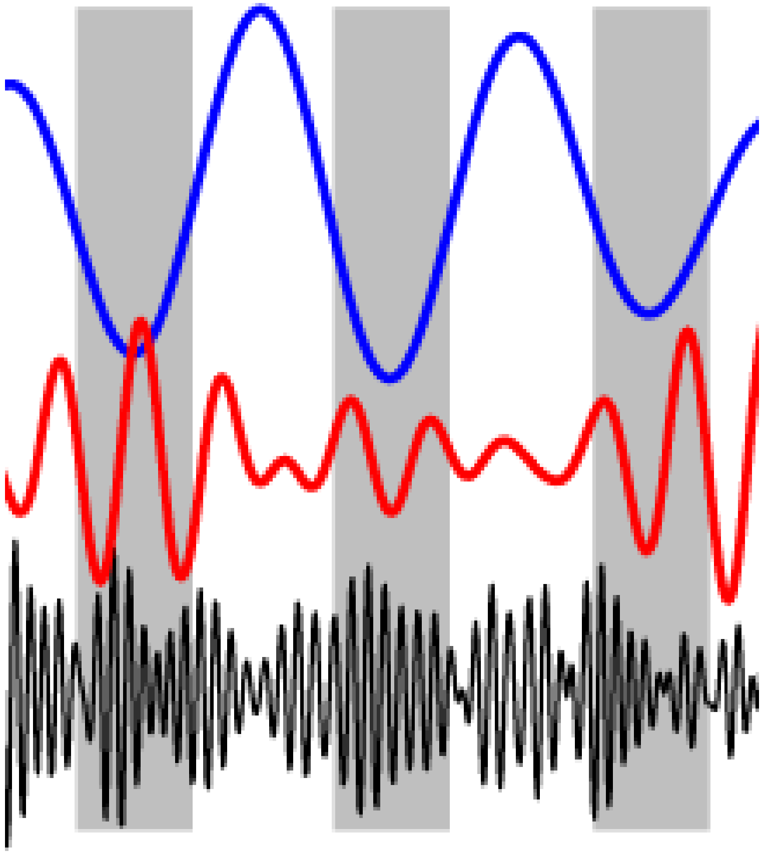
university of groningen



PSMCV-2
Data Collection & Analysis for Cognitive Neuroscience

Time Series Data

Olaf Dimigen

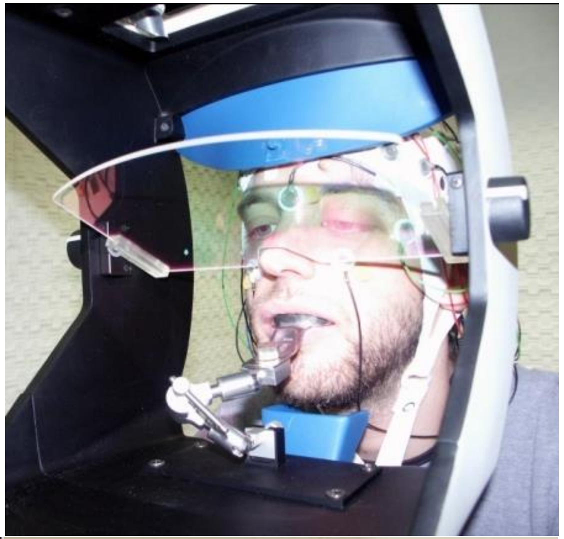
Today

1. A bit more on eye-tracking measurements
2. Analyzing time series data
   - Sampling theory & Aliasing
   - Filtering
   - Averaging

1. A bit more on eye-tracking measurements

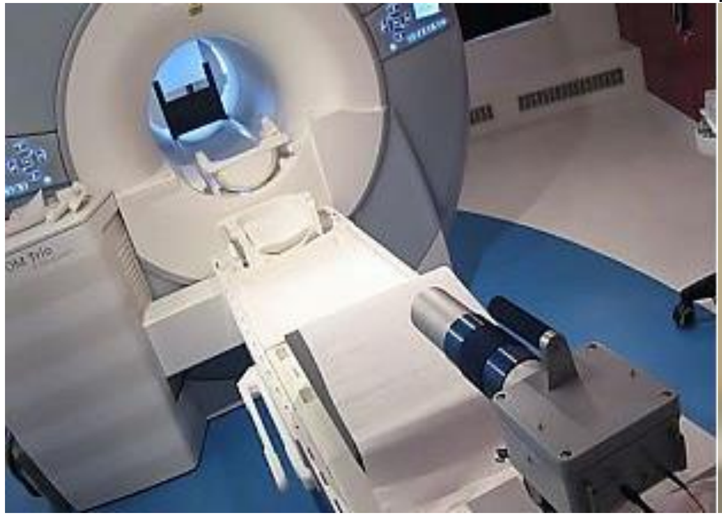
Video-based eye trackers

SR Research Eyelink 1000

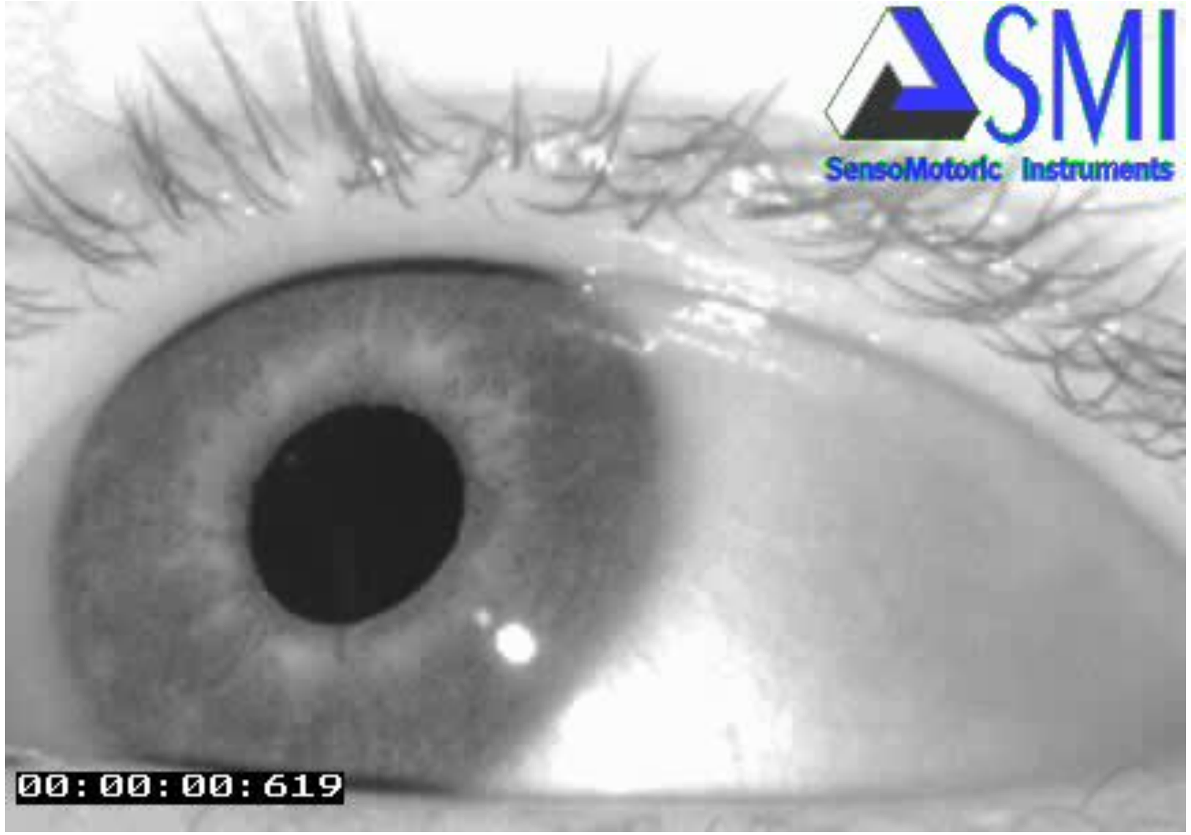


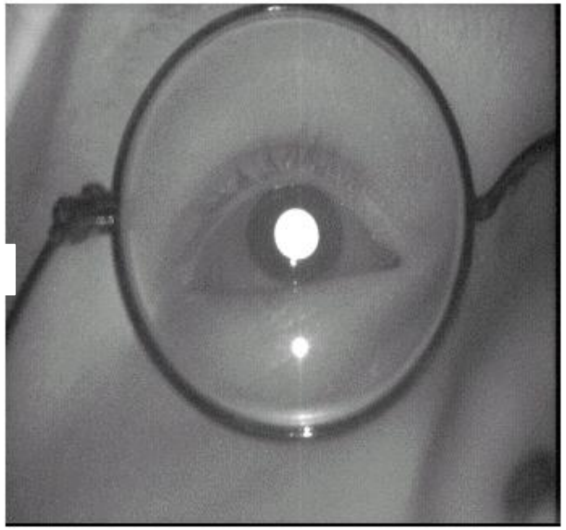
SMI Hi-Speed Tower

MR-compatible



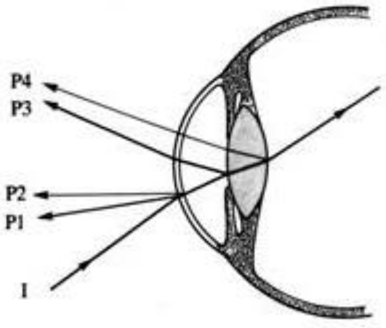
SMI Glasses



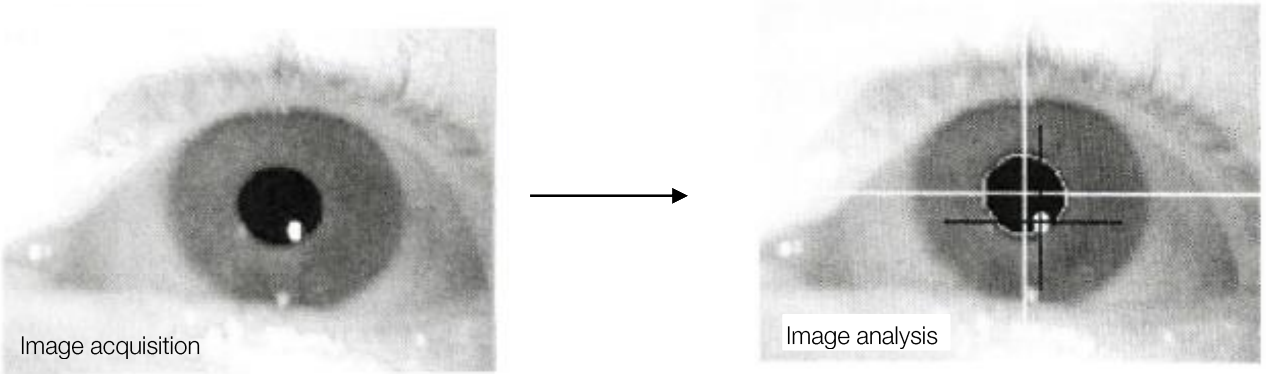


bright pupil technique

Eye raw video (1250 Hz sampling rate)



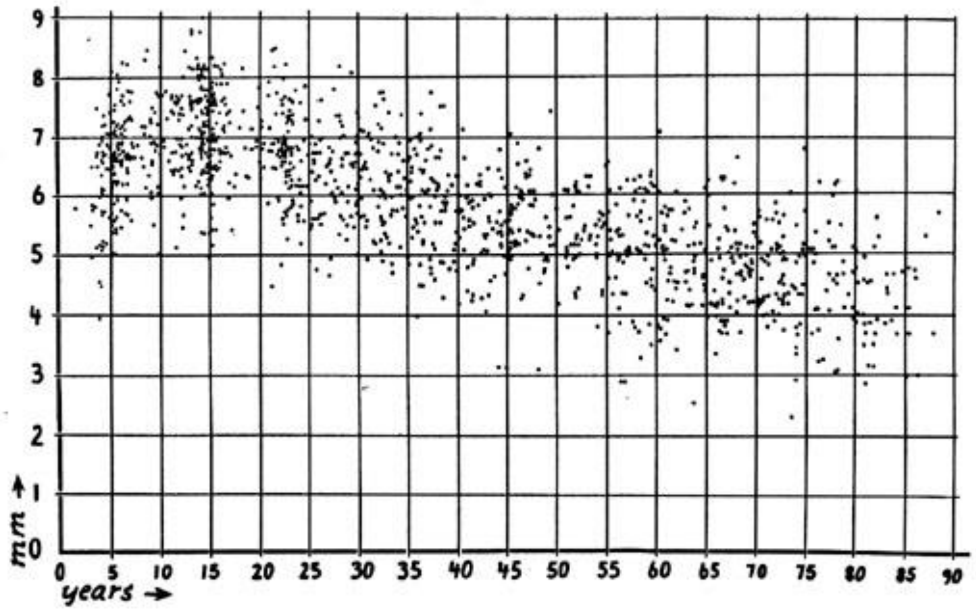
Purkinje Reflexes



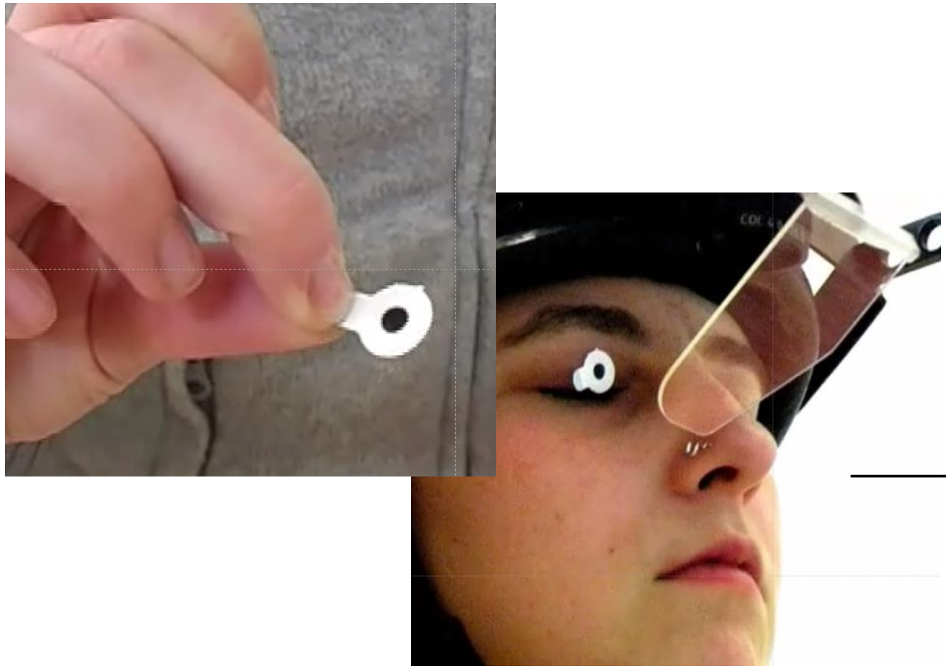
Calibrating of pupil *size*

- *Sometimes* we want pupil size as [mm]
- Convert pixels to [mm]

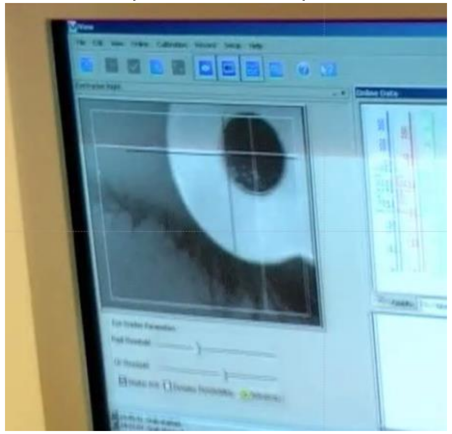
e.g., pupil size with age



Artificial pupil of known diameter (mm)



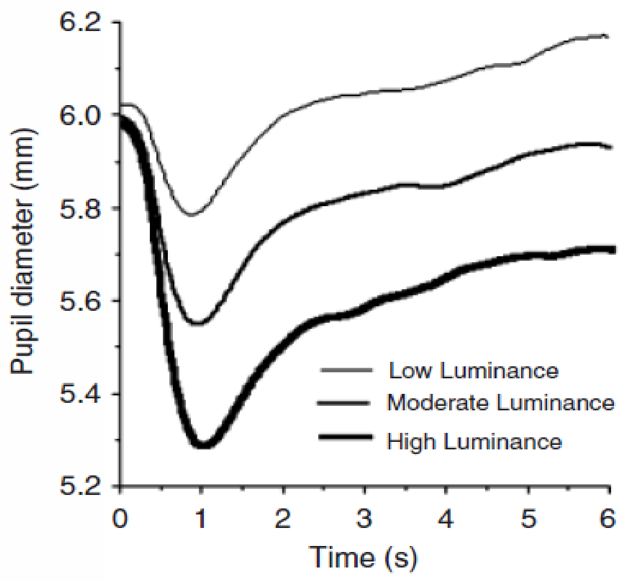
Map to video pixels



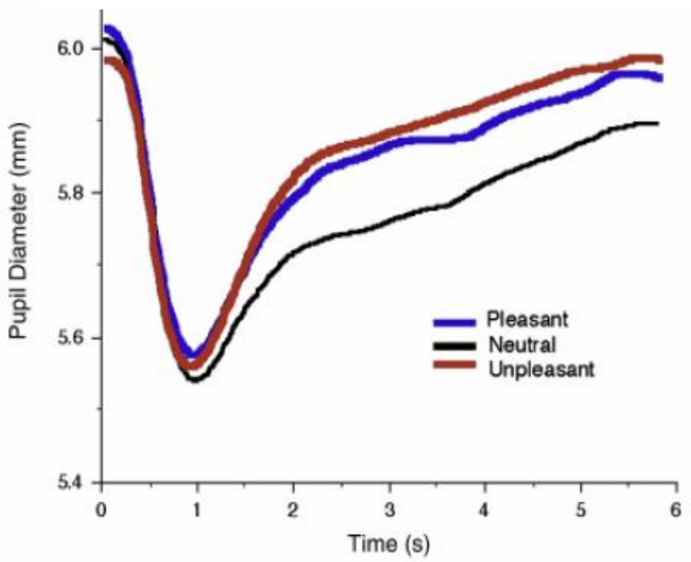
Pupil: Arousal vs. Luminance

International affective picture system (IAPS)

Split by luminance (confound)



Split by emotional valence (luminance matched)



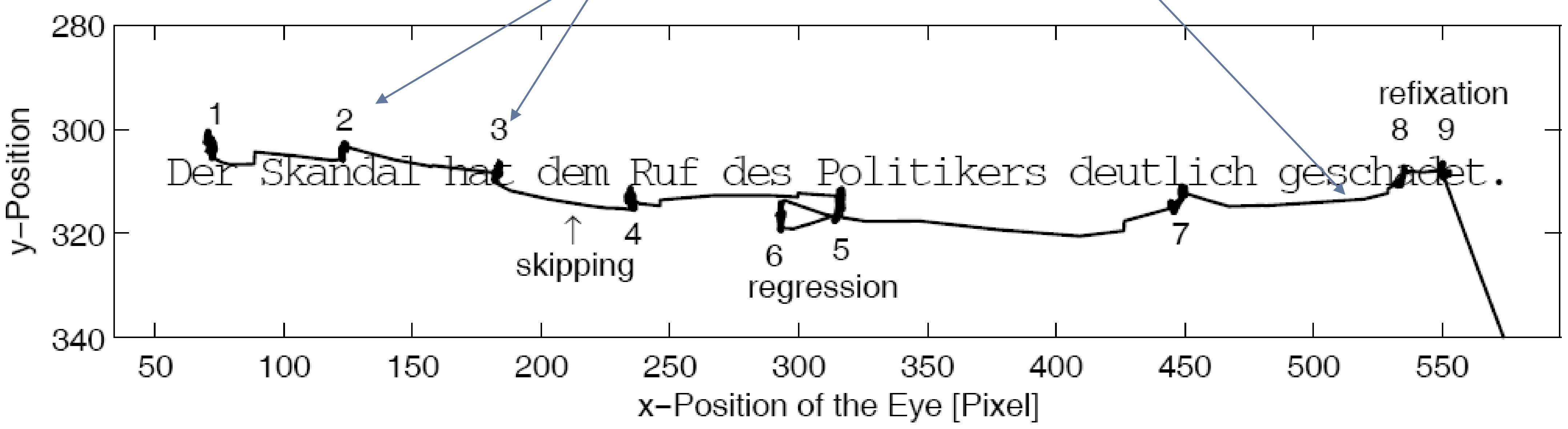
Bradley, Miccoli, Escrig & Lang (2008), *Psychophysiology,* 45, 602-607

Eye movements: Saccades & fixations

Example reading

Fixations
Typical duration: 200-250 ms

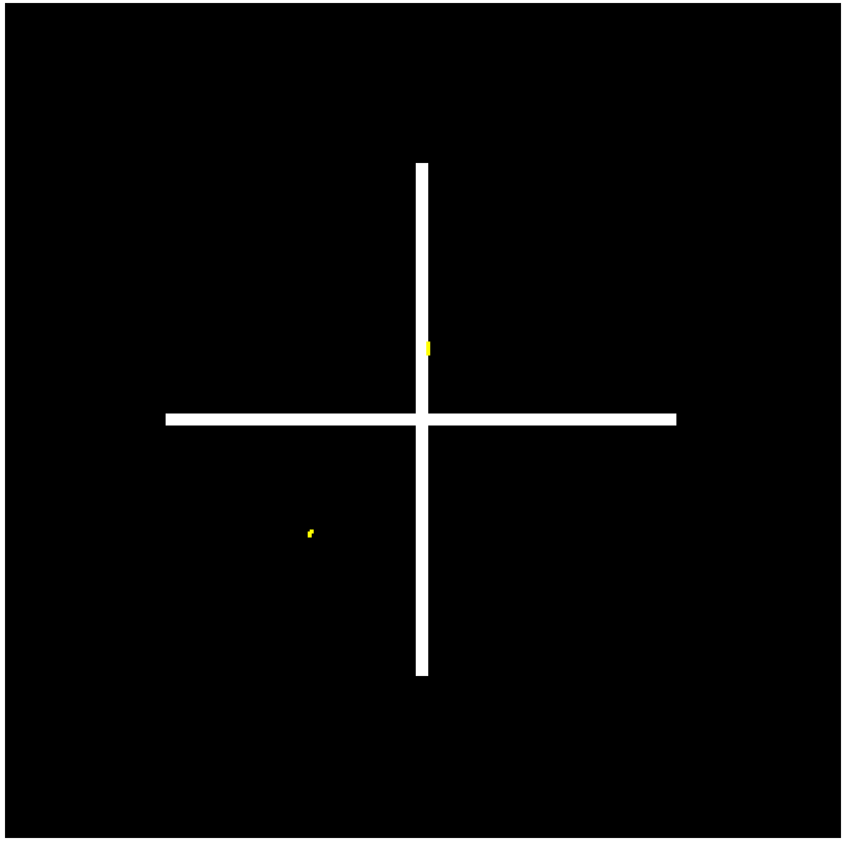
Saccades
Typical amplitude: 7-9 letters



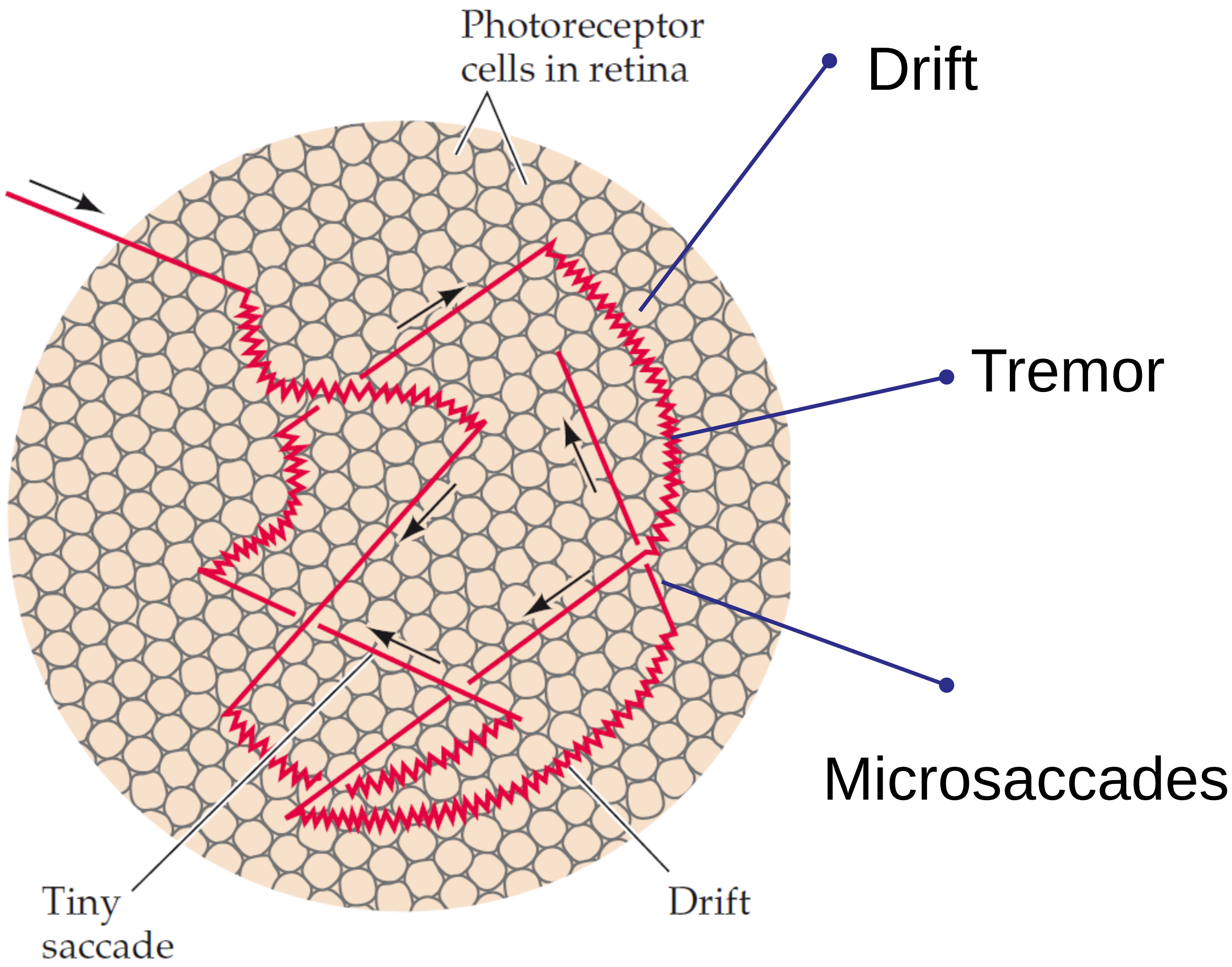
Eye movements: Saccades & Fixations

Example visual search

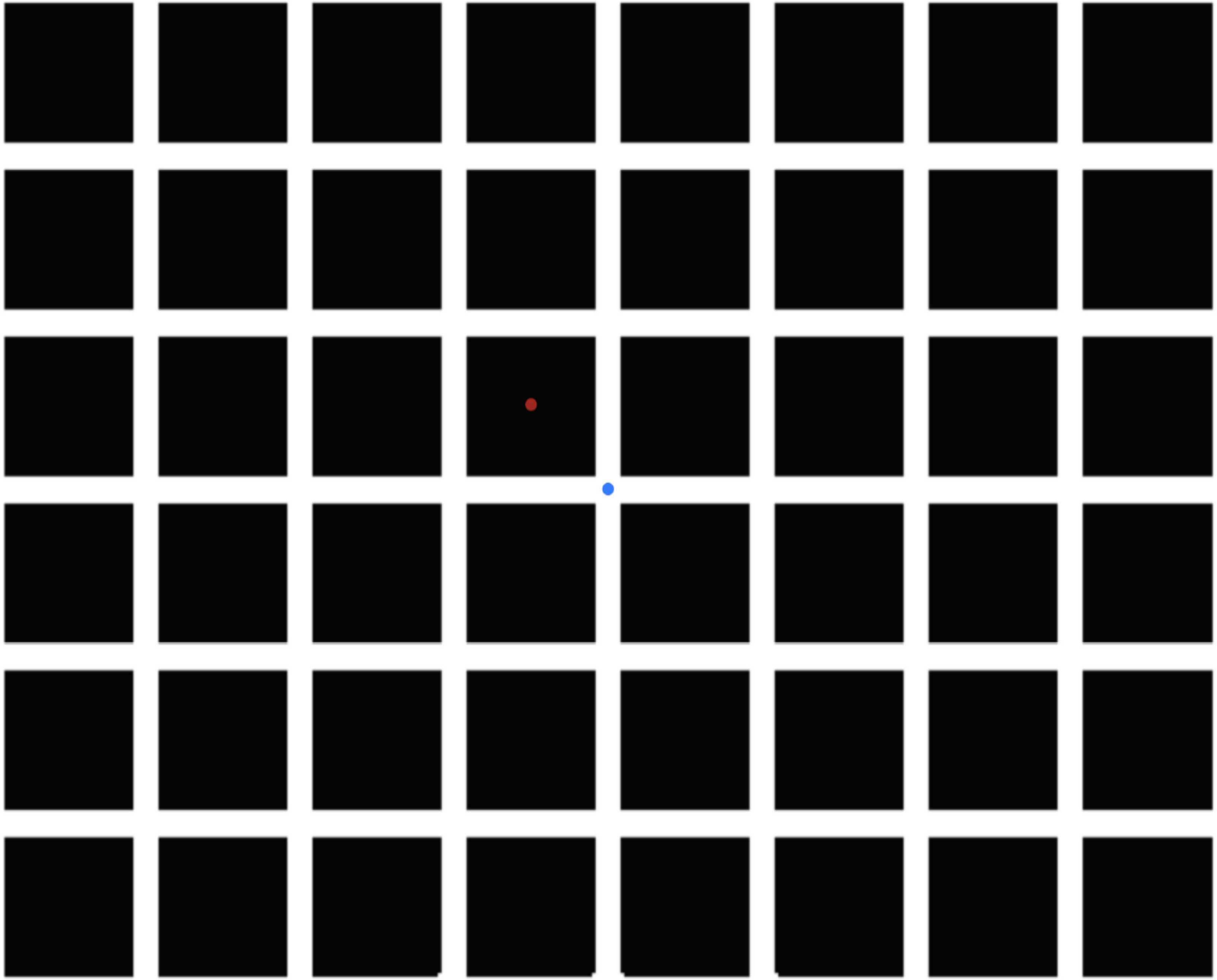
Example: Fixational eye movements



2.3 sec of fixation on small cross (0.73°)

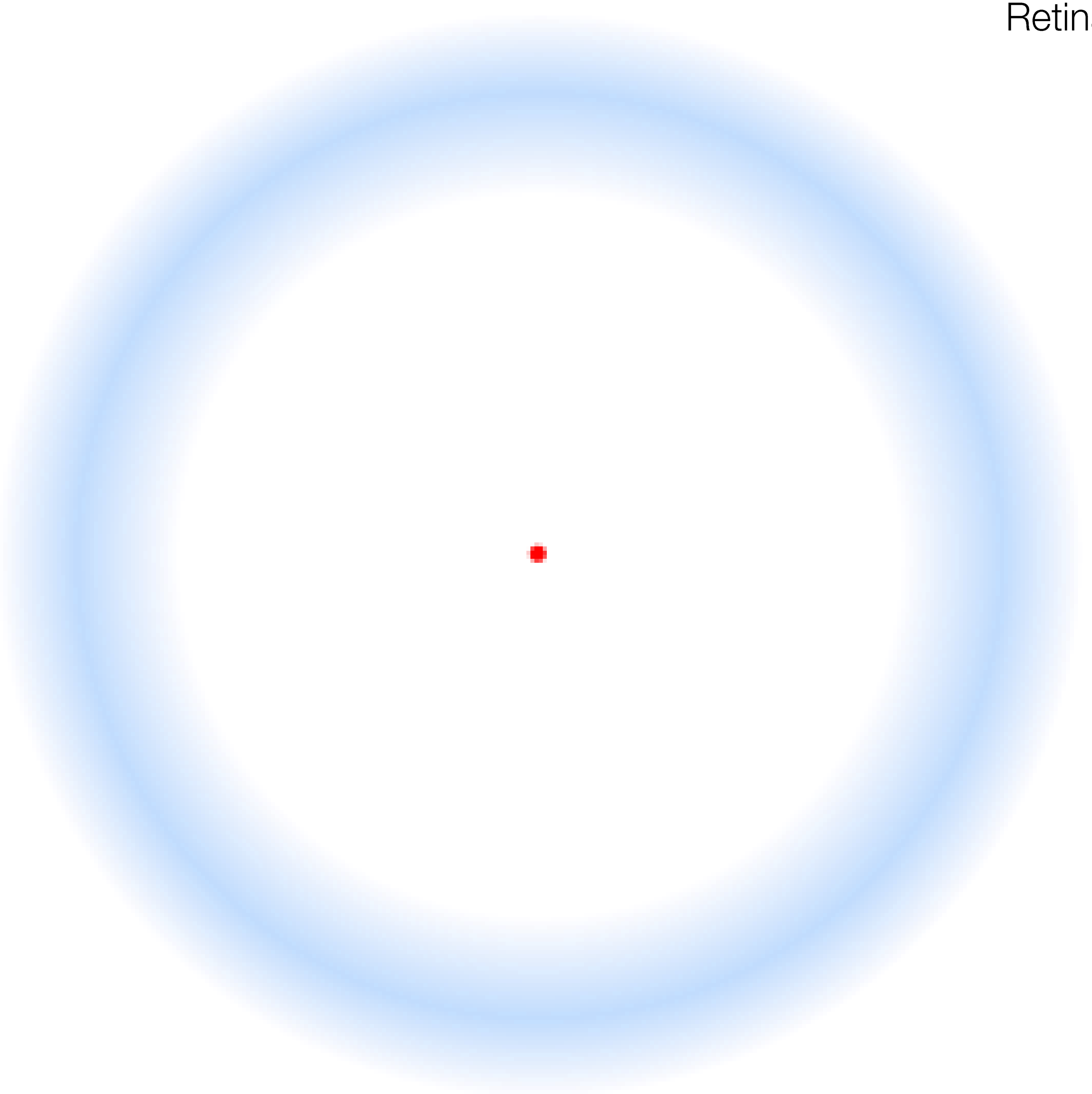


1
1



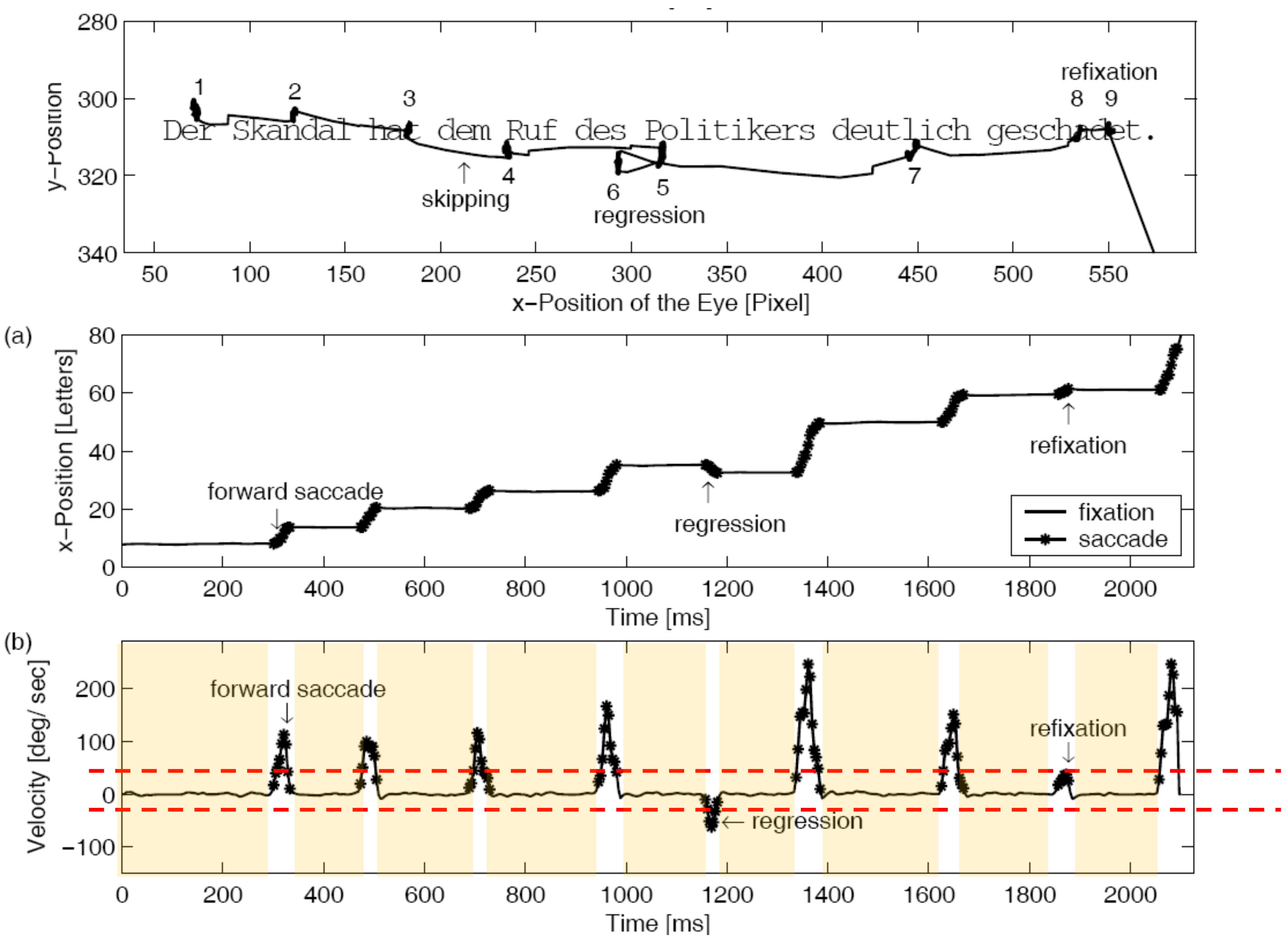
Verheijen, 1961

Retinal fading during perfect fixation



Troxler, 1804

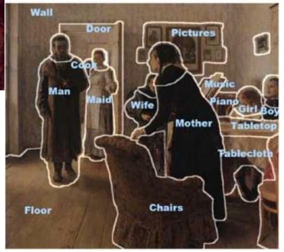
Detecting Saccades vs. Fixations



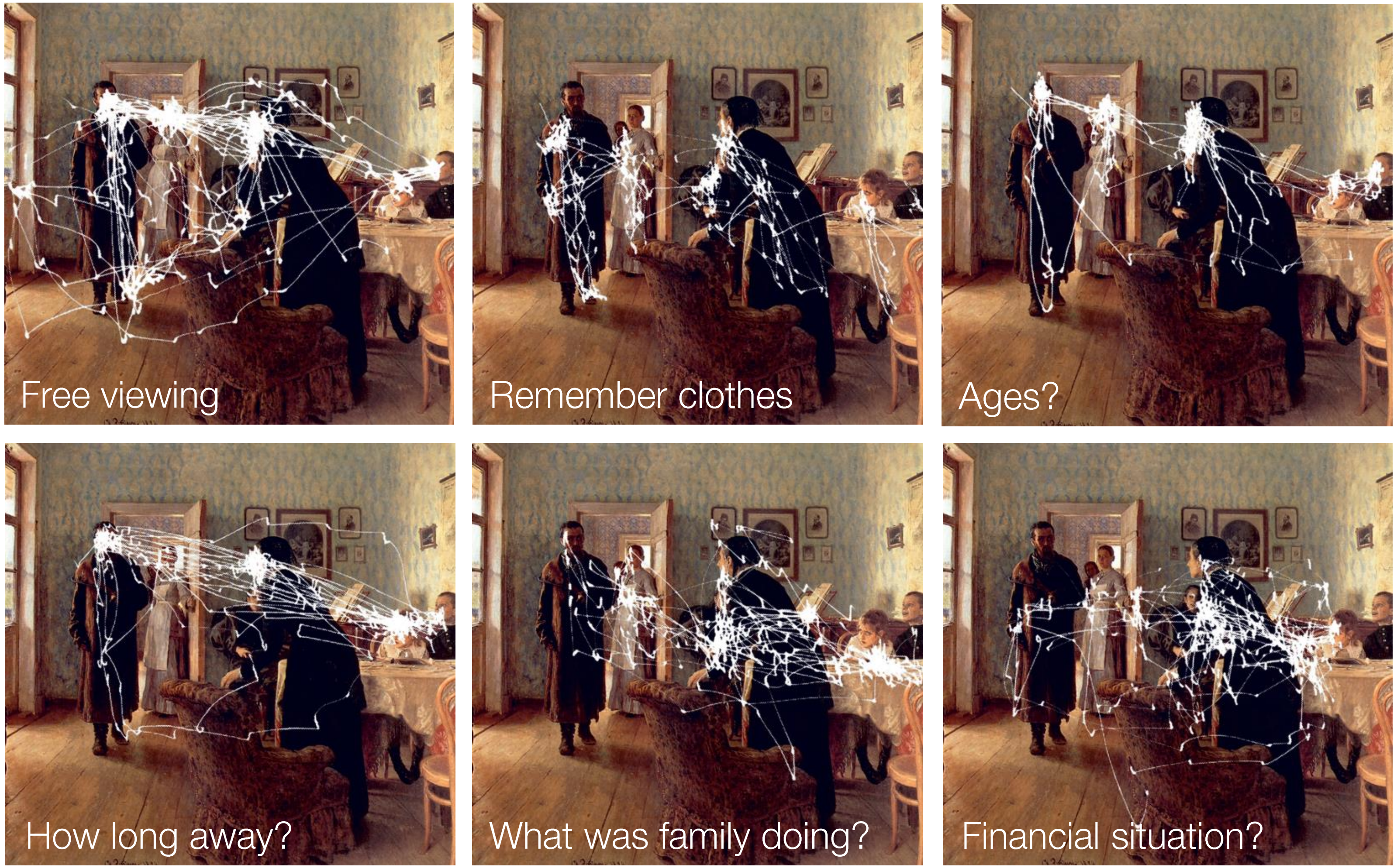
Threshold in eye velocity
e.g. > 30° per sec

from: Nuthmann (2005)

Eye movements



“The unexpected visitor”



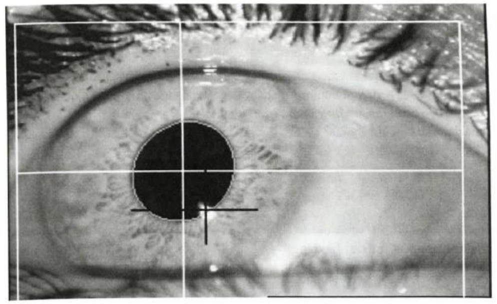
Yarbus (1967). *Eye Movements and Vision*, recreated by artist S. Archibald [2]

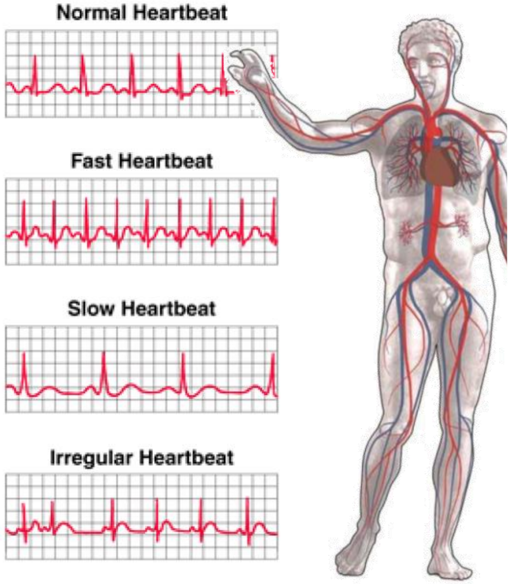
2. Analyzing time series data

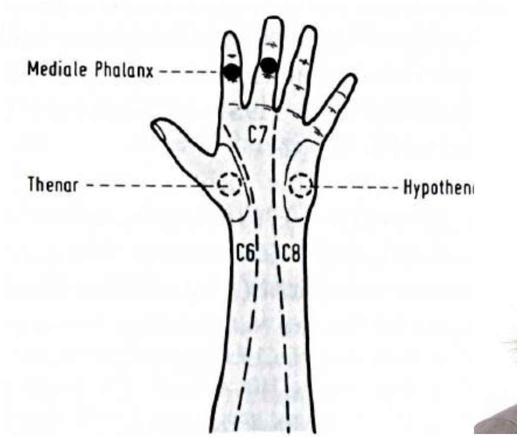
WIKIPEDIA:

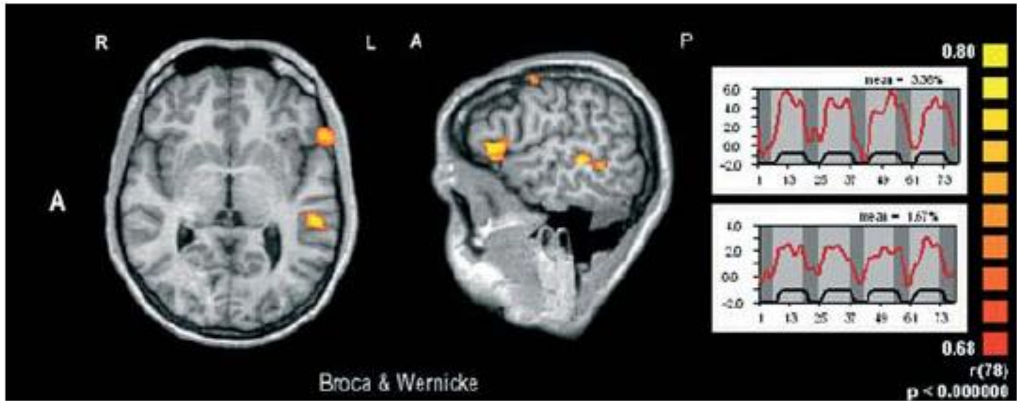
In mathematics, a time series is a series of data points indexed in time order.

Most biosignals are time series





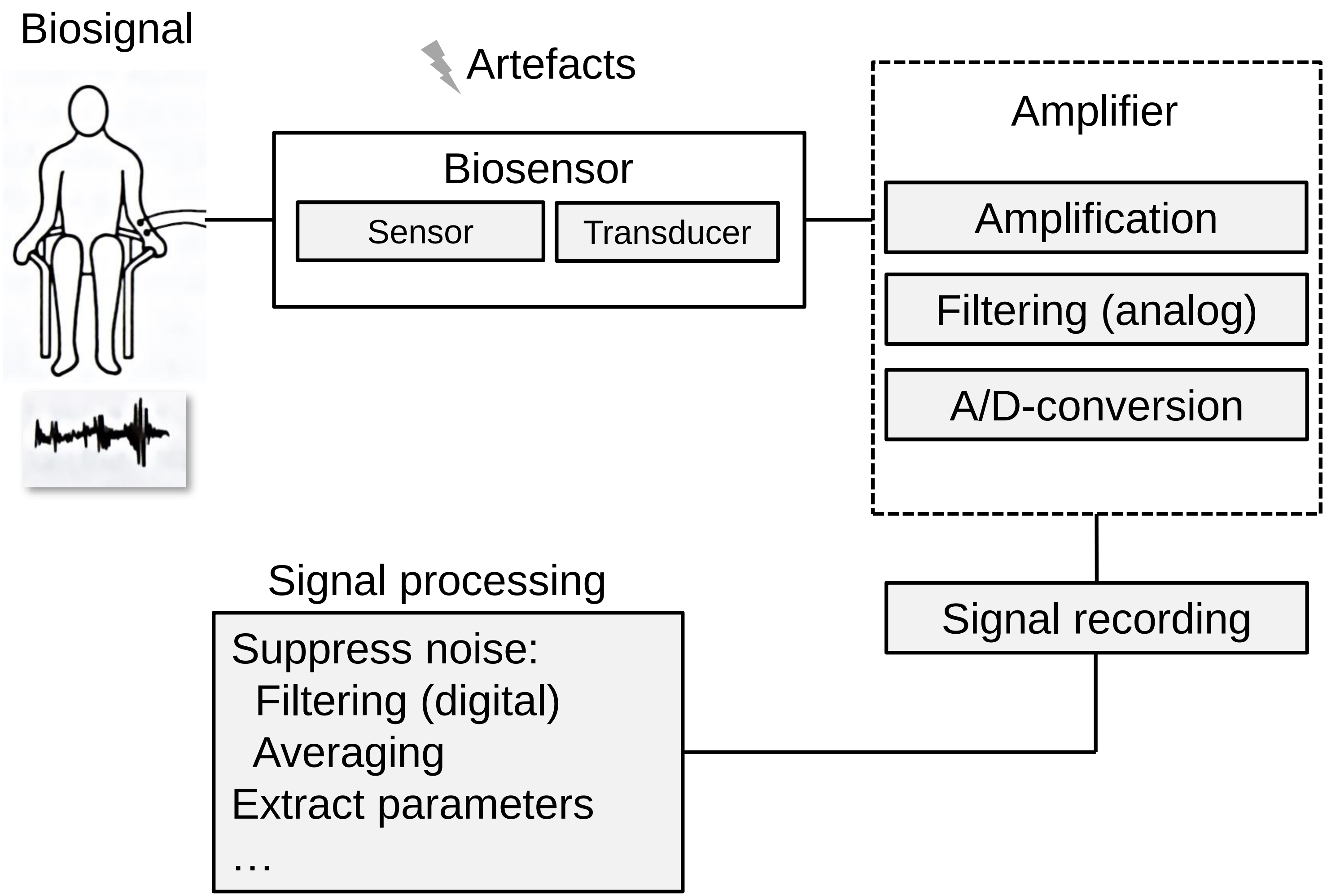




Most biosignals are time series

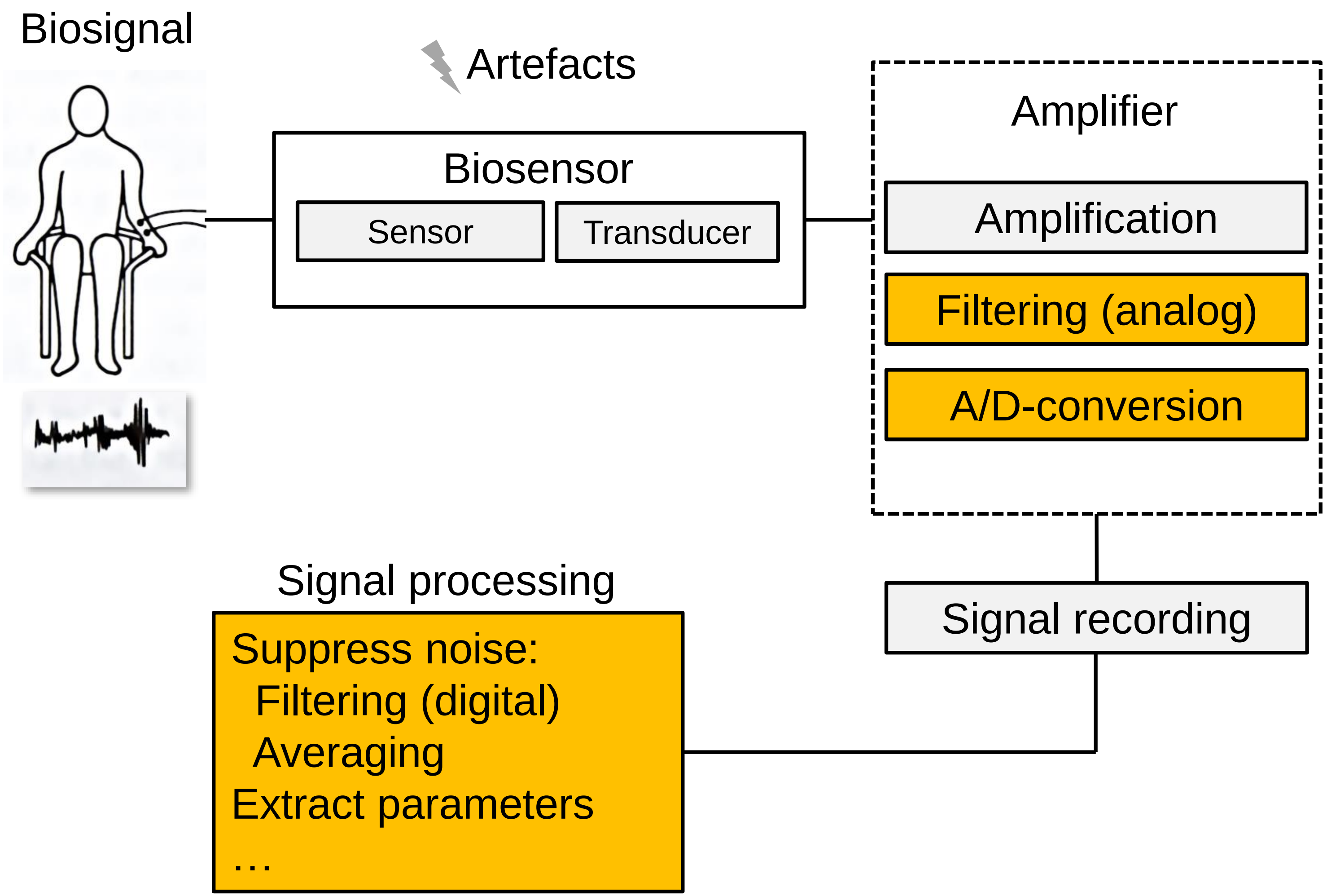
Type	Examples	Index of
Electrical	EEG ECG EMG EDA EOG	Brain activity (neurons) Heart activity (muscle cells) Muscles Sweat glands Eye movements
Magnetic	MEG fMRT	Brain activity (neurons) Brain metabolism (blood oxygenation)
Optical	Videobased eye-tracking Photo-plethysmography Near-infrared spectroscopy (NIRS)	Pupil size, eye movements Periphal blood flow (oxygenation) Cerebral blood flow (oxygenation)
Acoustic	Heart tones Korotkoff sounds	Heart cycle Blood pressure
Mechanical	Chest circumference	Breathing
Thermic	Body core temperature	Arousal/stress
Chemical	Cortisol level in salvia	Stress

The “journey“ of a biosignal



Adapted from Schandry, 1998

The “journey“ of a biosignal



Adapted from Schandry, 1998

Filtering

Reducing Noise

Measurement = Signal + Noise (+ Artefacts)

Noise

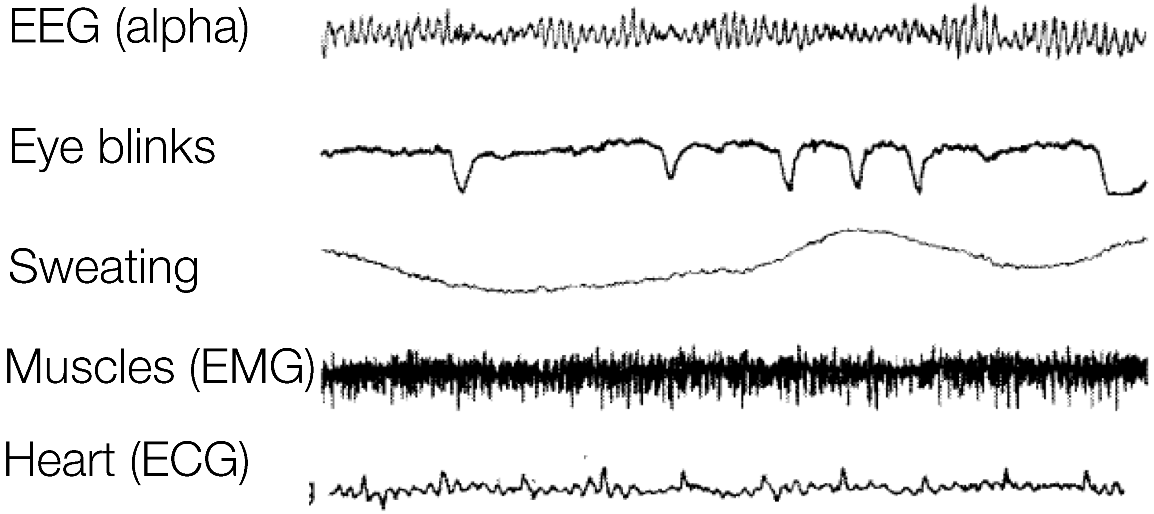
- Not correlated to signal or experimental condition
- Non-systematic signal fluctuations

- Improve signal-to-noise ratio (SNR) via…
    - 1. Filtering
    - 2. Averaging

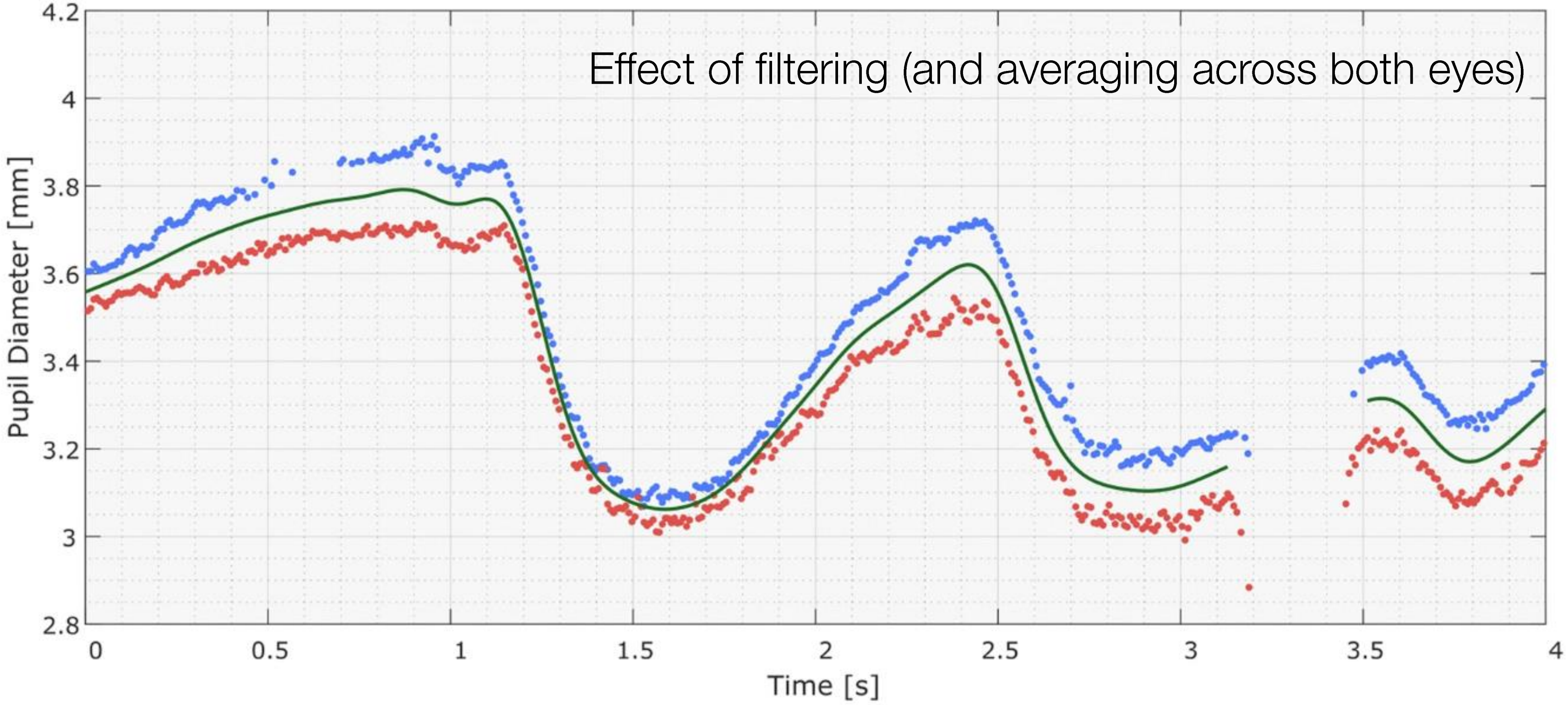
Enhancing the signal-to-noise ratio

Idea: Everything that is not signal is noise (or artefacts)

- Estimate frequencies (spectrum) of signal
- Attenuate unwanted frequencies via filtering

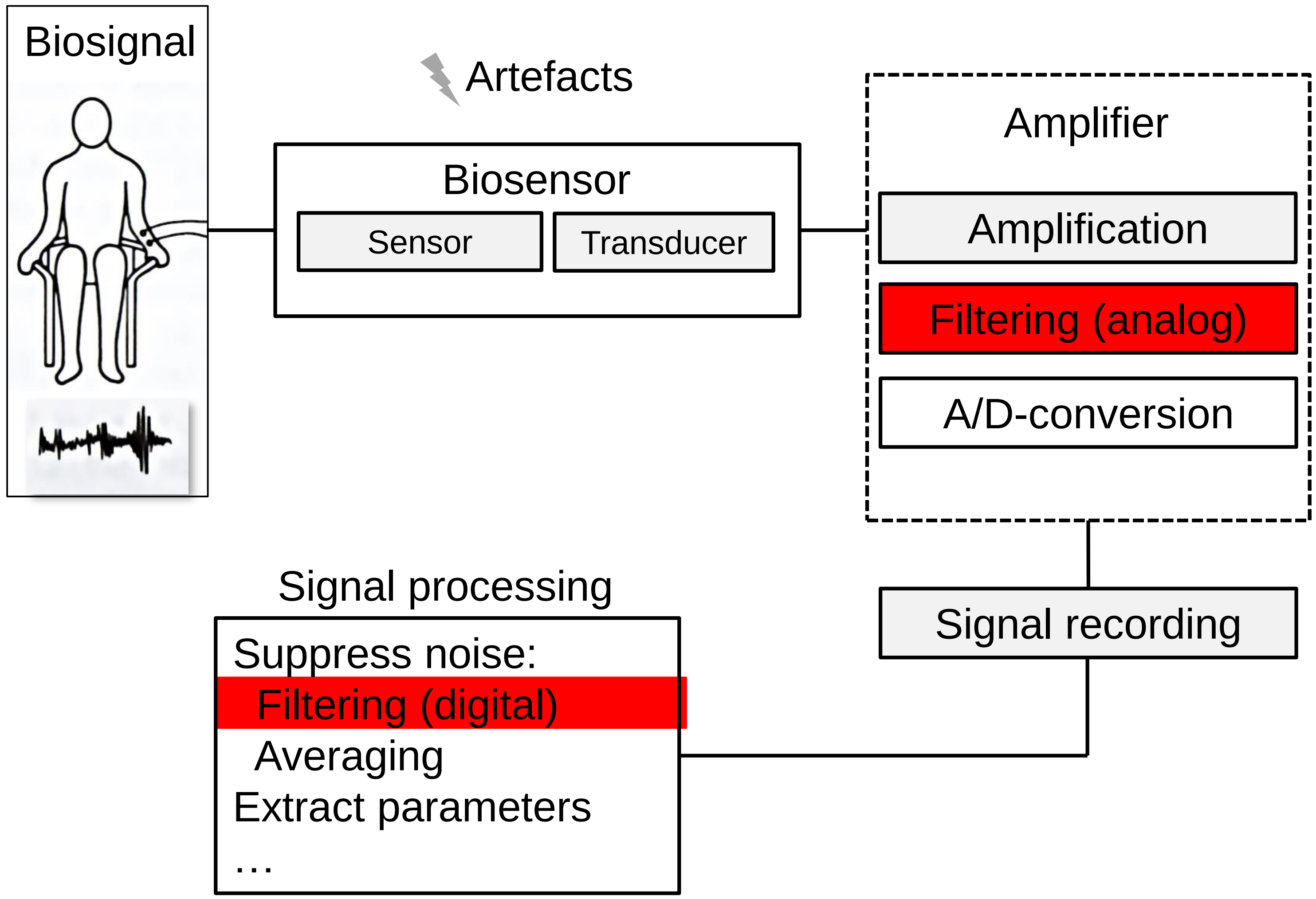


Example: Low-pass filtering of pupil data



From: Gret & Sjak-Shie, Behav. Res. Meth., 2019 [1]

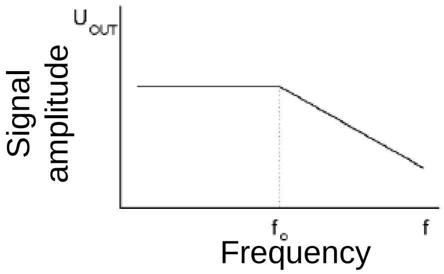
Filtering: Two possible time points



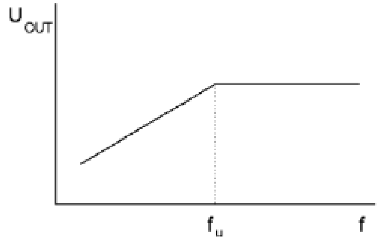
Adapted from Schandry, 1998

Classes of filters

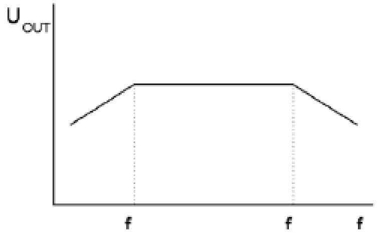
- Low-pass filter
  - lets <u>low</u> frequencies pass
  - also: *high cutoff filter*



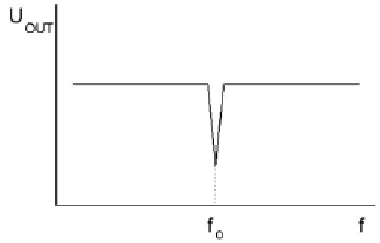
- High-pass filter
  - lets <u>high</u> frequencies pass
  - also: *low cutoff filter*



- Bandpass filter
  - combination TP + HP filter

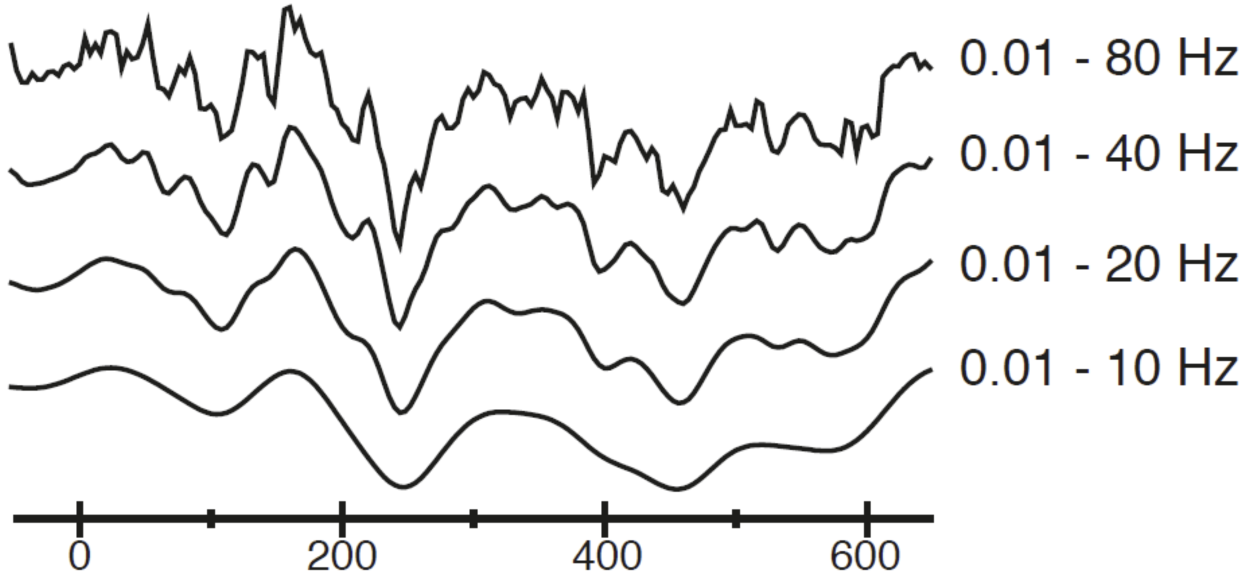


- Bandstop filter
  - also called *notch filter*



Low-pass filter

Let‘s low frequencies pass
attenuates fast changes in the signal



From: Luck (2014)

High-pass filter

Lets <u>high frquencies pass</u>, attenuates low frequencies

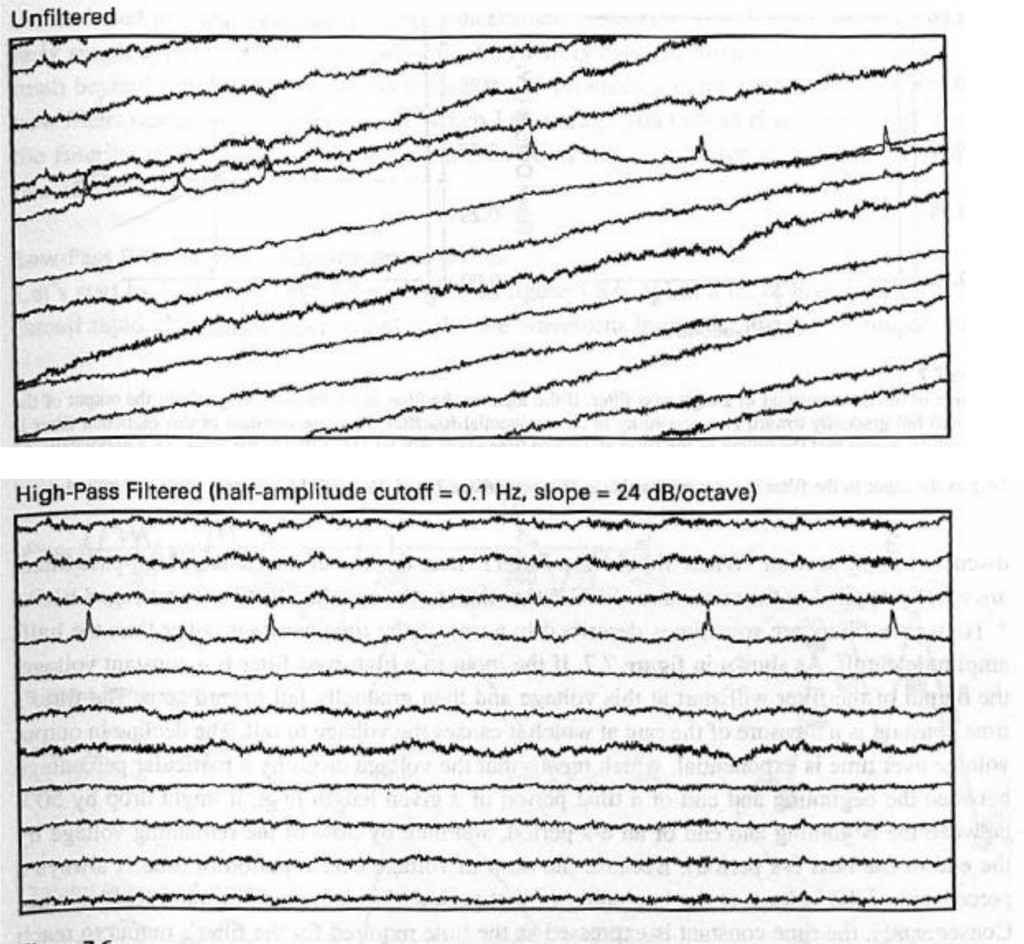
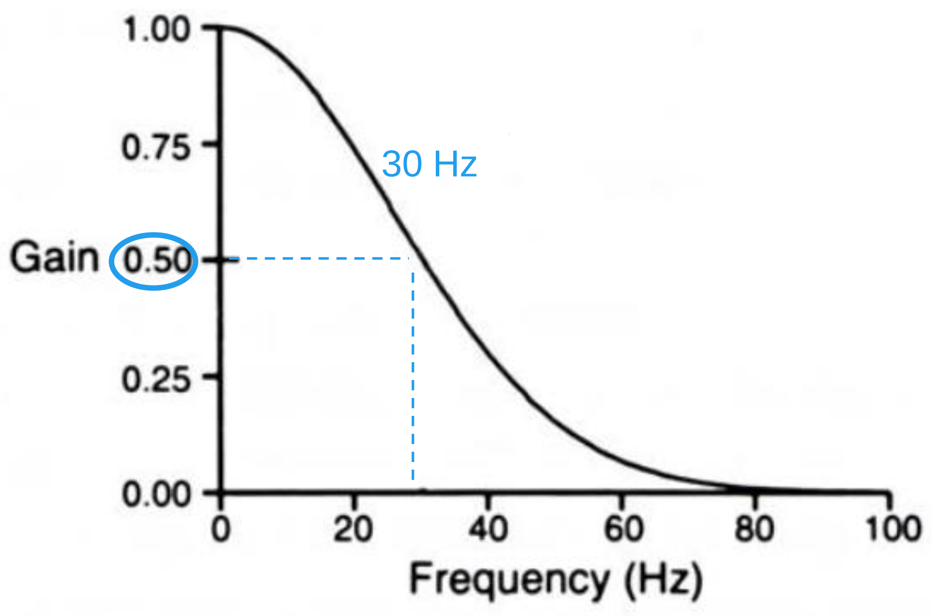


Figure 7.6
Example of a 30-s period of EEG without any filtering (top) and after the application of a high-pass filter with a half-amplitude cutoff of 0.1 Hz and a slope of 24 dB/octave (bottom). The filter eliminates the gradual upward drift in the data.

Luck (2014), 2nd edition

How can I describe and set filter properties?



Example: Low-pass filter with
cut-off at 30 Hz (half-amplitude cutoff)

cutoff frequency…

= frequency at which signal is attenuated to half

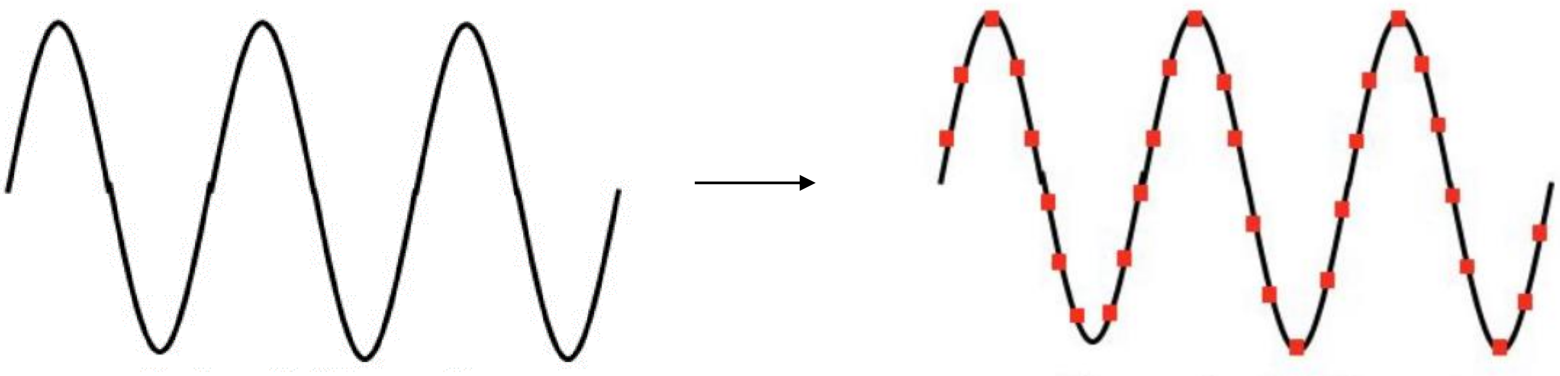
- ~71% (-3 dB, „half-power cutoff“) or
- 50% (-6 dB, „half-amplitude cutoff“)

…and steepness of filter
(also: *slope*, *roll-off*)

Abbildung adaptiert aus: Luck 2005, Abb. 5.1A

Analog-to-Digital (A/D) Conversion

- Conversion to digital signal allows for unlimited, flexible storage and processing
- But it is necessary to *digitize* the signal (make it discrete) → **sampling**



Analog (contin.)

Digitized (discrete)

→ Possible problem: Aliasing

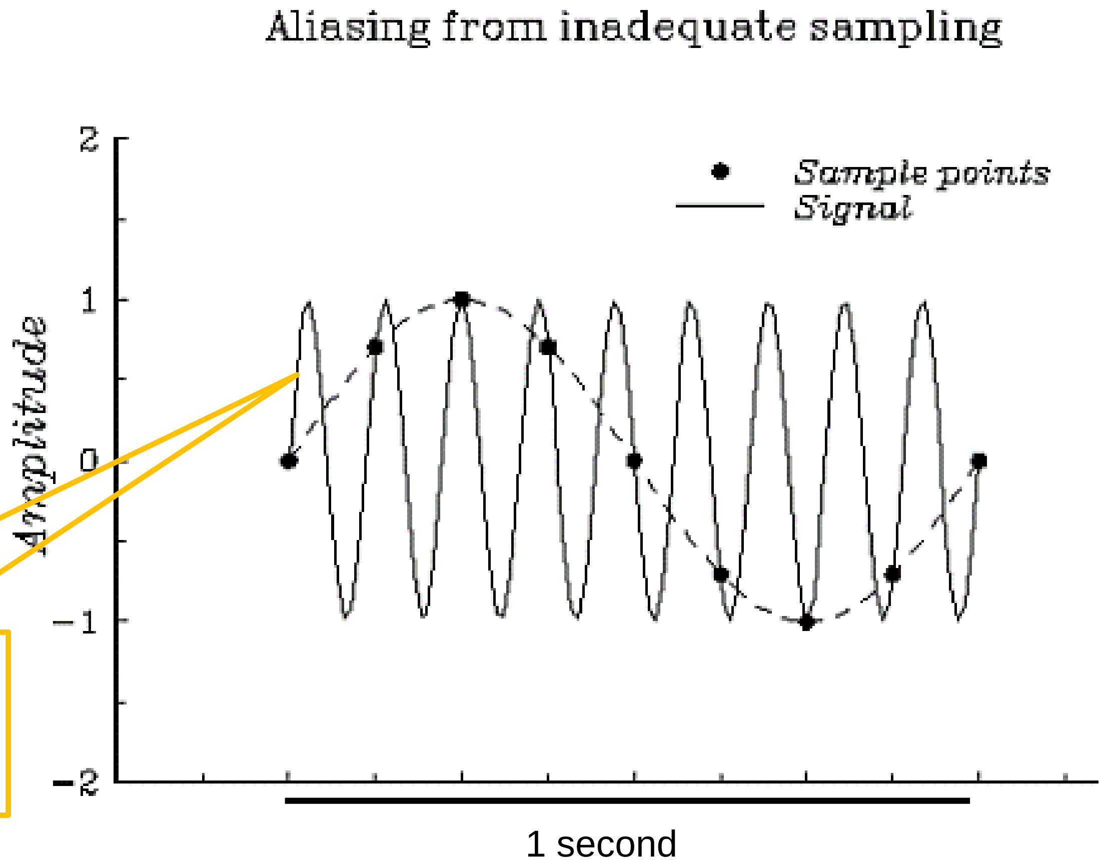
Question: With which frequency (per second = Hz) do I have to sample a signal?

The Aliasing Problem

Nyquist-Shannon Sampling Theorem: Sampling frequency must be more than twice of the highest frequency present in the signal (in practice: > 3-4 times)

Otherwise
- No truthful reconstruction of signal
- You may measure slow pseudofrequencies (= Aliasing)!

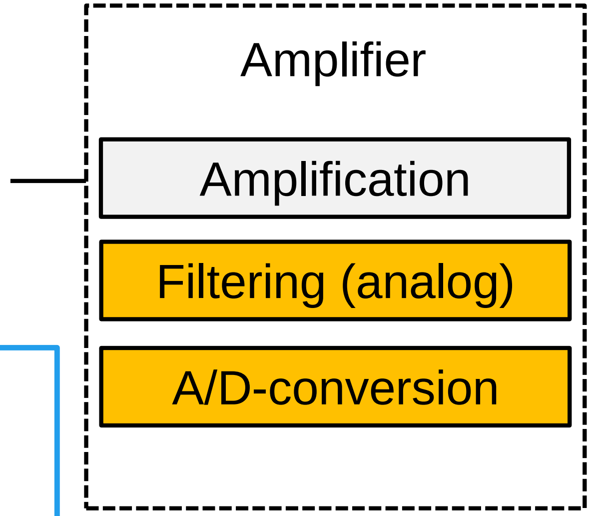
We are measuring 1 Hz
Really: 9 Hz



Aliasing: Solution

Nyquist-Shannon Sampling Theorem: Sampling frequency must be more than twice of the highest frequency present in the signal (in practice: > 3-4 times)

…because I usually cannot change or increase the sampling frequency of my hardware, I instead influence the highest frequency still present in the data
→ by filtering the data *before* it is digitized



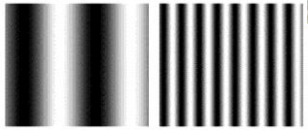
Solution: With an analogue low-pass filter, I remove the high frequencies from the signal, this only leaves me with frequencies lower than half the sampling frequency.
Result: Aliasing cannot occur anymore.

Aliasing: More examples

Insufficient sampling rate of video (24 Hz)
Wagon wheel effect

http://www.youtube.com/watch?v=jHS9JGkEOmA

Insufficient pixel resolution (Moiré effect)



Digital camera models with/without aliasing filter

Quiz time!

You are measuring some kind of biosignal. Your amplifier (A/D-converter) is able to digitize (sample) the raw signal with 500 Hz. With which of the following filter setting can you exclude the possibility of aliasing?

(a) High-pass filter at 100 Hz

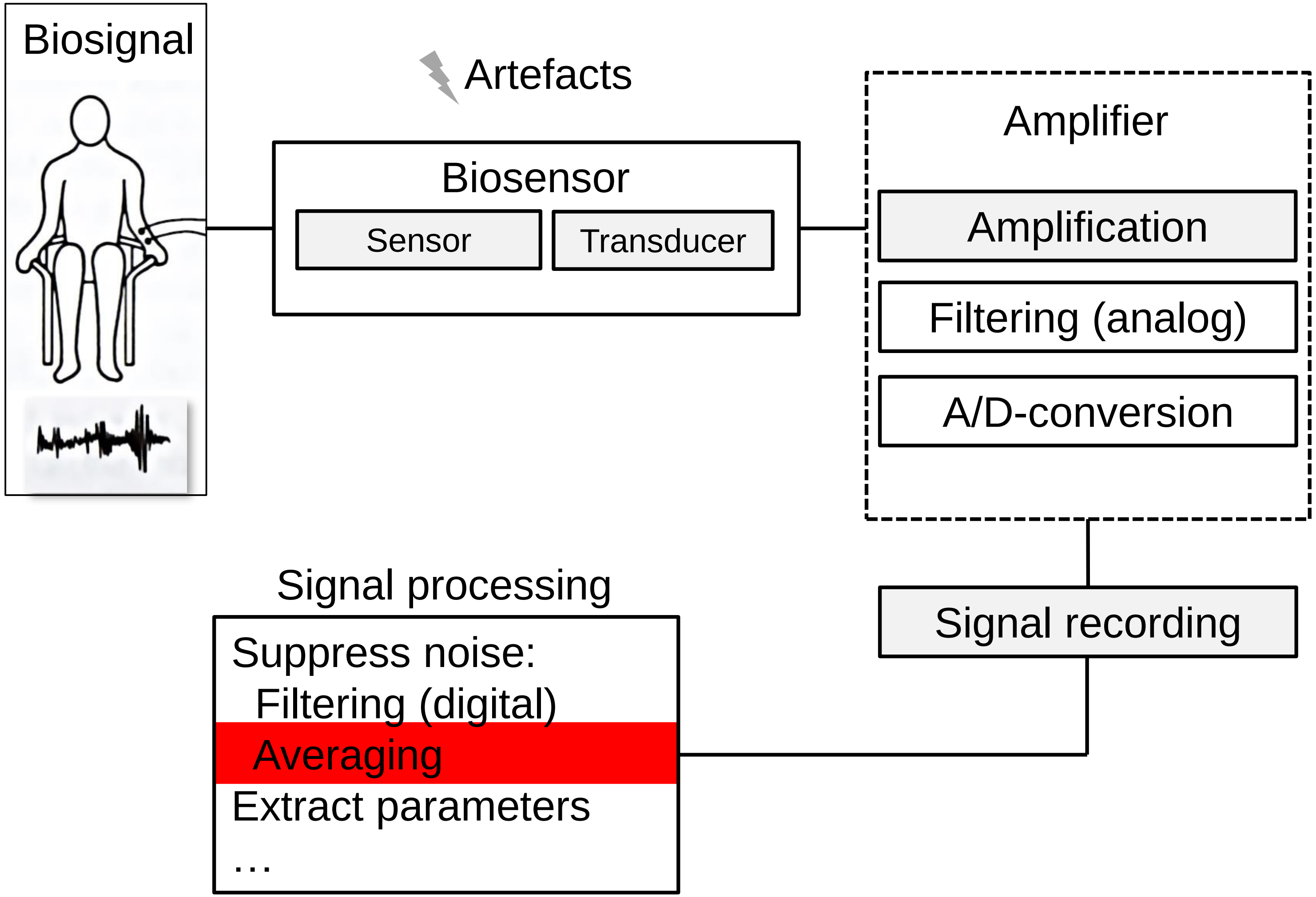
(b) Low-pass filter at 100 Hz

(c) Low-pass filter at 1001 Hz

(d) I won’t do anything - aliasing can‘t happen here!

Averaging

The “journey“ of a biosignal



Adapted from Schandry, 1998

Enhancing the signal-to-noise ratio

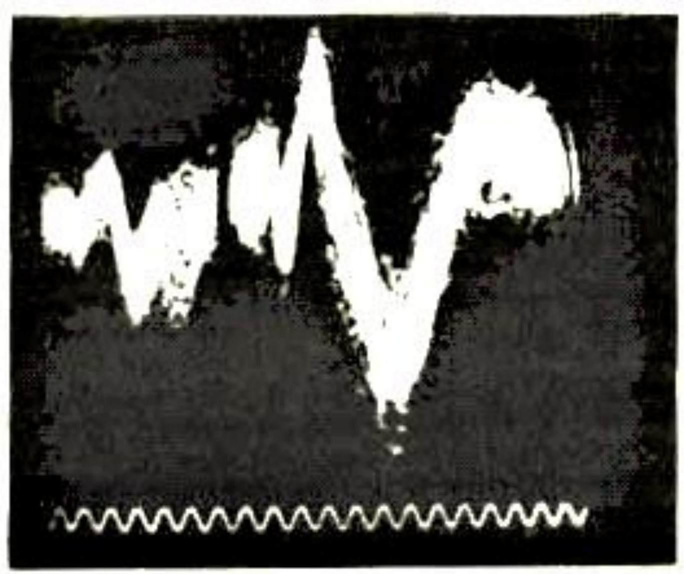
History: superposition technique

Francis Galton (ca. 1890)

Criminals/sick people

Race horses

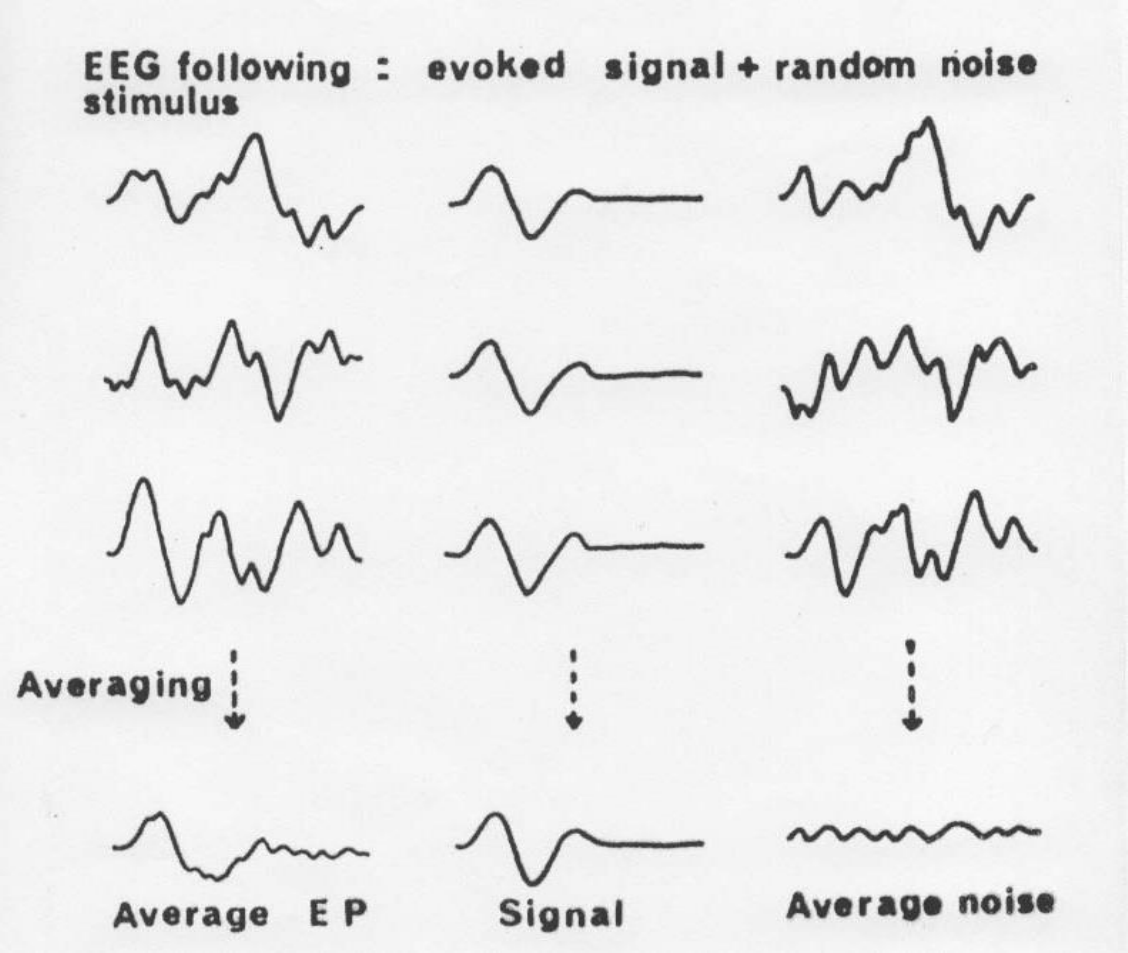
Dawson (1947): EEG



Event-related potentials (!)

Noise reduction via averaging

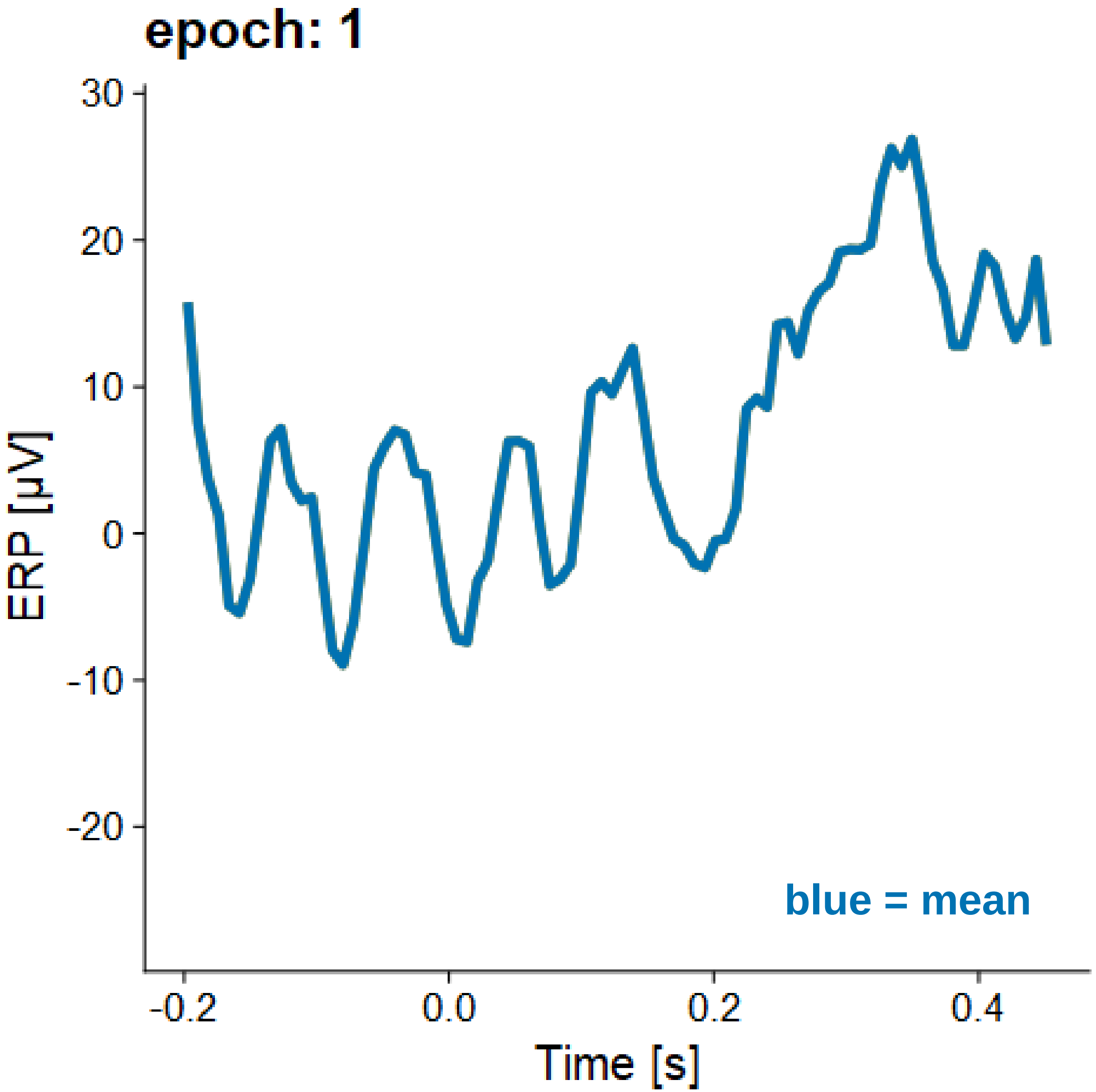
Idea: Since noise is not systematic and uncorrelated to signal,
it is eliminated by averaging many measurements



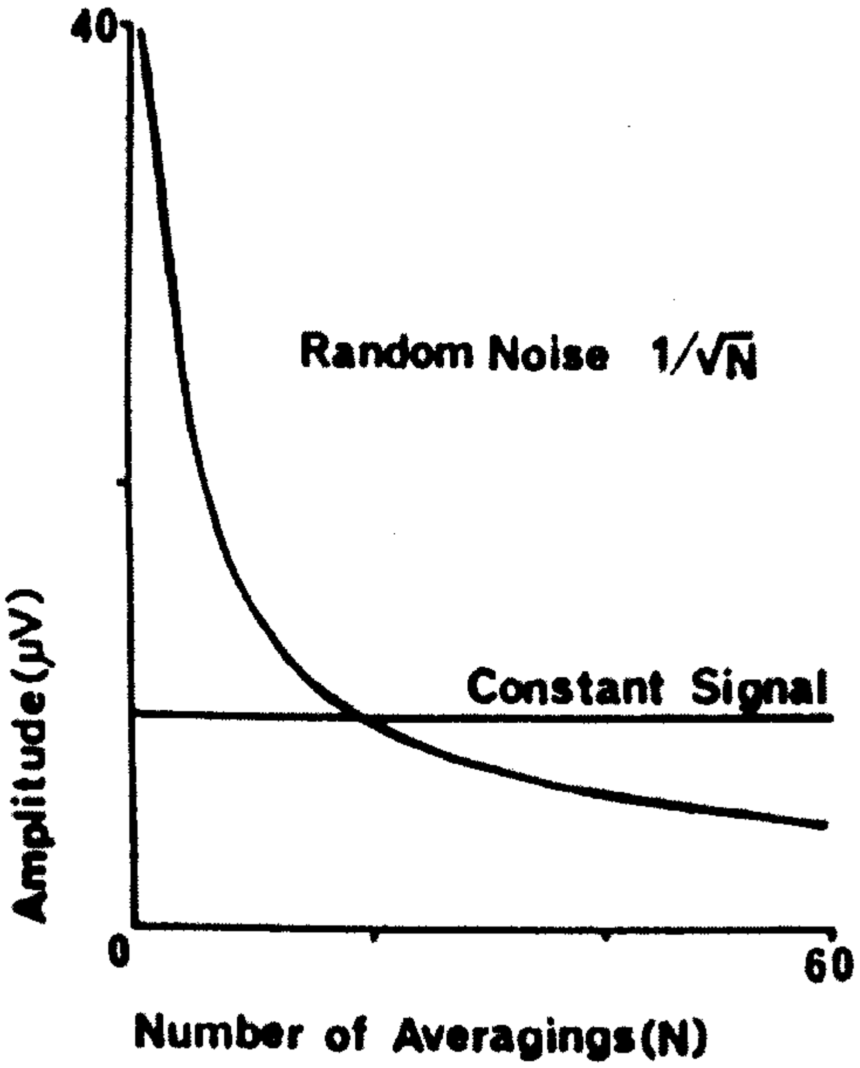
Assumptions

- Signal is constant across trials (!)
- Noise distributed randomly around zero
- Signal independent of noise (!)

Averaging of 80 epochs (EEG)



How does noise decrease with more trials?

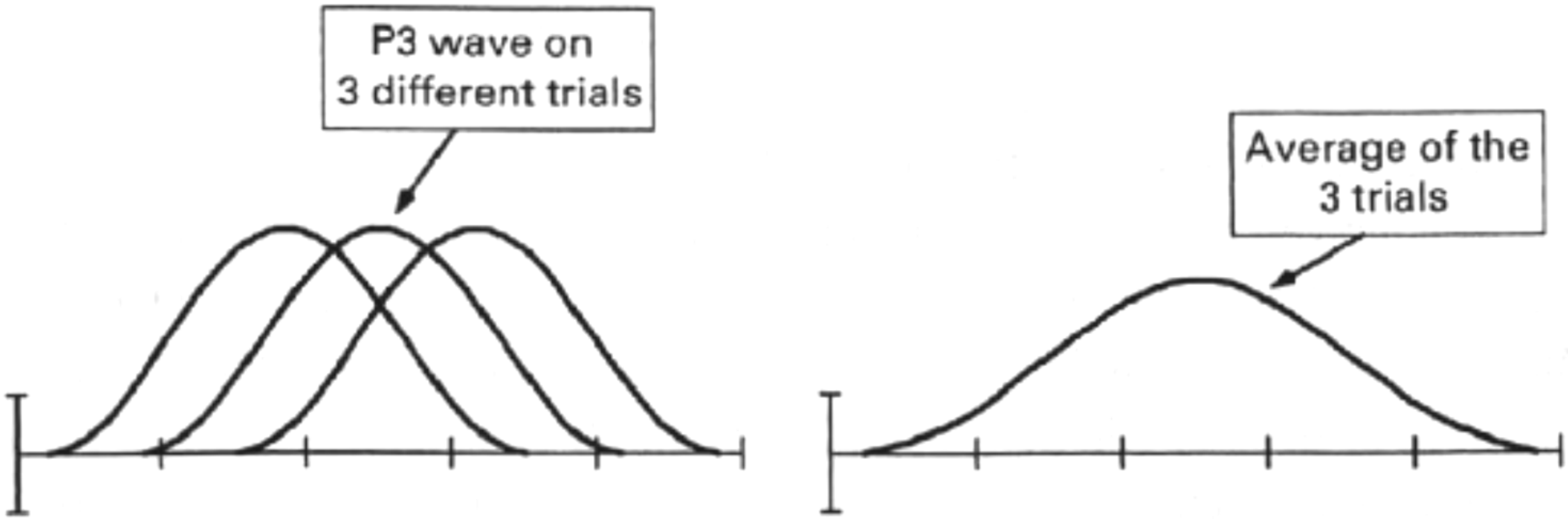


As the square root of the number of averaged trials

Why? See formulas here: https://en.wikipedia.org/wiki/Signal_averaging

Averaging: Problems

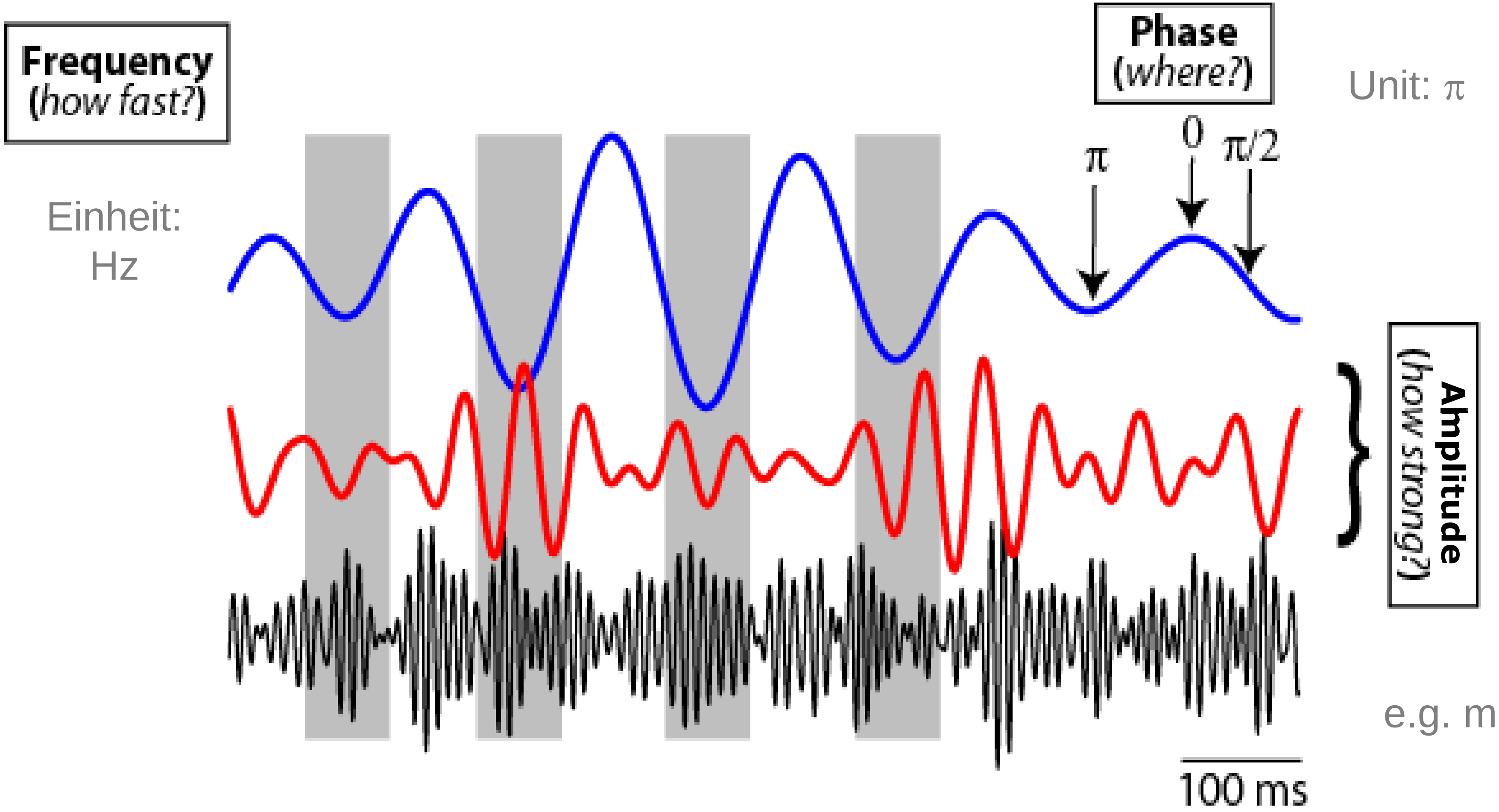
- Signal not really constant across time/trials (e.g., habituation, fatigue, …)
- Temporal smearing: Average is different from single-trials (also reflects variability)



From: Luck (2014), Fig. 2.6

Analyses in the Frequency Domain

Drei Merkmale von Oszillationen



Einheit: Hz

Unit: π

Unit e.g. milliVolt, mm

Power = Amplitude^2

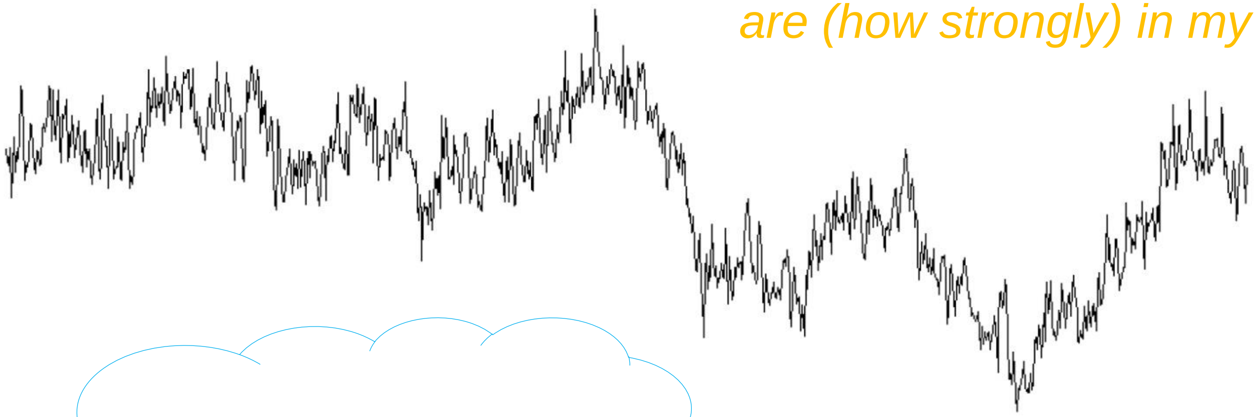
From: Cohen (2014): *Analyzing Neural Time Series Data*, Figure 3.2

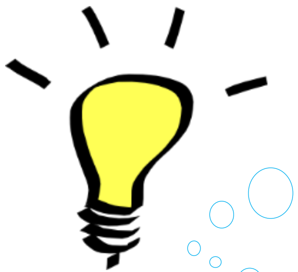
Fourier-Transformation

Problem: (Bio)signal always contain a multitude of different frequencies

How can I determine which frequencies are (how strongly) in my data?

EEG
(unfiltered)





Jean Joseph Fourier
1768-1830

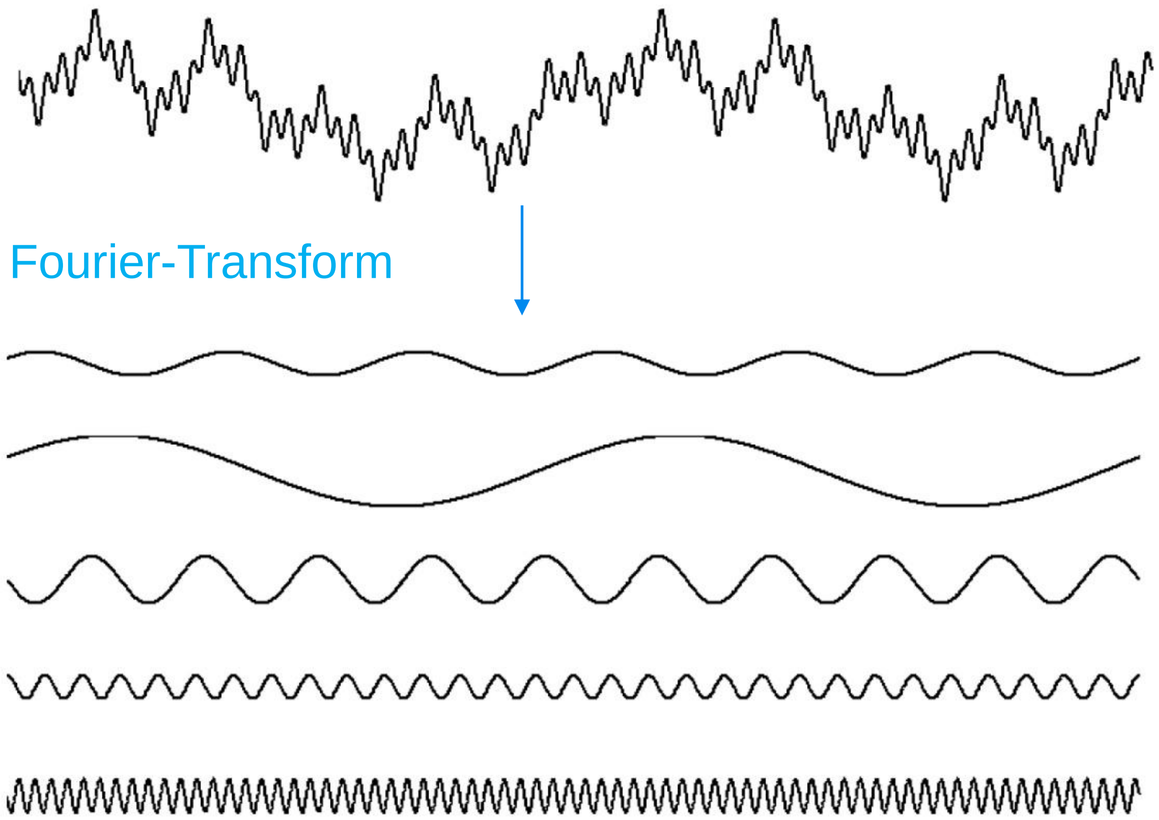
C'est magnifique!

Every signal can be described as a weighted sum of sine waves,
each with ist own frequency, amplitude and phase

$$f(t) = A_0 + \boxed{A_1 \cos(\omega t + \varphi_1)} + \boxed{A_2 \cos(2\omega t + \varphi_2)} + \ldots + \boxed{A_N \cos(N\omega t + \varphi_N)} = \sum_{n=0}^{N} A_n \cos(n\omega t + \varphi_n)$$

(A = amplitude, ω = frequency, φ= phase angle)

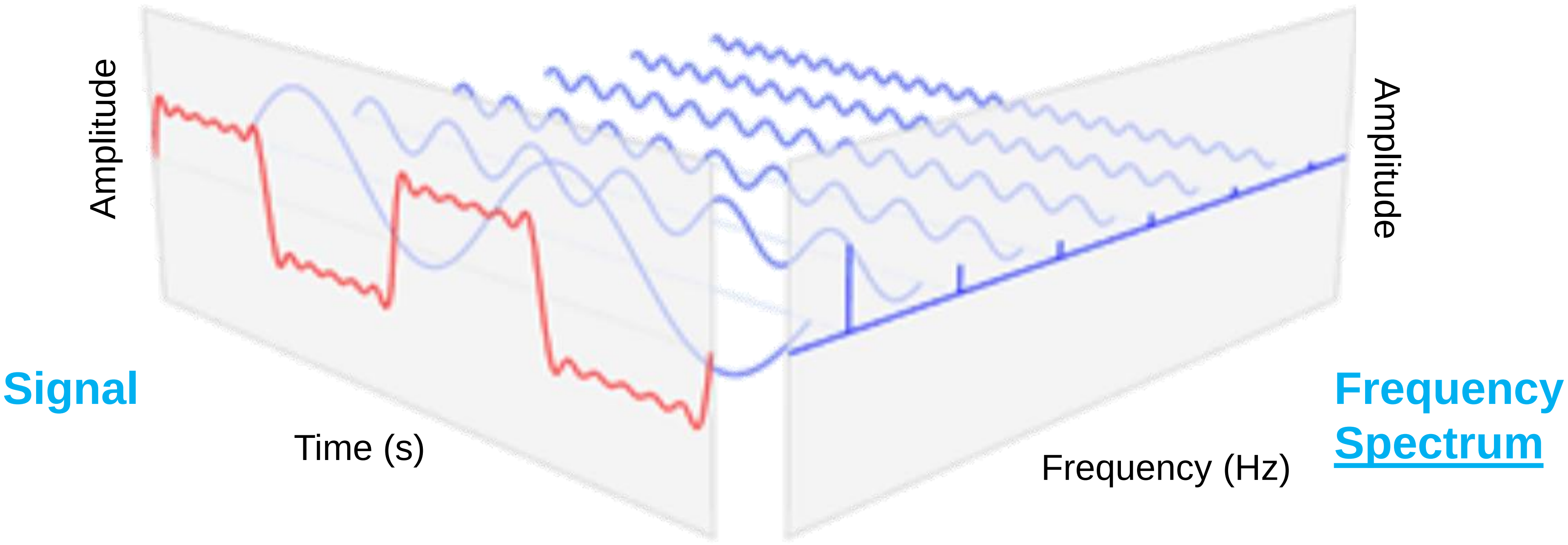
Signal



Sum of
sine waves of
different
frequency, amplitude
and phase

Fourier-Transformation

Transforms signal from the time domain to the frequency domain



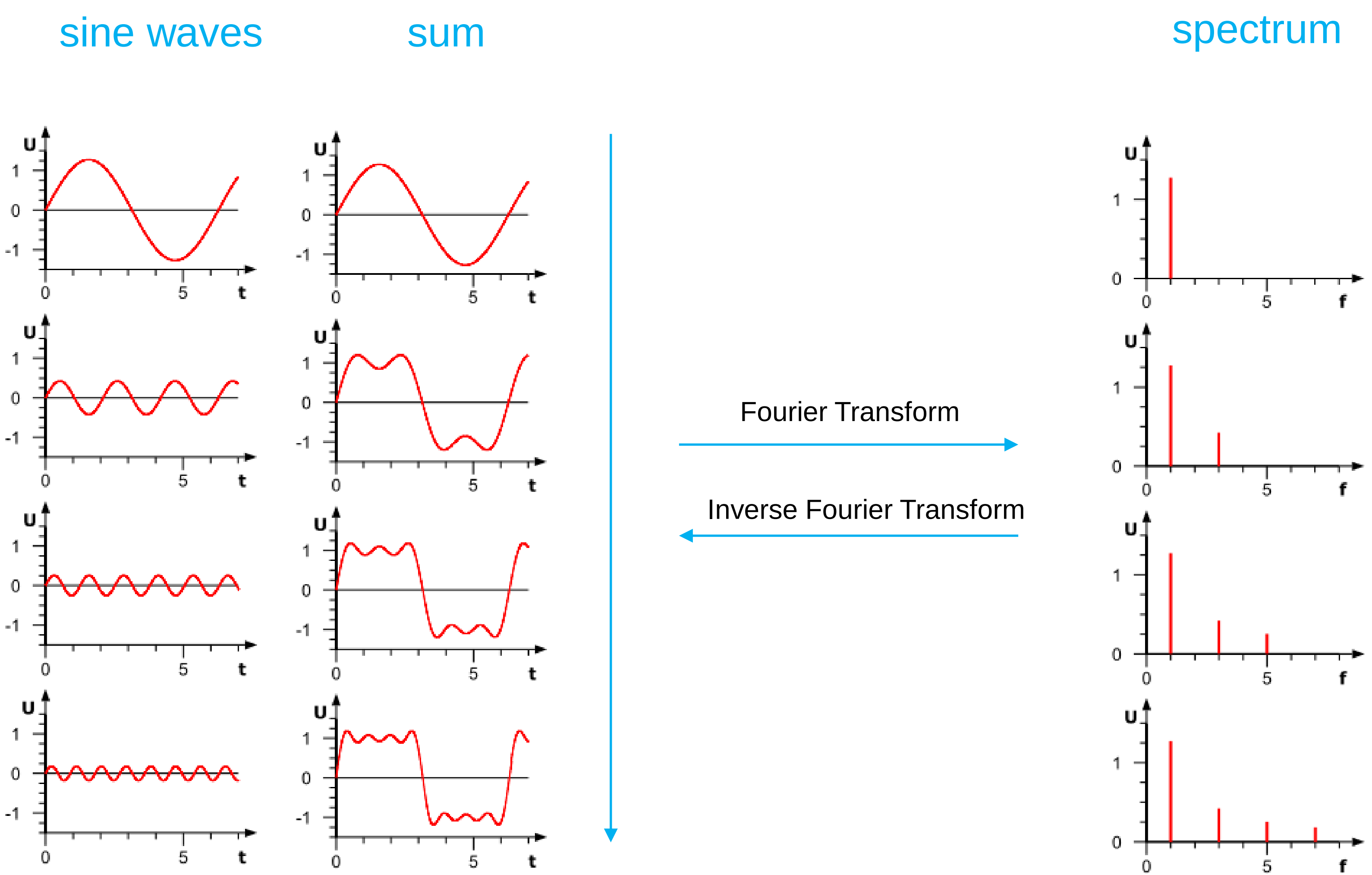
Time domain $\xrightarrow{\text{Fourier Transform}}$ Frequency domain

Time domain $\xleftarrow{\text{Inverse Fourier Transform}}$ Frequency domain

Abb.: Lucas V. Barbosa, Wikimedia Commons

FFT = *Fast* Fourier Transform

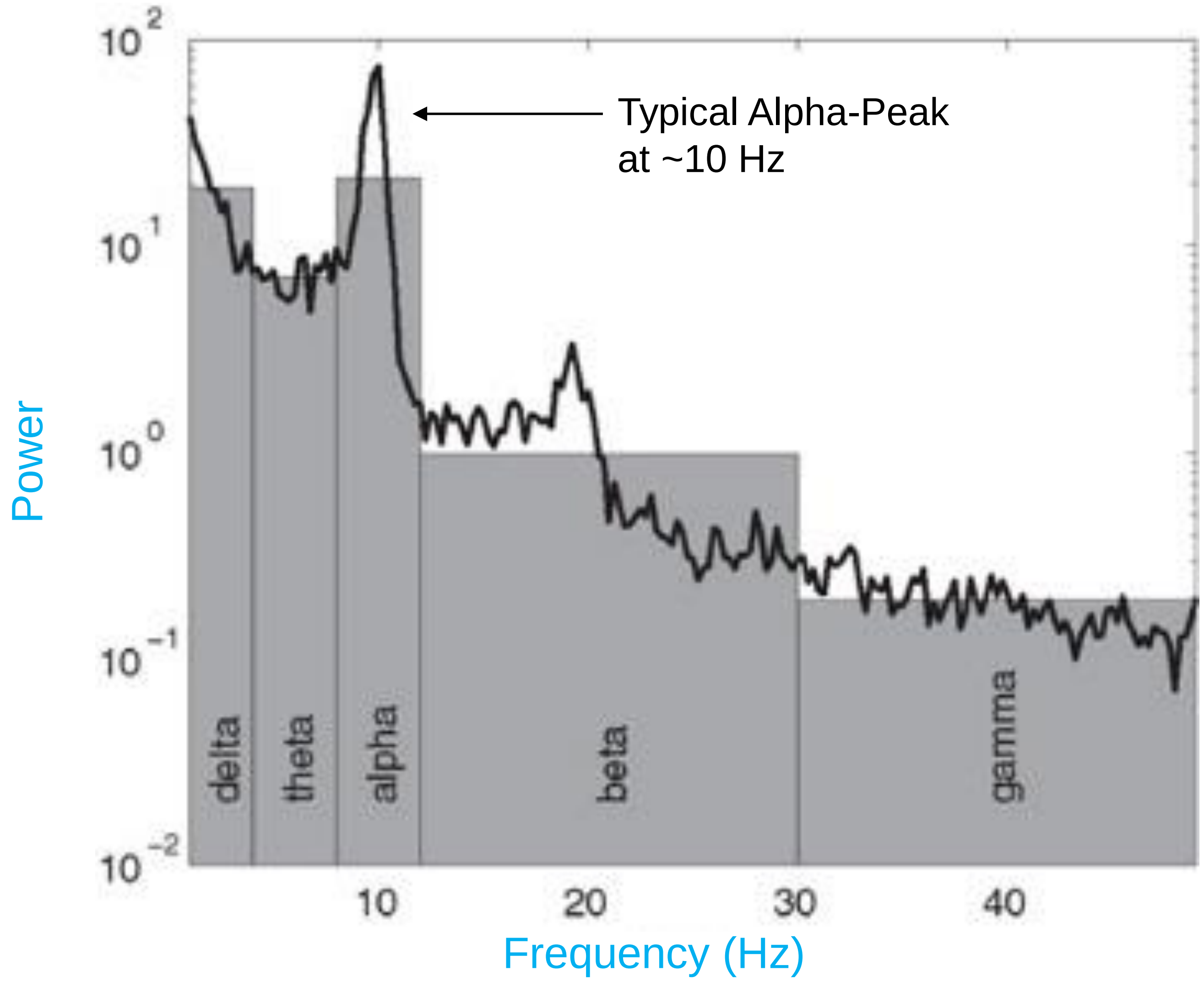
Fourier-Transformation



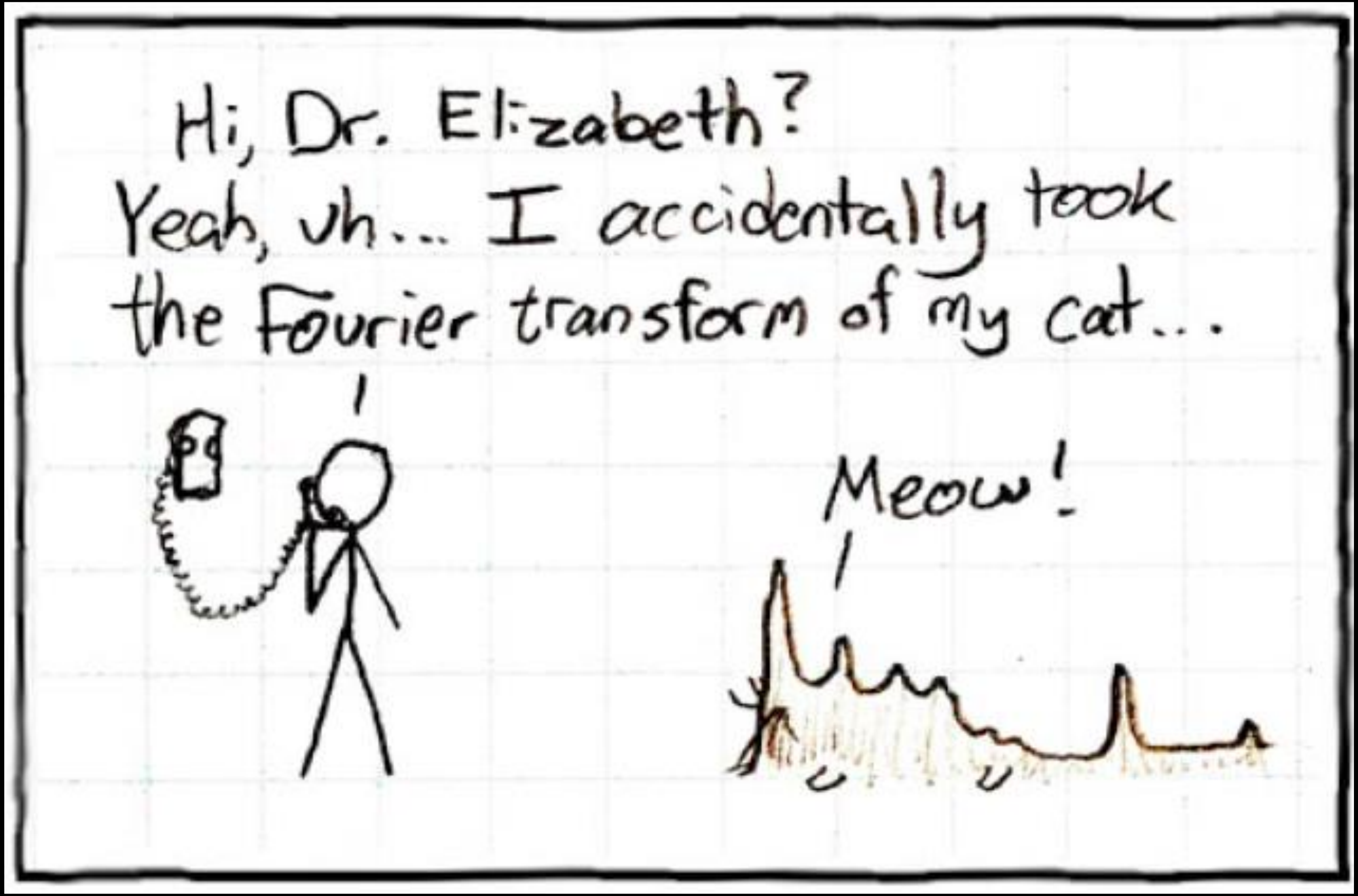
From: Wikipedia Common, “Fourier Transform”

Example: Spectrum of EEG

Which frequencies are presented how strongly?

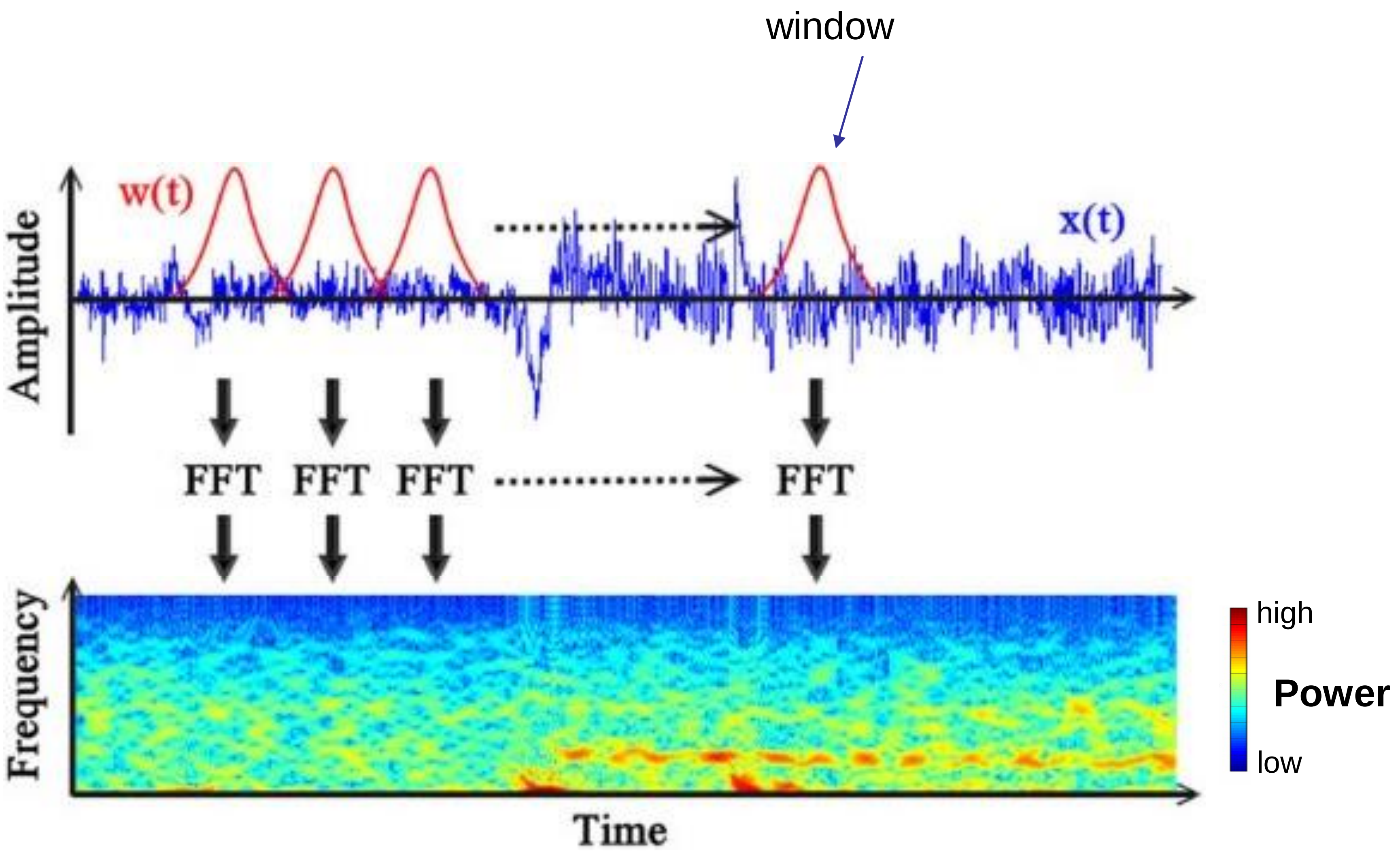


Bad FT jokes (sorry)



http://xkcd.com/26

Doing the FT in a window: Time-frequency analysis



Result: Spectrogramm

= visualization of frequency spectrum *as a function of time*

x-axis = time, y-axis = frequency, color = amplitude/power

Signal

Short term FT

Spectrogramm

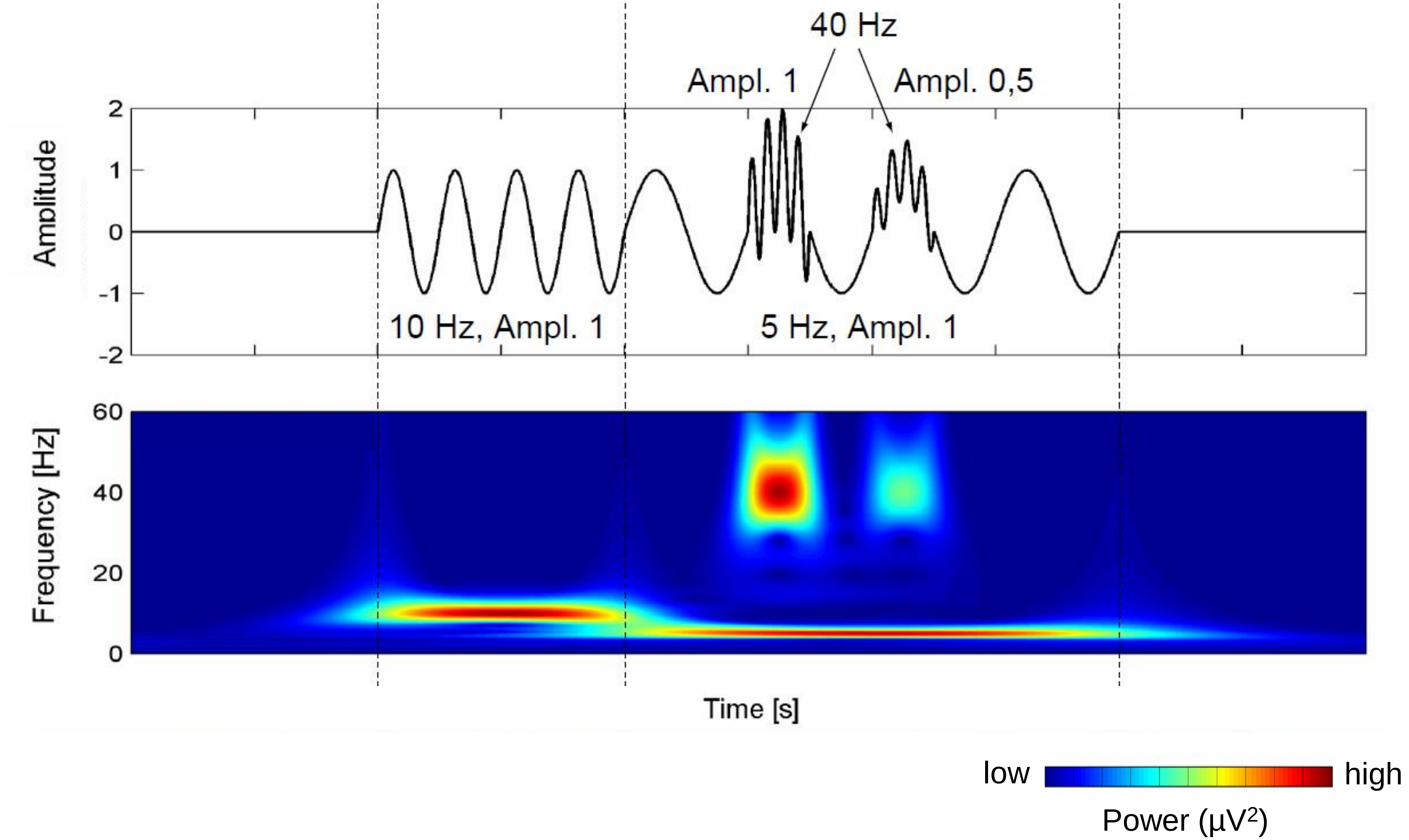


Image adapted from: Tamm (2005)

The End