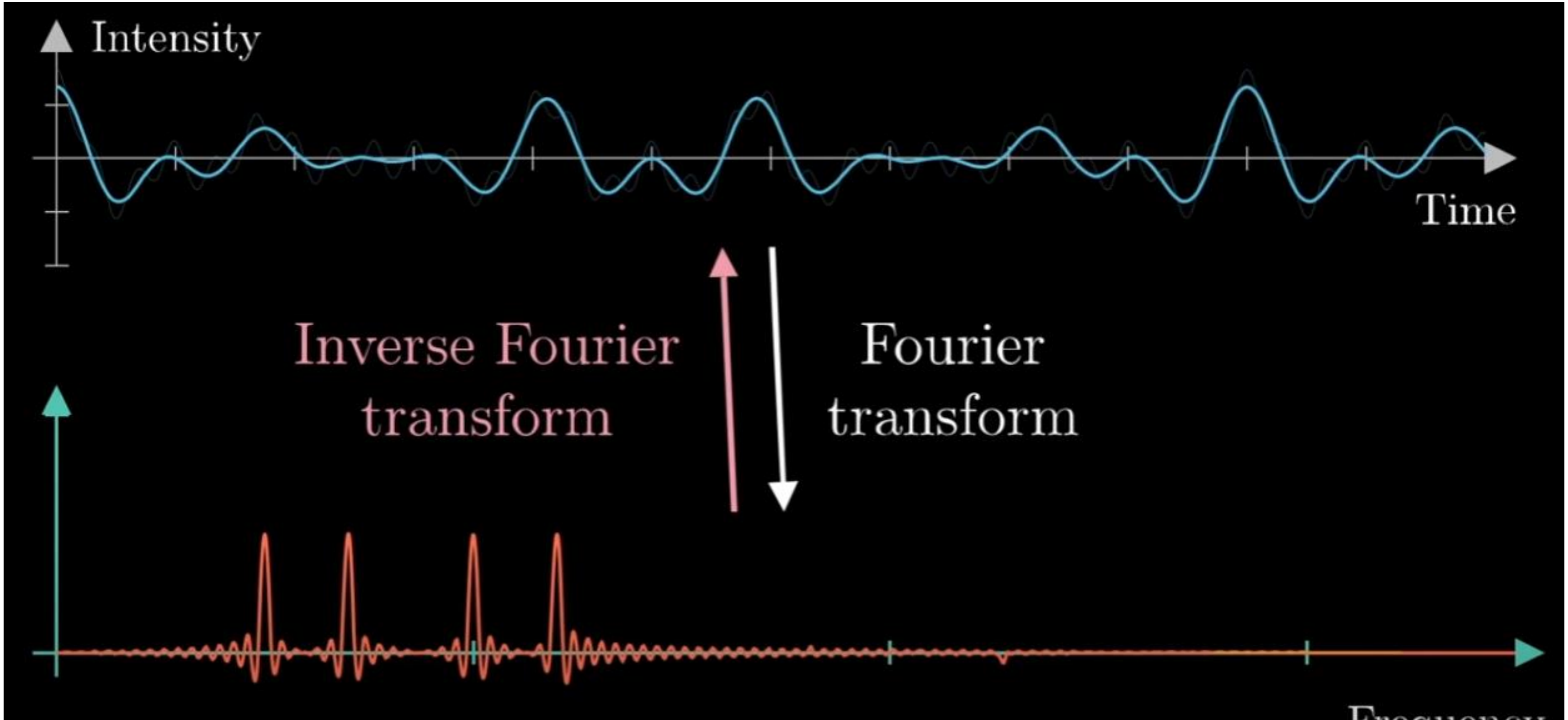

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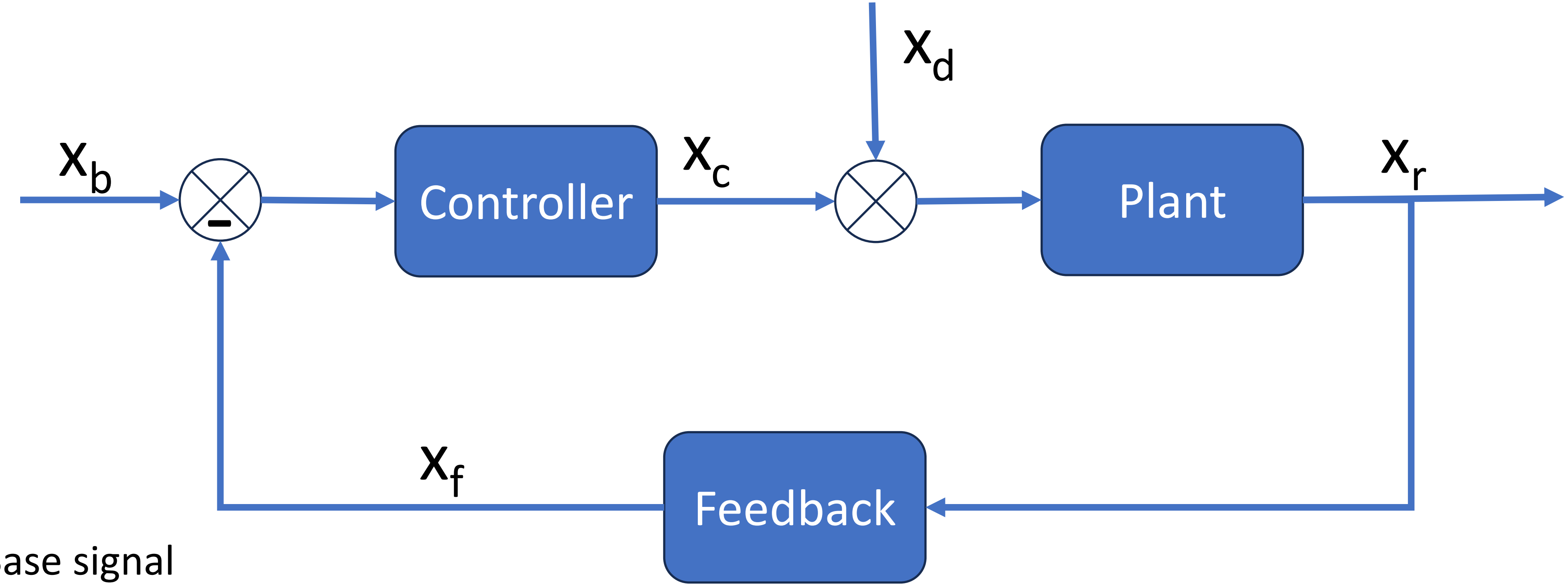
Canonical control loop



x_b: Base signal
x_c: Control signal
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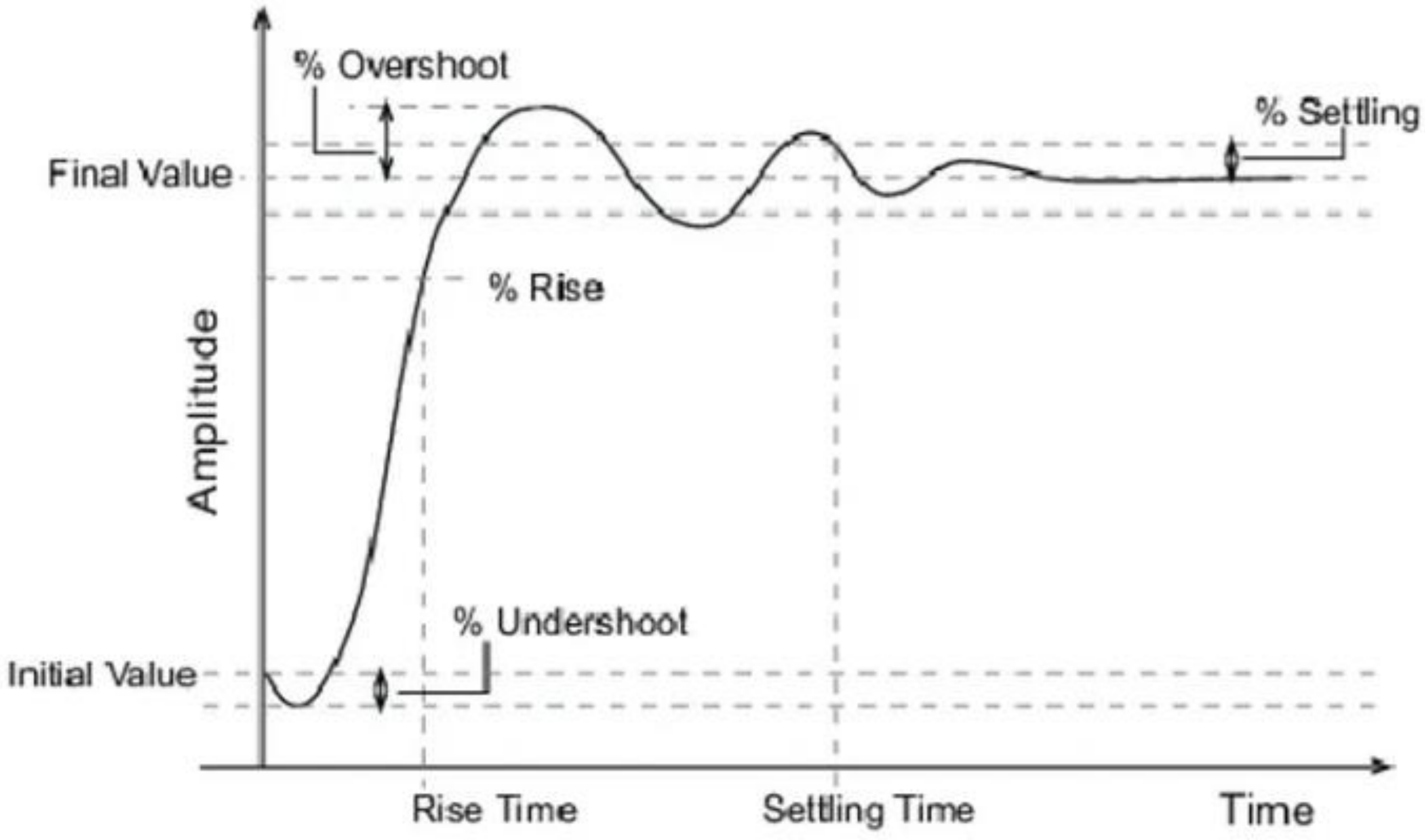
x_d: Disturbance signal

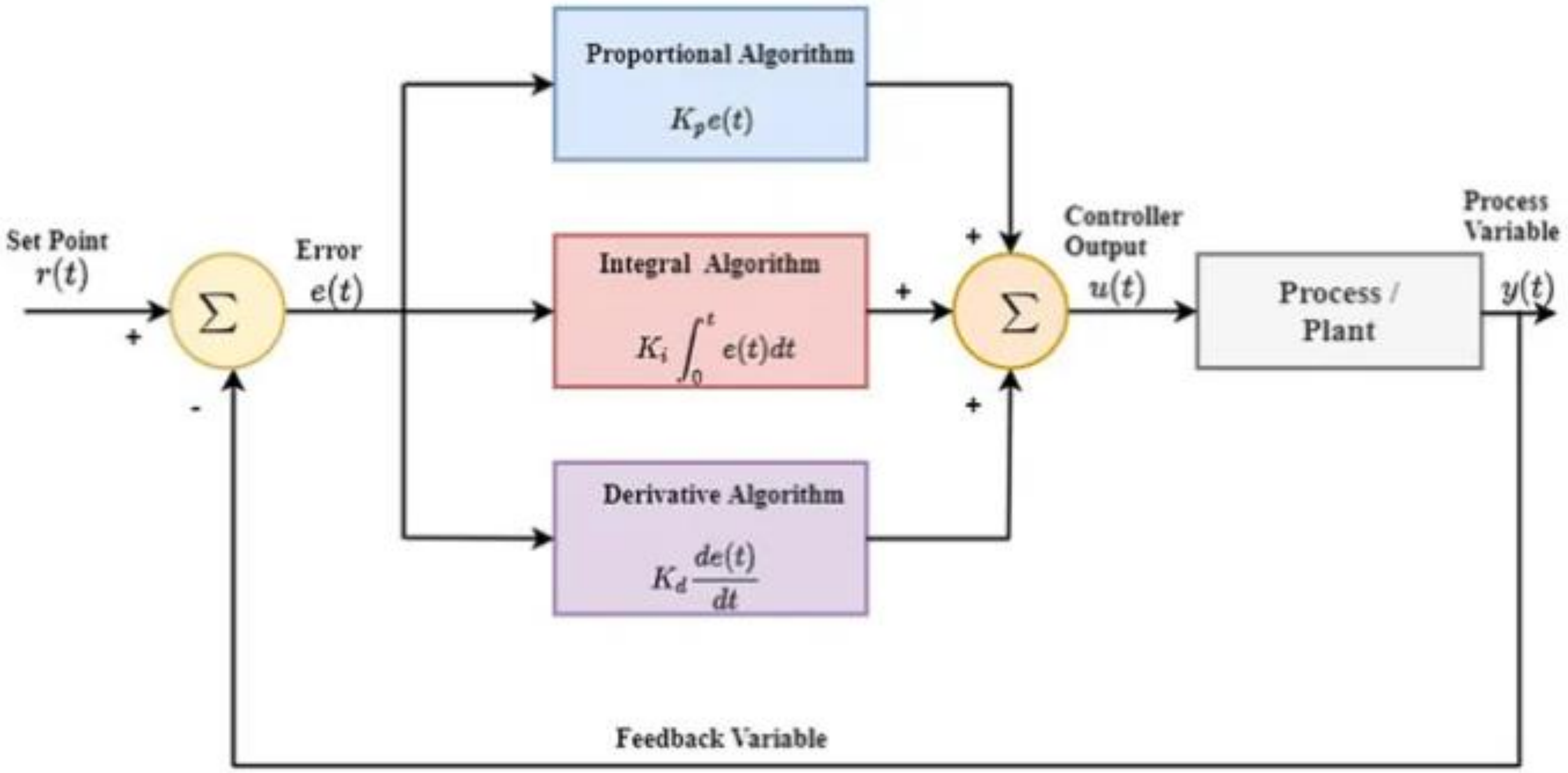
<u>Transfer function</u>
= mathematical model of the plant

Controlled signal



Bike turn example

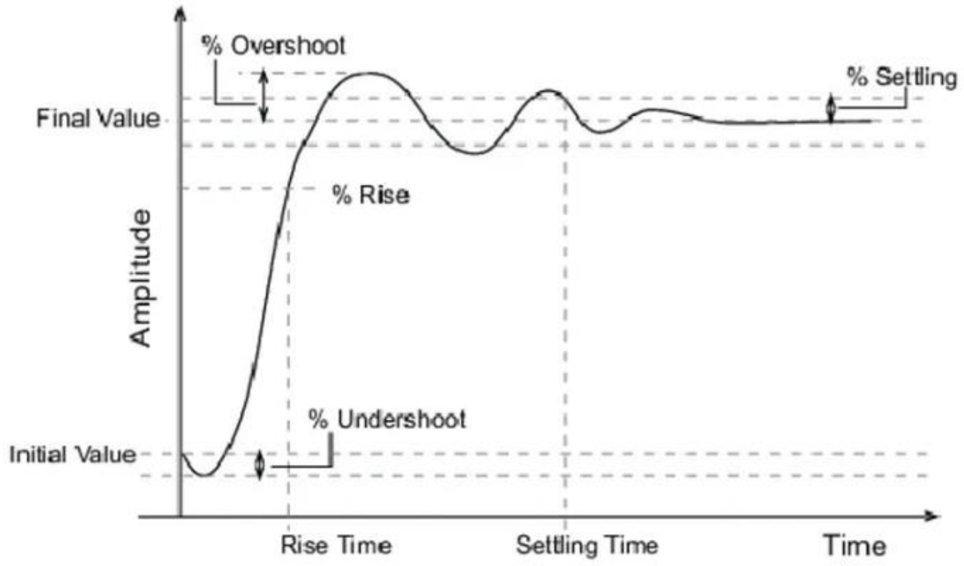
PID controller



https://vis-ro.web.app/robotics/pid

Controller types

- A **Proportional (P)** controller is used to reduce the rise time and speed up the response. This controller makes no changes in the phase response of the plant.
- A **Derivative (D)** controller is required to minimise the transient errors like overshoot and oscillations in the output of the plant. But this can create heavy instability in noisy environments. Be careful to use smaller gain with this controller. It provides a phase lead to the output when compared with the input. , usually with no change in magnitude.
- An **Integral (I)** controller corrects the time invariant errors. This provides a phase lag and no change in magnitude in the output.



Controller in action -> Behaviour

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Thank you for your attention!