Signal processing

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Medical practice is a series of decisions

The logic of a research scientist and a physician are similar:

Observation	Symptoms
Consideration, hypothesis	Preliminary (target) diagnosis
Experiment	Tests (laboratory, imaging)
Theory	Diagnosis

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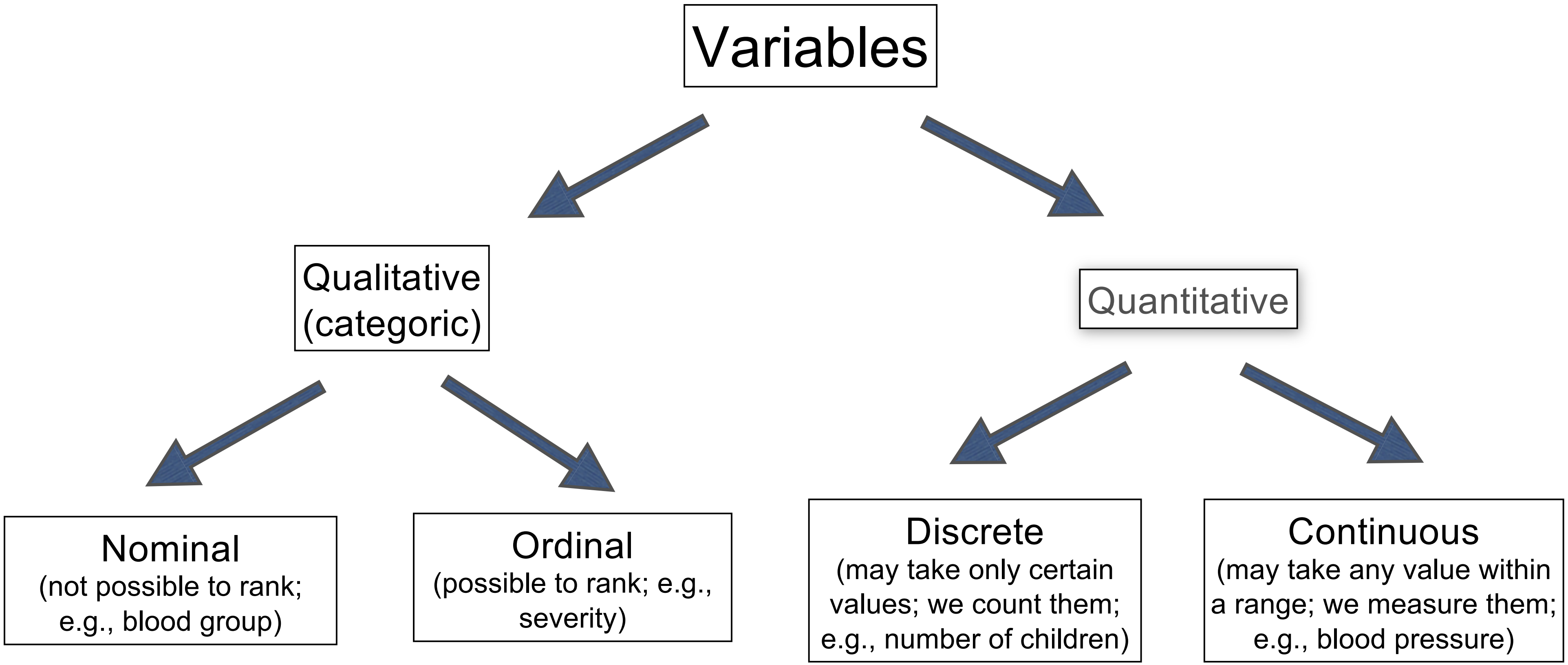
Therapy

In decision making, **data** are considered:
data collection, evaluation, differentiation

Data are values of stochastic variables



There is random variation in the values of the variable.

A special group of data is the signals from the human body

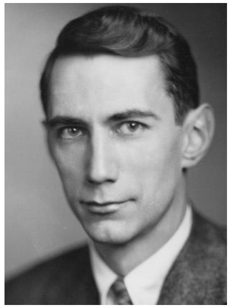
Signal: (physical) quantity that conveys, transmits or stores **information**

Information: statement that carries message; new knowledge that reduces uncertainty.

Information content of a statistically independent event (e.g., signal):

$$I(p) = \log_2\left(\frac{1}{p}\right) = -\log_2(p)$$

p: probability of occurrence of the given signal
I(p) unit: **bit** or **sh** (shannon)

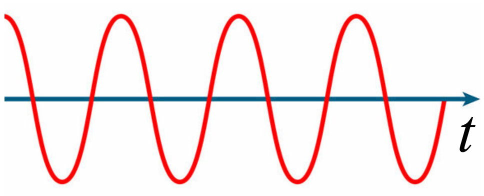


Claude Shannon
(1916-2001)

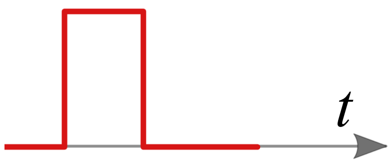
Classification of signals

static	dynamic (time-dependent)
periodic (quasi periodic)	non-periodic (aperiodikus)
random (stochastic)	deterministic
pulse	continuous
electric	non-electric
analog	digital

periodic, continuous

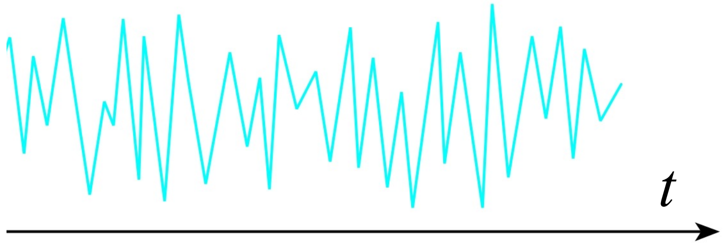


pulse

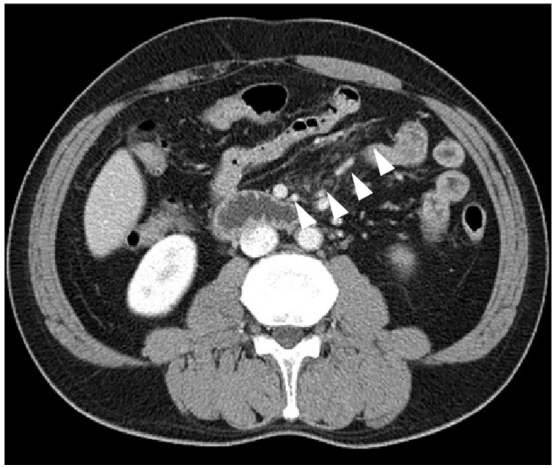


quasi periodic

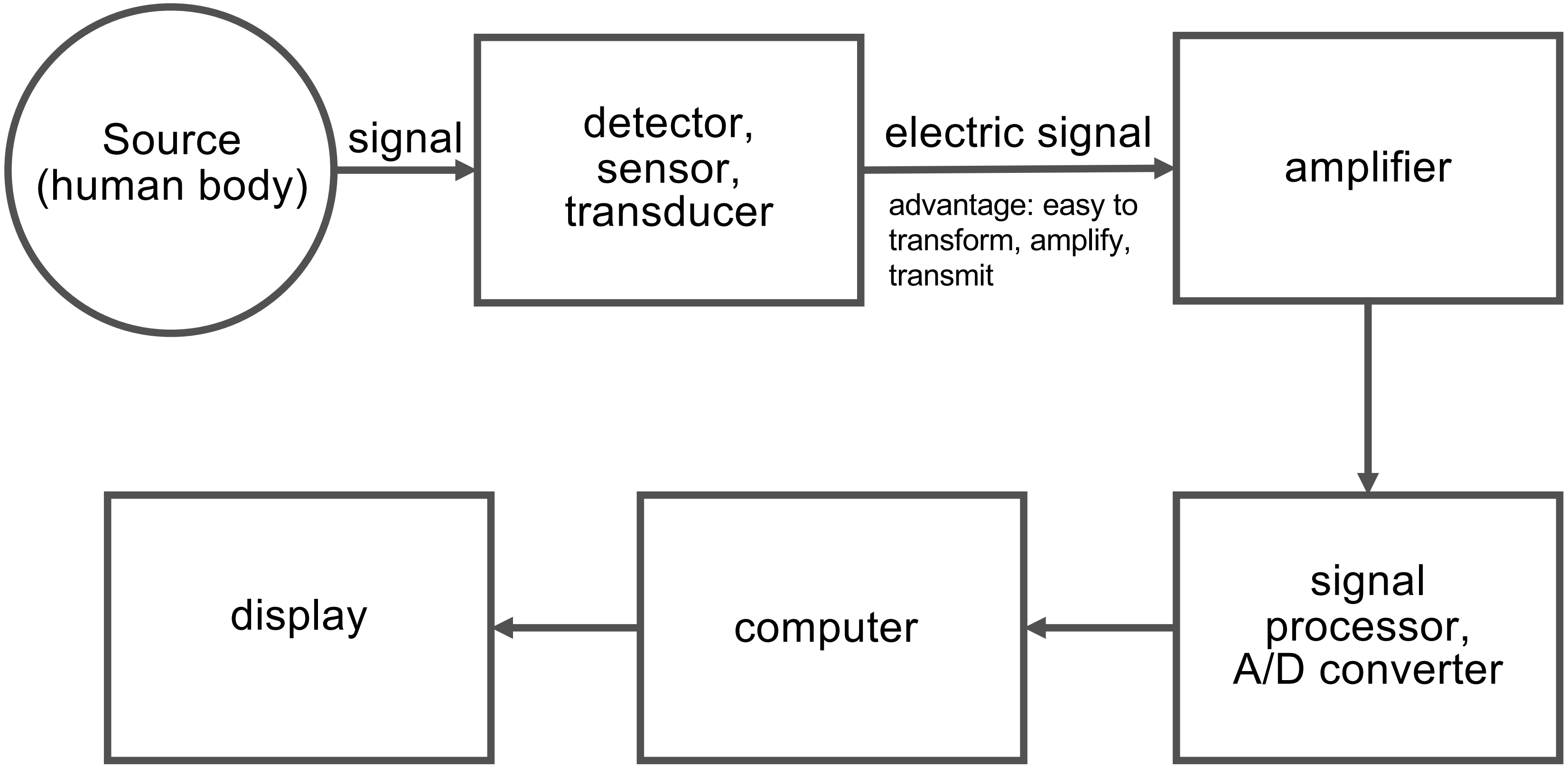
stochastic



spatially varying signal: image



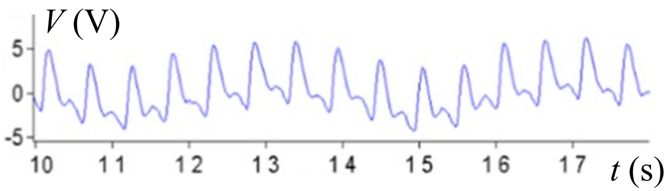
Steps of signal processing



Noise (useless ”signal”) may arise, to a varying degree, in each step.

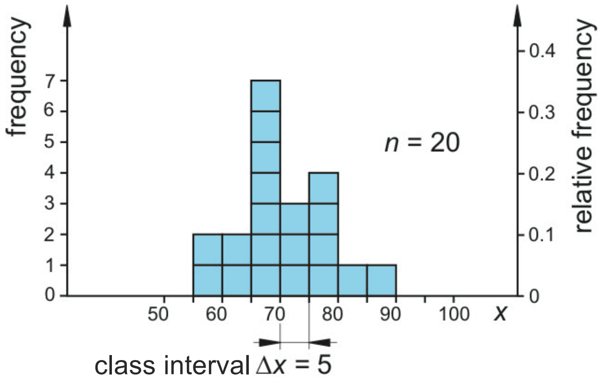
Description and comparison of signals

Signal: pulse wave, time-dependent change in arterial pressure

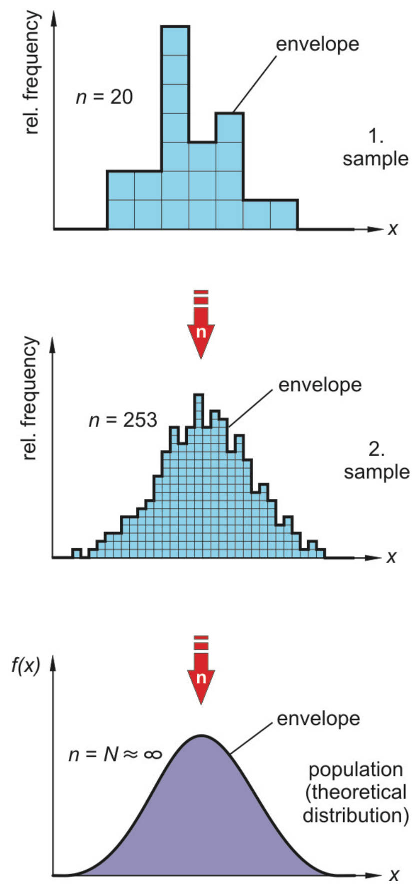


Data: frequency, pulse rate (bpm)

Histogram: frequency/relative frequency organized into classes



(frequency distribution, density function)



By increasing the sample size (n), we approach the properties of the statistical population.

Important parameters:

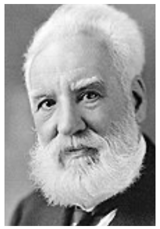
- central measures
- deviation

Comparison of signal size: **bel** scale

$$n = \lg\frac{P_2}{P_1}\,\mathrm{B} = \lg\frac{J_2}{J_1}\,\mathrm{B} = \lg\frac{E_2}{E_1}\,\mathrm{B}$$

power intensity energy

decibel scale $n = 10 \cdot \lg\frac{P_2}{P_1}\,\mathrm{dB}$

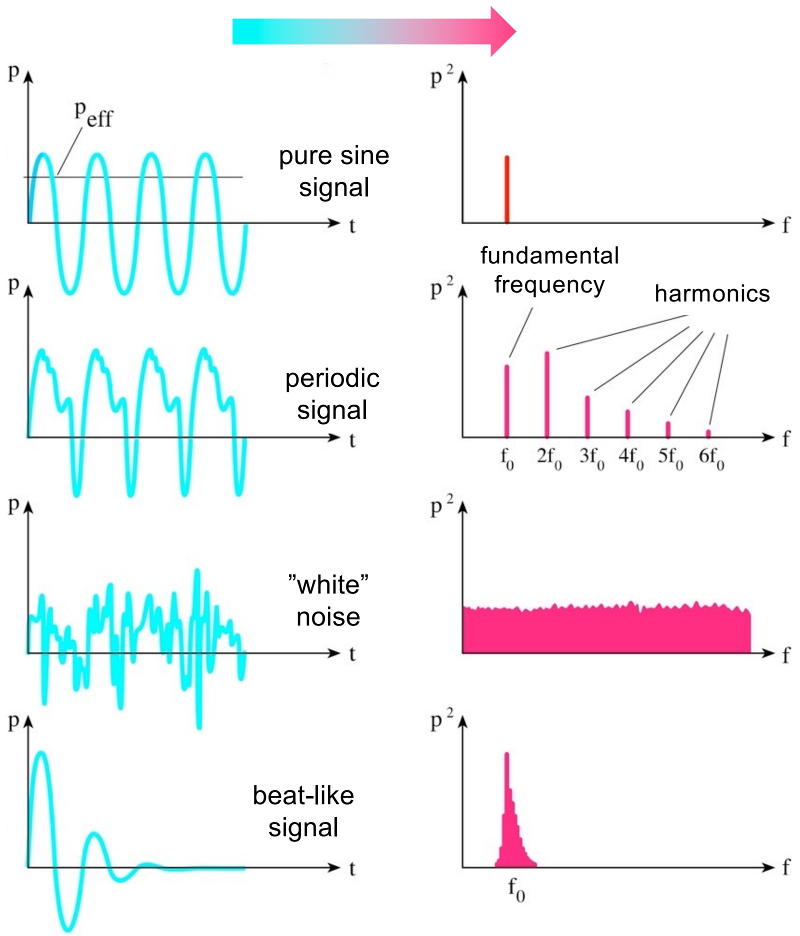


Alexander Graham Bell (1847-1922)

Frequency analysis of signals

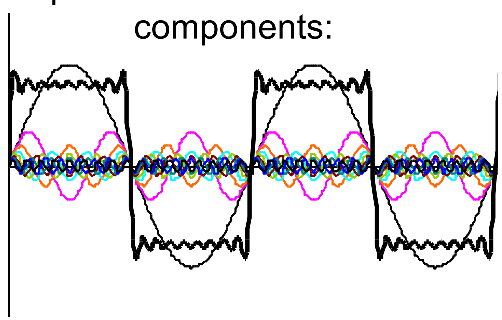
Fourier theorem: every function can be expressed as a sum of sines and cosines
(for a periodic function: fundamental frequency + harmonics)

Fourier analysis



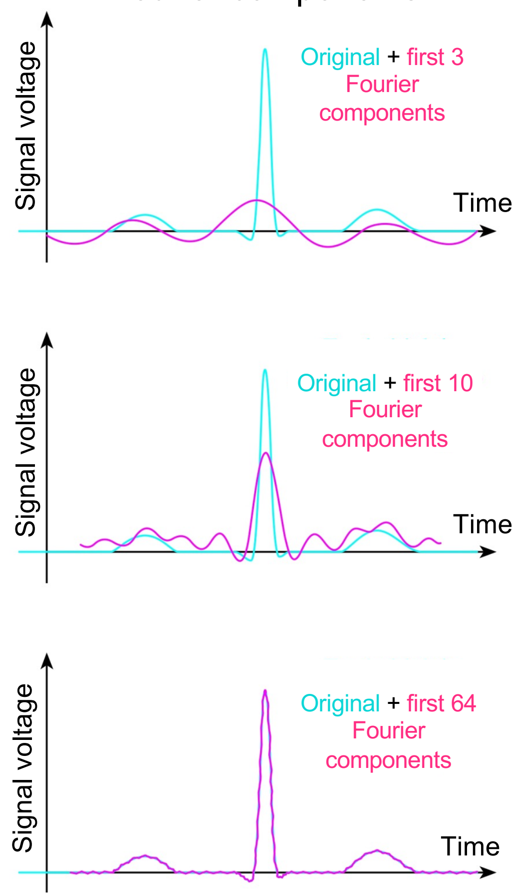
Process of Fourier analysis:

Square wave and its Fourier components:

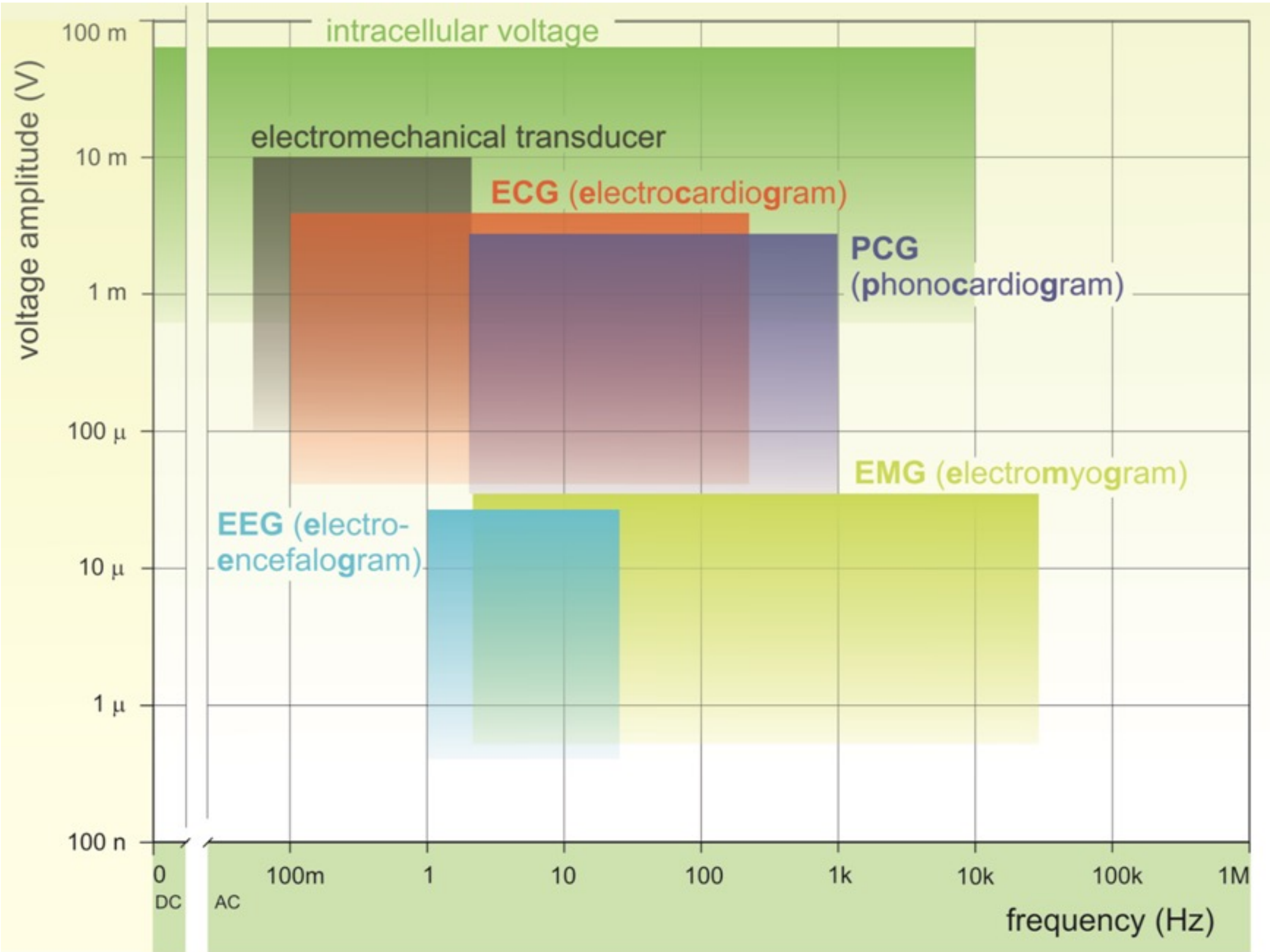


Fourier synthesis

ECG signal synthesis from Fourier components

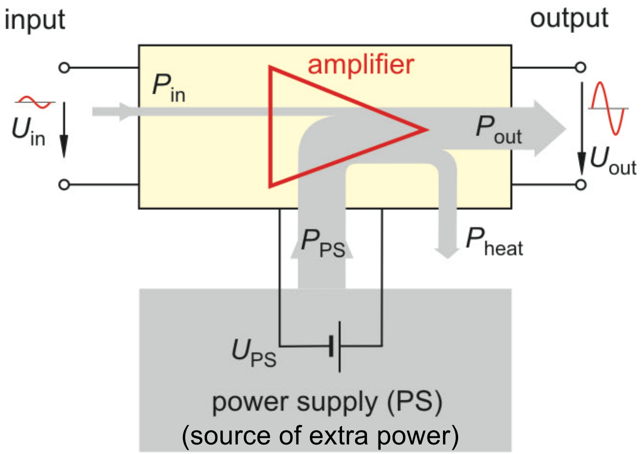


Frequency and amplitude ranges of medically important signals



Signal amplification

Amplifier: increases the power of the input signal



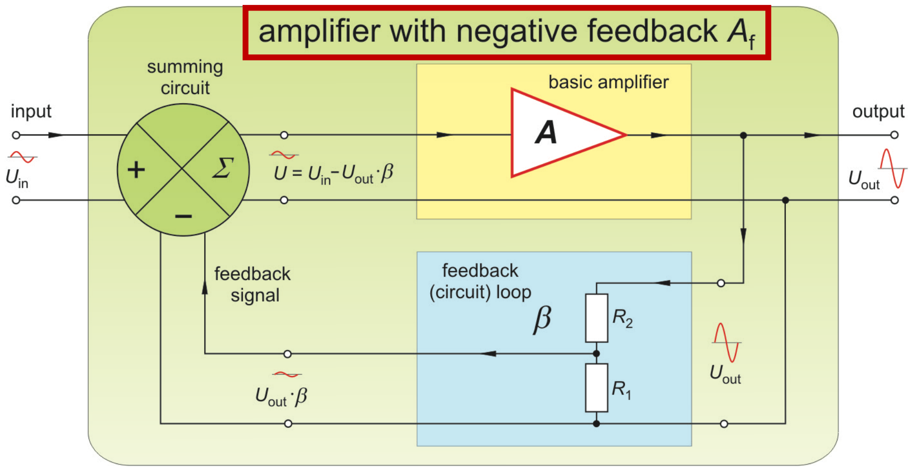
Measures of amplification

Voltage gain $A_U = \frac{U_{ki}}{U_{be}}$,

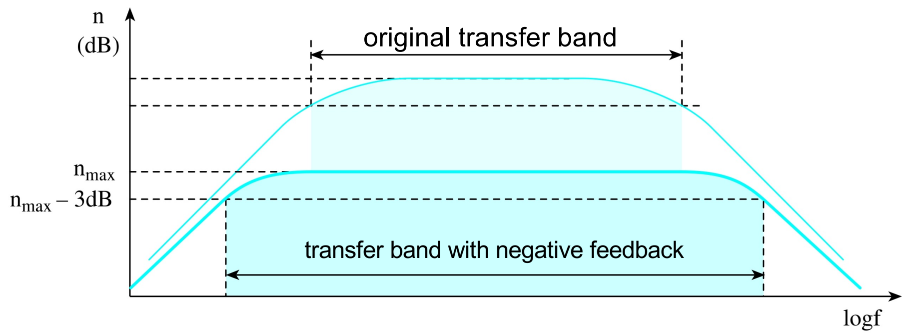
Power gain $A_P = \frac{P_{ki}}{P_{be}}$,

Gain level $n = 10 \lg A_P = 20 \lg A_U$

Properties of an amplifier: gain, distorsion, transfer bandwidth

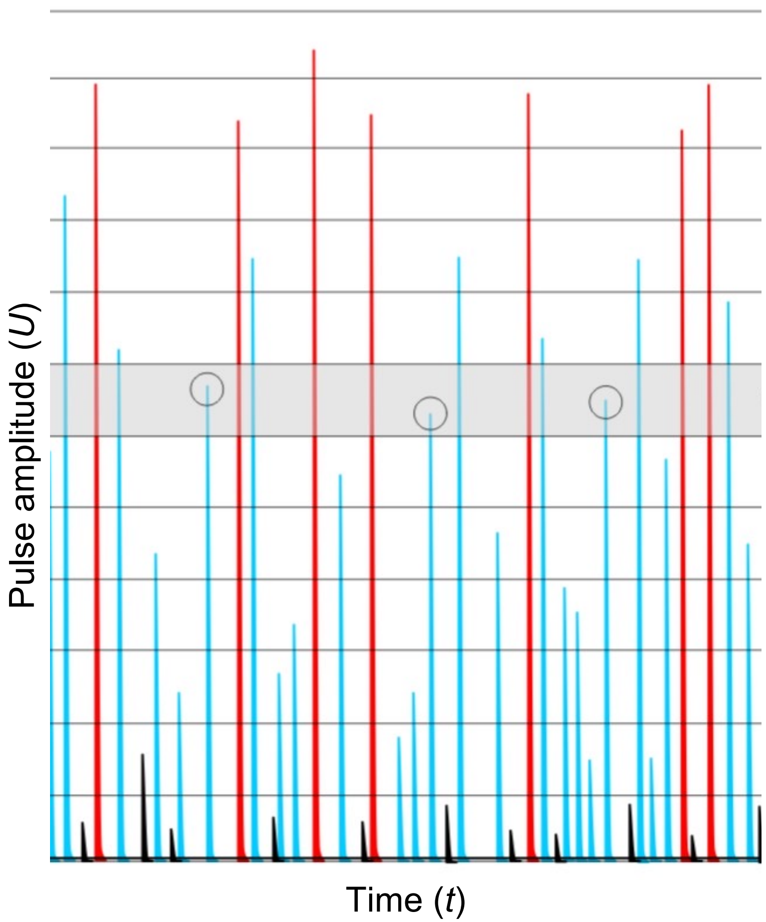


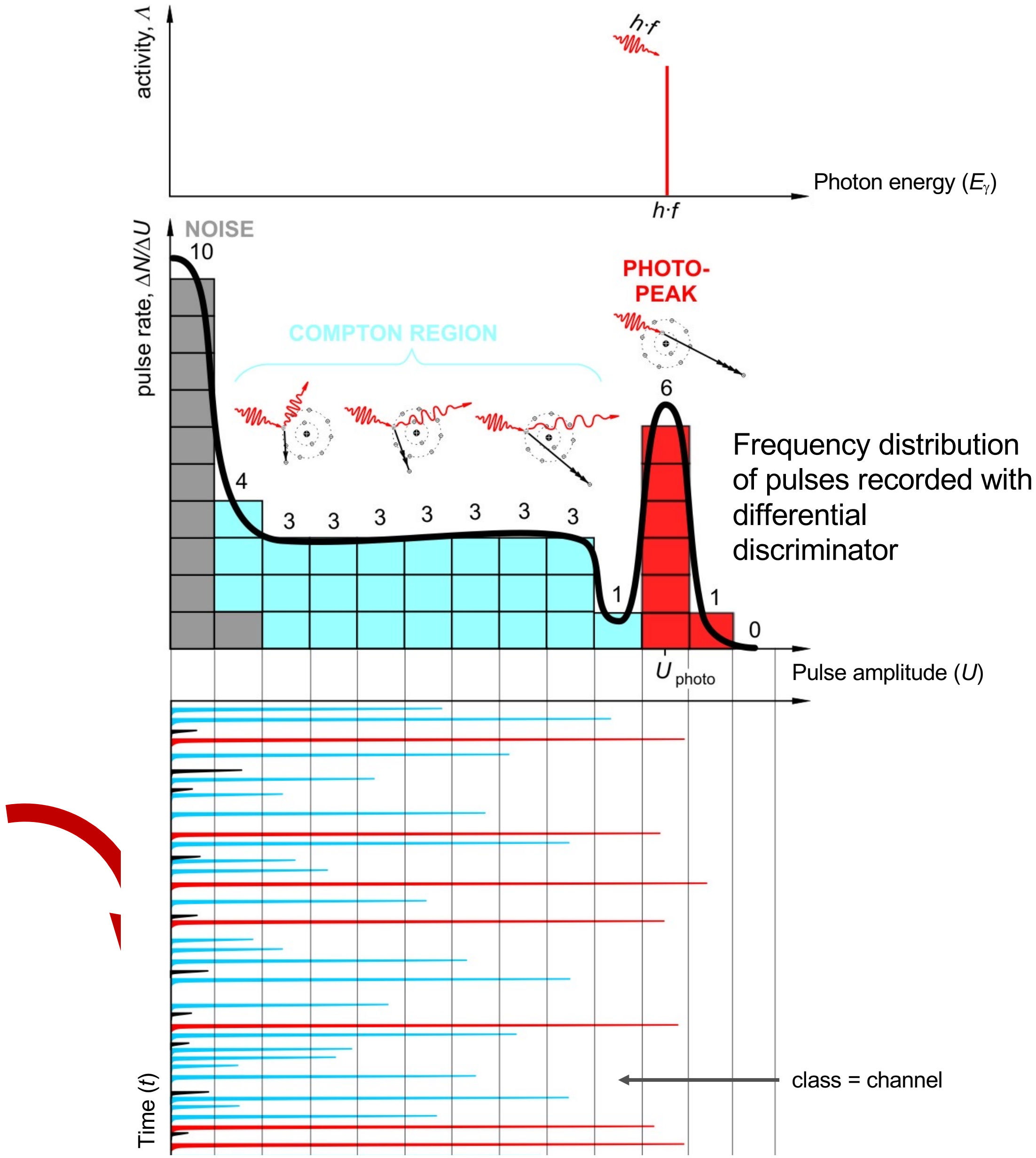
Voltage gain $A_f = \frac{A}{1 + \beta A}$



Signal analysis – pulses

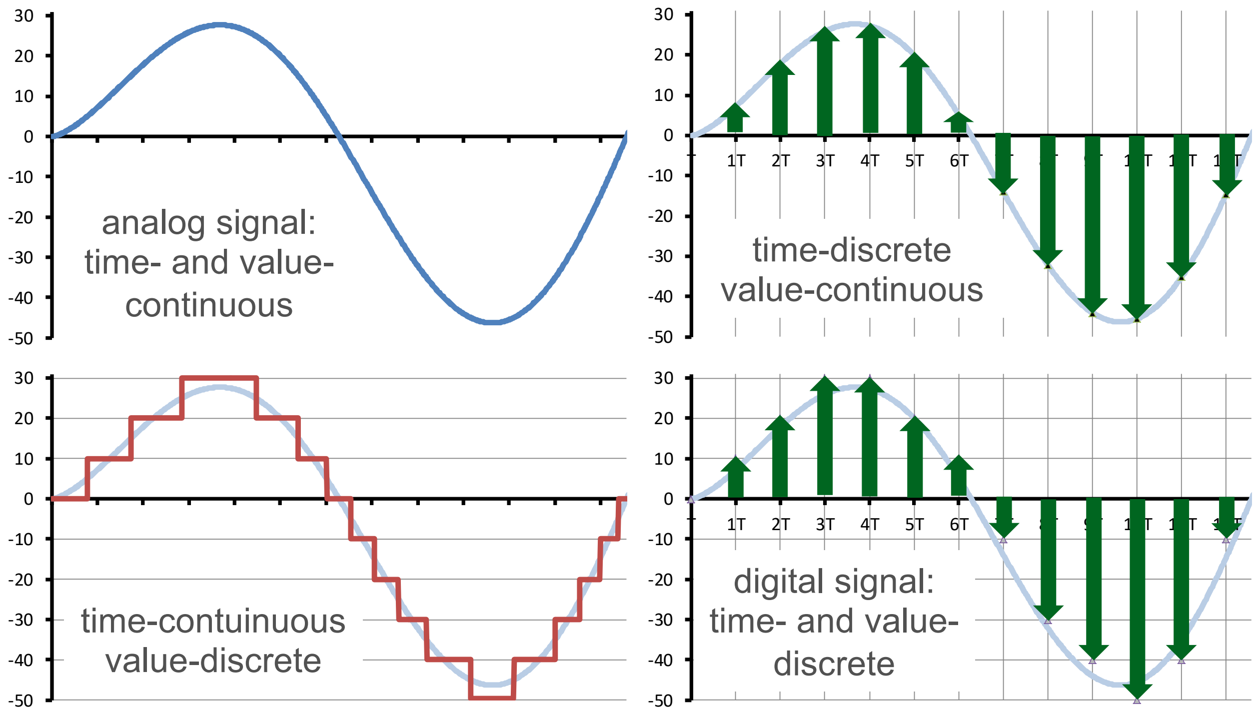
Differential discriminator (DD)



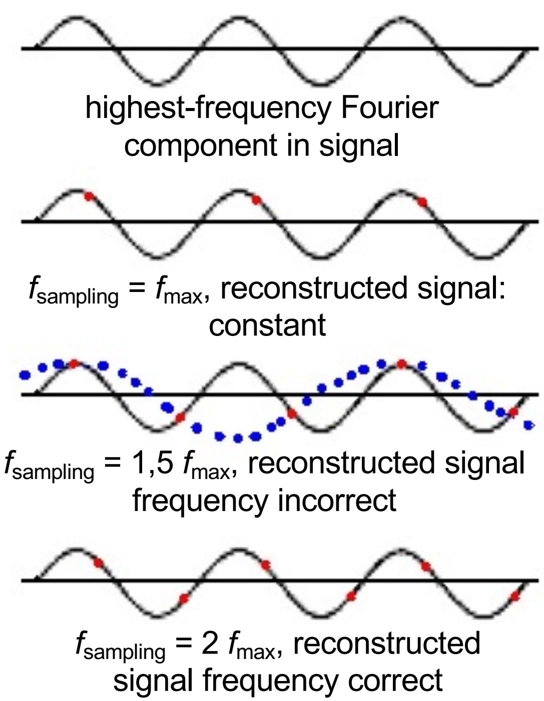


Signal digitization

Advantages of digital signals: easy to store, transmit, and the problem of noise is reduced



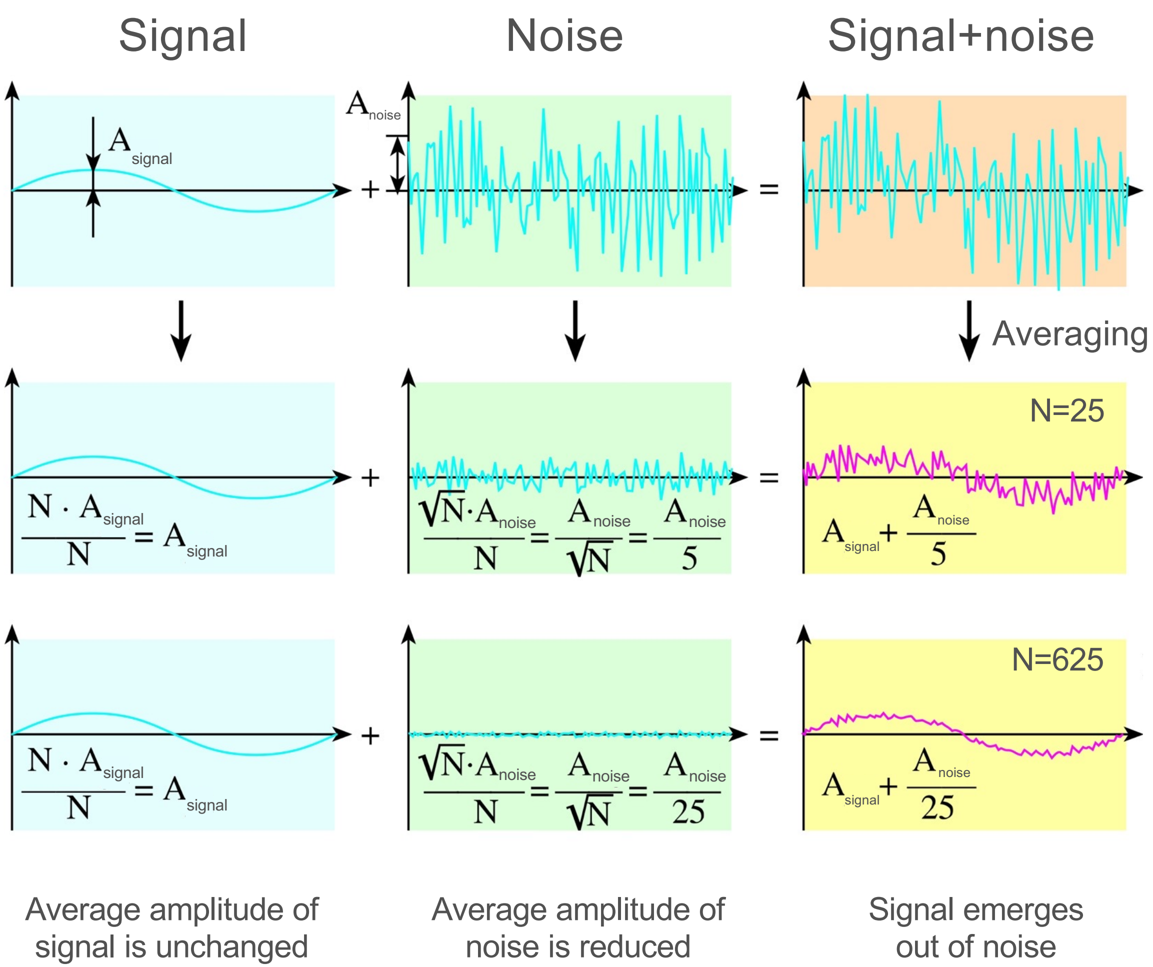
Problem of digitization:



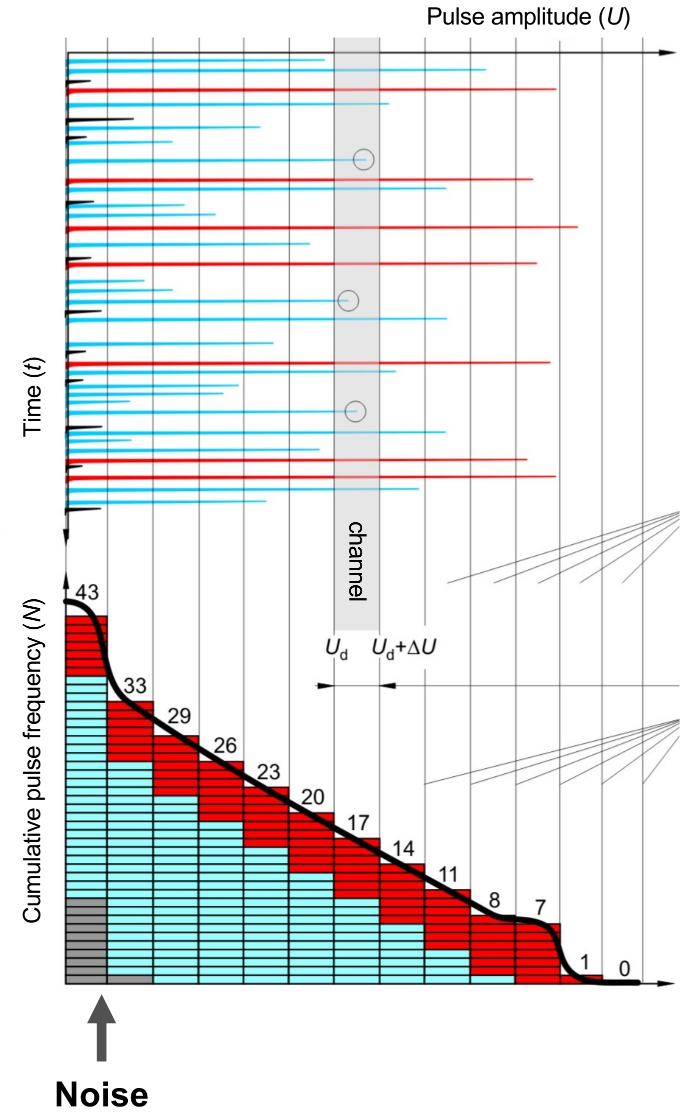
Shannon-Nyquist sampling theorem: the minimal sampling frequency must be twice that of the highest harmonic of the signal.

Noise reduction I.

Averaging



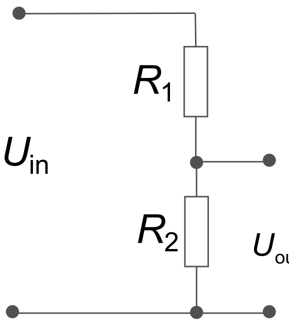
Integral discriminator



Noise reduction II.

Frequency selective signal transfer/amplification

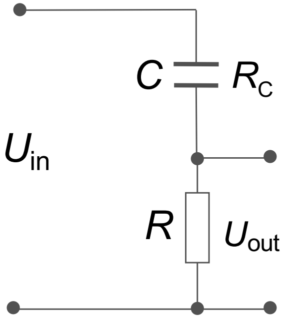
Voltage divider



$$U_{out} = \frac{R_2}{R_1 + R_2} U_{in}$$

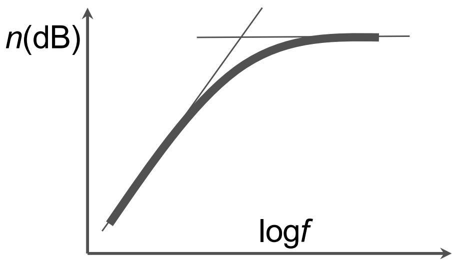
Distorsion-free, frequency-independent signal transfer

High-pass filter

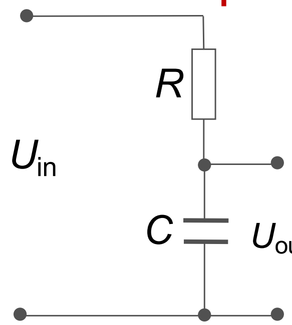


$$R_C = \frac{1}{C\omega}$$

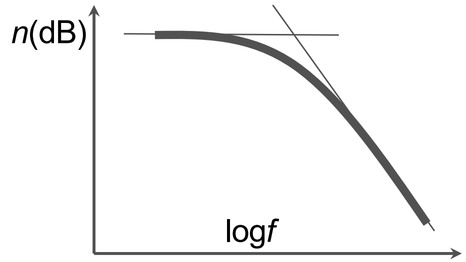
$$U_{out} = \frac{RC\omega}{\sqrt{1 + R^2C^2\omega^2}} U_{in}$$



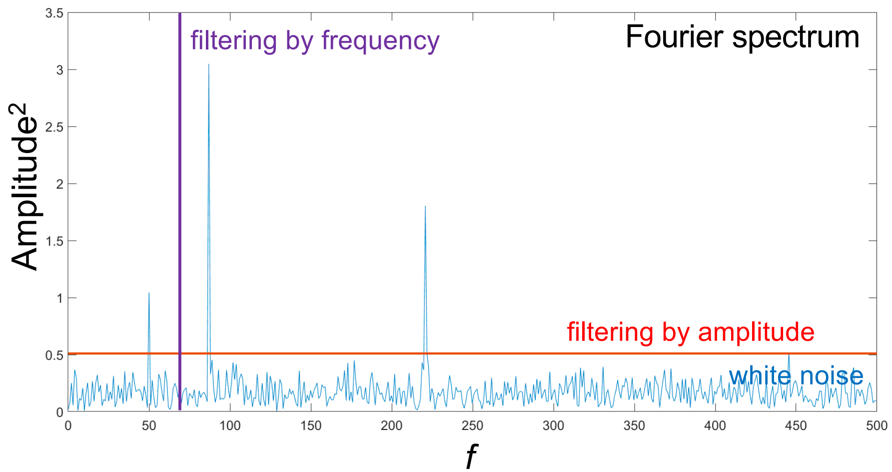
Low-pass filter



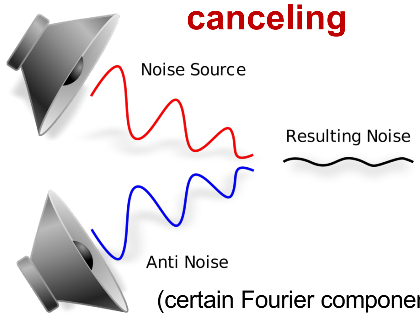
$$U_{out} = \frac{1}{\sqrt{R^2C^2\omega^2 + 1}} U_{in}$$



Noise reduction based on Fourier analsis

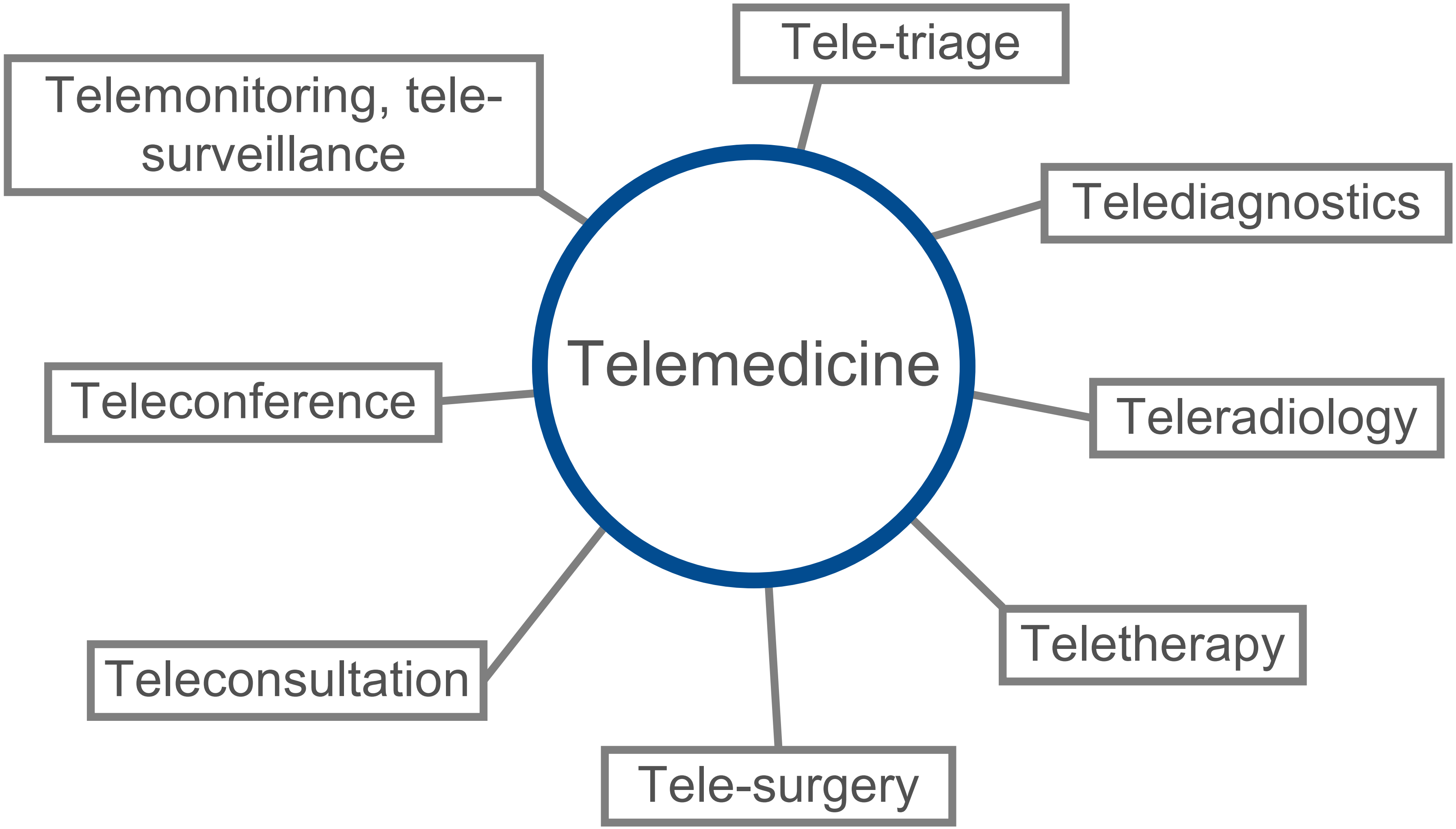


Active noise canceling



(certain Fourier components are played back after a 180˚ phase shift)

Cloud-based storage, transfer and processing of medical signals: telemedicine



Feedback

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