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NARODOWA STRATEGIA SPÓJNOŚCI

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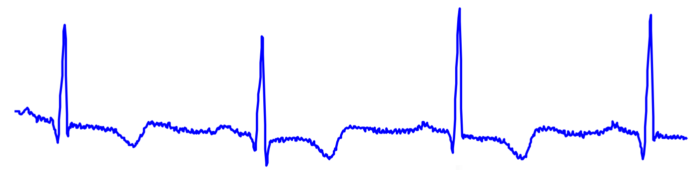
„SIGNAL PROCESSING"

Prezentacja multimedialna współfinansowana przez Unię Europejską w ramach Europejskiego Funduszu Społecznego w projekcie pt.

„Innowacyjna dydaktyka bez ograniczeń - zintegrowany rozwój Politechniki Łódzkiej - zarządzanie Uczelnią, nowoczesna oferta edukacyjna i wzmacniania zdolności do zatrudniania osób niepełnosprawnych"

Biomedical Engineering

Signal Processing



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INSTITUTE OF ELECTRONICS

Medical Electronics Division

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Course form and assesment

- Lectures: 30h
- Laboratories and projects: 30h

- Test: 50% of the mark
- Laboratories and project: 50% of the mark

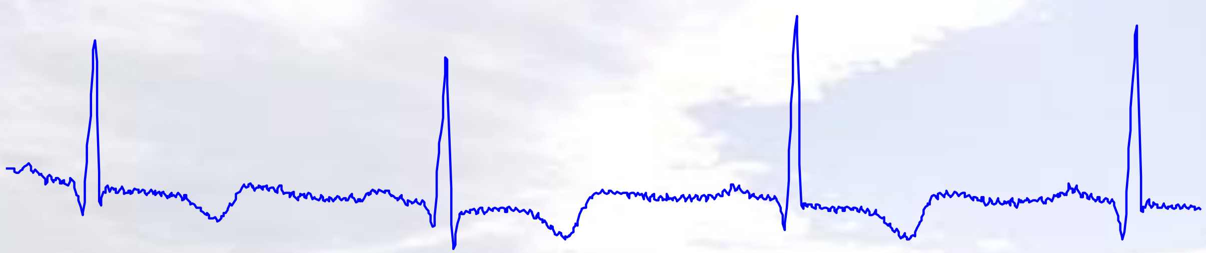
Literature

- Lecture notes (*.pdf) available at: http://www.eletel.p.lodz.pl/pstrumil
- „The Scientist and Engineer's Guide to Digital Signal Processing”, Steven W. Smith

  www.DSPguide.com
- W. J. Tompkins (Ed.) „*Biomedical Digital Signal Processing*”, Prentice-Hall, 1993
- T. P. Zieliński, „*Digital processing of signals*” (in Polish) WKiŁ, 2005
- M. Tadeusiewicz, „*Signals and systems*”, Technical University of Lodz, 2004.
- D.C. Reddy, *Biomedical signal processing: principles and techniques*, Tata McGraw Hill education Private Limited, 2005.

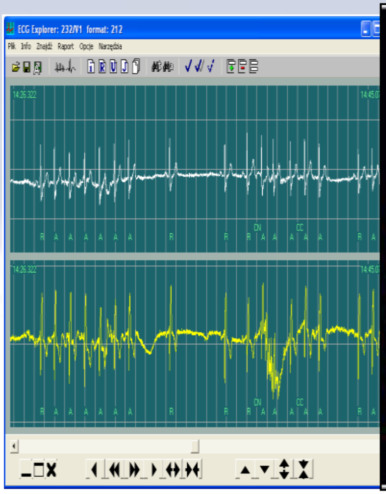
Laboratories and projects

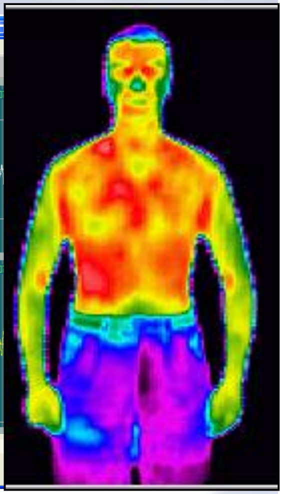
- Practical examples and exercises in Python™
- Projects on practical applications of methods for processing and analysis of biological signals

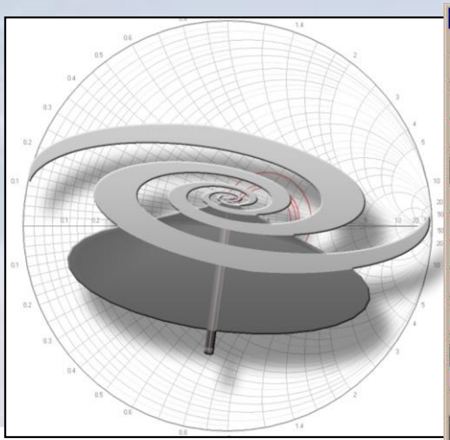


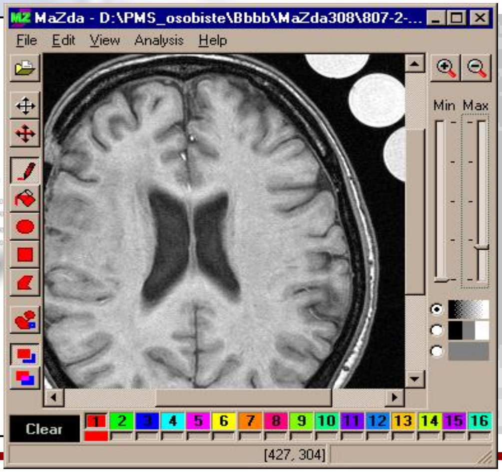
Medical Electronics Division

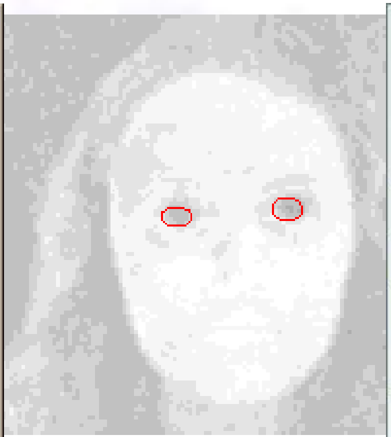
- *medical electronics (image and signal analysis), human computer interfaces, assistive technologies for the disabled*
- *electronic circuits and computed termography*
- *telecommunication systems*

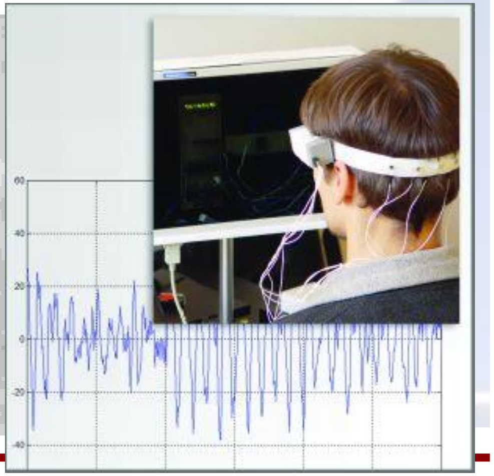




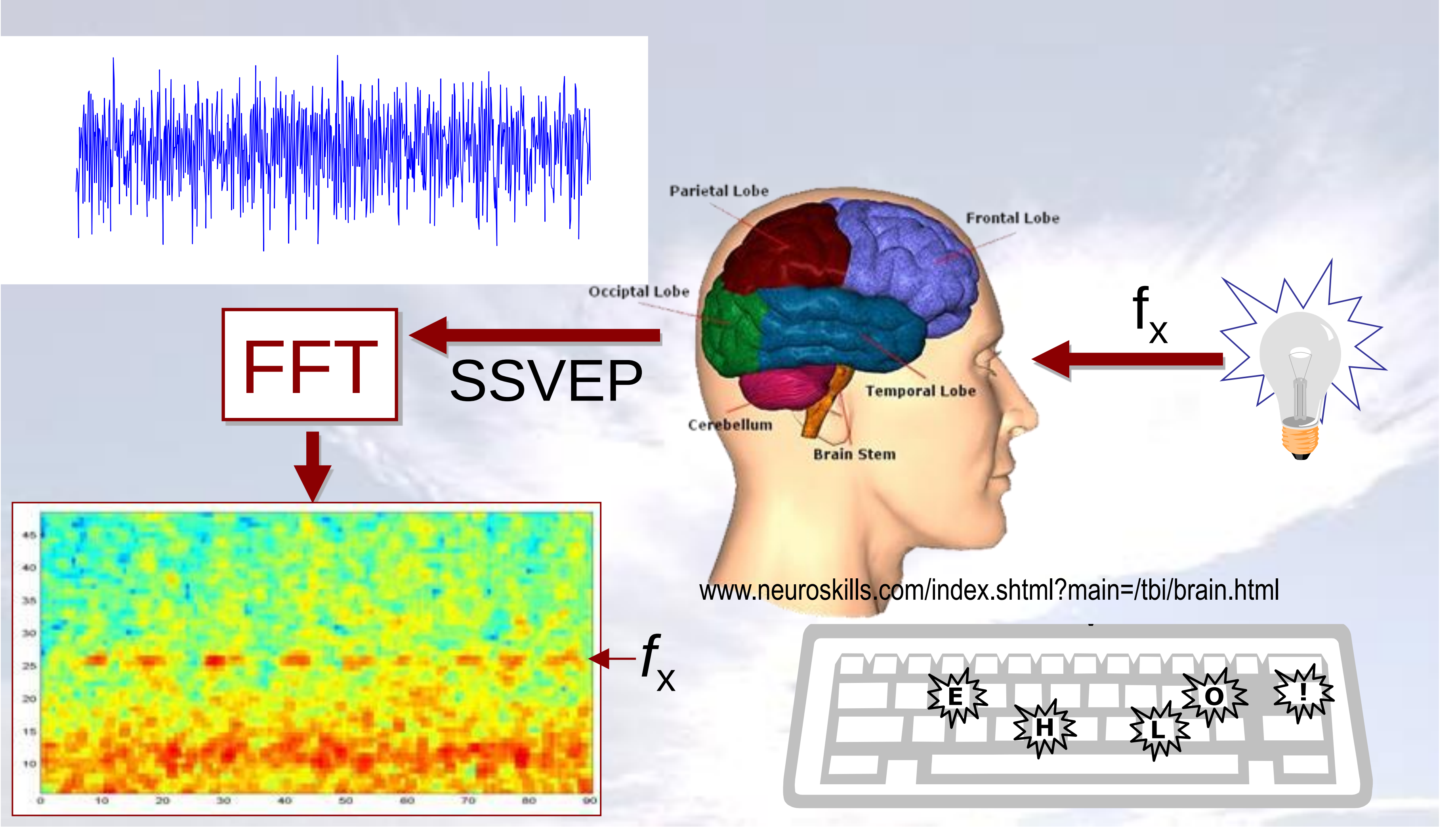








Steady-State Visual Evoked Potentials (SSVEP)



Brain Computer Interface

Detection time:

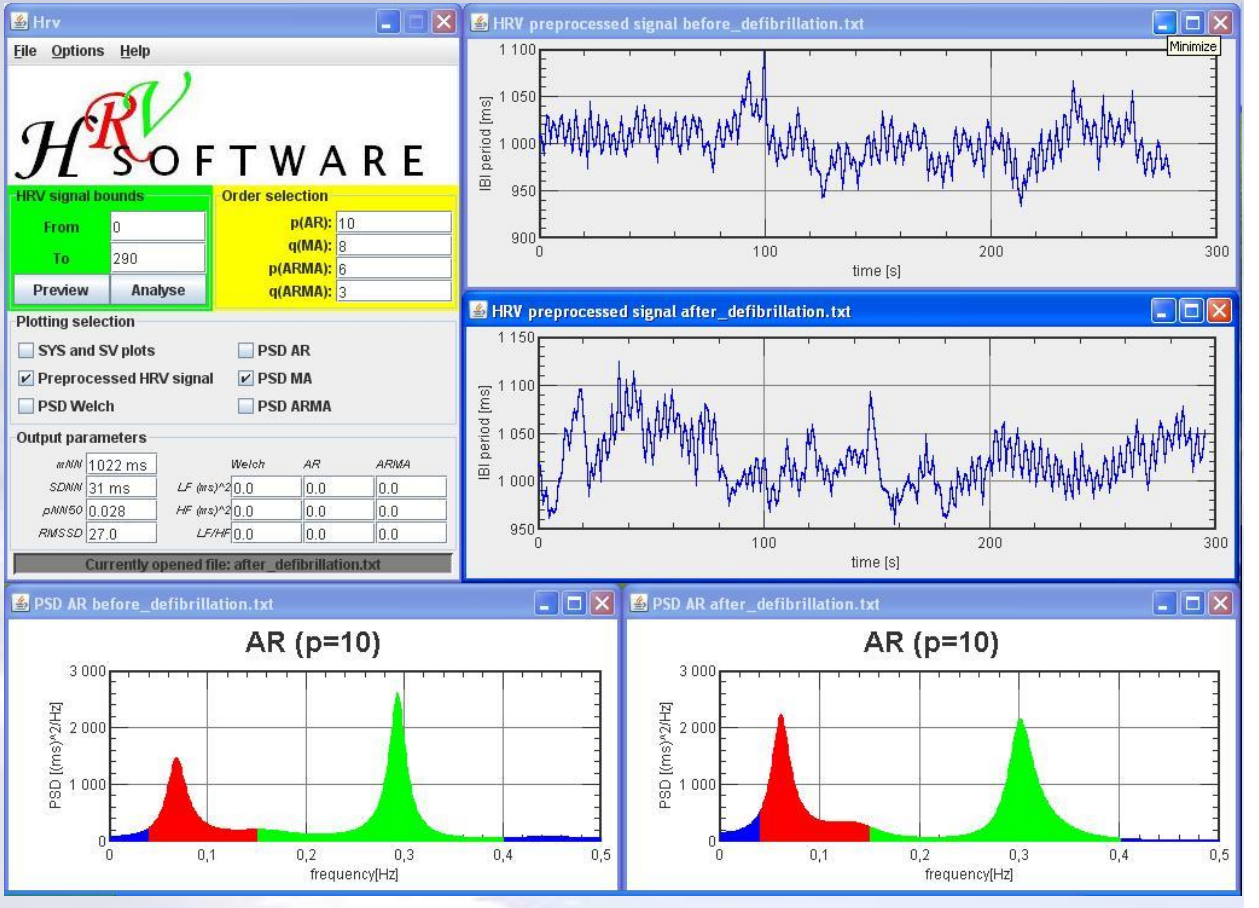
3-5 s

dr Marcin Byczuk

Computed ECG analysis

Dr Krzysztof Kudryński –
„***HRV analysis***”
MSc Thesis

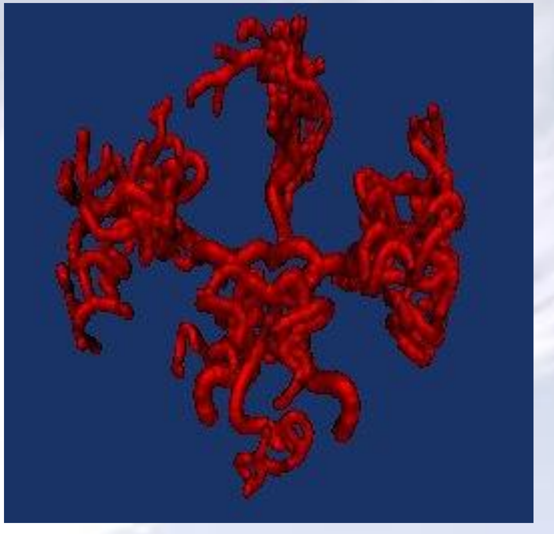
I prize in SEP
contest in 2007



Modelling of blood vessels

Reconstructed 3D MRI images

Image segmentation



Geometric model for dianosis support

mgr Marek Kociński

Course overview:

Signal Processing basics:

- Signals and their models (eg. deterministic and random)
- Spectral representation of the signals (*Advanced Spectrum Analyzer for Android*)
- Sampling and AD/DA conversion
- Digital filtering
- Signal compression methods (JPG, MPEG,MP3)

Signal analysis:

- Biological signals – genesis, classification and properties
- Biological signals acquisition (amplifiers, noise)
- Biological signal analysis (detection, classification, interpretation)
- Example systems and programs for biomedical signal analysis.

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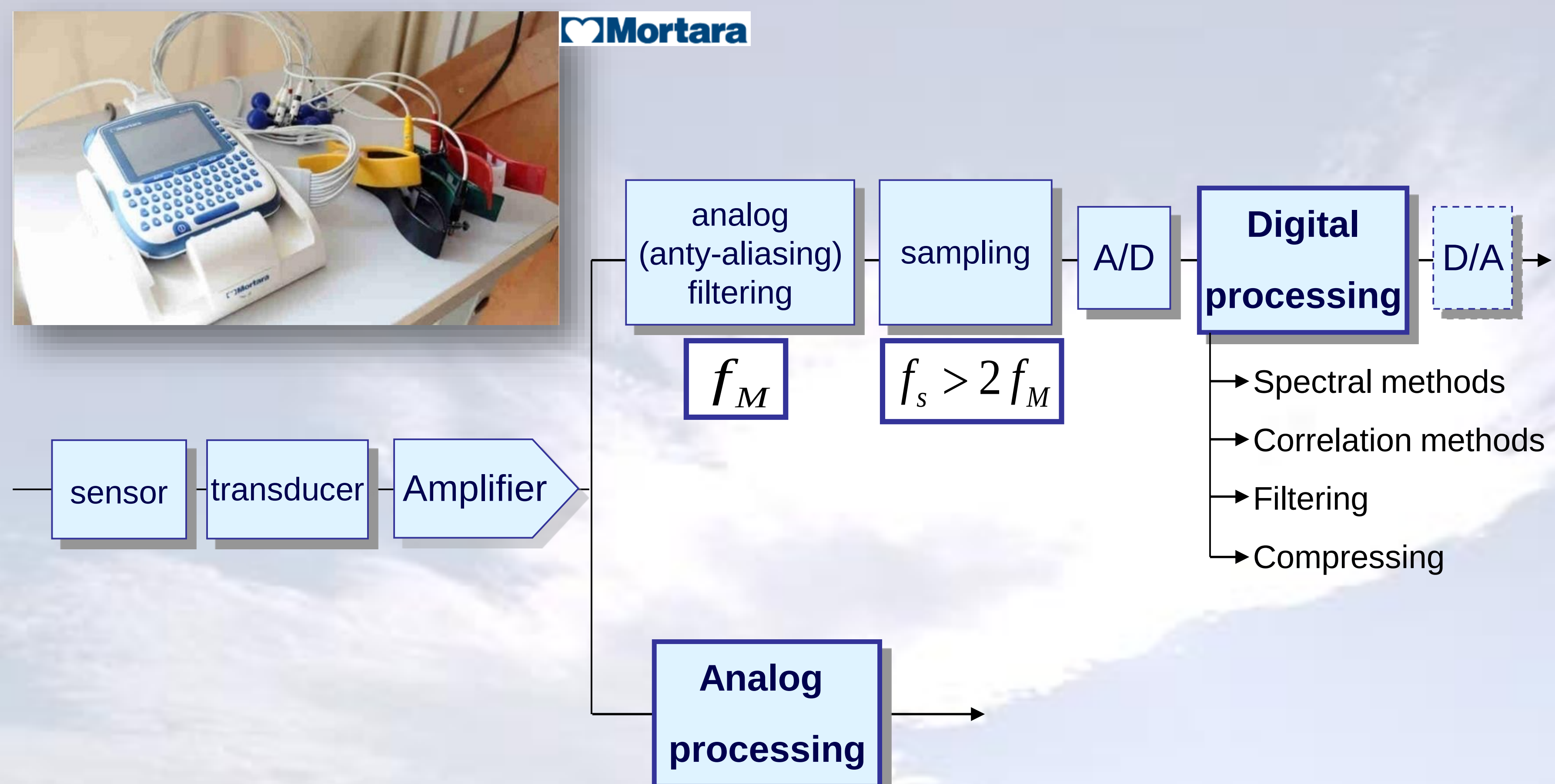
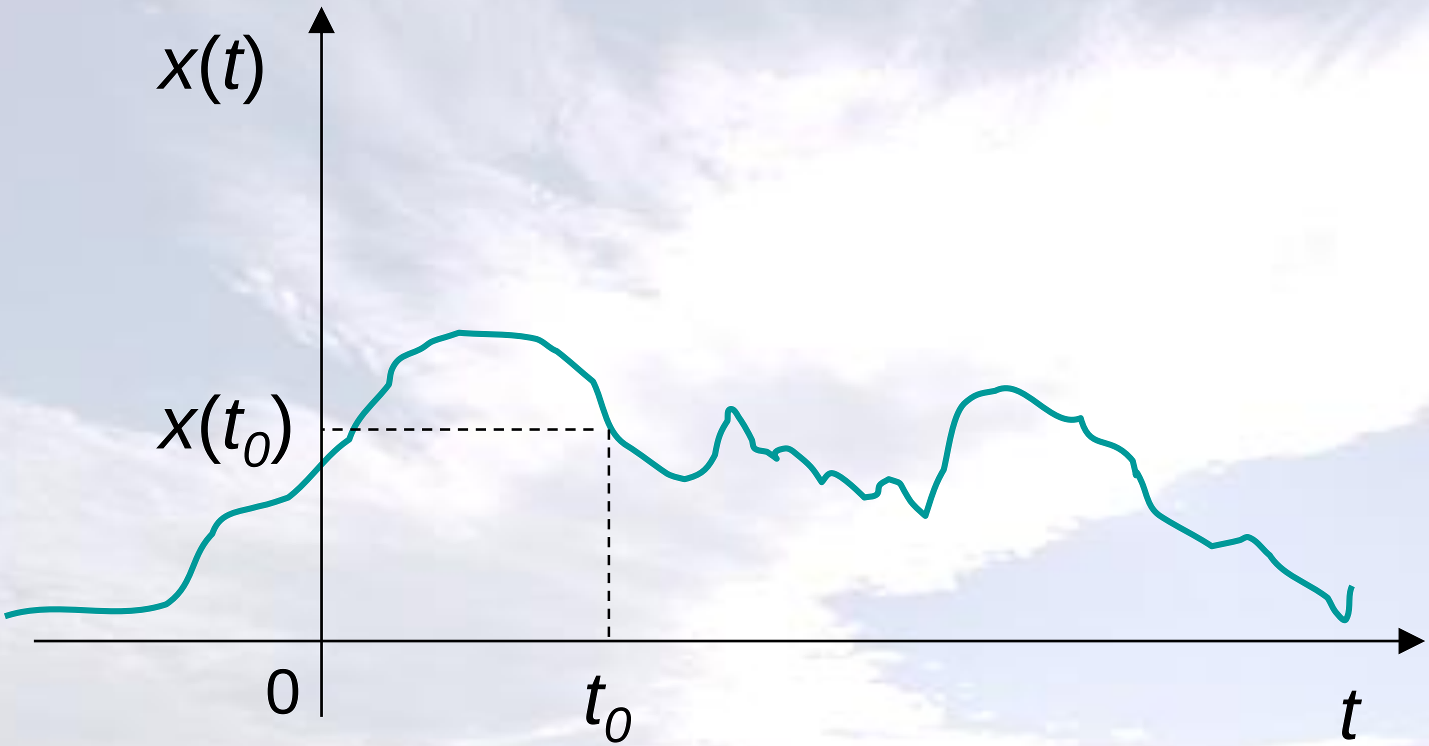
Signal processing system



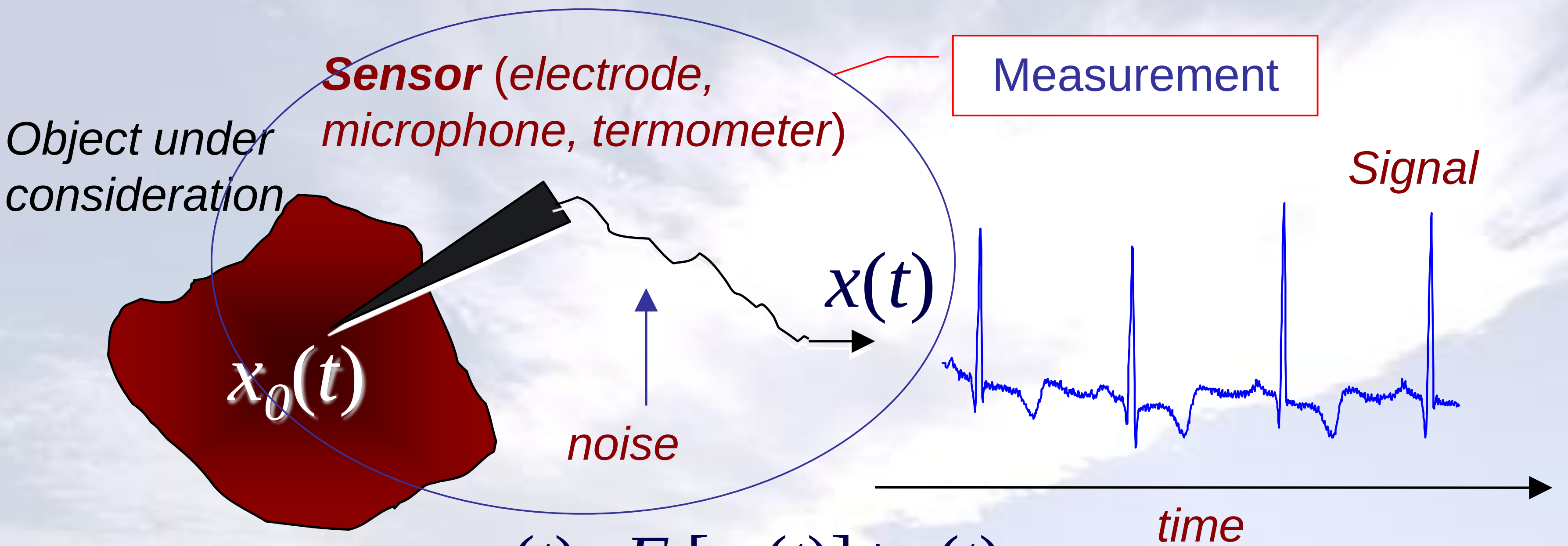
Signal – what is that?

Signal is a function of time $x(t)$ usually not given in an analytical form → *a need for defining models of signals*



Signals – what for?

Recording, processing and analysis of signals are the ways to examine the surrounding environment, eg. the human body, eg.?



$$x(t)=F\,[x_0(t)]+n(t)$$

sensor characteristic *F*[.], e.g. bandwidth

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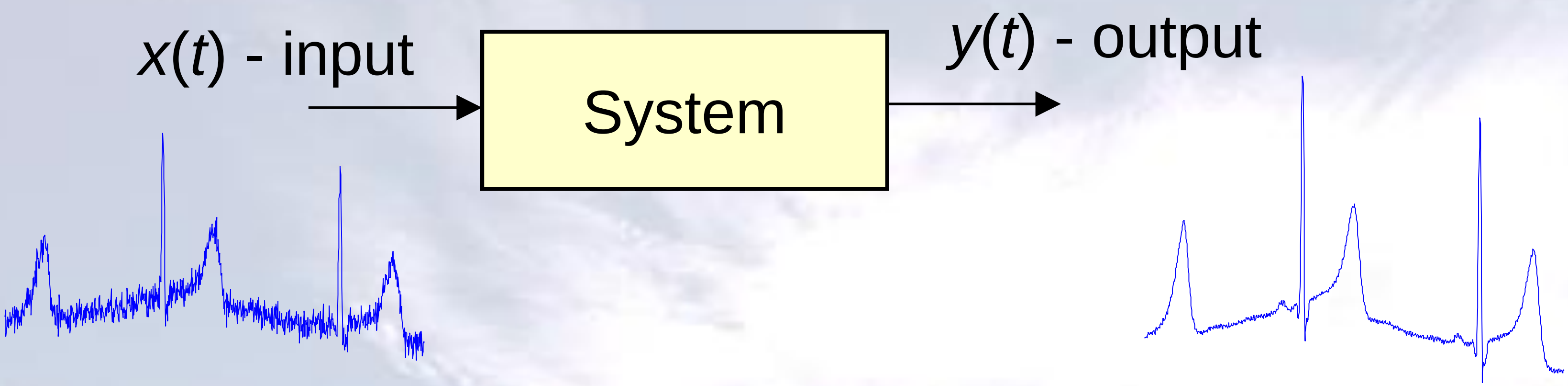
Systems for processing signals

To record, process or analyse signals we need **systems**:

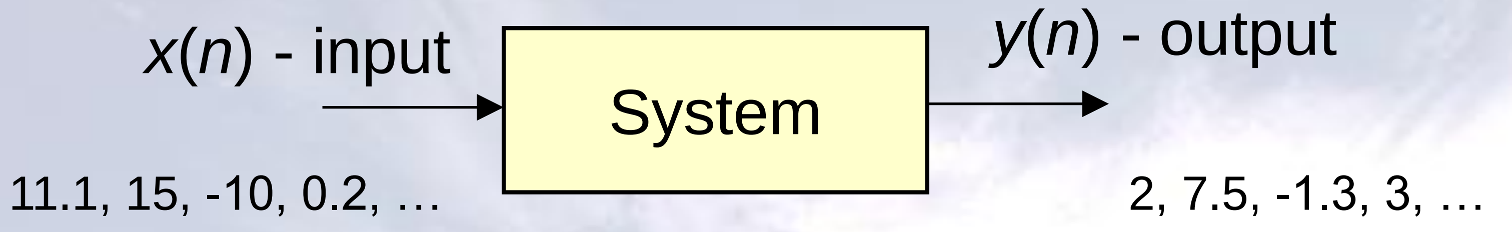


$x(t) \rightarrow y(t)$?

How to design systems for dealing with signals?

Human brain is a very powerful signal processor and analyzer (of images too …).

What are discrete time signals?



Issues:

- How to connect discrete systems do analog world?
- sampling frequency?

Note: Signal processing systems can be implemented in hardware or in software

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- **Different forms of signals** → various sensors and tranducers are necessary
- **Low amplitudes (non-invasive measurement)**→ amplification necessary (EEG ~μV, ECG ~1 mV)
- **Noise** → noise reduction needed
- **Costly registration** → high quality of the measurement devices, memory to store the data
- **High quantity of registered signals** → economical ways to store data, signal compression algorithms.
- **Diagnostic information often „hidden" within multiple features unseen in 'naked eye' examination** → advanced analysis methods necessary

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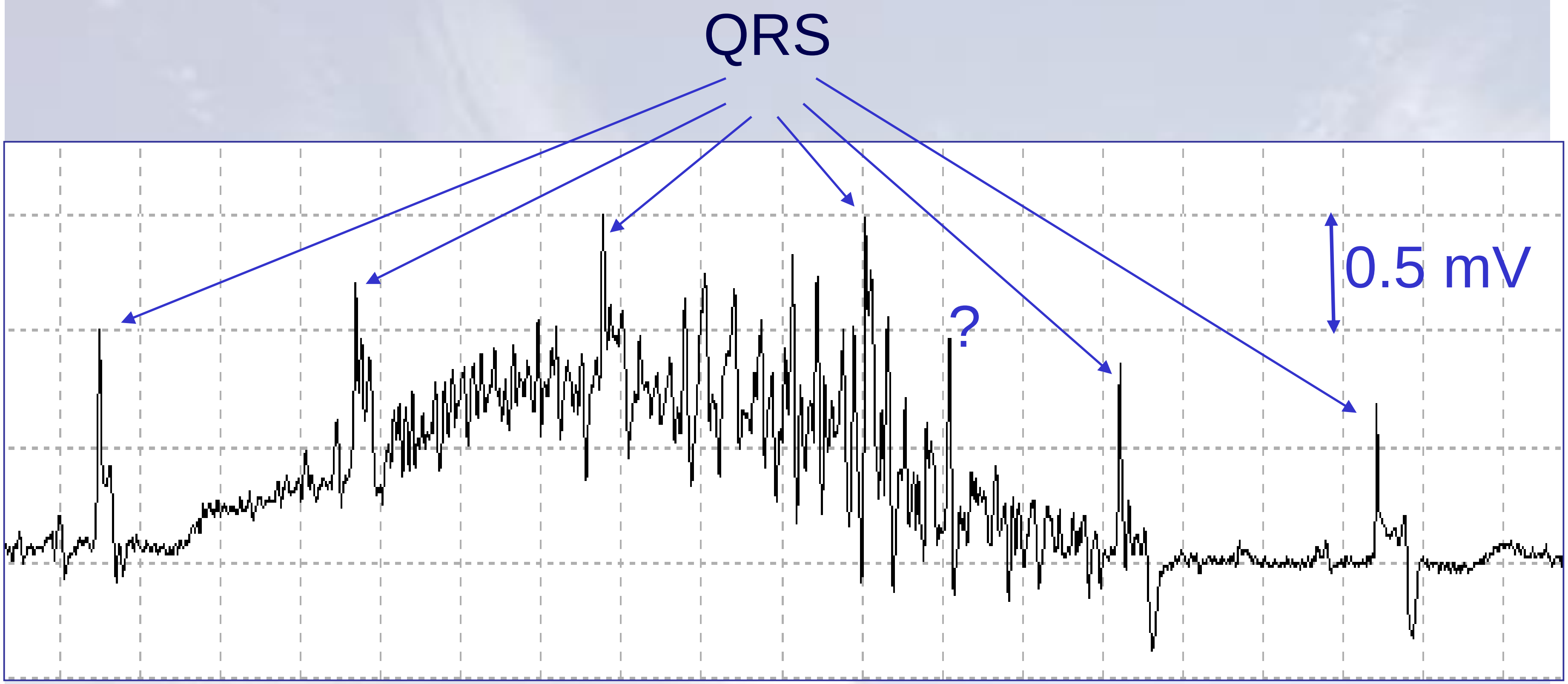

Example of noisy ECG signal
(MIT/BIH #104 database)

Classification of biomedical signals

- **Bioelectric**
  electrocardiographic (ECG), electroencephalographic (EEG), electromyographic (EMG), electrooculographic (EOG)
- **Bioacoustic**
  sound of blood flow in the heart, air flow in the lungs
- **Biomechanical**
  motion, displacement, pressure, flow
- **Biochemical**
  e.g. concentration of various ions or glucose in the blood
- **Biomagnetic**
  magnetoencephalographic (MEG)
- **Biooptical**
  e.g. oximetry
- **Bioimpedance**
  e.g. skin resistance

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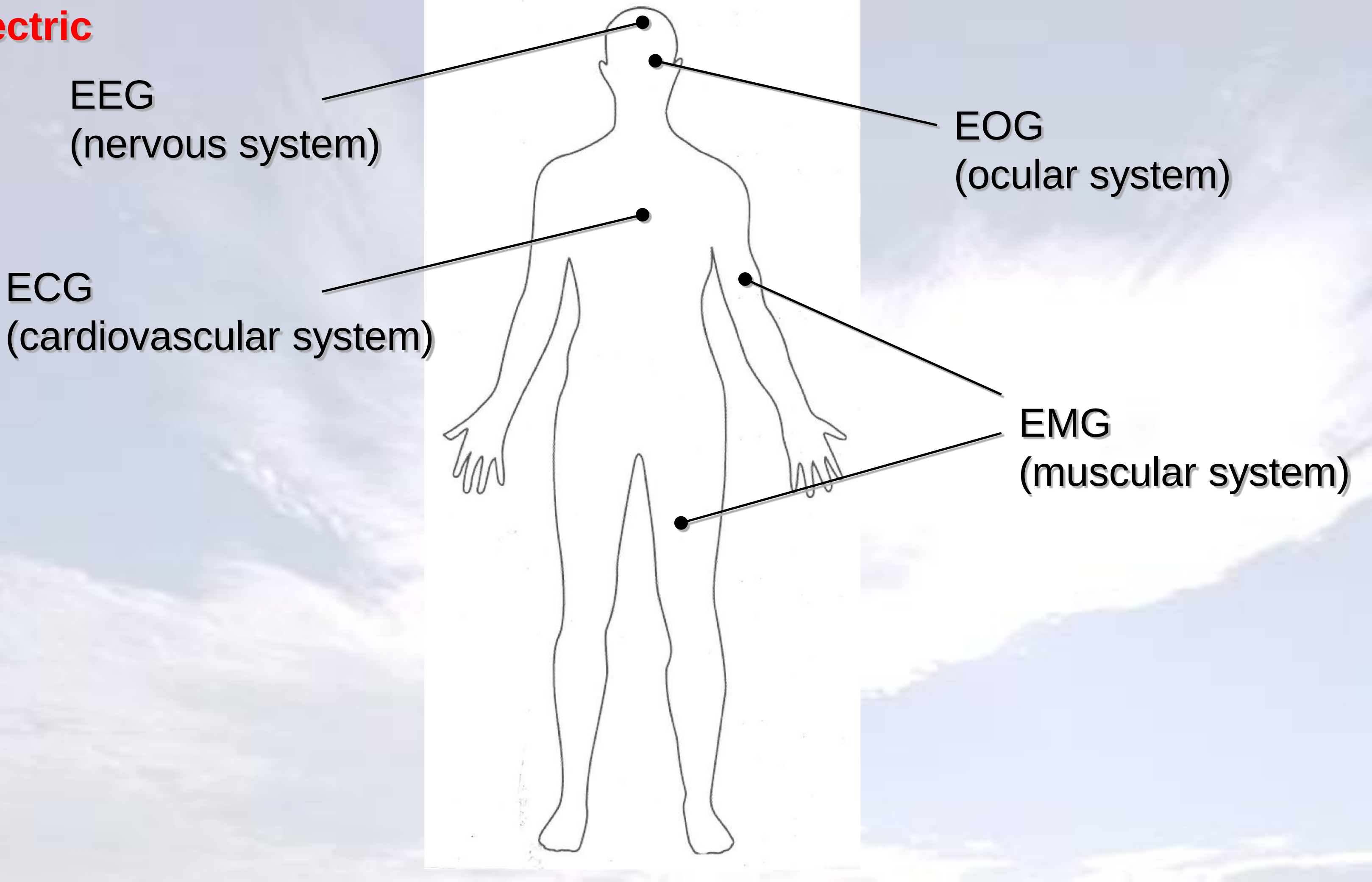
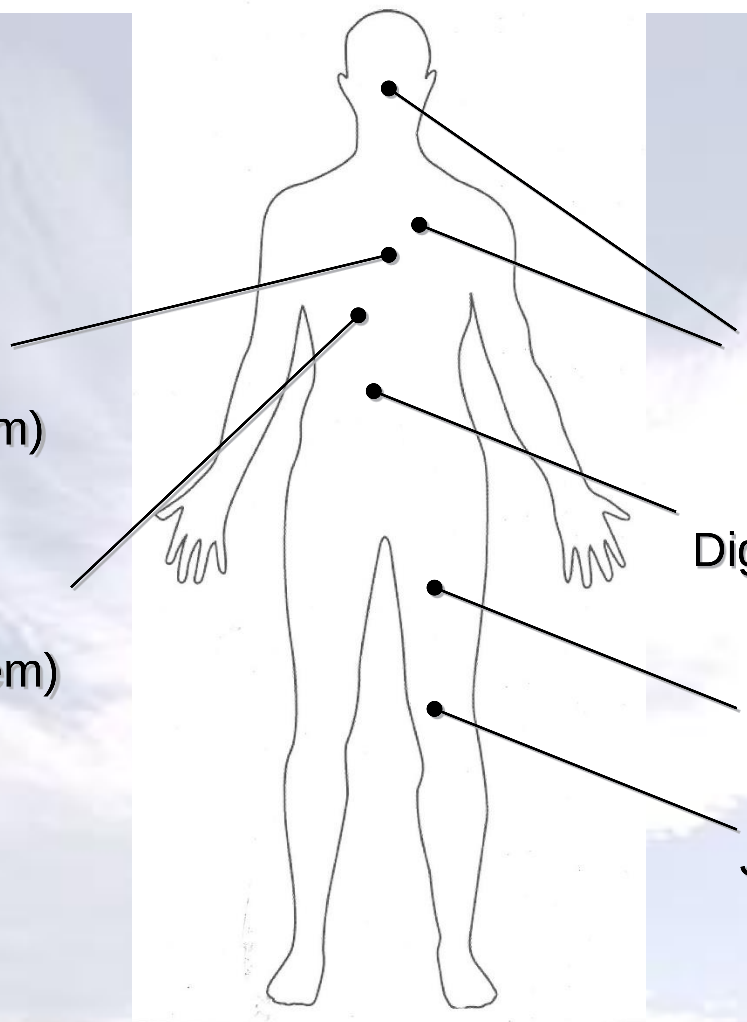
Sources of biomedical signals

Bioelectric



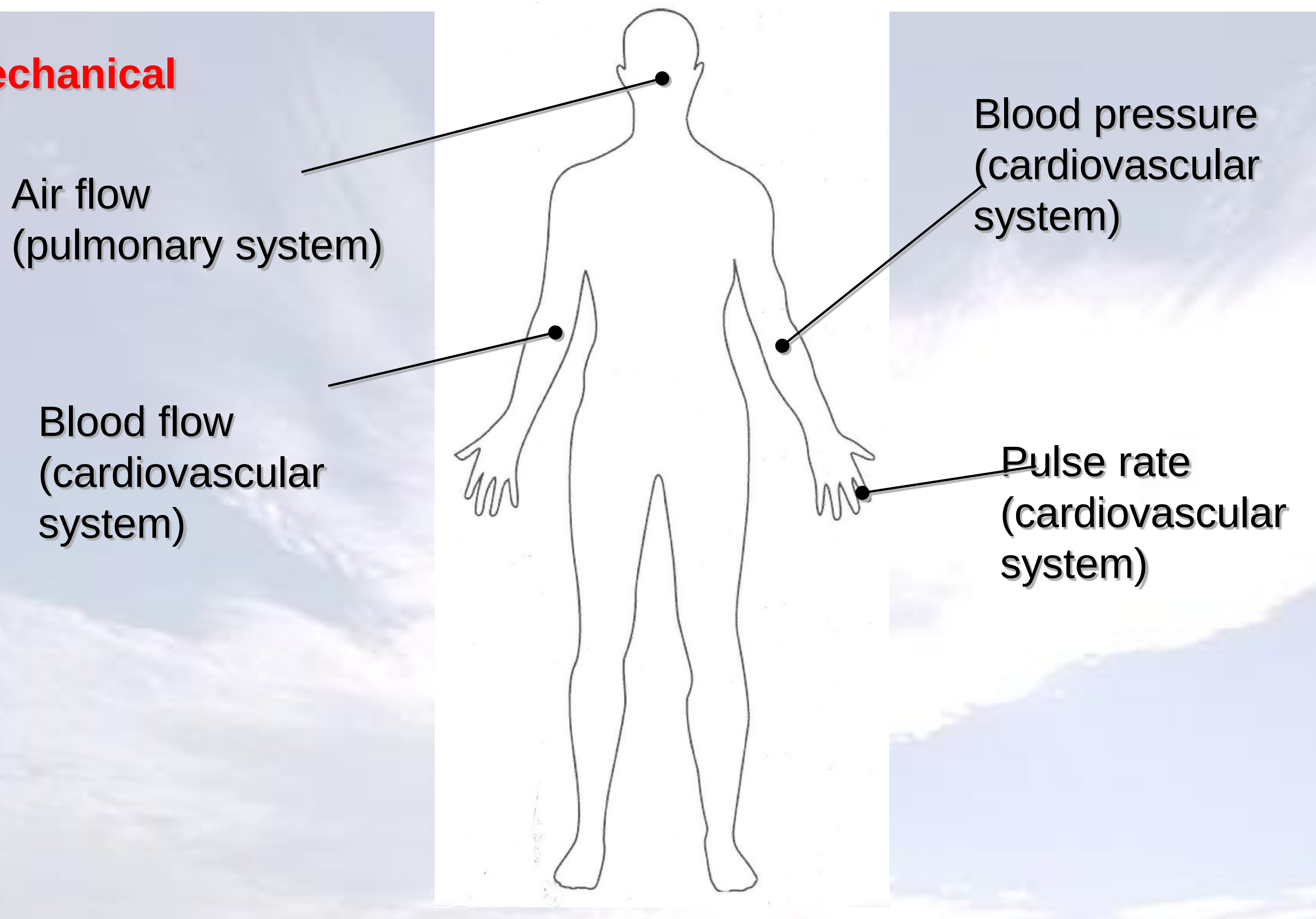
Sources of biomedical signals

Bioacoustic



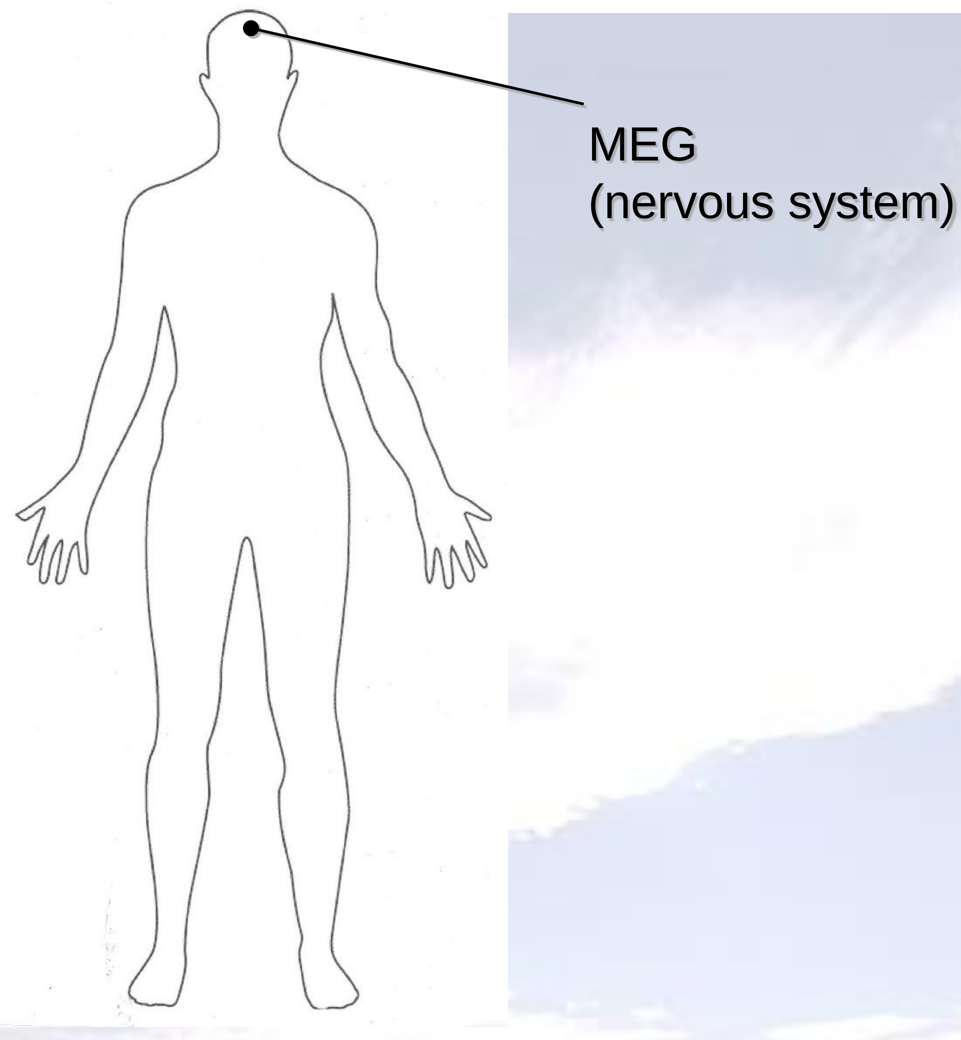
Sources of biomedical signals

Biomechanical



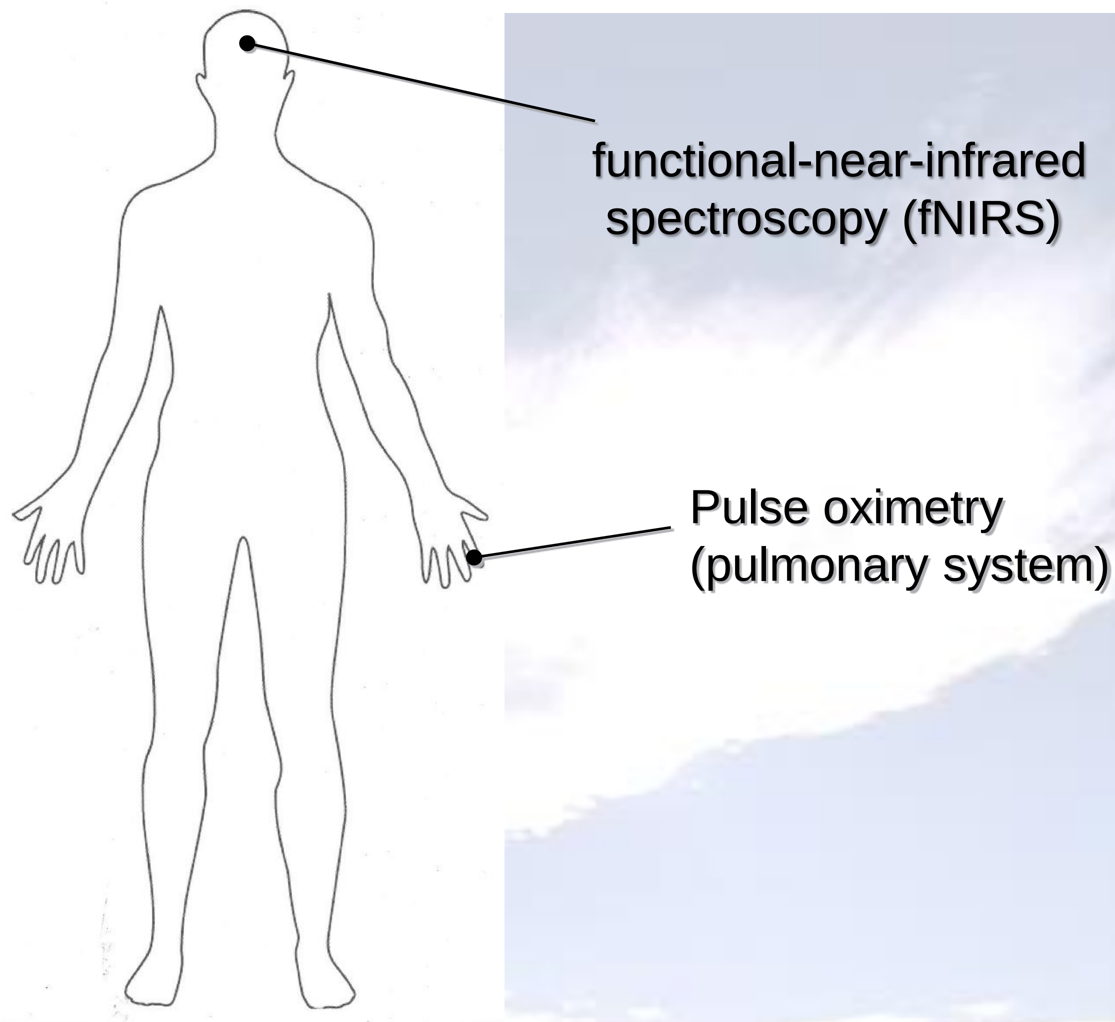
Sources of biomedical signals

Biomagnetic



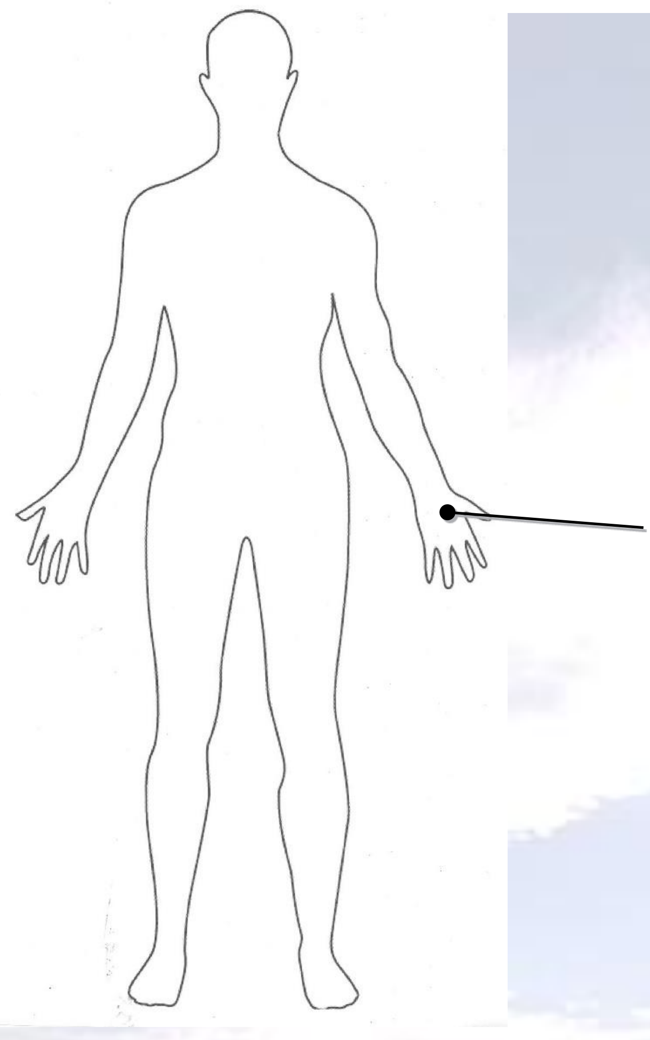
Sources of biomedical signals

Biooptical



Sources of biomedical signals

Bioimpedance



Examples o biological signals

Signal type	Frequency pectrum	Amplitude range
ECG	0.05 – 100 Hz	10❍mV – 5 mV
EEG	0.5 – 60 Hz	15 - 100 uV
EMG	10 – 200 Hz	Depending on electrode (several mV)
Blood pressure	DC – 60 Hz	40-300 mm Hg (arteries) 0 - 15 mm Hg (veins)
Breath frequency	14 – 40 cycles per minute	-

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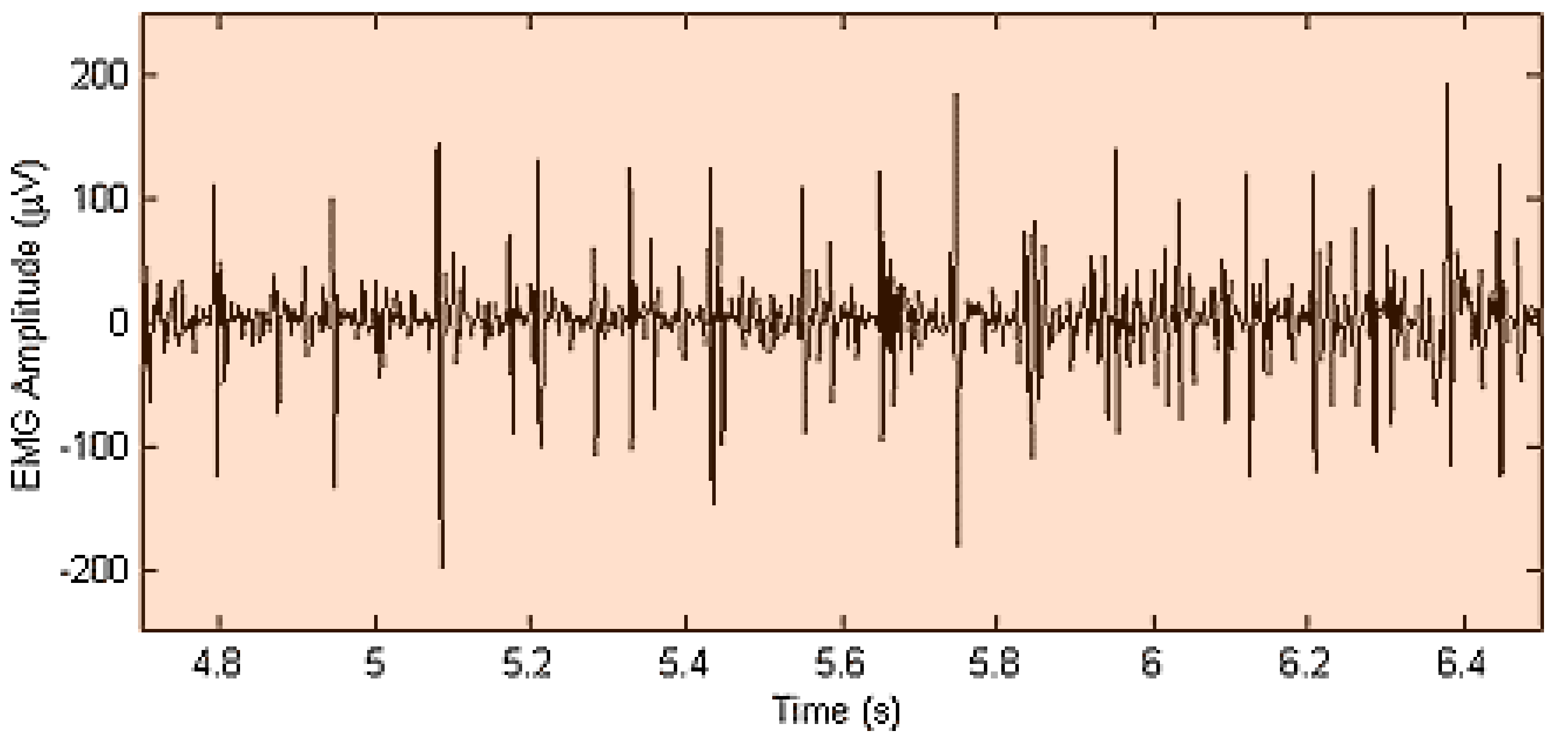
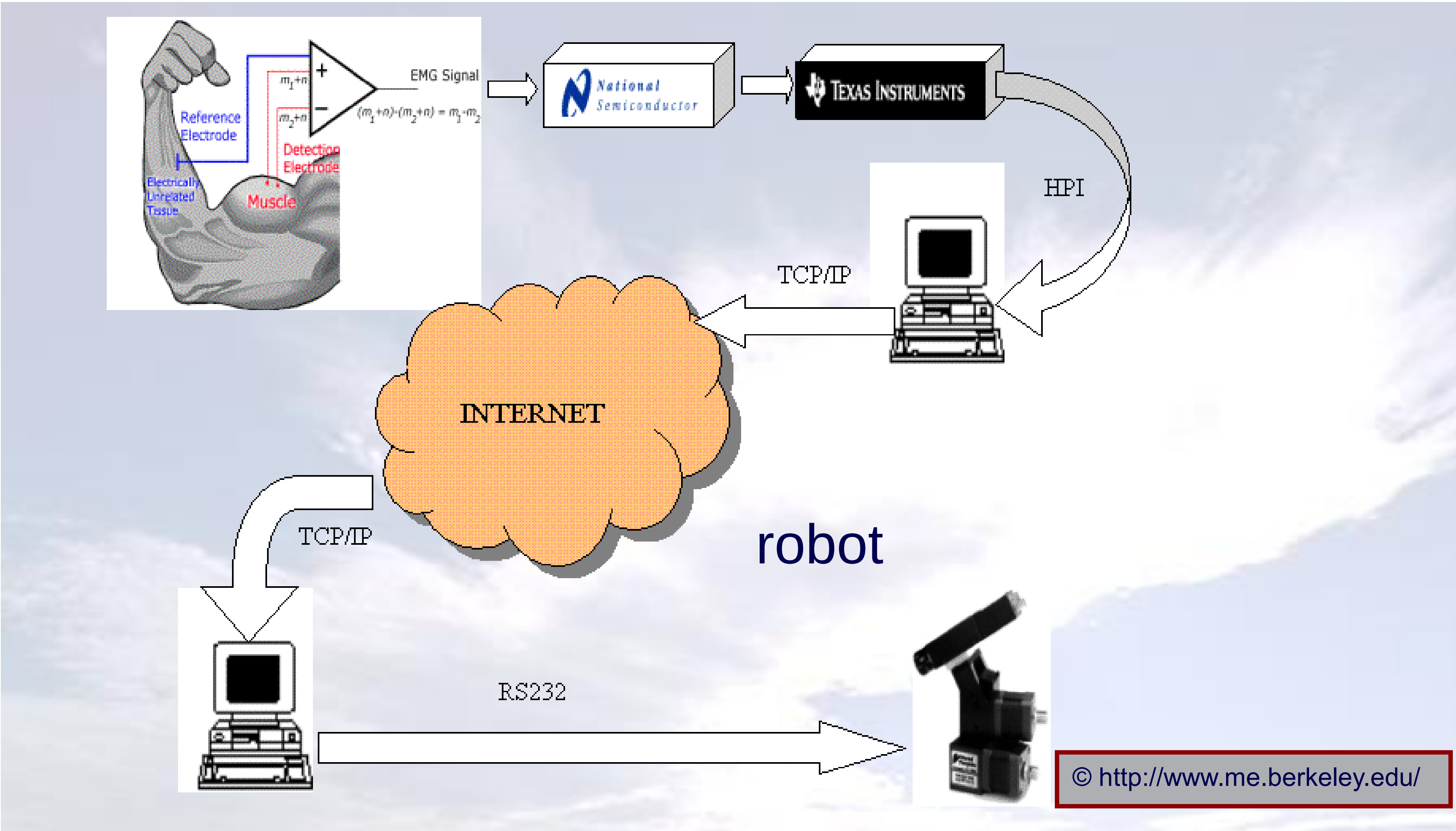
Examples of biological signals

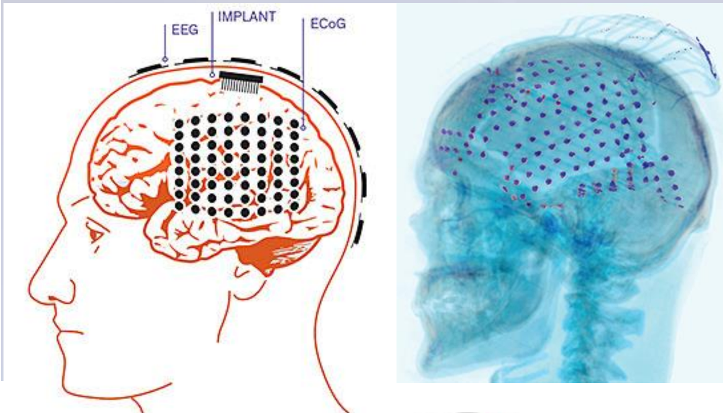


Example plot of EMG during muscle contraction

Transmission of signals…



From Mind to Machine



„Combining brain commands with information from other sensors may provide more sophisticated control of a robotic limb."

IEEE Spectrum

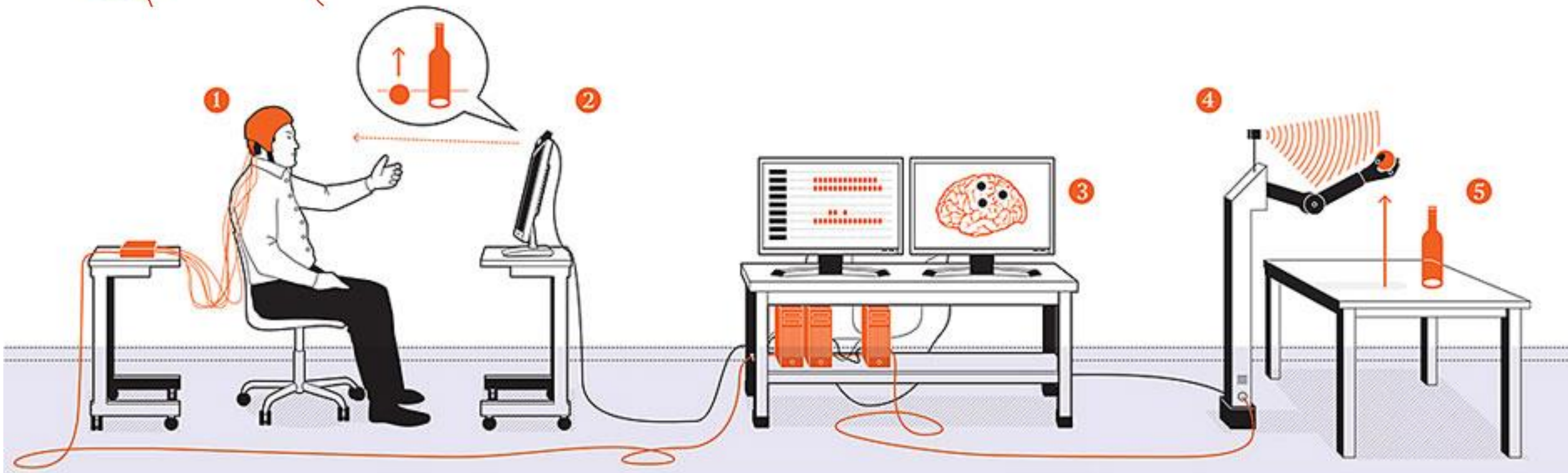


Illustration: Nicolas Rapp

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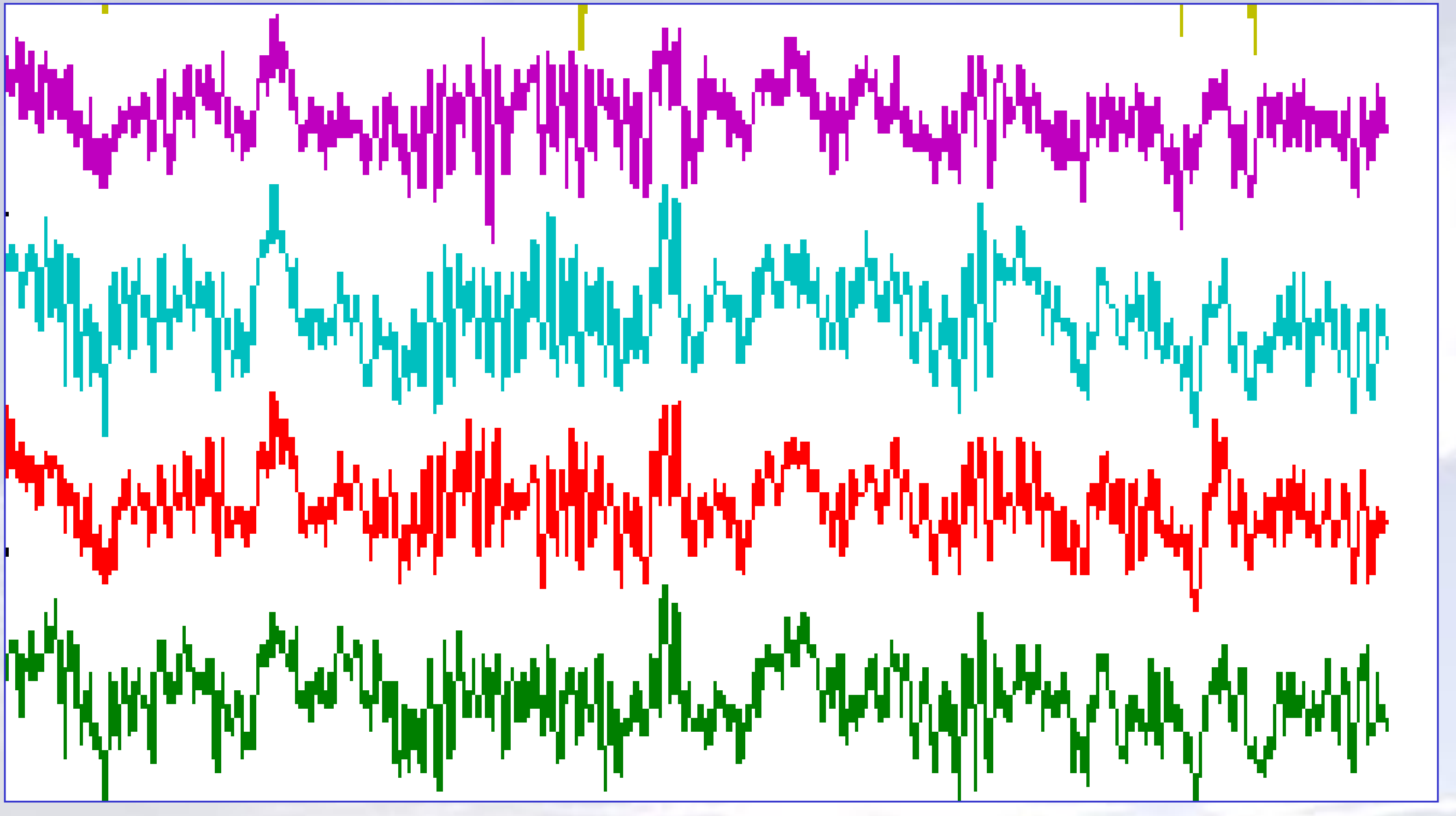
Example EEG recording

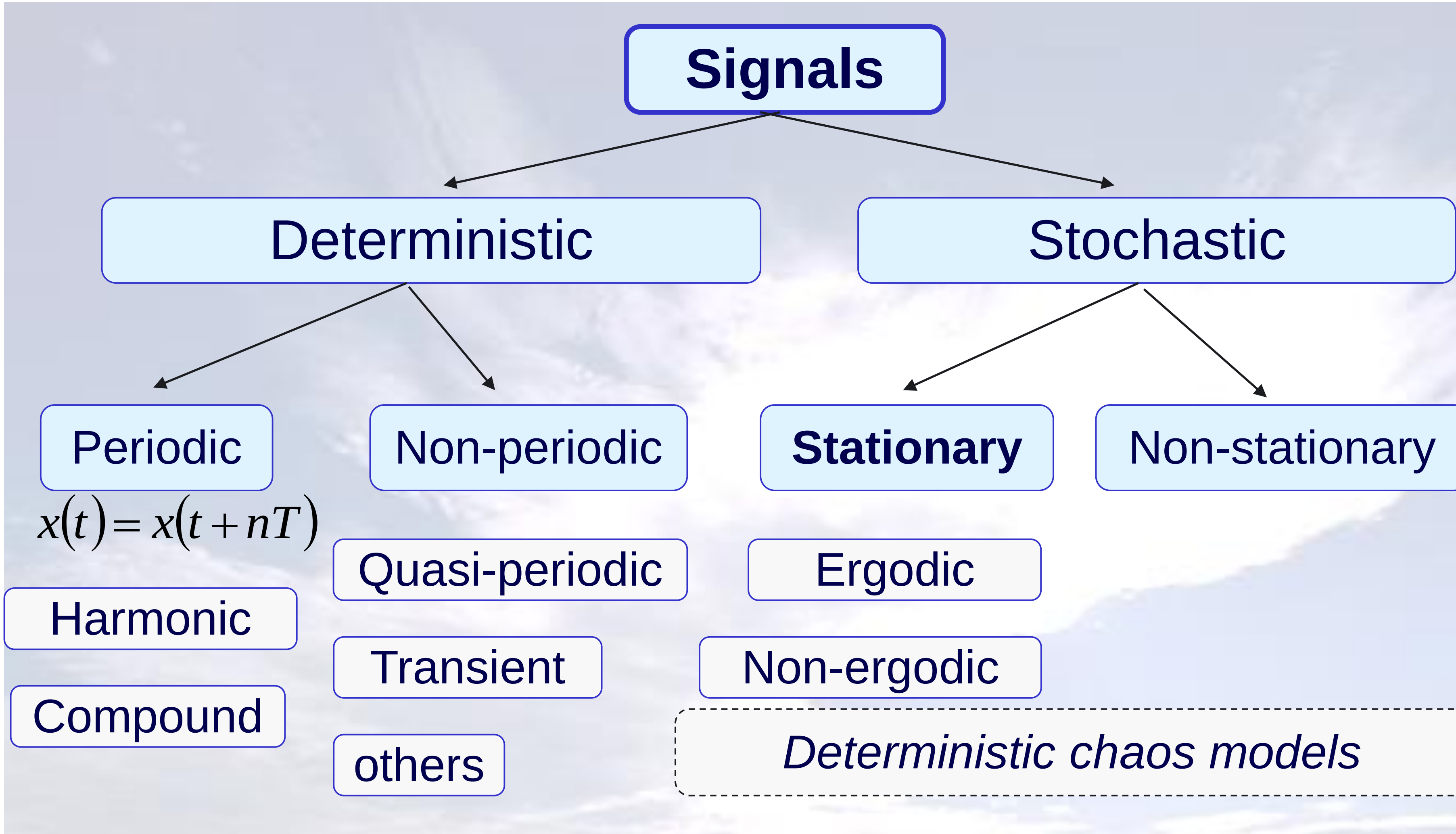
Amplitude: 1-10 μV, Spectrum: 0.15 - 300 Hz



HealthWatch

https://www.youtube.com/watch?v=4k4NUsFZWNE

Signal models



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Signal models

Signals

Signals of limited/unlimited energy:

$$E[x(t)] = \int_{-\infty}^{+\infty} [x(t)]^2 \, dt$$

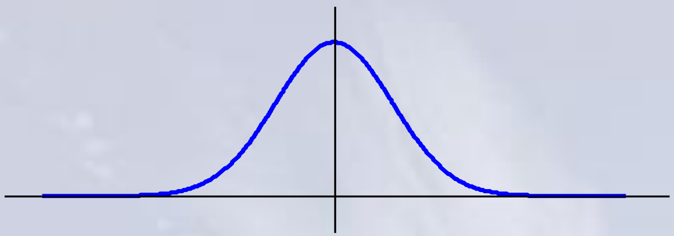
Signal power?

RMS (root mean square)?

Time-limited/unlimited signals :

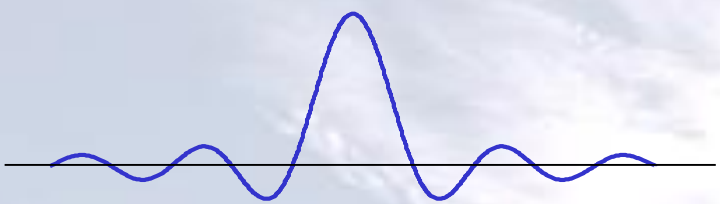
Examples!

Signal models (unlimited time, limited energy)



Gaussian signal

$$x(t) = e^{-t^2}$$



Sinc signal

$$x(t) = \begin{cases} \frac{\sin t}{t} & for \quad t \neq 0 \\ 1 & for \quad t = 0 \end{cases}$$

Exponential signal

$$x(t) = Ae^{-\alpha t}, \quad t \geq 0$$

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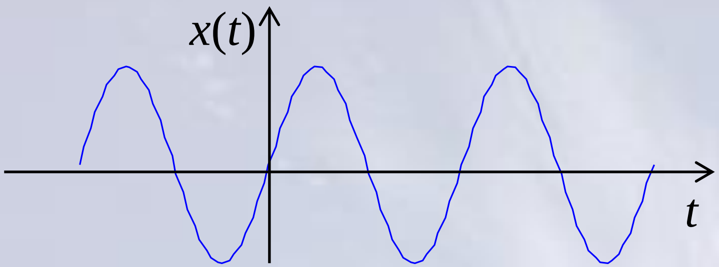
Sinusoidal signal

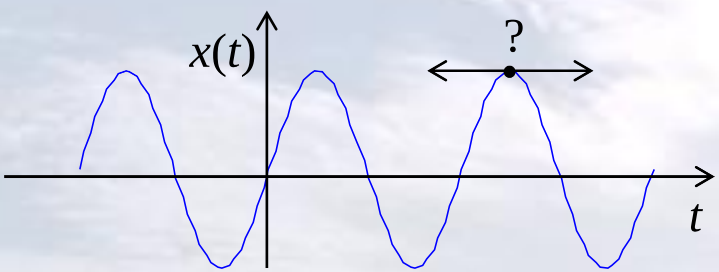


$$x(t)=\sin(\omega t)=\sin(2\pi f t)=\sin\left(\frac{2\pi}{T}t\right)$$

Angular frequency [rad/s]

Physical frequency [Hz]

Period [s]



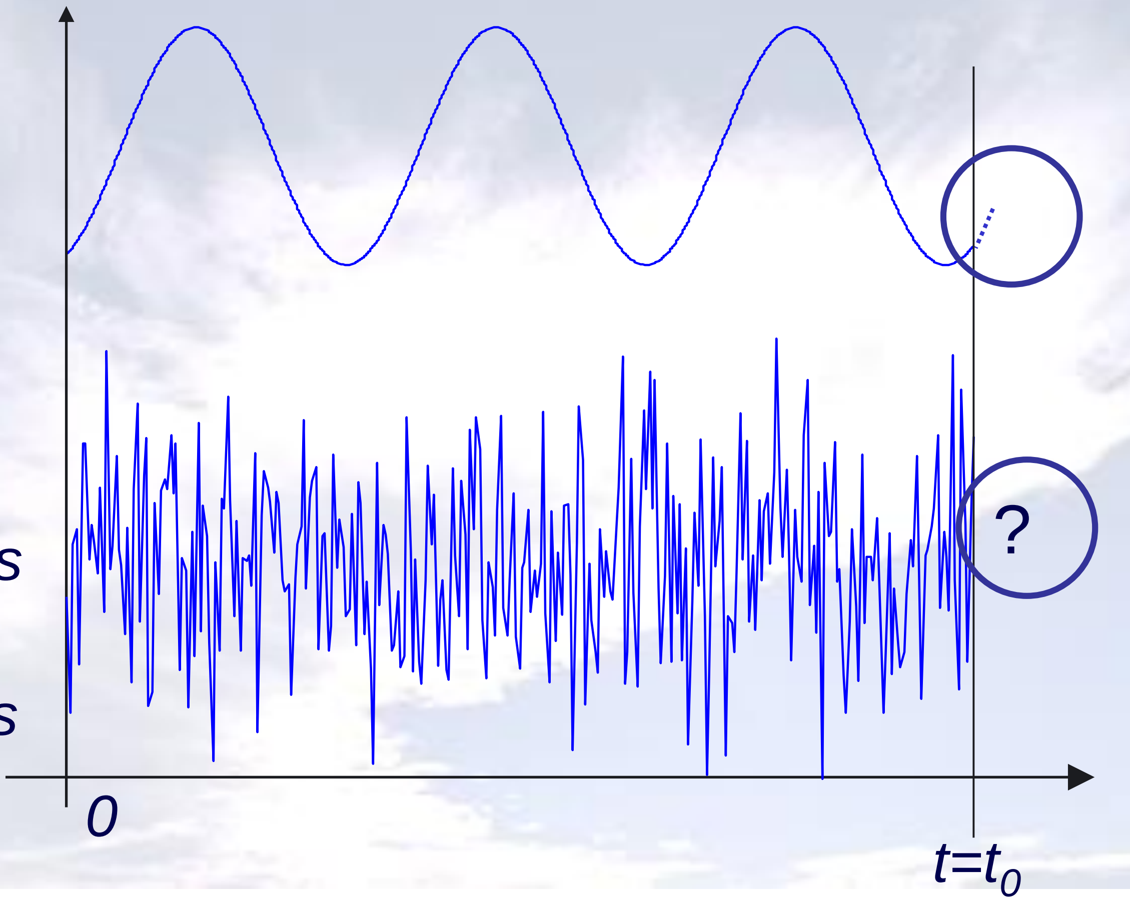
$$x(t)=\sin(\omega t+\varphi) \Rightarrow x(0)=\sin(\varphi)$$

Phase [rad]

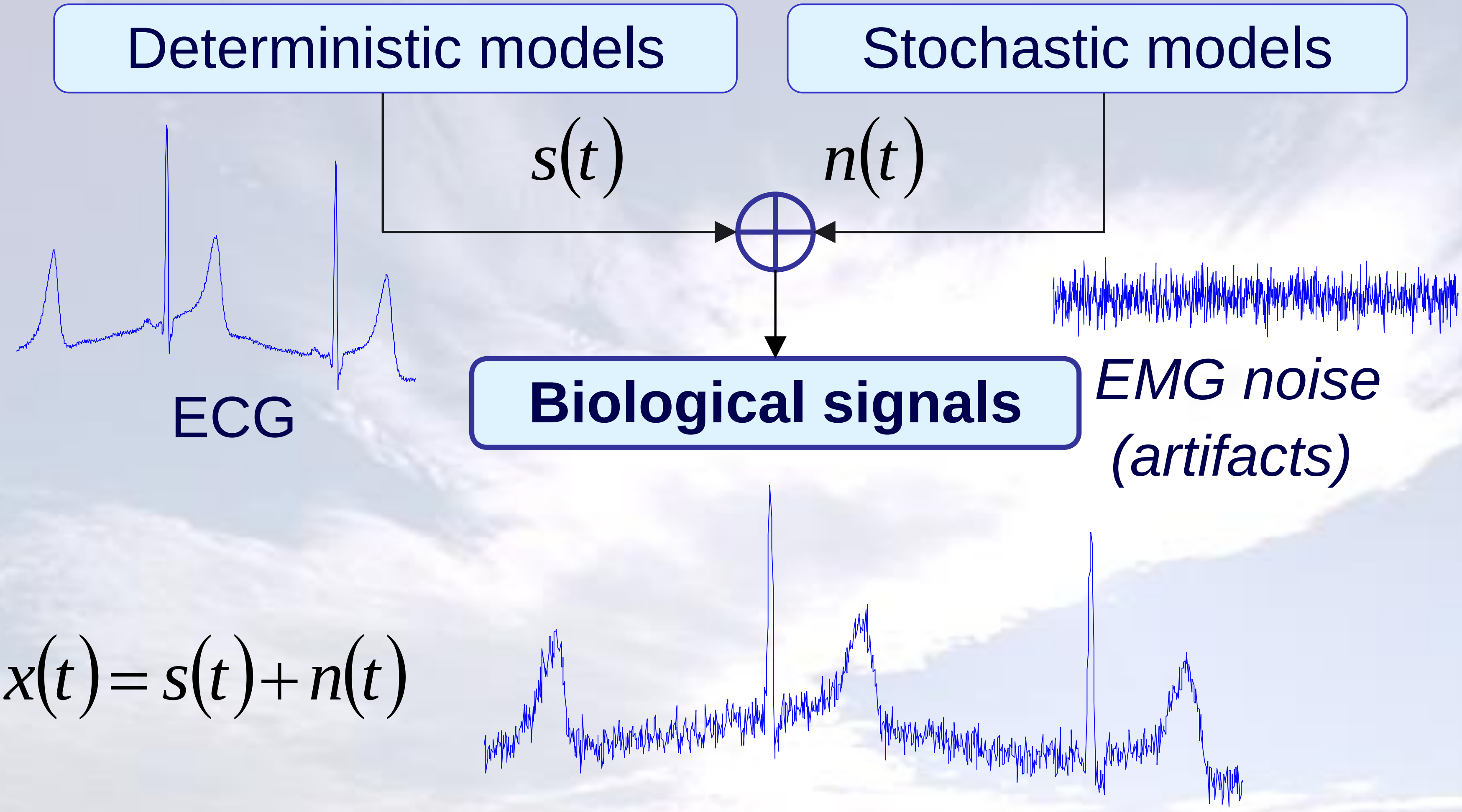
Random vs stochastic signals

deterministic
(samples may be predicted with high accuracy)

random
(unpredictable values of samples, only statistical parameters may be estimated)



Biological signals

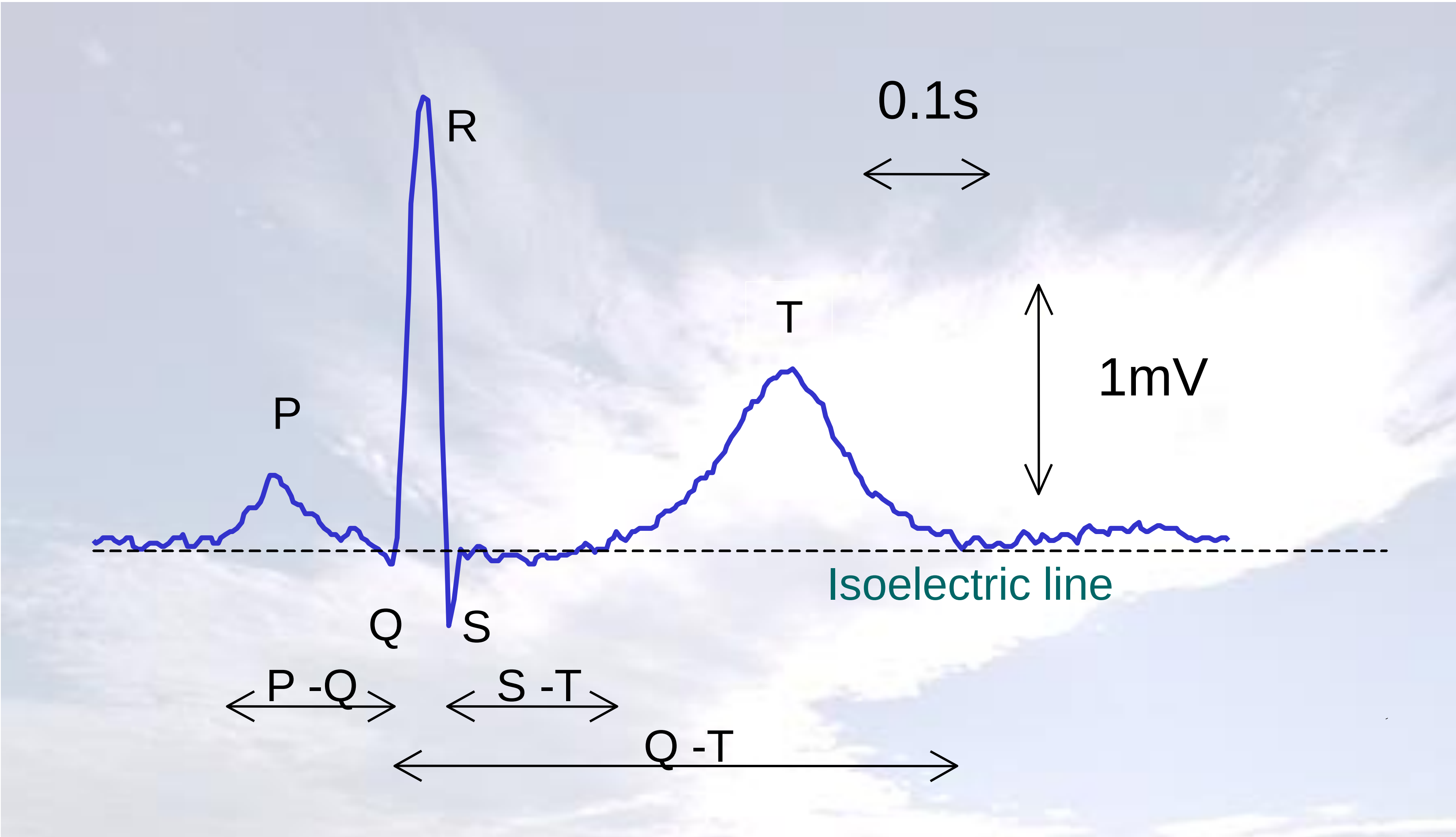


$$x(t) = s(t) + n(t)$$

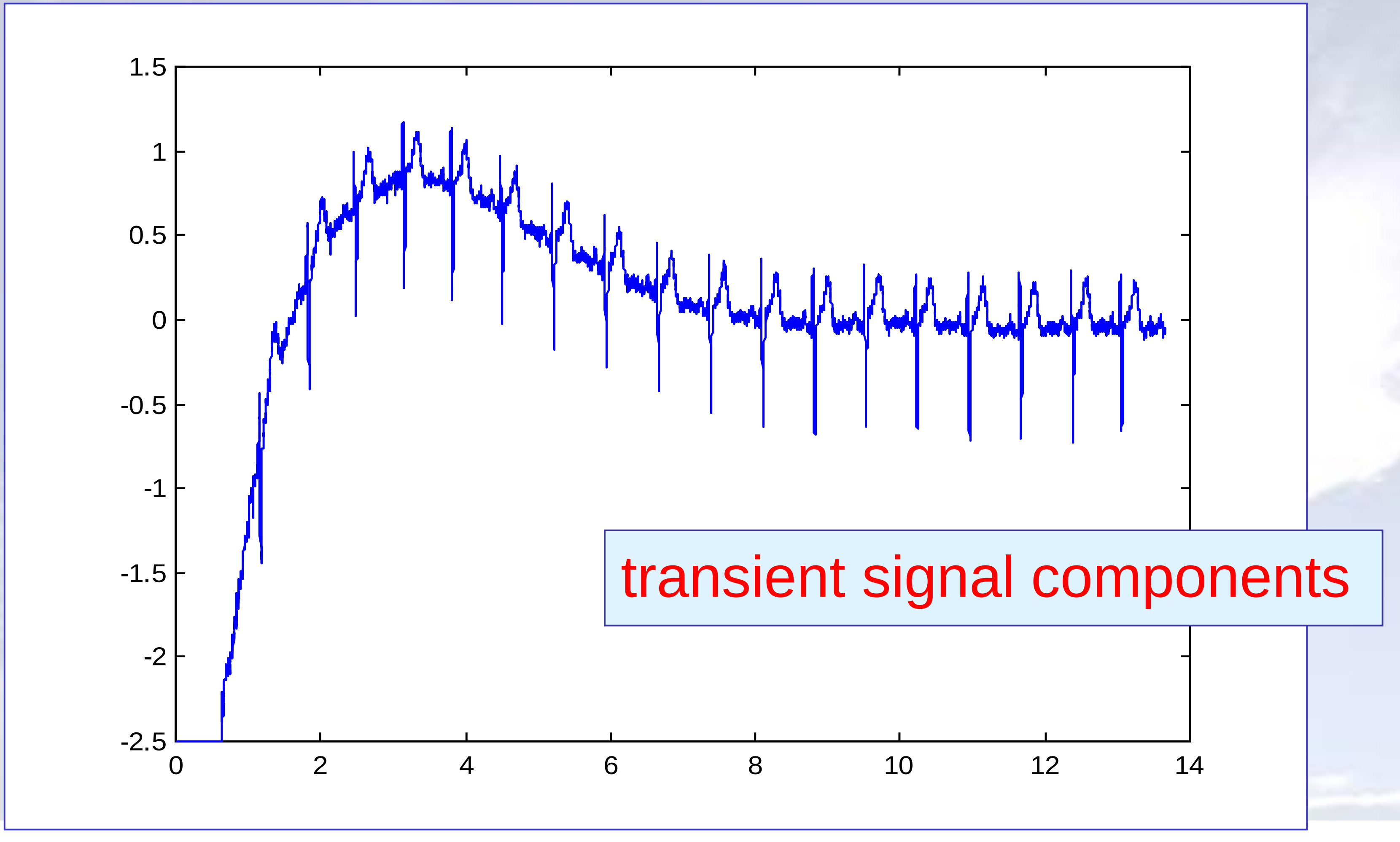
Methods of signal analysis

- **Time analysis** (detection and feature evaluation and analysis in time domain)
- **Statistical analysis** (random models, correlation analysis)
- **Spectral analysis** (analysis of signal properties in frequency domain – the Fourier transform)

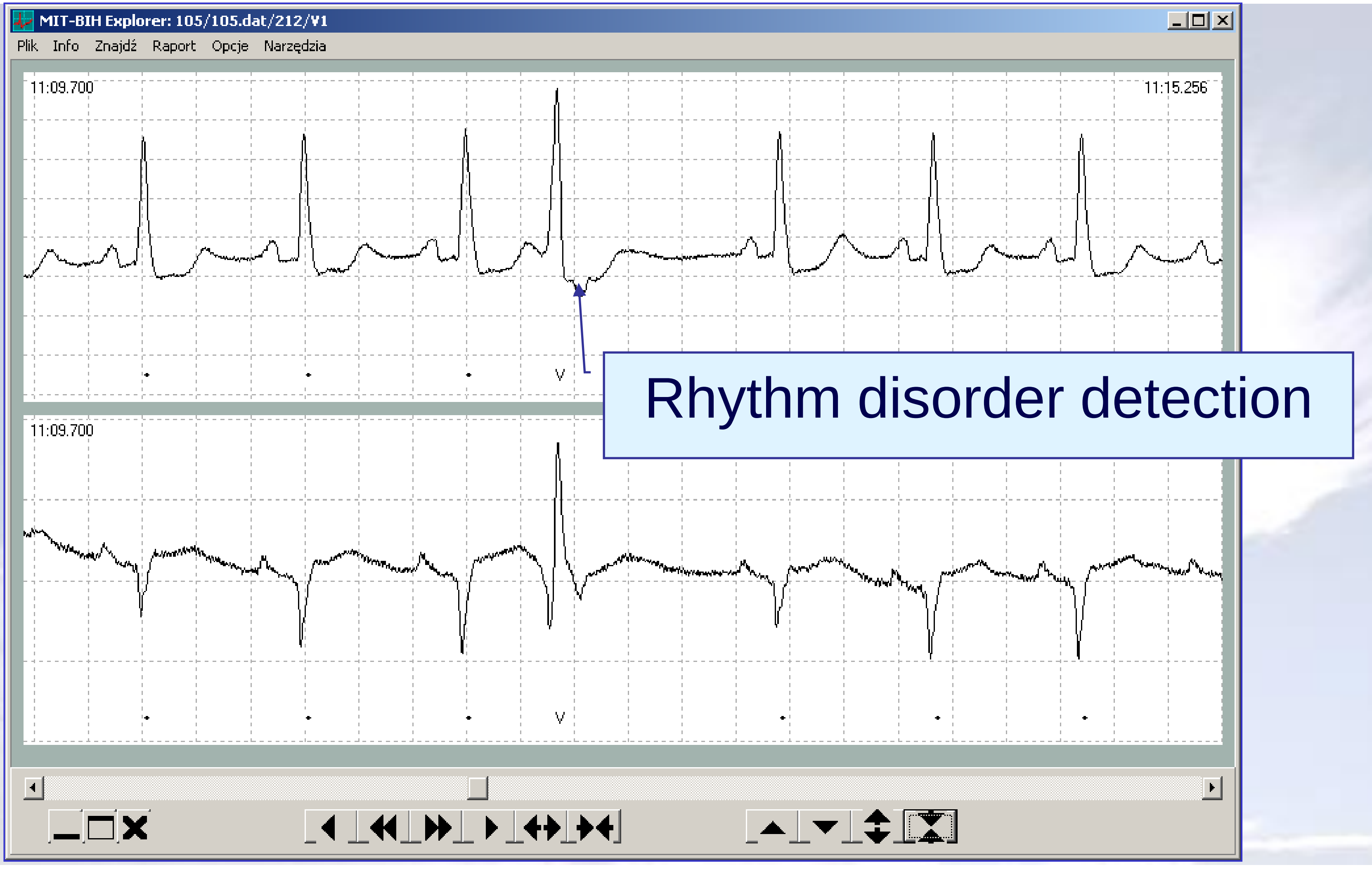
Time domain analysis



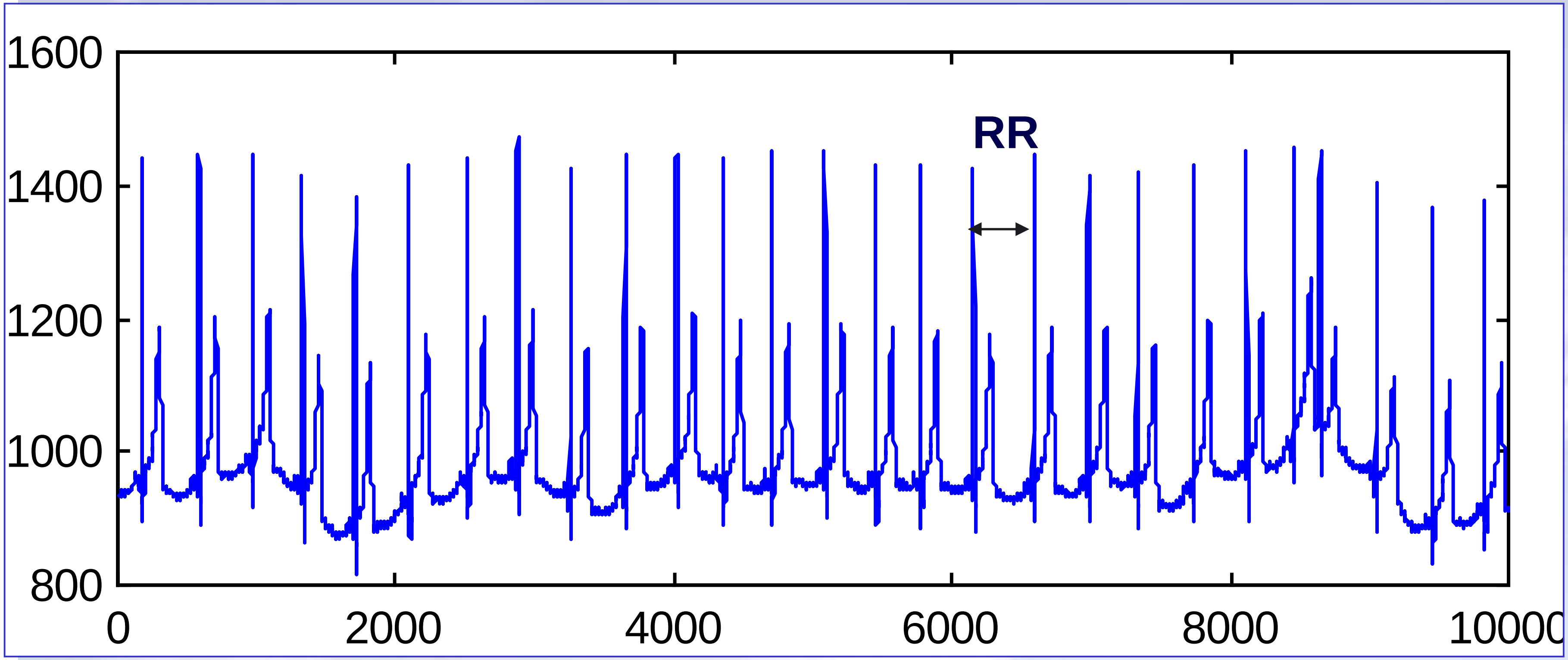
Time domain analysis



Time domain analysis

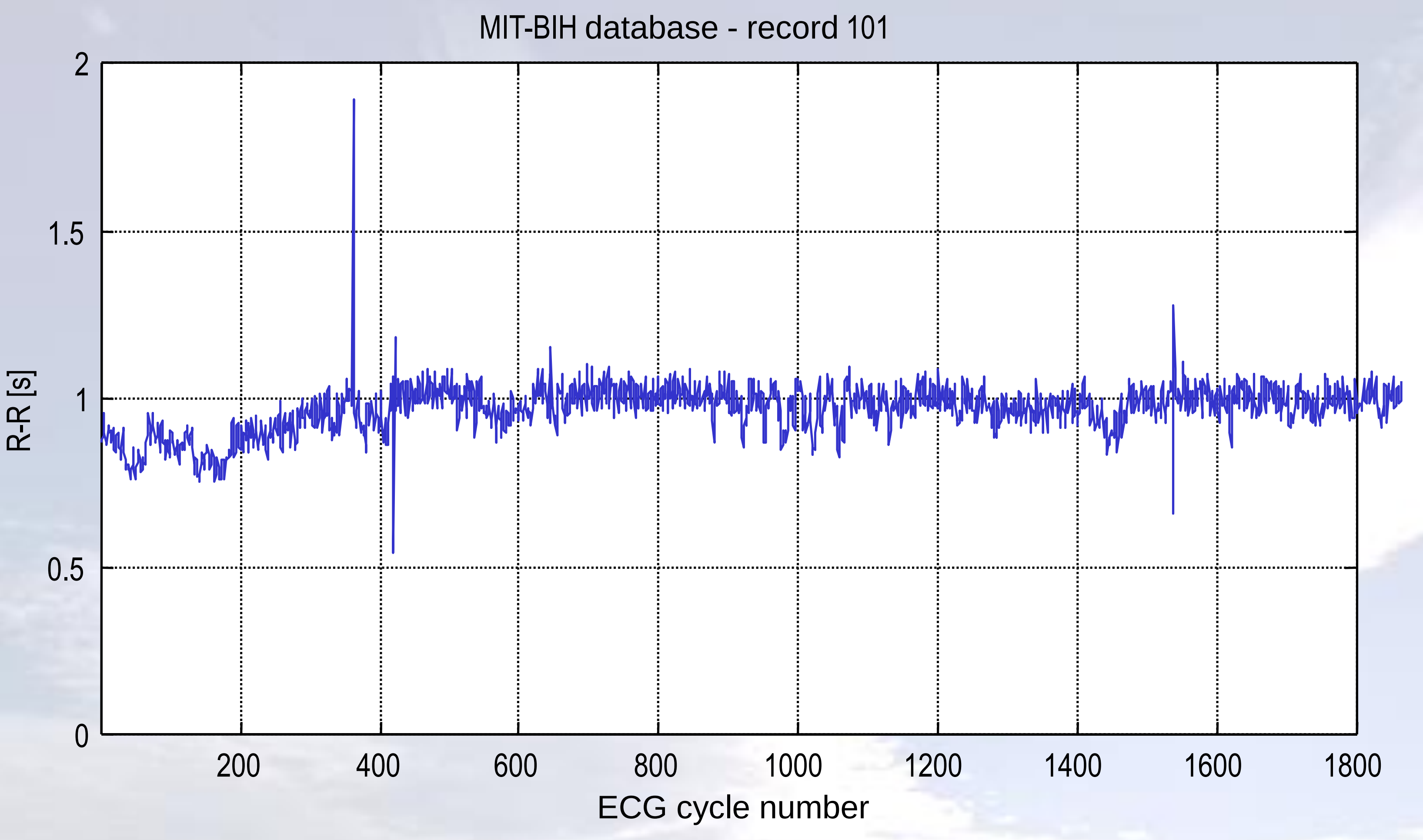


Statistical analysis

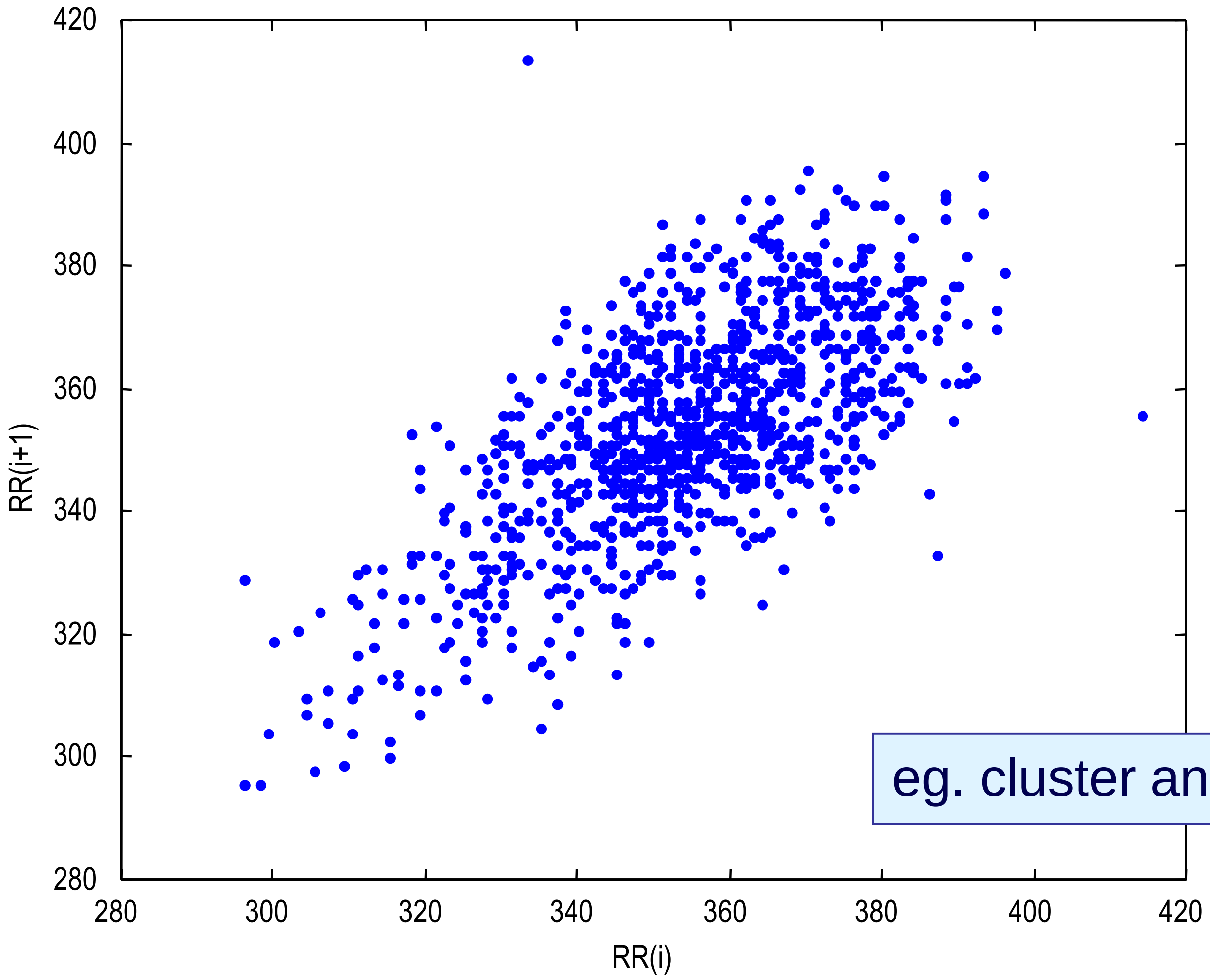


eg. RR time series analysis

Statistical analysis



Statistical analysis



eg. cluster analysis

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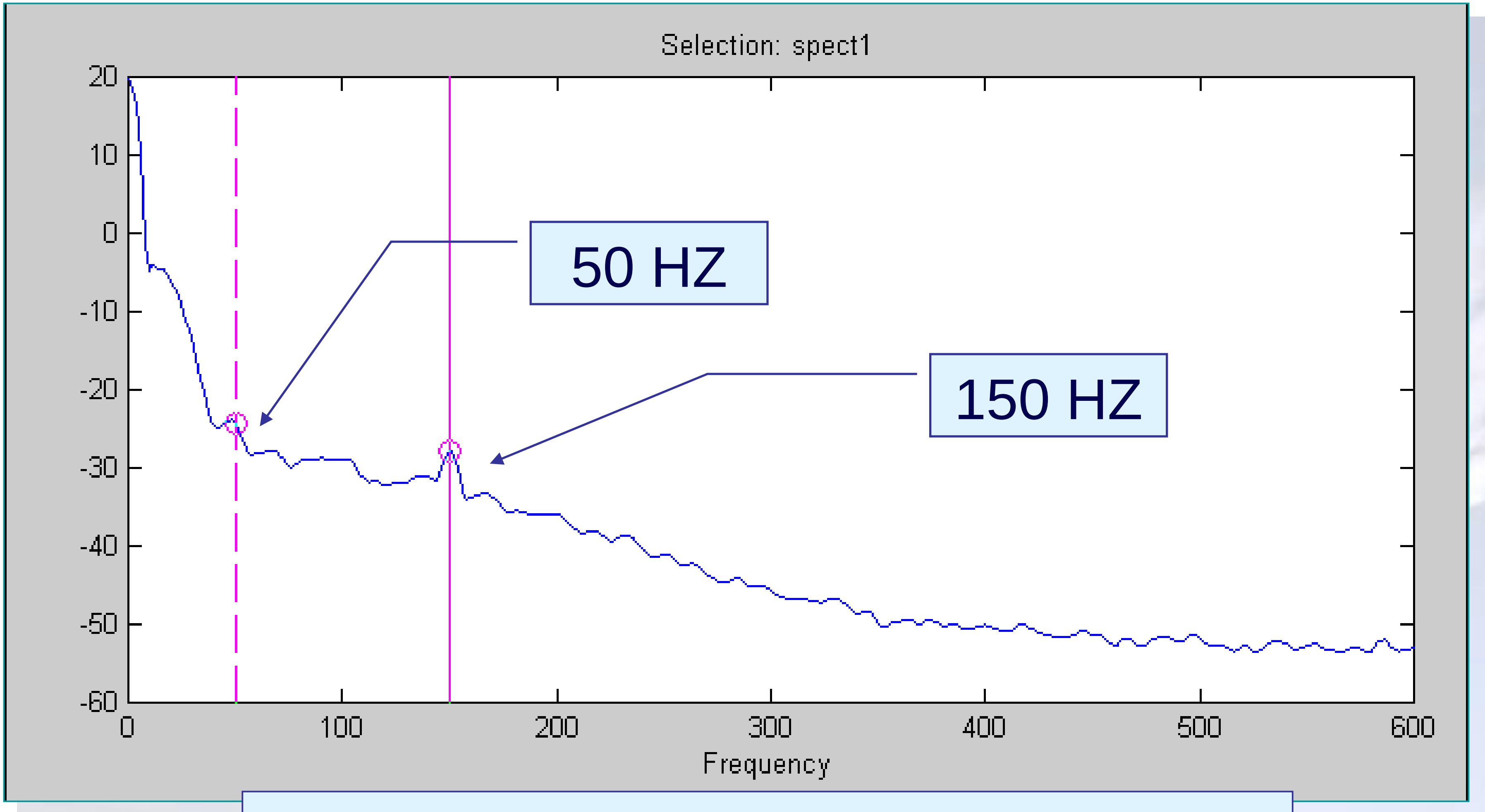
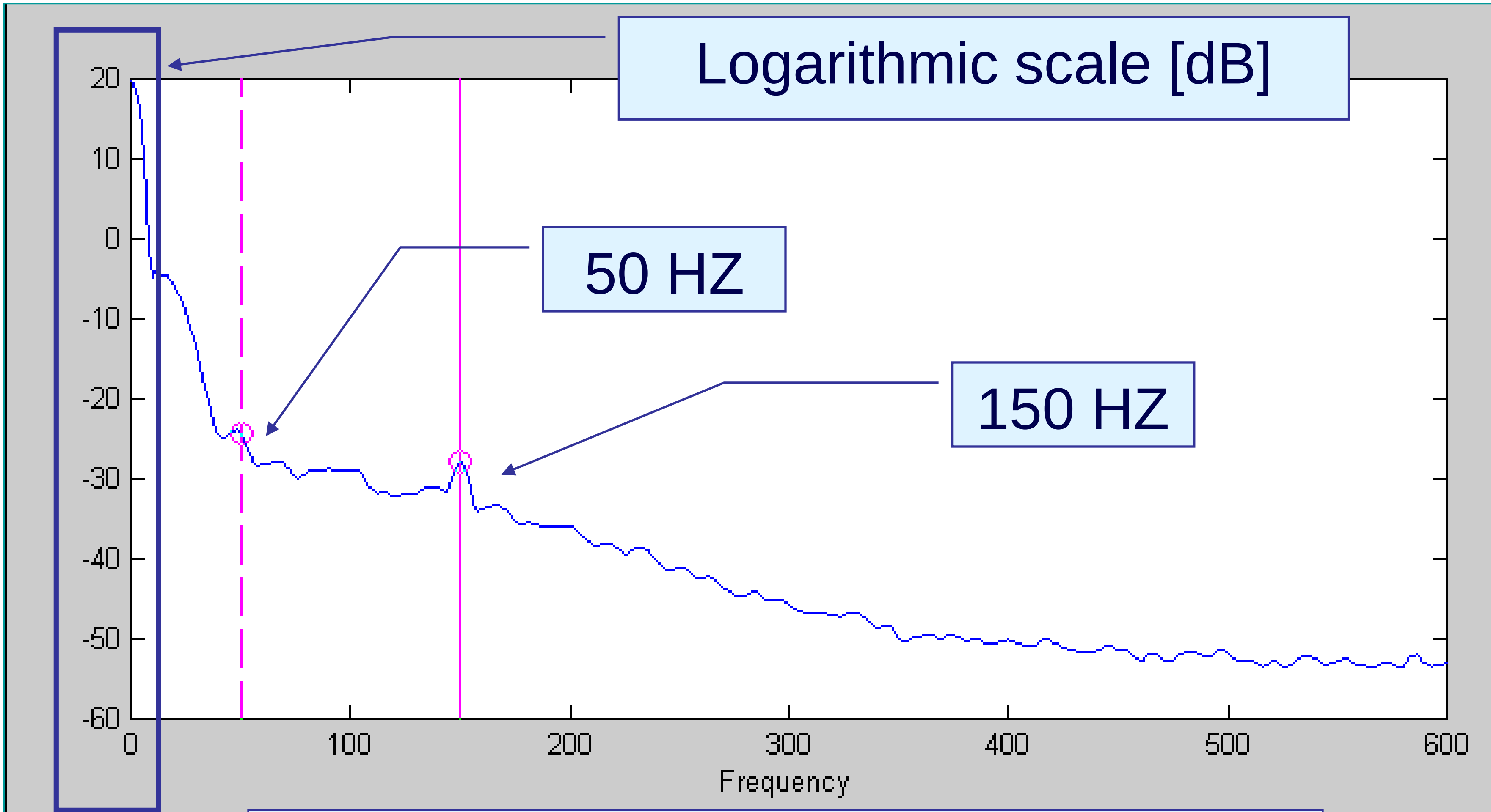
Spectral domain analysis



Power Spectral Density of ECG signal

Spectral domain analysis



Power Spectral Density of ECG signal

The logarithmic scale

Decibel is a unit defining the ratio of two powers is the logarithmic scale:

$$\left.\left(\frac{P}{P_0}\right)\right|_{dB} = 10\log_{10}\left(\frac{P}{P_0}\right)\ [dB]$$

(*Graham* ***Bell*** *– telephone inventor in 1876*).

P_0/P_i	P_0/P_i [dB]
1	0
1,26	1
2	3
10	10
100	?
10^6	?
1/2	?

eg. a logarithmic scale is used in electronics and for measuring acoustic noise level ($P_0=10^{-12}$ W/m^2)

P_0 – threshold of hearing sound intensity

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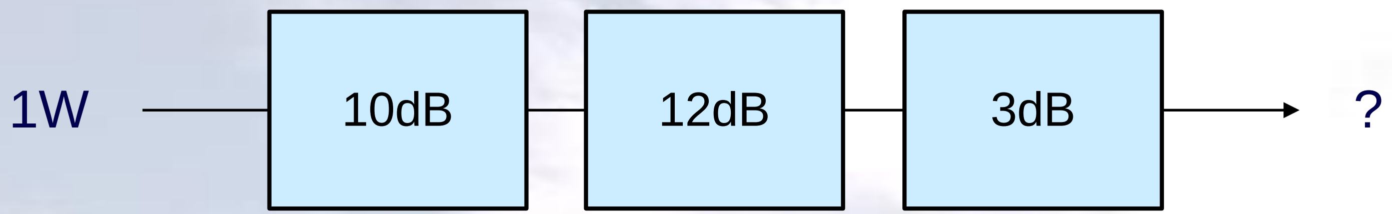
Example

Remember that:

$$\log(x \cdot y \cdot z) = \log(x) + \log(y) + \log(z) \quad \text{and} \quad \log(x/y) = \log(x) - \log(y)$$

Three amplifiers connected in cascade (power ratio):



Total power gain: G = 10dB + 12dB + 3dB = 25dB

What is the amplifier output in Watts?

Note that: 25dB = 10dB + 10dB + 3dB + 1dB + 1dB

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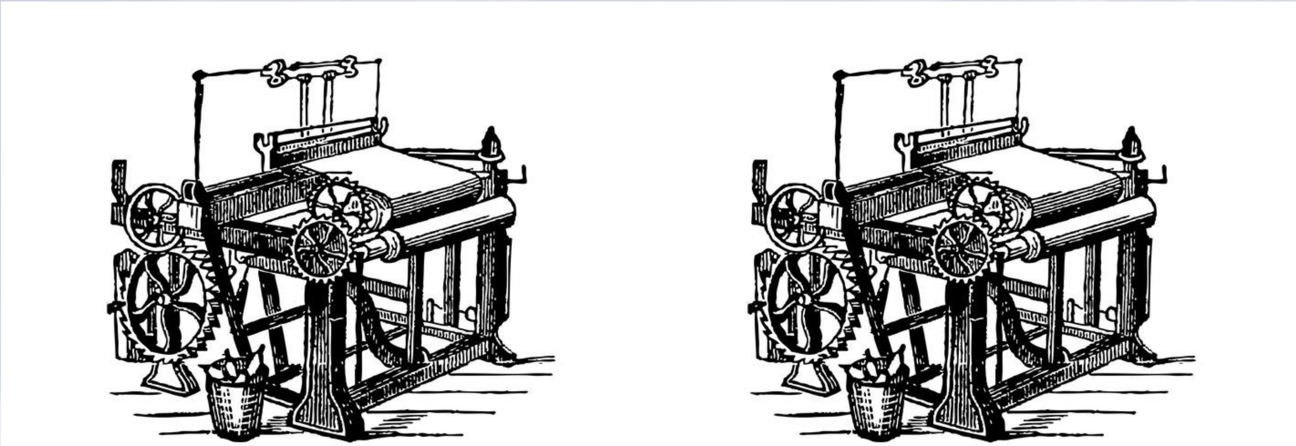
Quiz question

There are two heavy machines working, each generating 90dB of noise power.



90dB 90dB

What is the total noise power if the two machines start working together?

The logarithmic scale

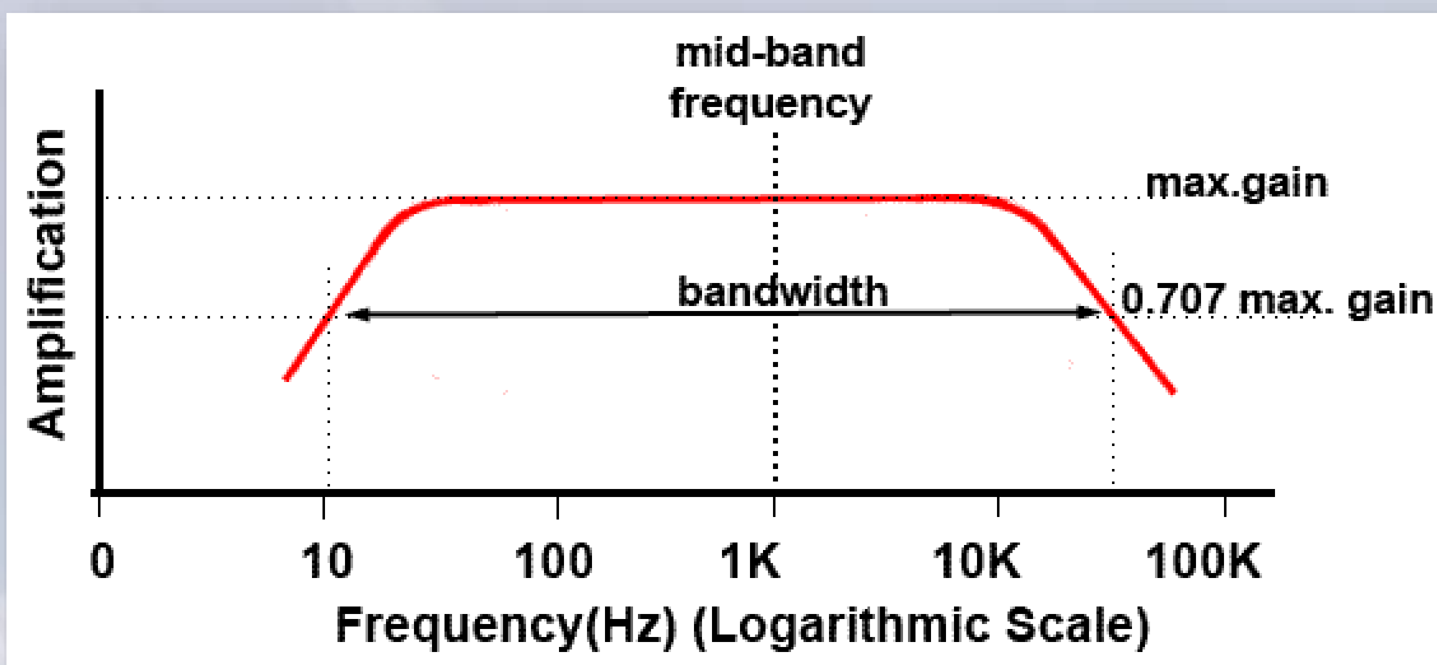
Decibels can be also used to compare voltages and currents:

$$10\log_{10}\left(\frac{P}{P_0}\right)=10\log_{10}\left(\frac{V^2/R}{V_0^{\,2}/R}\right)=10\log_{10}\left(\frac{V^2}{V_0^{\,2}}\right)=10\log_{10}\left(\frac{V}{V_0}\right)^2=20\log_{10}\left(\frac{V}{V_0}\right)$$

or:

$$10\log_{10}\left(\frac{P}{P_0}\right)=10\log_{10}\left(\frac{I^2R}{I_0^2R}\right)=10\log_{10}\left(\frac{I^2}{I_0^{\,2}}\right)=10\log_{10}\left(\frac{I}{I_0}\right)^2=20\log_{10}\left(\frac{I}{I_0}\right)$$

Amplifier bandwidth



Thus: $\frac{U}{\sqrt{2}} \cong 0.71U \Rightarrow \left(\frac{U}{\sqrt{2}}\right)^2 = \frac{U^2}{2} \approx \frac{P}{2} \Rightarrow -3dB$ drop of power by a factor of 2

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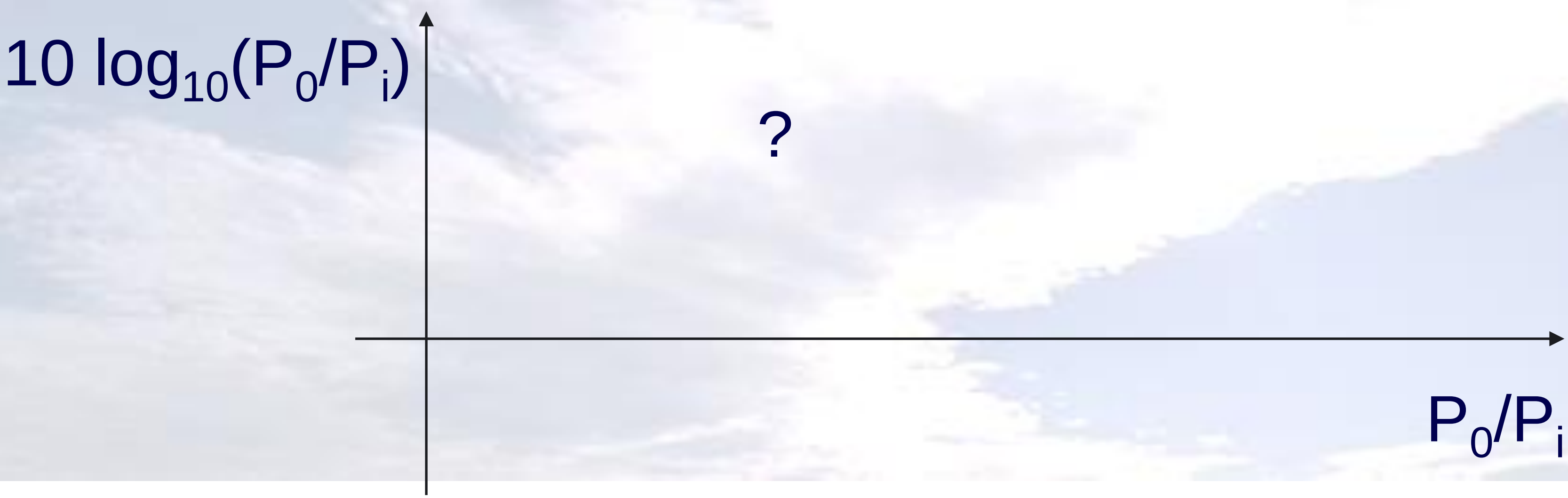
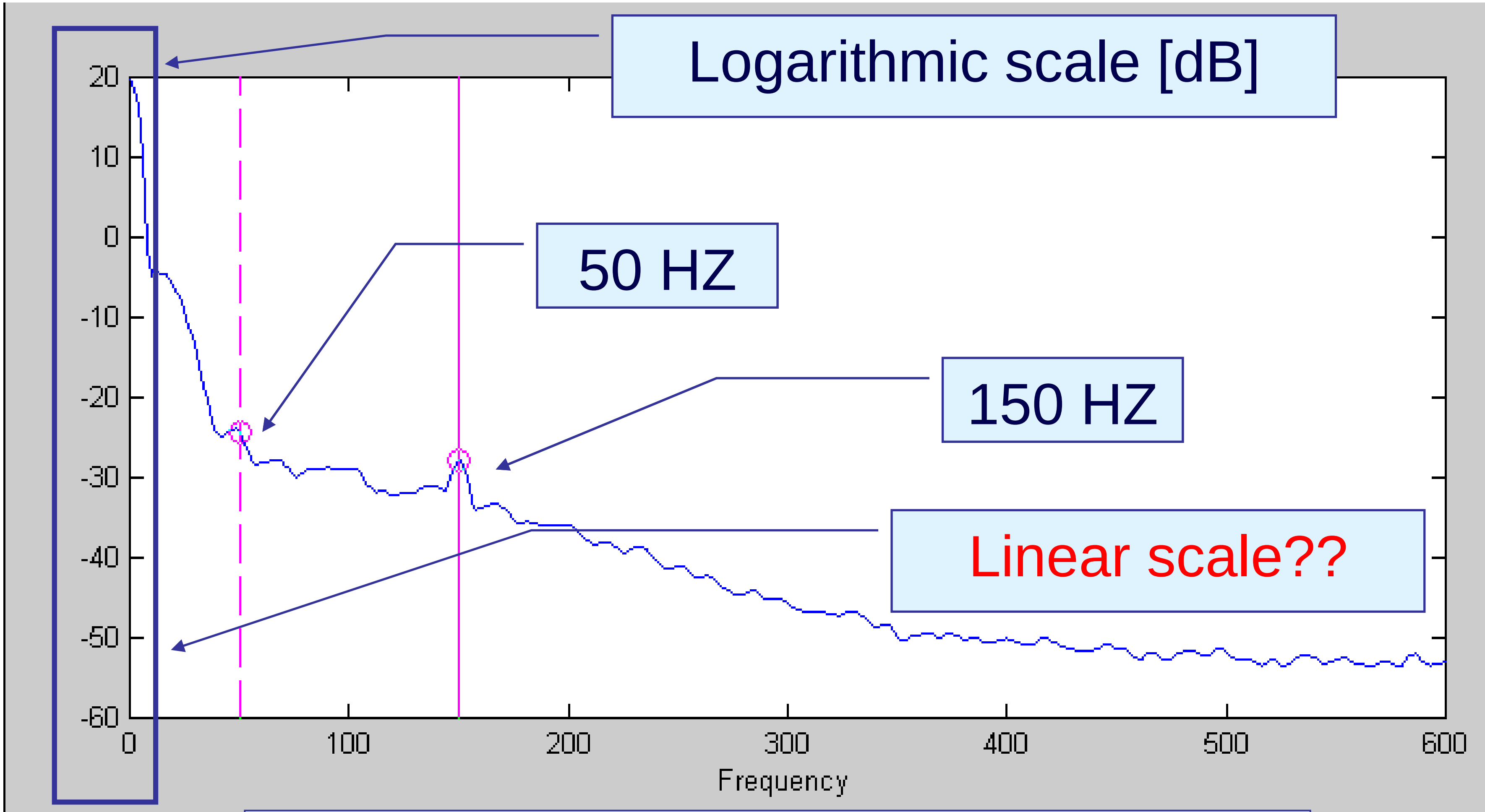
The Logarithmic scale

Exercise:

Plot the function $10\ \log_{10}(P_0/P_i)$ for $(P_0/P_i) \in (0,1000>$

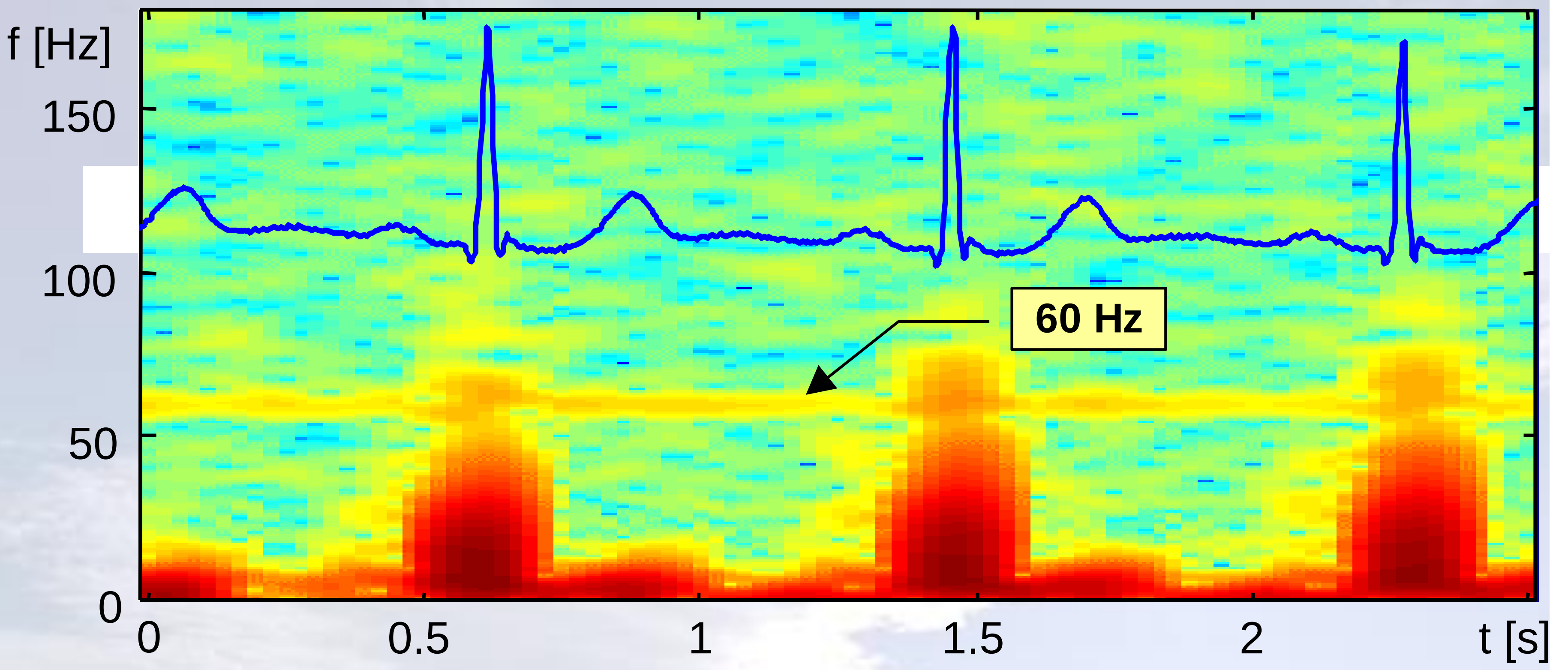


The power spectrum of a signal

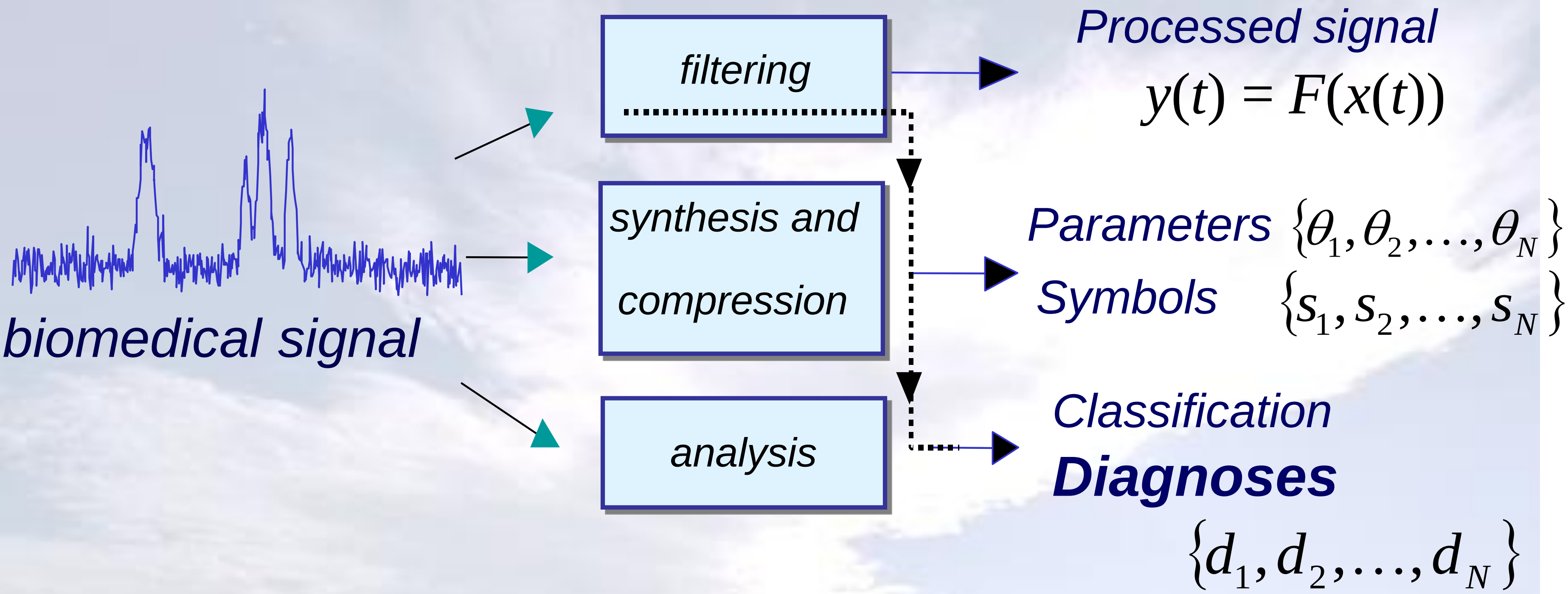


Power Spectral Density of ECG signal

Signal spectrogram (sample from MIT/BIH Database)



Biological signal analysis - overview



Electrophysiological signal databases

- MIT/BIH Database (*Massachusetts Institute of Technology and Beth Israel Hospital*) – American database containing ECG, pressure, respiration signals available online (http://ecg.mit.edu/)
- CSE Database (*Common Standards for Qualitative Electrocardiography*) – European database of ECG signals

MIT/BIH Explorer presentation

Quiz questions

1. Why we process and analyze signals?
   a) signals have finite amplitudes and are defined on a limited interval
   b) analysing signals is possible on computers
   c) processing and analysis of signals are the ways to examine the surrounding environment
   d) processing signals can be performed in real-time

2. Which definition best describes a discrete-time signal?
   a) a sequence of integer numbers
   b) a sequence of numbers
   c) a sequence of numbers defined in a limited time period
   d) a sequence of voltage levels

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Quiz questions

3. Voltage drop of -3dB corresponds to:
   a) drop of power by a factor of 2
   b) drop of energy by a factor of 2
   c) drop of voltage by a factor of 3
   d) drop of power by a factor of 20

4. The reason for using a logarithmic scale to display signals is:
   a) logarithm values are positive for arguments larger than 1
   b) computing logarithm is simple using a computer
   c) because humans hear intensity of sound signals in a logarithmic scale
   d) we can fit larger amplitude variations of signals in a limited range of available scale

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