TÉCNICO LISBOA

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Principles of Biosignals and Biomedical Imaging

3rd year, P_3 (ECTS: 3.0), LEBiom

2022/2023

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Department of Bioengineering
Instituto Superior Técnico
University of Lisbon

Outline

- Presentation
- Motivation

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Presentation

Main objectives

Principles of Biosignals and Biomedical Imaging was designed to give students fundamental concepts and tools for biomedical signal and image processing, such as

- Linear algebra (e.g. vector, matrix, standard and internal product) applied for the manipulation and processing of 1D, 2D (images), 3D (volumes) and 4D signals.
- Types of noise. Linear, FIR and IIR filters, and non-linear filtering, Median.
- Detection and segmentation in noisy, distorted and incomplete data.
- Signal and image reconstruction algorithms.

It is expected that students after attending this UC

- Gain experience and familiarity with some tools normally used for manipulation and signal processing, such as MatLab and Phyton and
- Gain skills to design and implement simple signal and / or image processing algorithms.

Organization

João Sanches (IST)

Luís Rosário (FMUL)

TAs

Hemaxi Narotamo

Diogo Vieira

The course is organized in

- one weekly 2 hour theoretical session
- laboratory session (1h30)

Program

1. Introduction and motivation to signal and image processing
2. Mathematical representation of signals and images
3. Types of noise and models of image formation.
4. Linear and non-linear filtering. FIR, IIR and median digital filters. 2D convolution masks.
5. Contour detectors. Sobel, Prewitt and Canny.
6. Signal similarity. Match filter.
7. Radon transform and tomographic image reconstruction.
8. Image registration.

Assessment

The assessment of the discipline is performed in three components.

1) Exam (30%)
   Minimum score: 8
2) Laboratories (30%) – 2 laboratories
   Minimum score: 9.5

- Monday (11h00 am - 12h30 am) (Hemaxi)
- Tuesday (10h00 am – 11h30 am) (Hemaxi)
- Thursday (10h00 am – 11h30 am) (Diogo)
- Friday (10h00 am – 11h30 am) (Diogo)

3) Project (40%)
   Minimum score: 9.5

The classification of the project will be obtained based on the evaluation of a report (8 pp maximum) according the following assessment grid.

Report		8 pp max
Format/Graphical issues	10%	
Title, authors and Abstract	10%	1/2
Introduction and motivation	10%	1
State-of-the-art	10%	1/2
(Mathematica) Problem formulation	10%	1
Methods and Algorithms	10%	2
Validation and Testing	20%	2
Conclusions	10%	1/2
References	10%	1/2

Laboratories

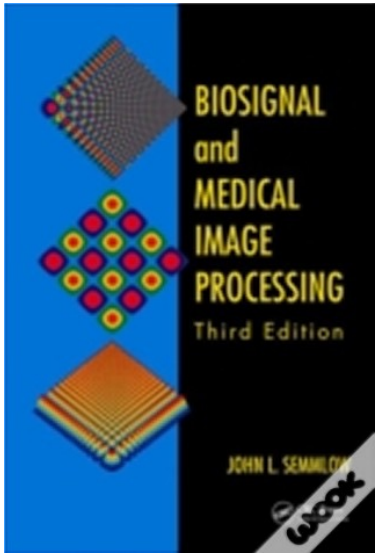
- Three laboratory sessions (30%)
  - First week (23/2 and 24/2 at 10am) – not assessed
    Lab 0 - Introduction to MatLab (Remote)
    https://videoconf-colibri.zoom.us/j/3999298037
  - Second week (27/2 – 3/3) and third week (6/3 – 10/3) – assessed (15%)
    Lab1 Signal and Image manipulation
    Report deliver: 12/3, 24h
  - Fourth week (13/3 – 17/3) – assessed (15%)
    Linear and non-Linear Filtering
    Report deliver: 19/3, 24h
- Reports: MatLab script commented with the answers to the guide's questions.
- Groups of two (2) elements

Project

- Sessions to support project
  20/3 - 24/3, 27/3 – 31/3, 10/4 – 14 /4
- Report Delivery 14/4, 24h

Report		8 pp max
Format/Graphical issues	10%	
Title, authors and Abstract	10%	1/2
Introduction and motivation	10%	1
State-of-the-art	10%	1/2
(Mathematica) Problem formulation	10%	1
Methods and Algorithms	10%	2
Validation and Testing	20%	2
Conclusions	10%	1/2
References	10%	1/2

Bibliography



Biosignal And Medical Image Processing, Third Edition, John L. Semmlow, 2014, TAYLOR & FRANCIS INC, ISBN: 9781466567368

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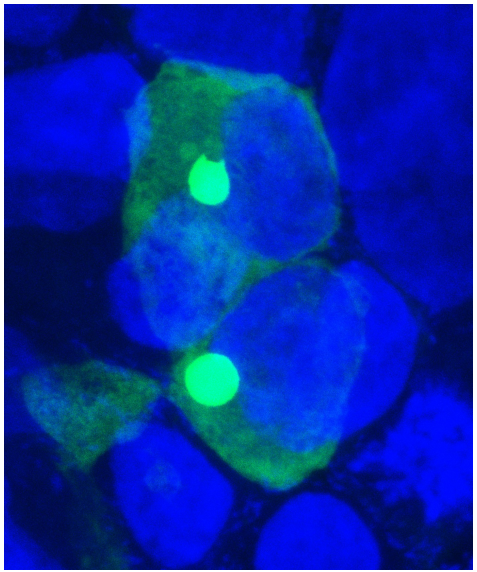
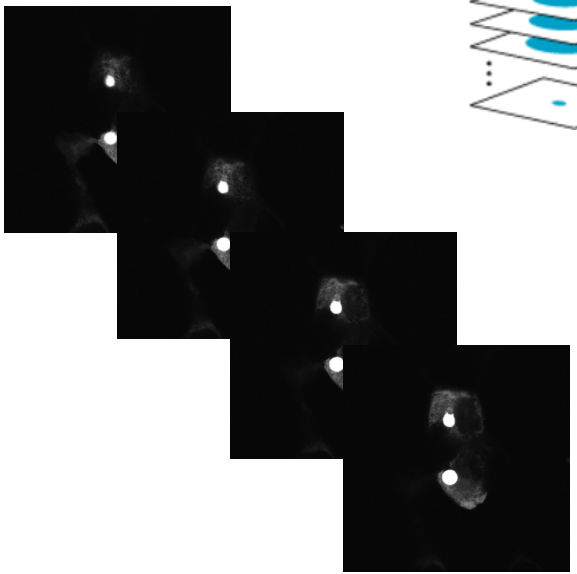
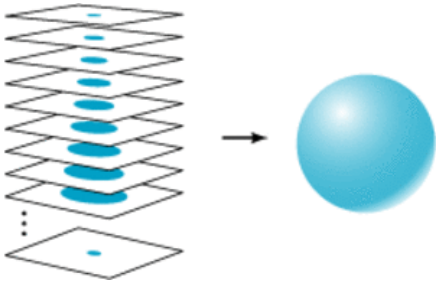
Interval

Project

Denoising
Segmentation
3D reconstruction
Registration







Digital Technology in Medicine

CT

Godfrey Hounsfield

1972

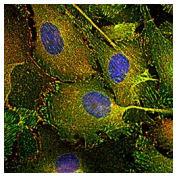
The first commercially available CT scanner was created by British engineer Godfrey Hounsfield of EMI Laboratories in 1972. He co-invented the technology with physicist Dr. Allan Cormack. Both researchers were later on jointly awarded the 1979 Nobel Prize in Physiology and Medicine. (https://catalinaimaging.com/history-ct-scan/)

Signals

Any way of transmitting information:

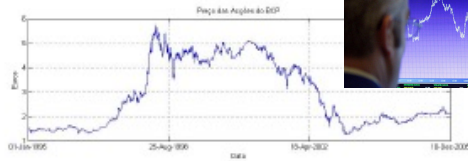
Smoke

- Electrical
- Chemical / Biochemical
- Acoustic
- Mechanical



Bio-chemical and electrical signaling

Stock Market



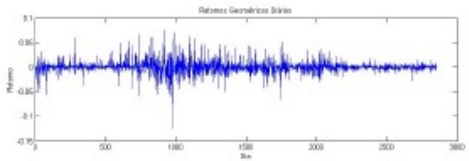


Figura 8: Cotações e retornos geométricos do BCP de 1995 a 2005

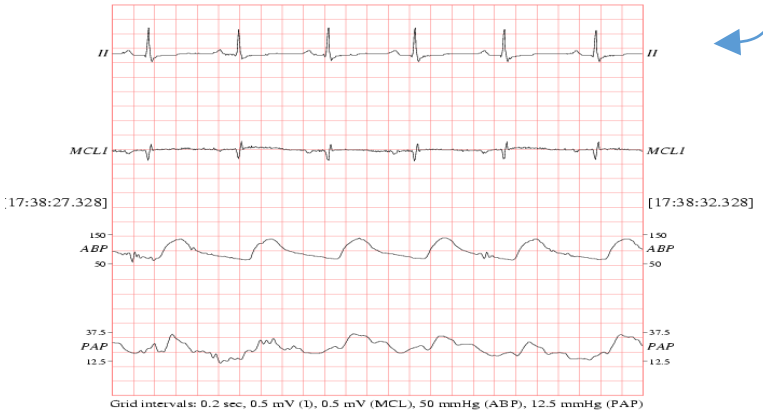
Bell Phone (circa 1876)

Acoustic Signal

1D signals

$x(t): R \rightarrow R$

Univariate Continuous



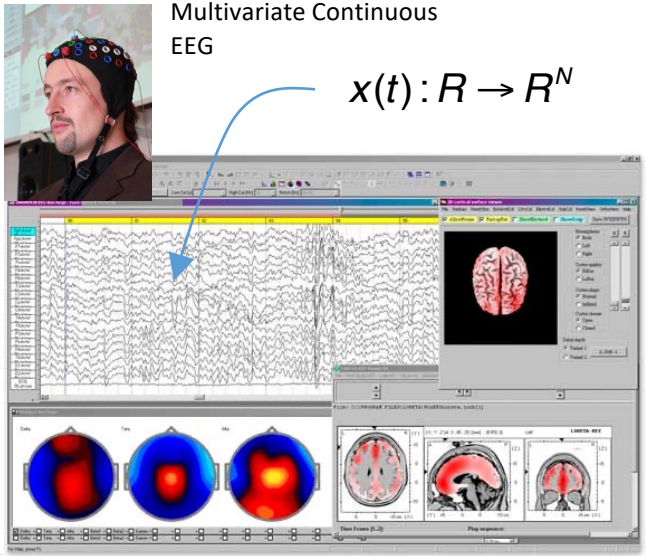
From top to bottom: Two leads of ECG (II and MCLI), arterial blood pressure (ABP) and pulmonary arterial pressure (PAP).

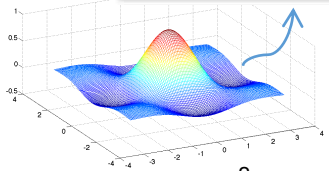
User Guide and Documentation for the MIMIC II Database, Gari D. Clifford, Daniel J. Scott and Mauricio Villarroel

Multivariate Continuous

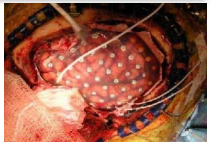
EEG

$x(t): R \rightarrow R^N$



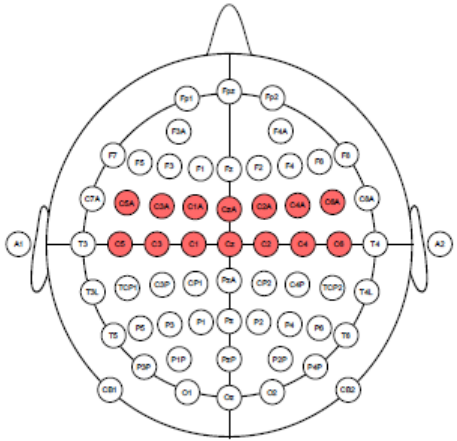


$y = f(x): R^2 \rightarrow R$



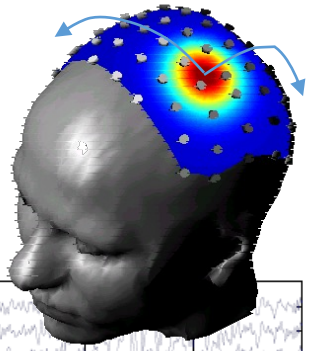
ScienceDaily (Sep. 14, 2006)

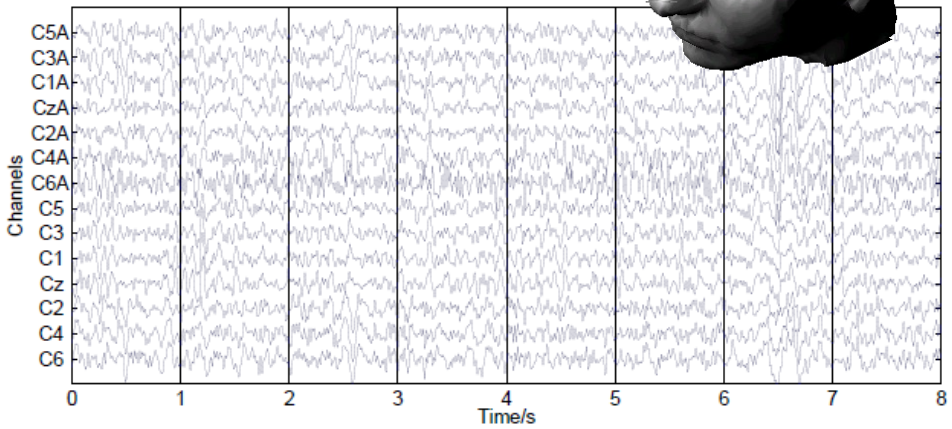
Time varying Bi-Dimensional Continuous



$$f(x,y,t): R^3 \rightarrow R$$

Continuous Field

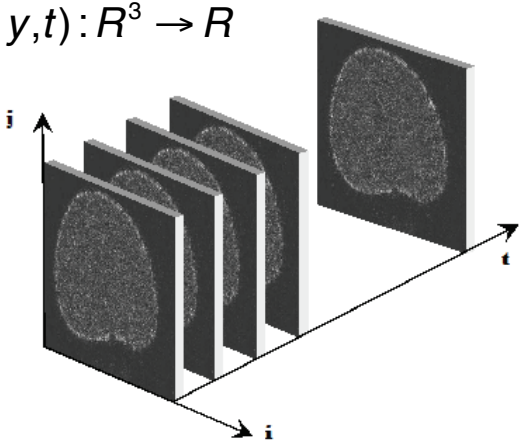




Time sequences

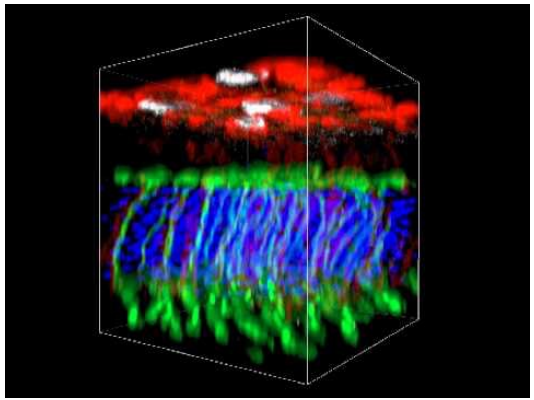
- 3D = 2D+T
  - Video
  - Time lapse microscopy

$f(x,y,t): R^3 \rightarrow R$



- 4D = 3D + T
- MRI volume sequences (4D = 3D + T)

$f(x,y,z,t): R^4 \rightarrow R$

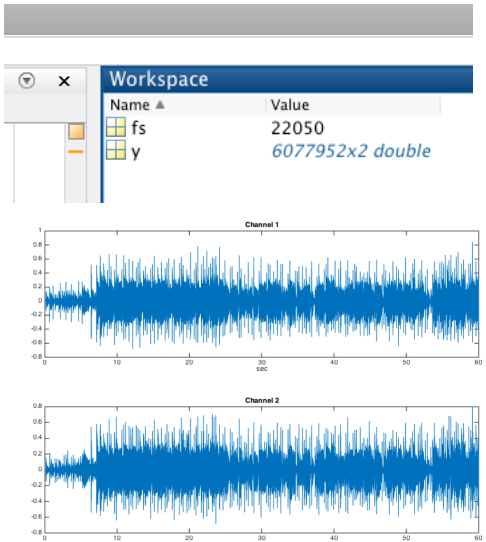


Mathematical Formulation

- Signals are vectors and matrices
- Systems are mapping functions

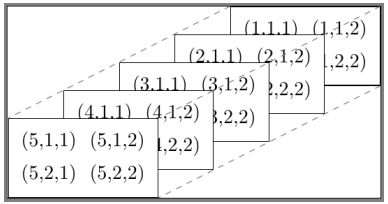
Audio data

[y,fs]=audioread('Santana_CorazonEspinado.mp3');



Images

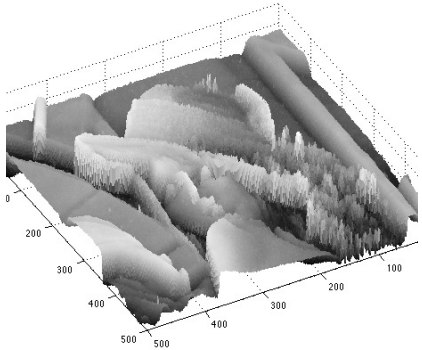
Stack of matrices



RGB

MatLab command

x=imread('filename.jpg')



$$\mathbf{x} = \begin{bmatrix} x_{1,1} & x_{1,2} & \cdots & x_{1,M} \\ x_{2,1} & x_{2,2} & \cdots & x_{2,M} \\ \cdots & \cdots & \cdots & \cdots \\ x_{N,1} & x_{N,2} & \cdots & x_{N,M} \end{bmatrix}$$

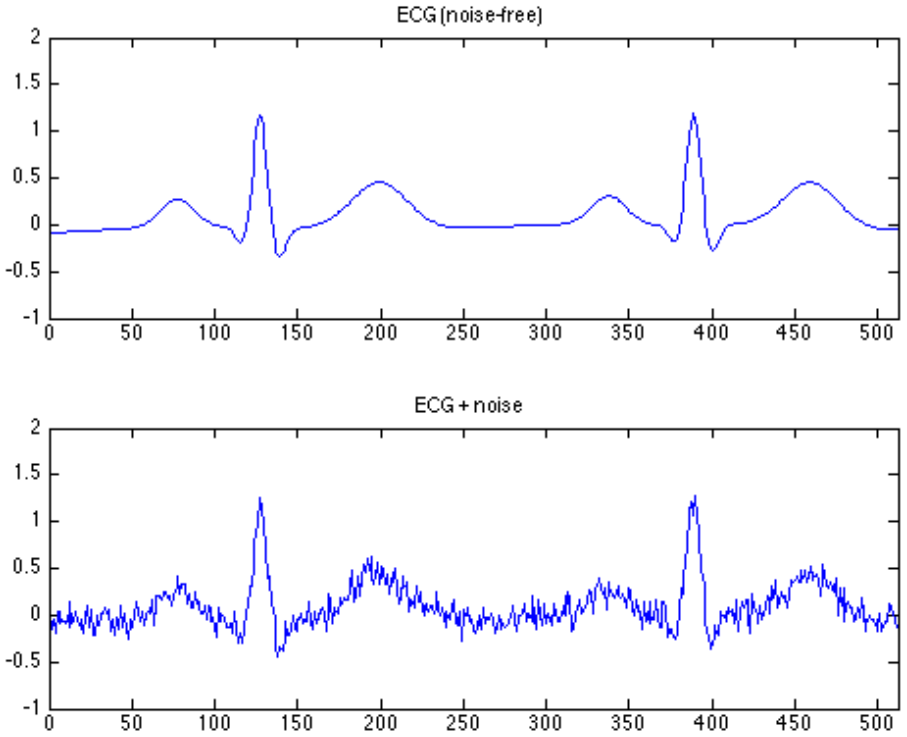
$$\mathbf{x} \in R^N x R^M \sim R^{NM}$$

$$N \times N \rightarrow R$$

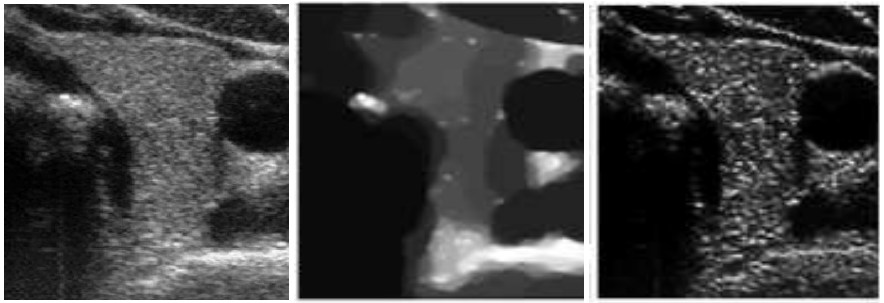
Typical signal & image processing

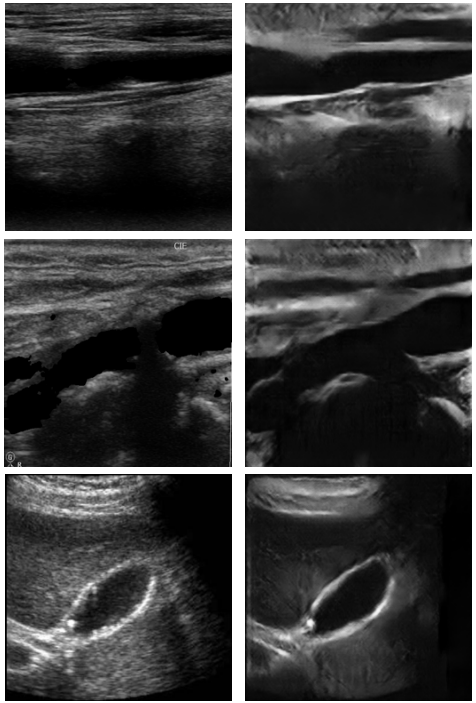
- Signal smoothing and noise removal
- Signal and Image deblurring
- Peak detection
- (Signal) Detection
- Segmentation
- Image reconstruction

Smoothing

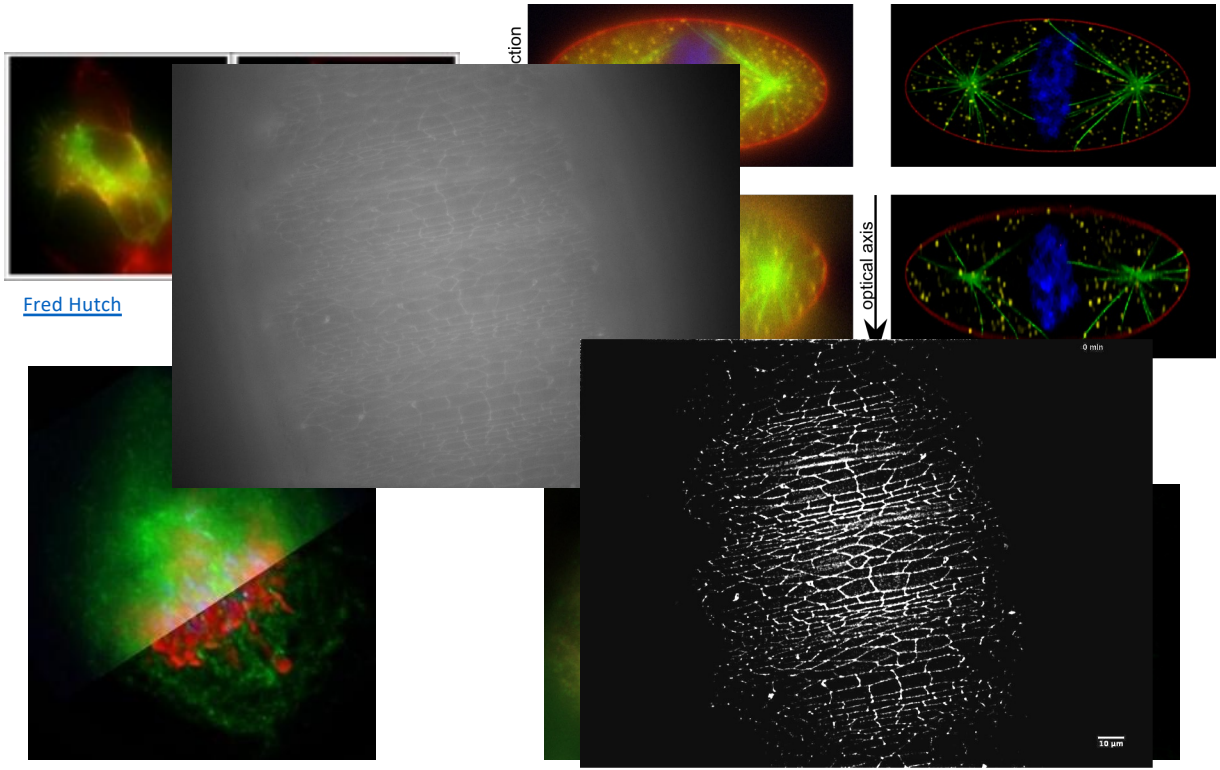

ECG (noise-free)
2
1.5
1
0.5
0
-0.5
-1
0
50
100
150
200
250
300
350
400
450
500
ECG + noise
2
1.5
1
0.5
0
-0.5
-1
0
50
100
150
200
250
300
350
400
450
500

Denoising

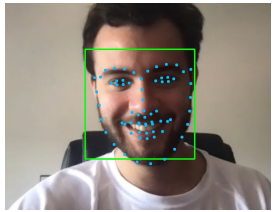


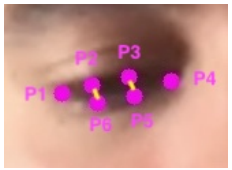


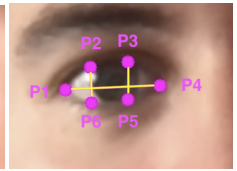
DeBlurring



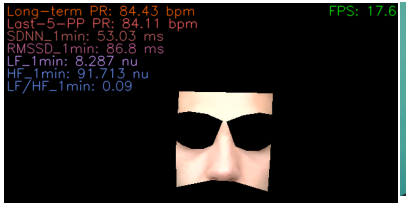
Peak detection

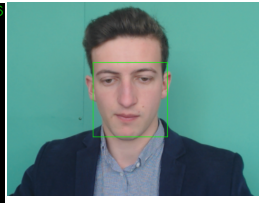


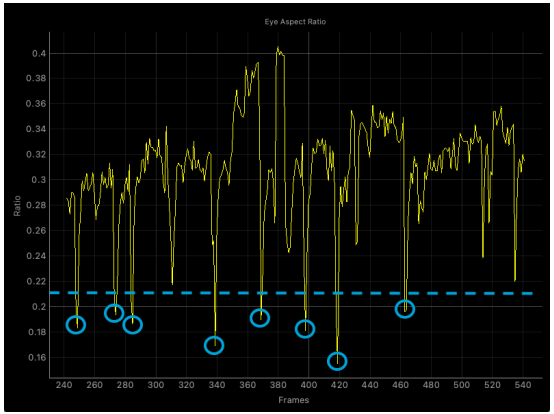


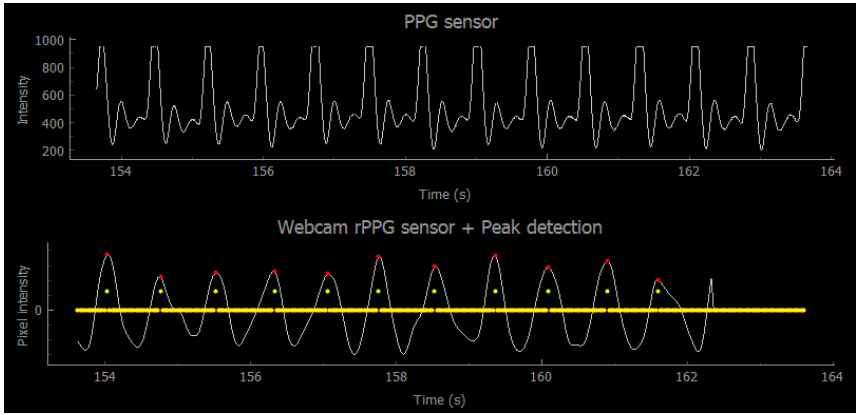


(a) Eye closed **(b)** Eye open

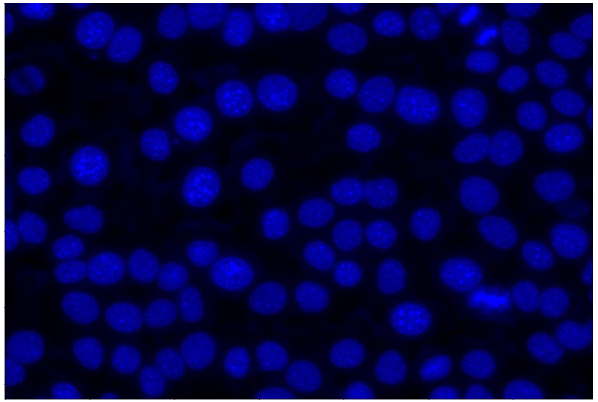


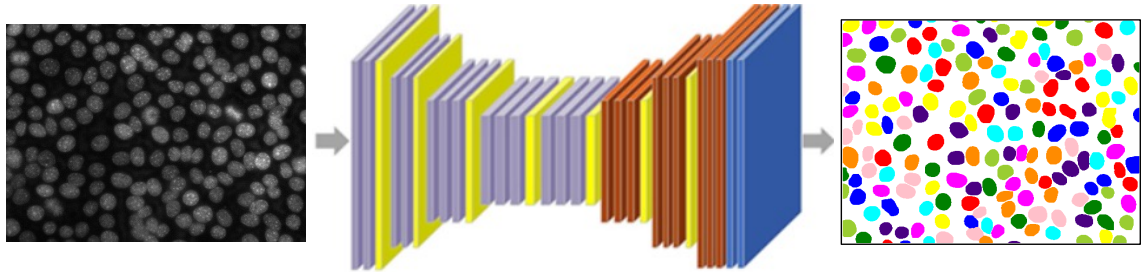




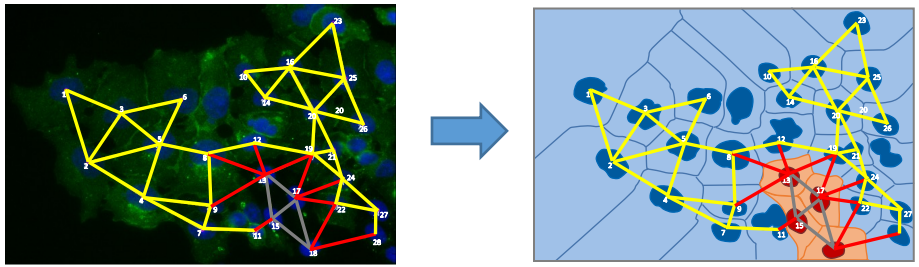


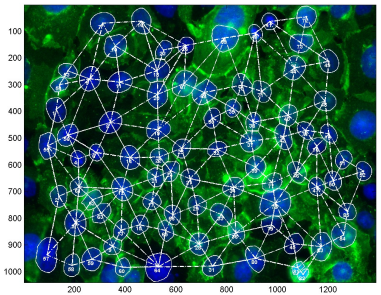
Cell nuclei segmentation



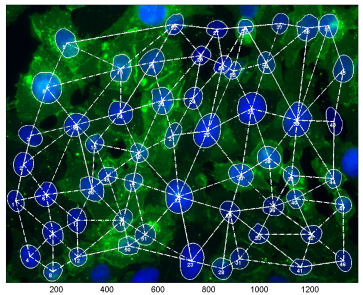


Topological characterization

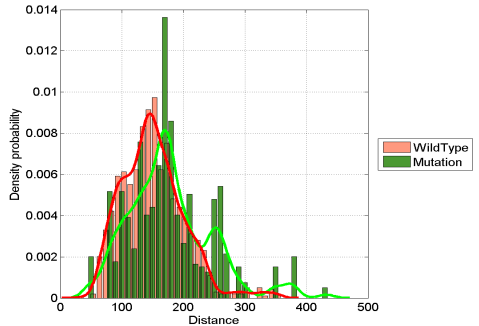




E-Cadherin wild-type cells



Mutant cancer cells



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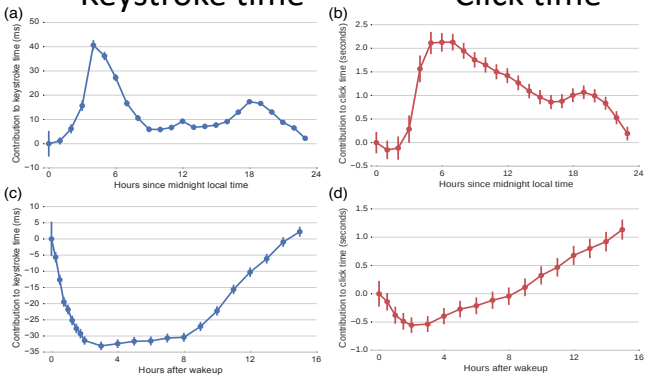
Practical examples

Behavioral

Keystroke time

Click time



[Tech Watches You for Digital Symptoms of Brain Disorders]

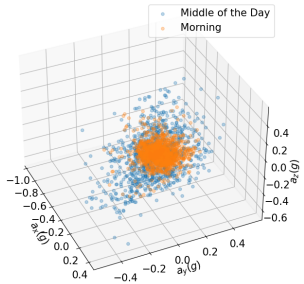
Depression, Alzheimer's, and other syndromes leave their mark in the way you type and talk

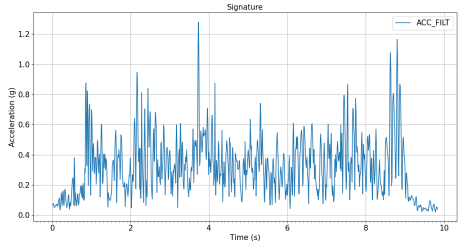
By Eliza Strickland

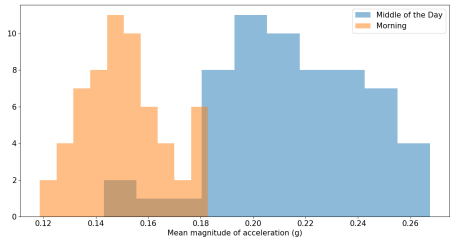
Face-to-face consultation

Quantification of Psychomotor retardation

Signature dynamics



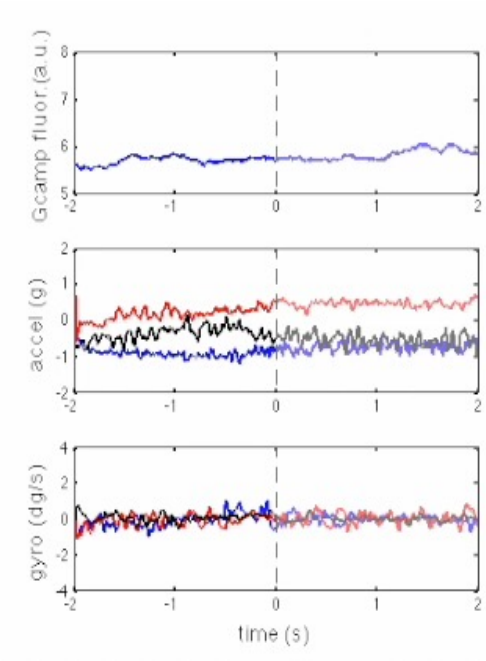


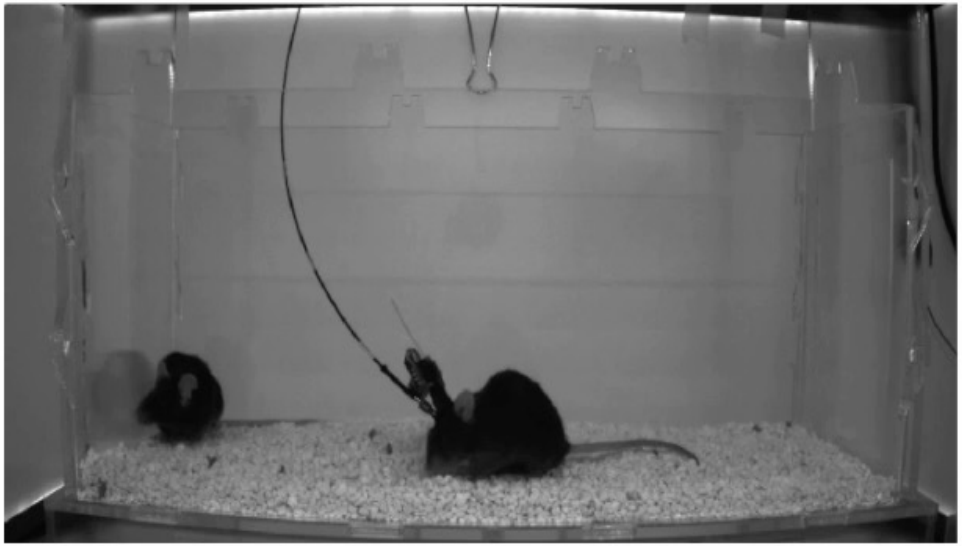


Vasco Duarte

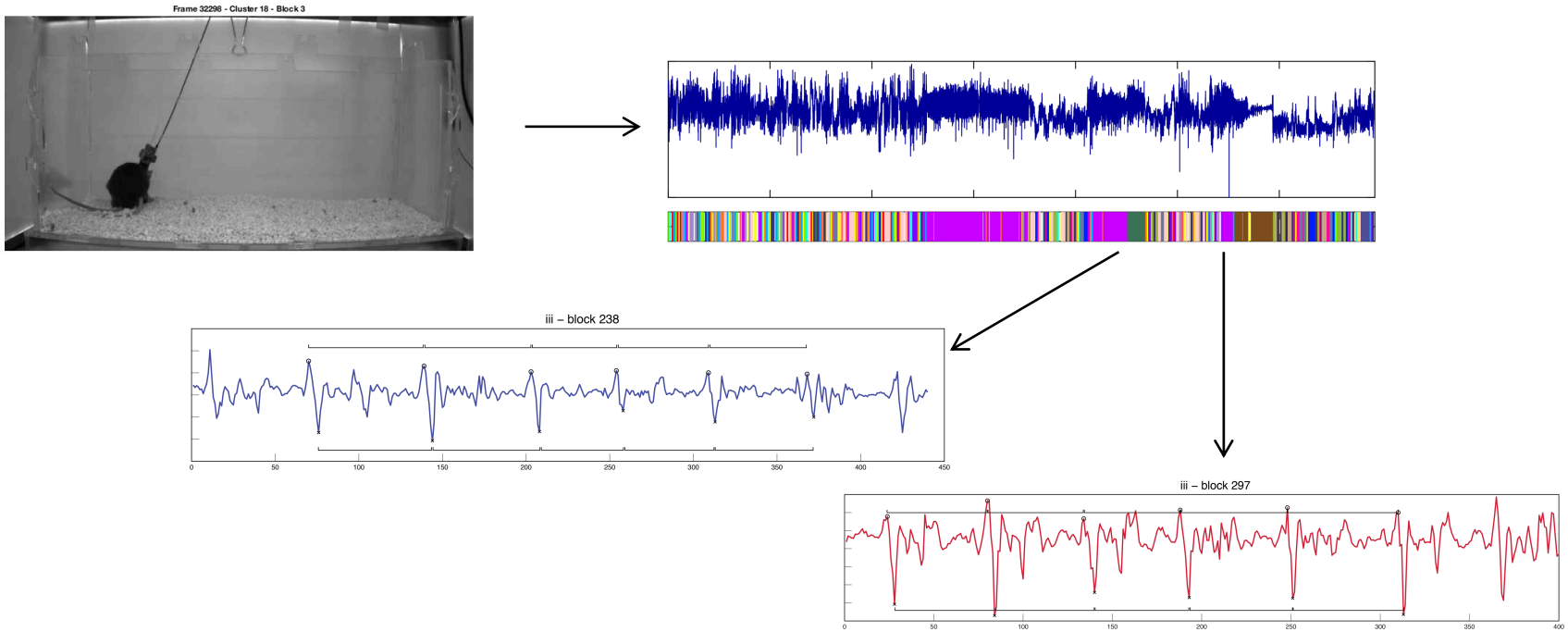
Hospital (face-to-face)

Mounts, Intromissions and Ejaculation





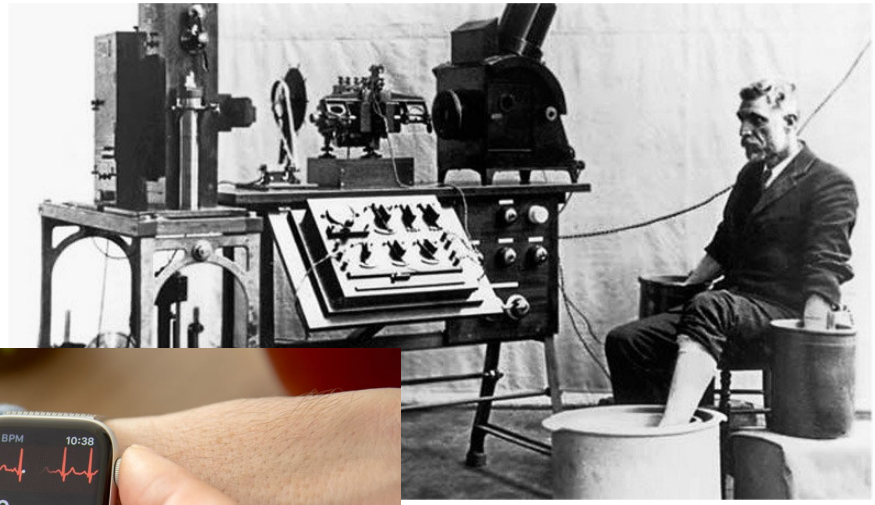
Different behaviours/postures can be automatically clustered



Electrocardiography

ECG (1912)

Dutch physiologist Willem Einthoven developed the string galvanometer in 1902



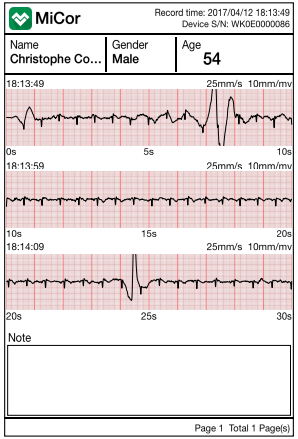
Electrocardiography

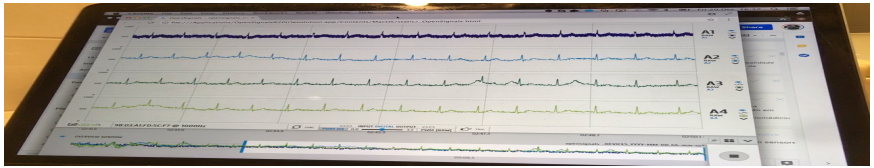
E4 wristband

PPG Sensor
3-axis Accelerometer
EDA Sensor
Infrared Thermopile

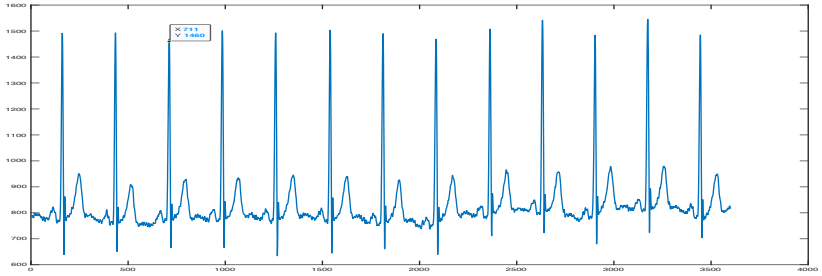
Invisibles

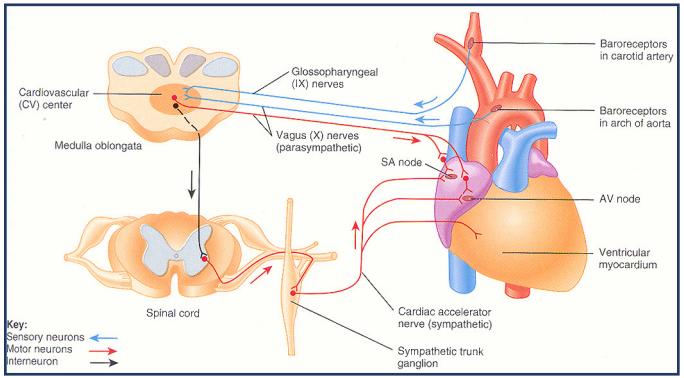
MioCARE™



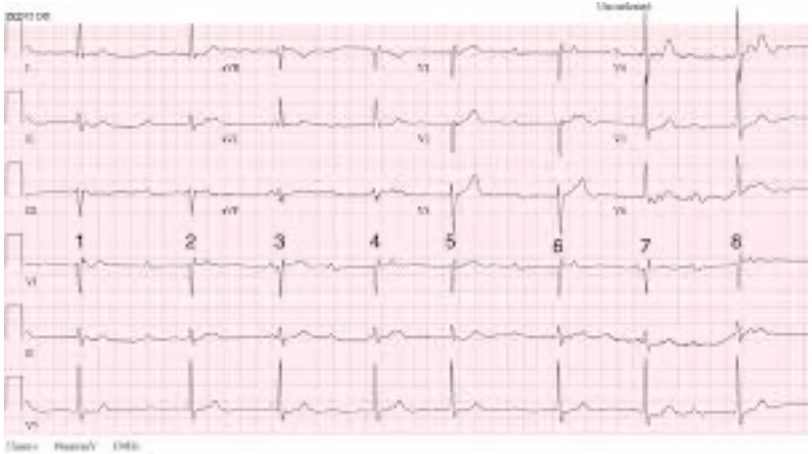


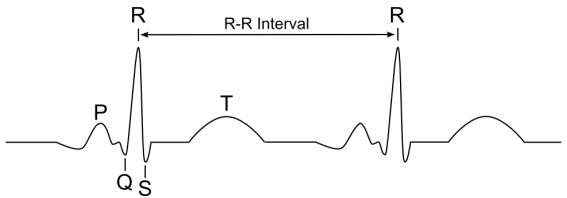
Heart Rate Variability (HRV)

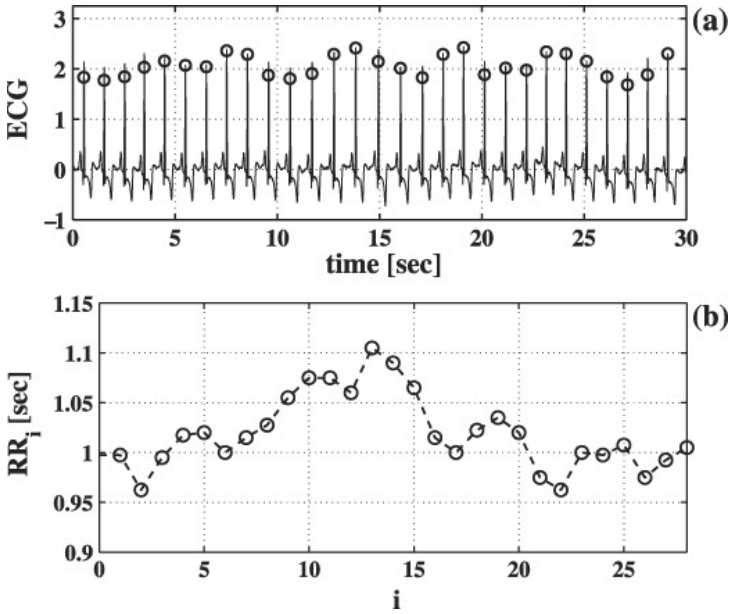




RR and HRV







Heart Rate Variability (HRV)

• ULF is the power density number for the ultra low frequency range (<0.003Hz), and **its prognosis of sudden cardiac death** taken from 24 hour ECG recordings is highly accurate.

• VLF is power density number for the very low frequency range (0.003-0.04Hz), and it is thought to be connected to thermoregulation, the renin-angiotensin system, and changes in physical activity.

• LF is the power density number for the low frequency range (0.04-0.15Hz) that is generated **mainly by sympathetic activity**. It is hypothesized that baroreceptor modulation is a major component of LF power.

• HF is the power of the high frequency zone (0.15-0.40Hz) and is derived **from vagal activity** which is modulated by respiration.

TÉCNICO LISBOA