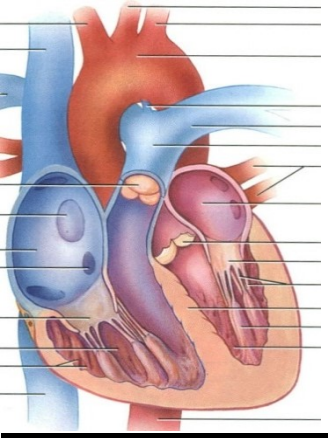
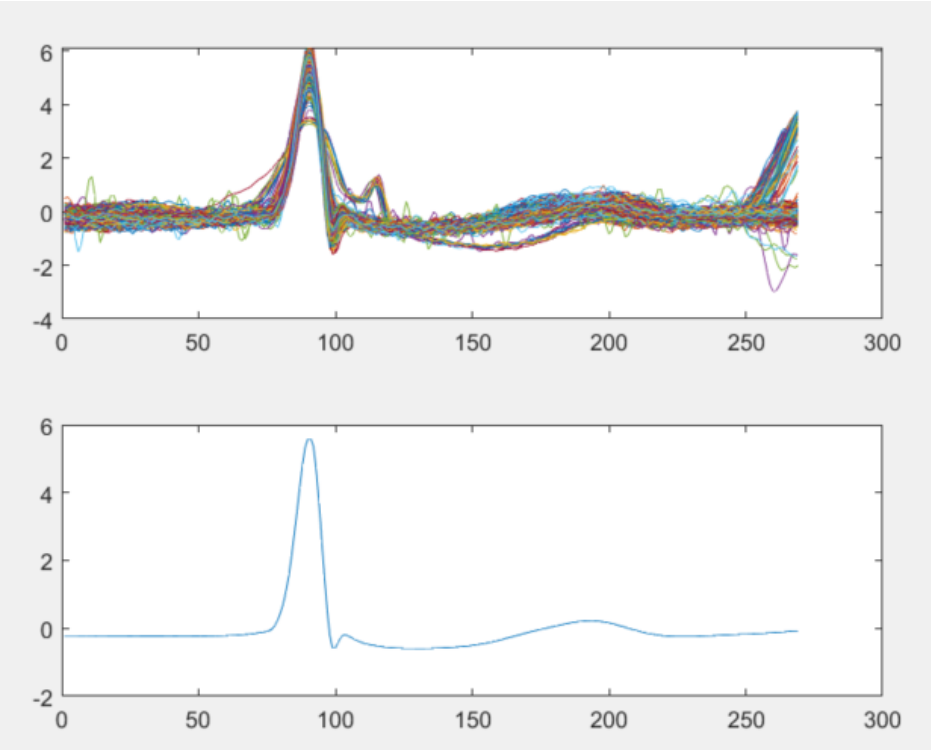


TP3 – Heart rate + arrhythmias



DEI, IM / ICST

Jorge Henriques, Paulo de Carvalho

November 2019

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Planning

	Setembro		Outubro						Novembro			Dezembro		
Semana	12	19	3	LATADA	17	24	31	7	14	21	28	5	12	19
Teórica	introducao	HL7	HL7		DICOM	DICOM	Telem	Telem	PPG	Rui	PPG	ECG	ECG	ECG
Prática	introducao	Biosinais	HL7		HL7	DICOM	DICOM	HR	HR	PPG	PPG	PPG	ECG	ECG

21/11 - Theoretical class
Talk by ***Eng. Rui Gomes*** - Head of information systems - Centro Hospitalar e Universitário Coimbra

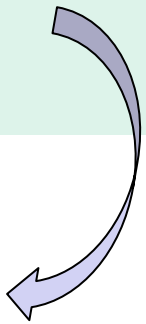
Summary

- **1| Objectives**
- R peak detection + average beat
- PVC detection
- AF detection
- Datasets/validation & evaluation

1. Objectives

- **Detection of arrhythmias – ECG analysis**
  - 1. ECG Segmentation – R peak
  - 2. Arrhythmias detection
    - PVC – Premature Ventricular contractions
    - AF – Atrial fibrillation

- **1. ECG signal (today and next week)**
  - Physiology
  - Heart rate - detect R peaks
  - Estimation of the average beat



- **2. Arrhythmias detection (next module)**
  - PVC detection
  - AF detection

Summary

- Objectives
- **2| R peak detection + average beat** *(today and next week)*
- PVC detection
- AF detection
- Datasets/validation & evaluation

2. R peak detection - segmentation

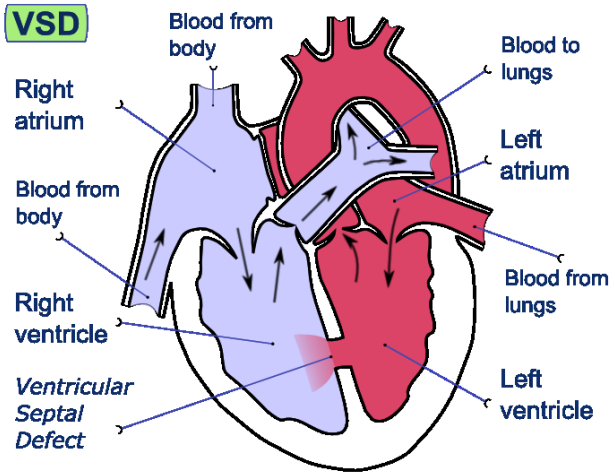
- **R peak detection**
  - Physiology
  - Detect R peaks – segmentation of ECG beats
  - Pan and Tompkins algorithms
- **Average beat**
  - Normalization process

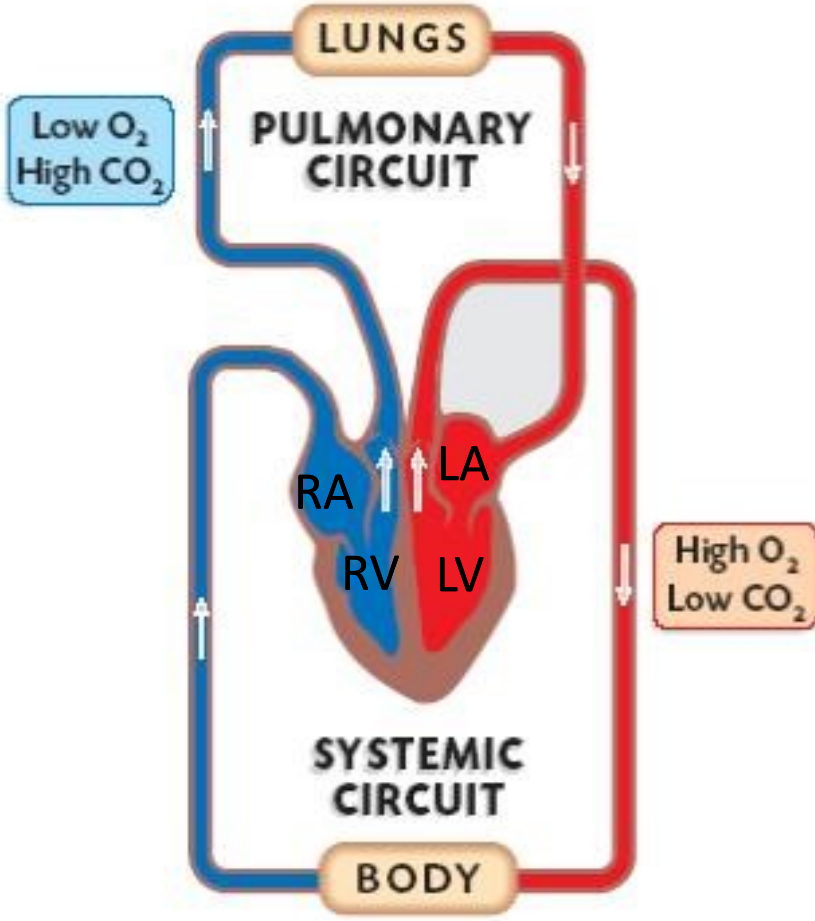
2. R peak detection - segmentation

- **R peak detection**
  - **Physiology**
  - Detect R peaks – segmentation of ECG beats
  - Pan and Tompkins algorithms
- **Average beat**
  - Normalization process

1. Physiology – heart function

- **Heart's role is basically to provide oxygen to the body organs.**
  - How it works ?
    - Myocardium, valves, septum, atria, ventricles, …
    - Large circulation - Systemic circuit
    - Small circulation – Pulmonary circuit

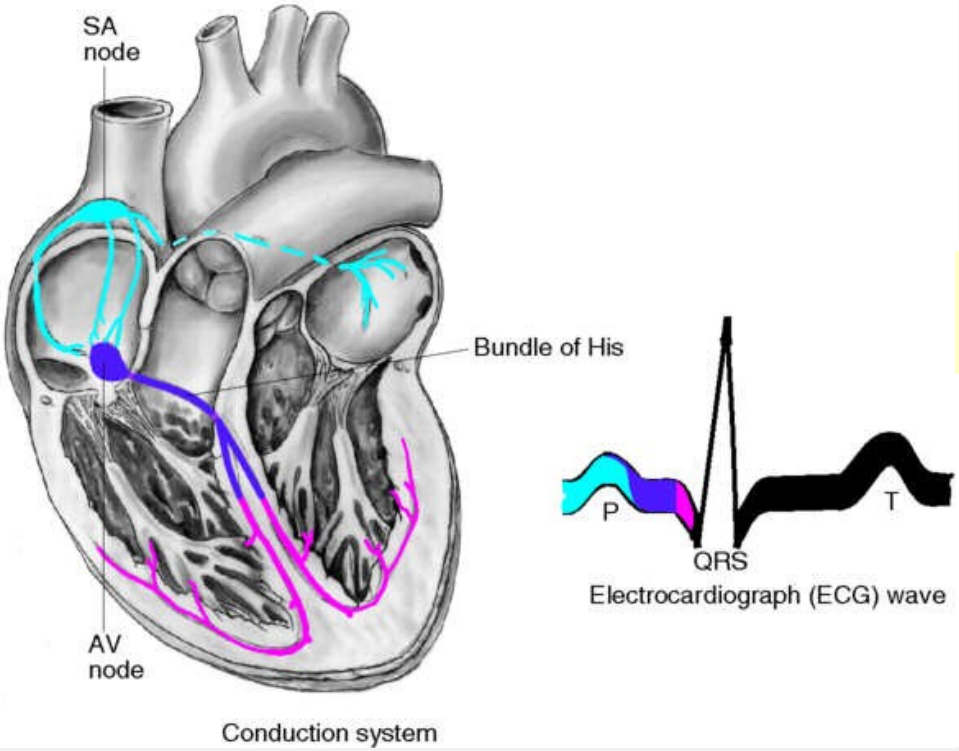




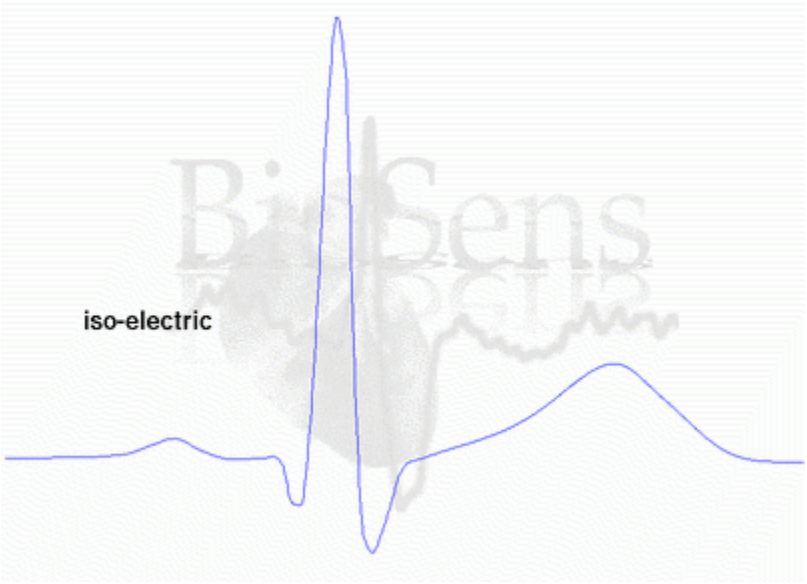
1. Physiology – cardiac cycle

Systolic = contraction

Diastolic = relaxation



Conduction system



ECG ?

Register of the electrical activity of the heart

1. Physiology – main waves and intervals

Main waves

Atrial activity

- **P wave**

Ventricular activity

- **QRS complex**
- **T wave**

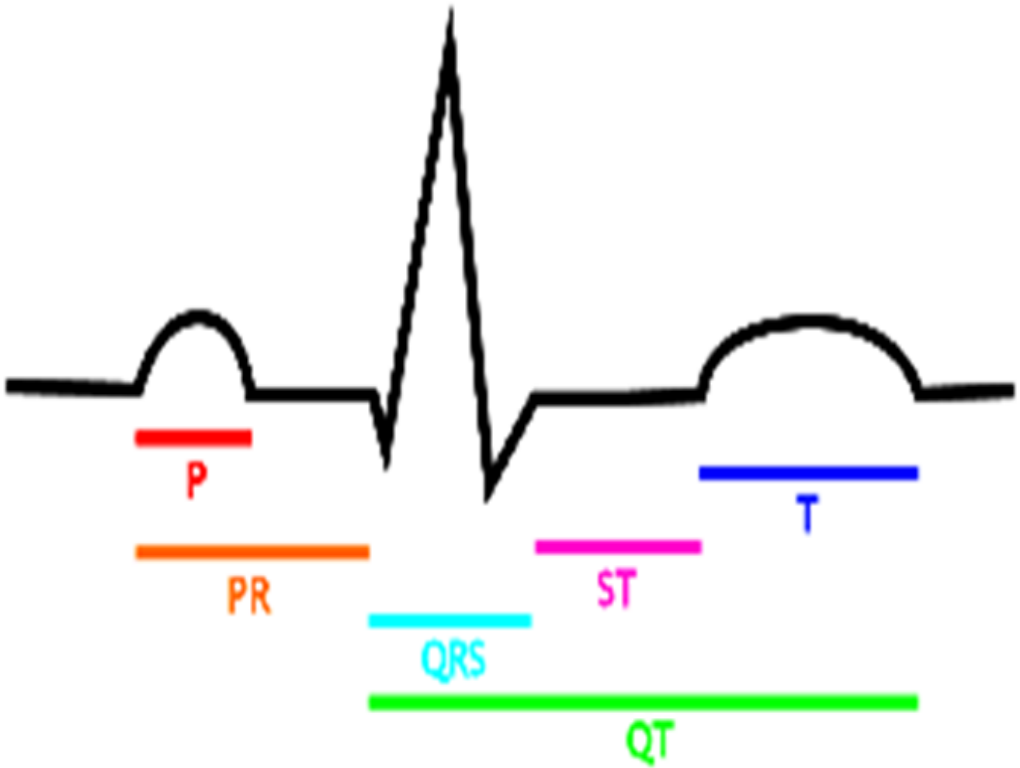
Intervals:

Atrial activity

- **PR interval**

Ventricular activity

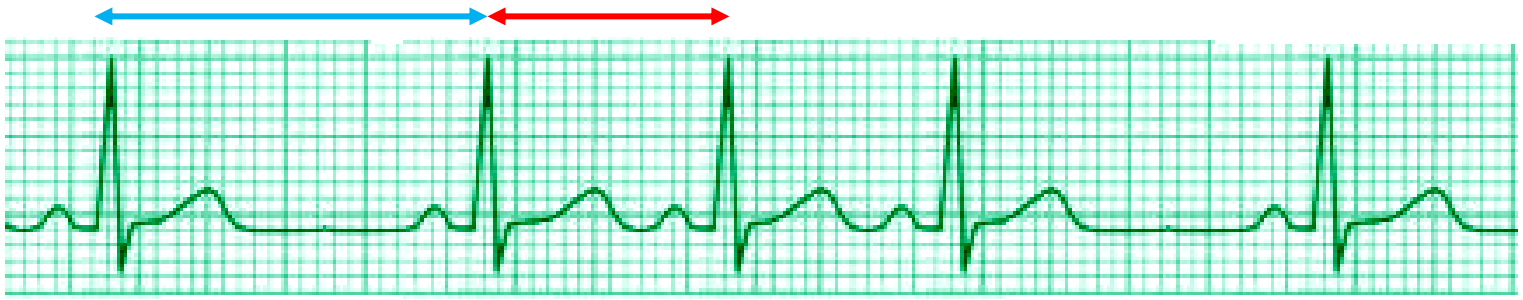
- **QRS, QT, ST intervals**



1. Physiology – normal rhythm

- **Normal rhythm**
  - 60-100 beats / min
  - P waves before the QRS complex
  - PR interval [0.12 - 0:20] seconds, and approximately constant
  - QRS interval [0.06 - 0.12]

- **Abnormal rhythm**



2. R peak detection - segmentation

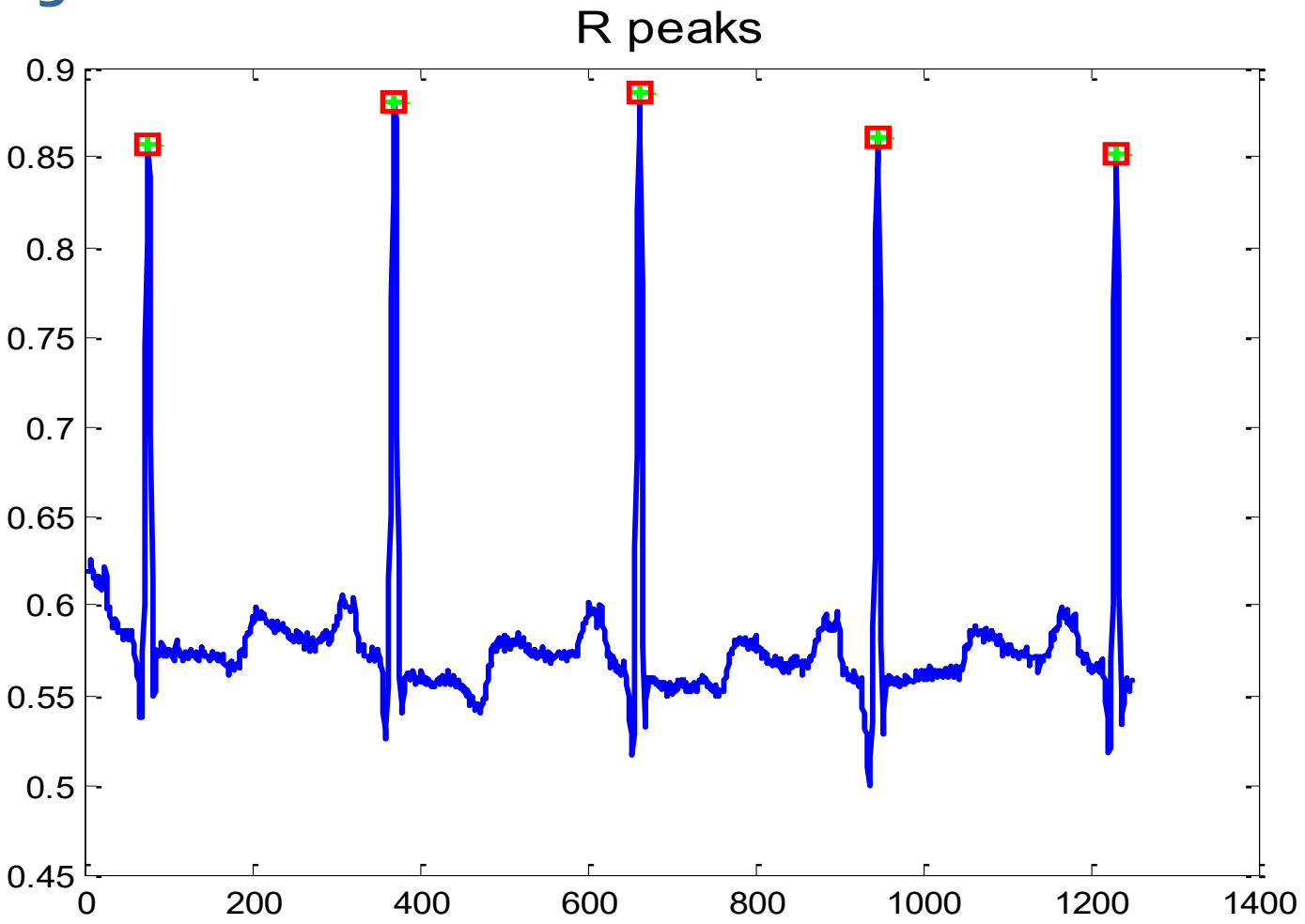
- **R peak detection**
  - Physiology
  - **Detect R peaks – segmentation of ECG beats**
  - **Pan and Tompkins algorithms**
- **Average beat**
  - Normalization process

2. R peak detection

- **Typically involves the R peak detection**
  - Number of Rpeaks = number of beats
  - Number of beats – compute heart rate

2. R peak detection - segmentation

- **Final goal**



2. R peak detection - segmentation

- **Final goal**

```
>> heartRate

================================================
----------- Duration : 15 seconds
----------- Num beats: 15

----------- beats/min: 60
================================================
>>
```

2. R peak detection

Detection of R peaks

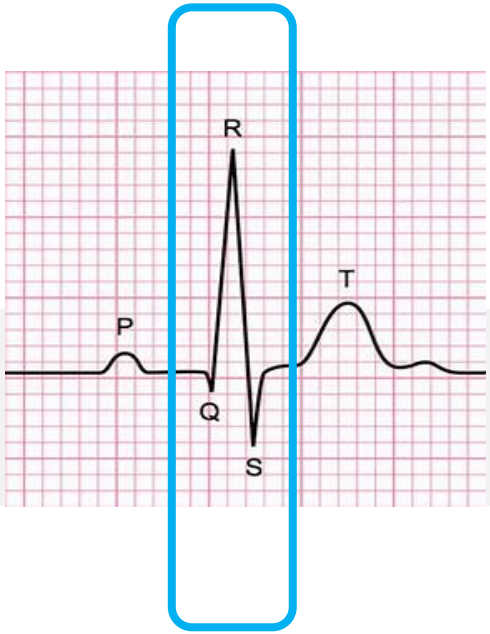
- **Can be done in several domains:**
  - Time: typical parameters
  - Frequency: Fourier, …
  - Time-frequency: wavelets

- **Several Algorithms/ techniques**
  - Based on derivatives
  - Wavelets
  - Neural networks
  - Genetic algorithms
  - Morphological operators
  - …
  - Energy detection: Pan-Tompkins algorithm

- **Off-line / on-line (real-time)**

2. R peak detection - segmentation

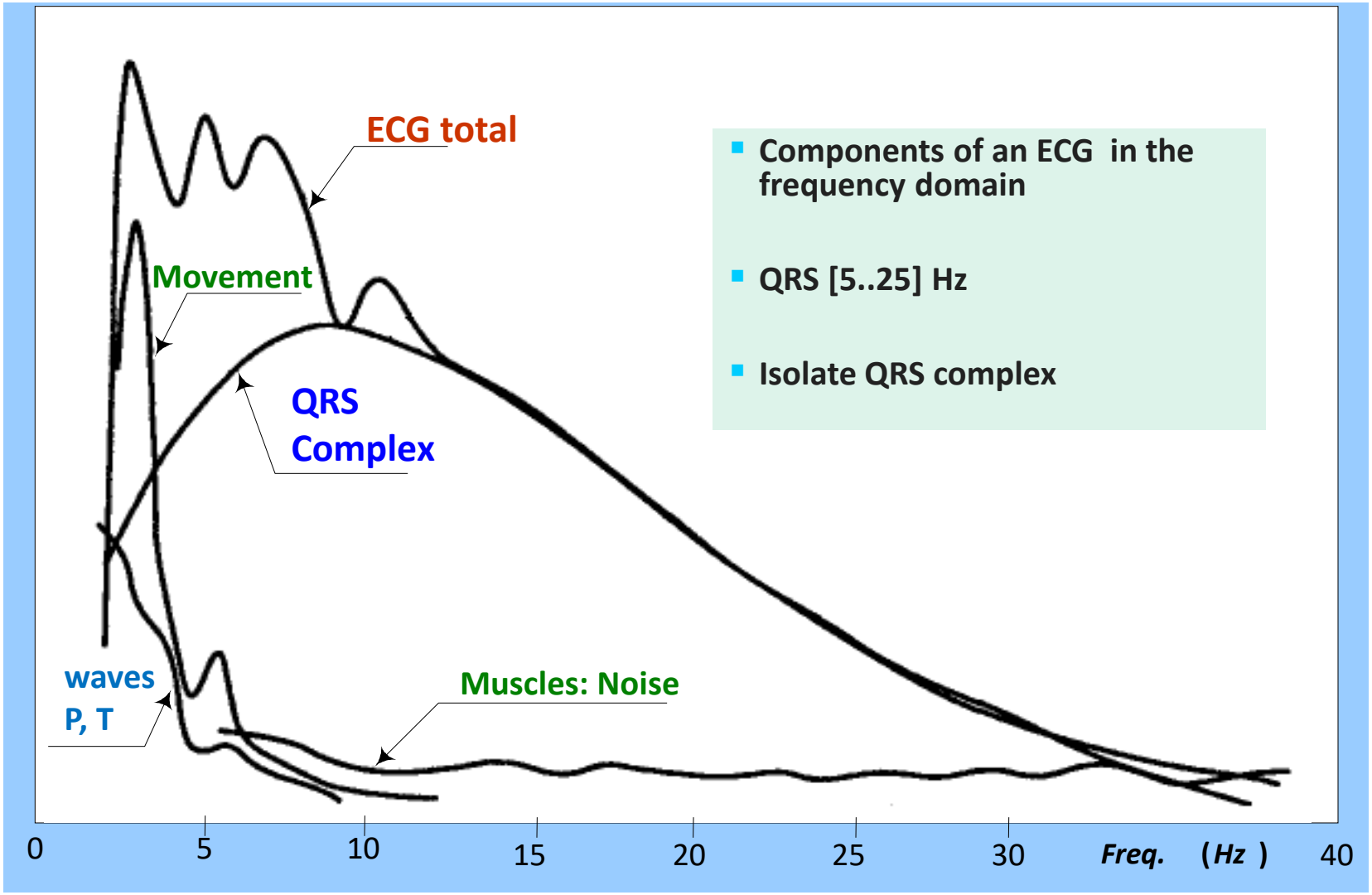
- **Pan Tompkins (1985)**
- **Key idea: detecting energy levels**
  - Pan J. and J. Tompkins,
  - A Real-Time QRS Detection Algorithm,
  - IEEE Transactions Biomedical Engineering, 32, pp 230-236, 1985.



- **Instants of higher energy - R peak**

- It consists of two phases
  - A. Signal energy estimation
  - B. Identification of energy values above a given threshold.

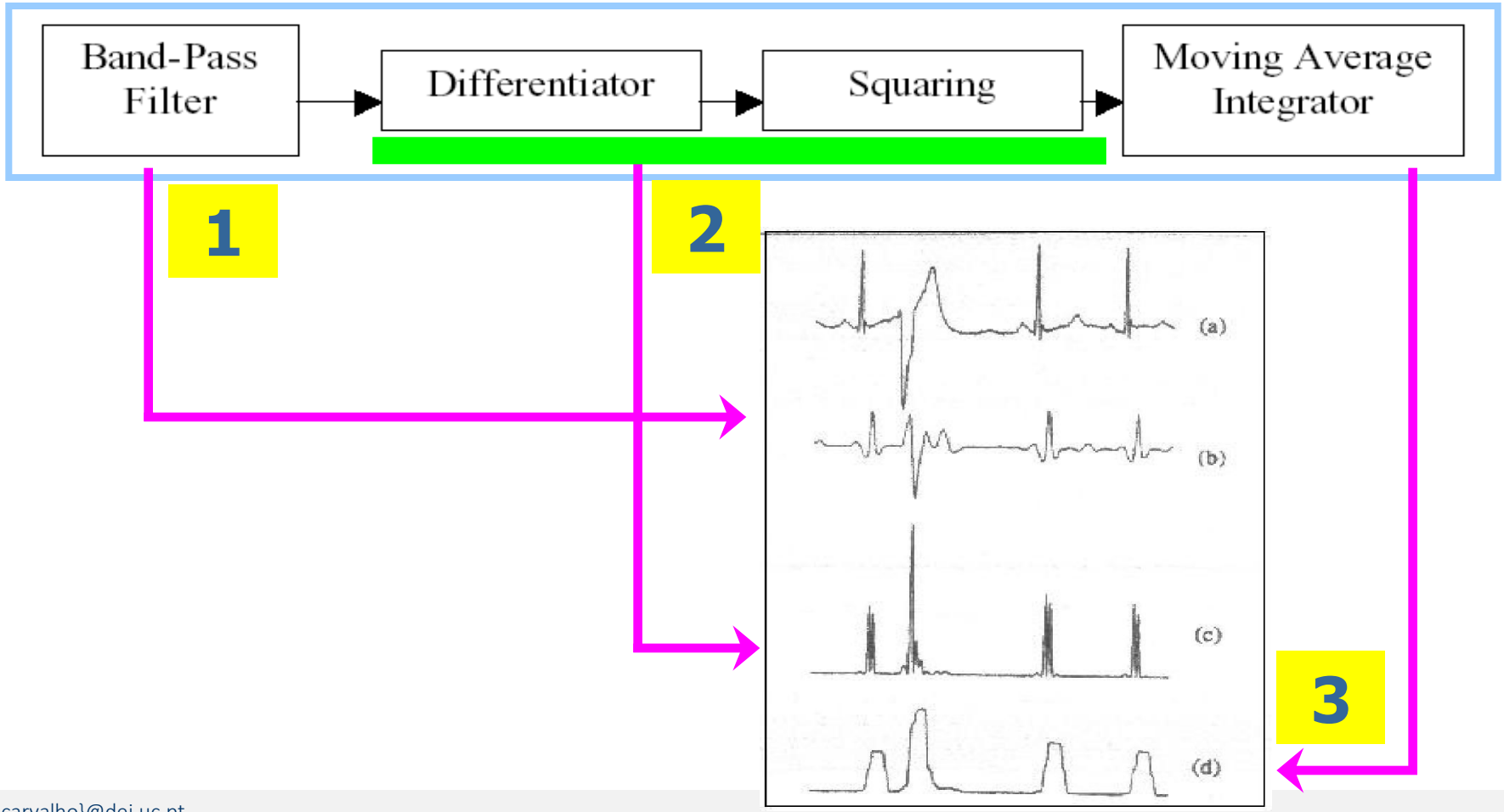
2. R peak detection - segmentation



- Components of an ECG in the frequency domain
- QRS [5..25] Hz
- Isolate QRS complex

2. R peak detection - segmentation

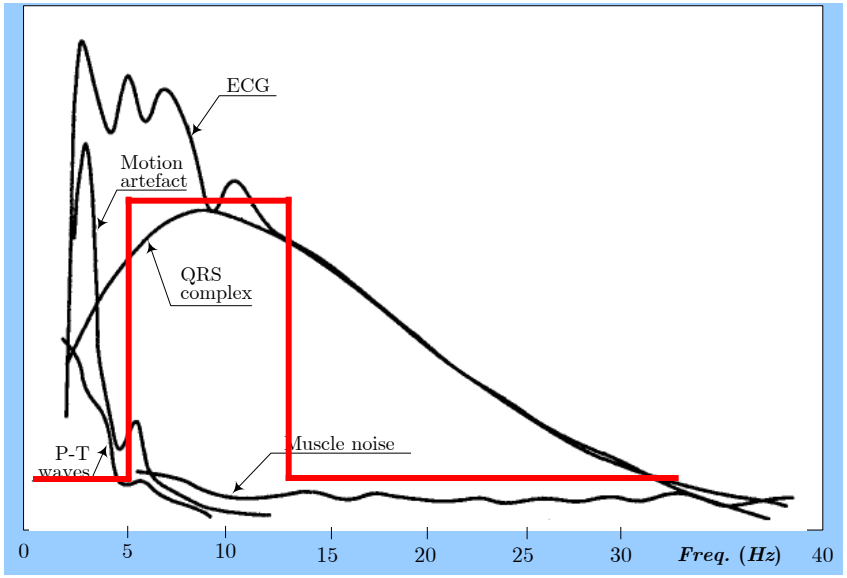
- **Main phases**



2. Rpeak

- **1. Band Pass Filter**
  - Filter frequency components in which the ***QRS complex is more significant***
  - Eliminate the influence of P and T waves, as well as other components (noise, for example)
  - **The range [5-15] Hz is a common option**

- **It requires the design of a digital filter**
  - Digital filters (*first class*)



2. Rpeak

- **2i. Differentiation**
  - QRS peaks having the highest variation in the signal,
  - Differentiation ***highlight the presence of the QRS complex***

$$der(y(k) \approx y(k+1) - y(k)$$

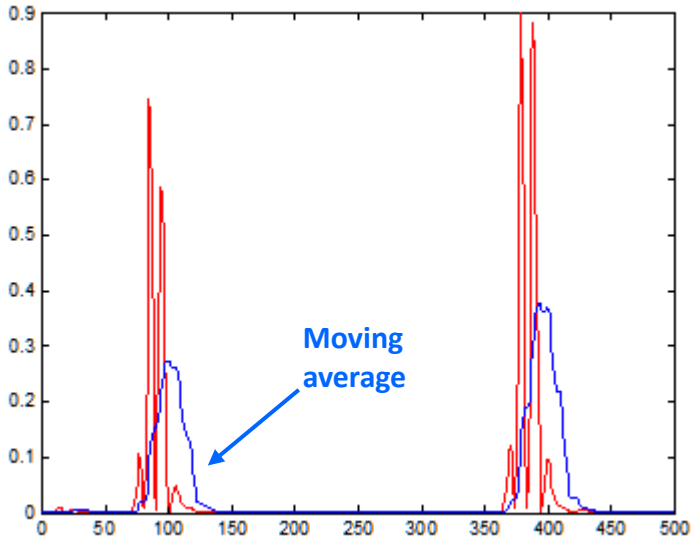
- **2ii. Potentiation** (square)
  - Nonlinear operator
  - Guarantee that data values ***are positive***

$$y(k) \rightarrow y(k)^2$$

3. Moving Average

- Removes "multiple waves", so that only the most significant wave is taken into account
- **Usually implemented with a digital filter!**
  - *Moving average*

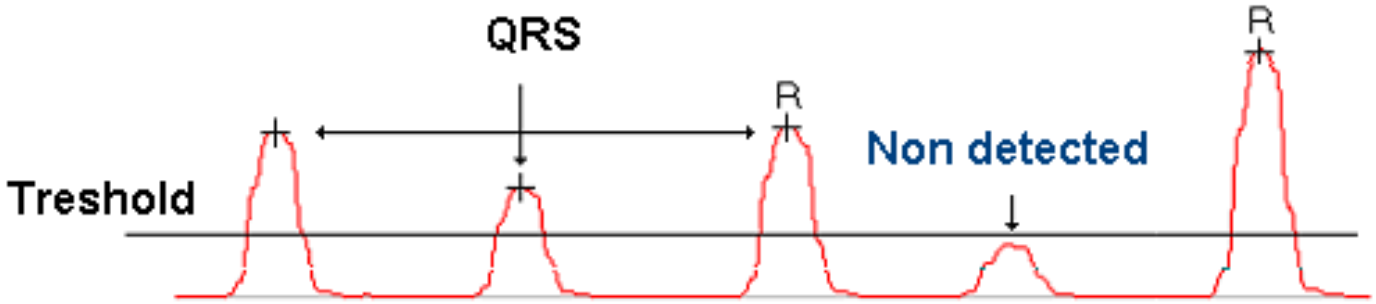
$$x(k) = \frac{1}{N}\sum_{i=0}^{N-1} x(k-i)$$



2. R peak

B - Threshold

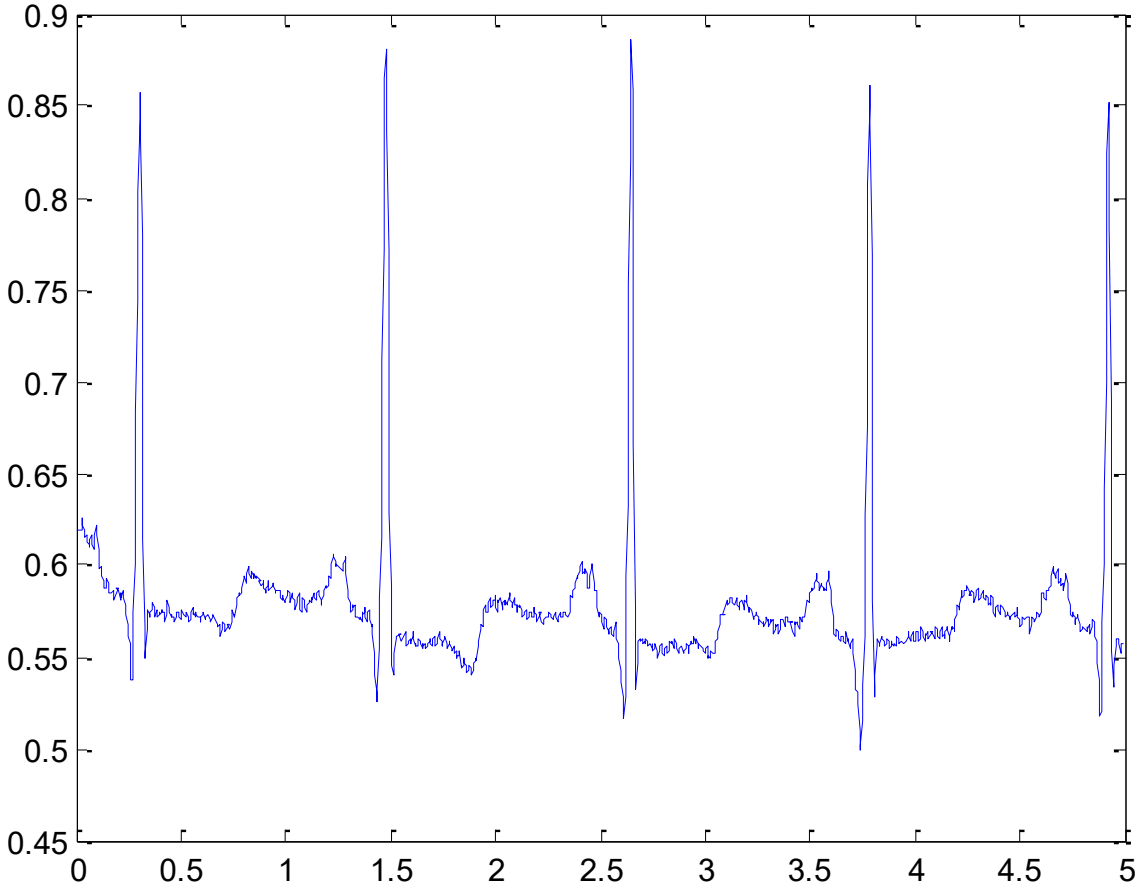
- After determining the energy of the signal, a threshold should be established:
  - If energy is greater than the threshold - **QRS detection**
  - If energy is lower than the threshold - not a peak



Example Matlab

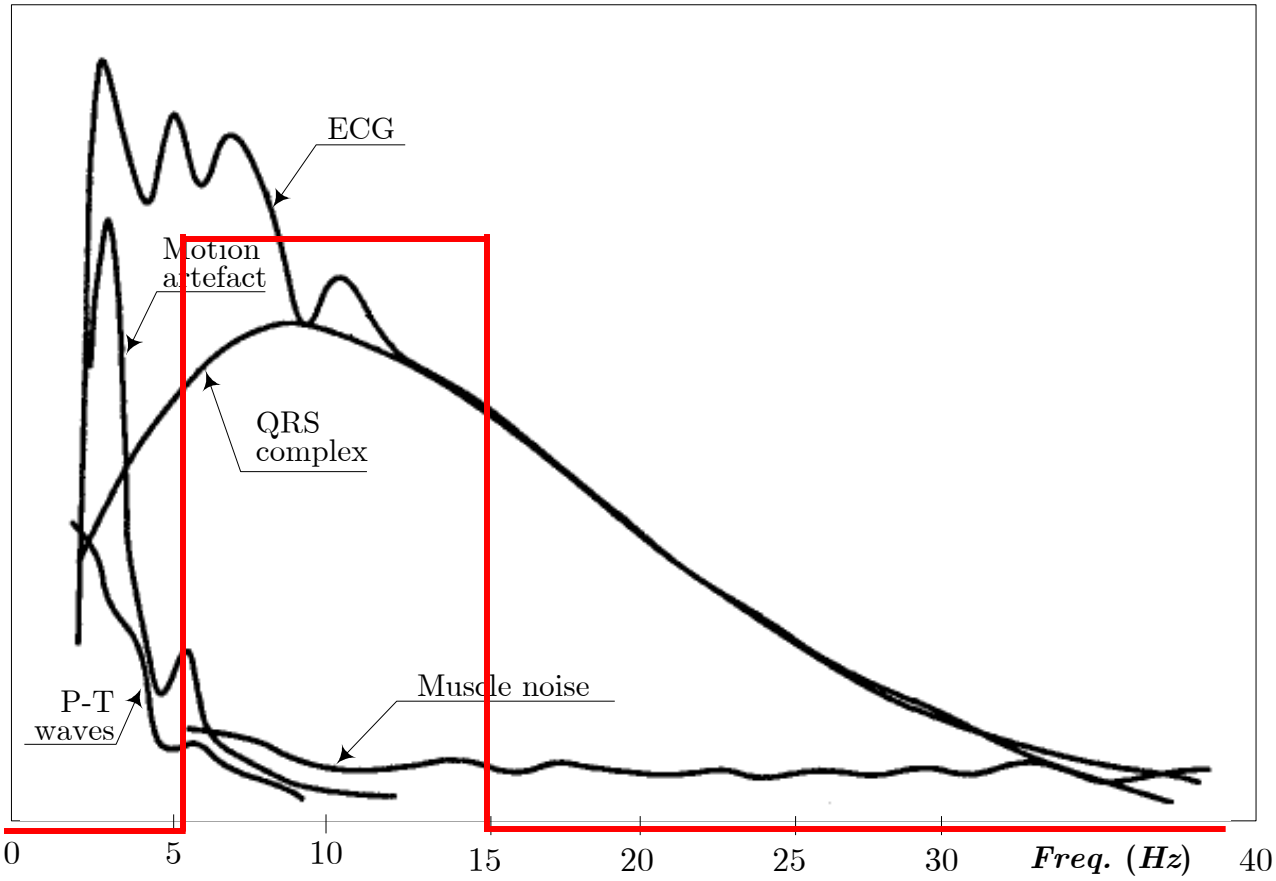
- **1. ECG**

```
load ecg.dat
```



Example Matlab

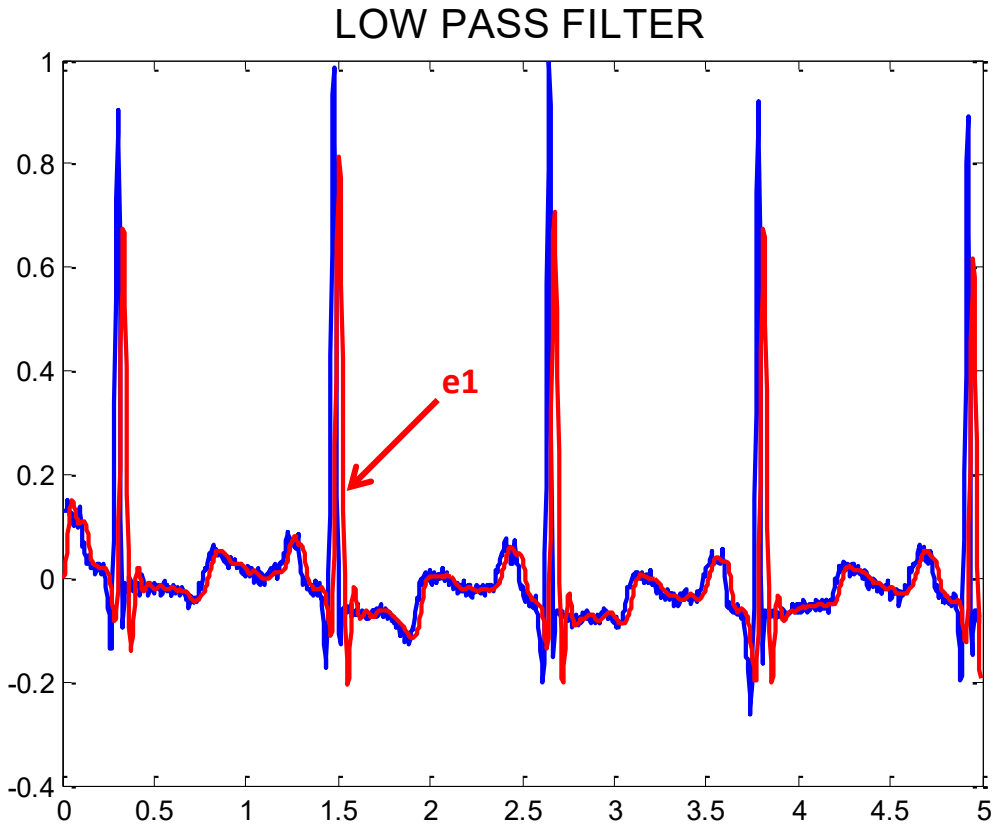
- **1. filter passband**



Example Matlab

- 1. lowpass filter (wc = 25)

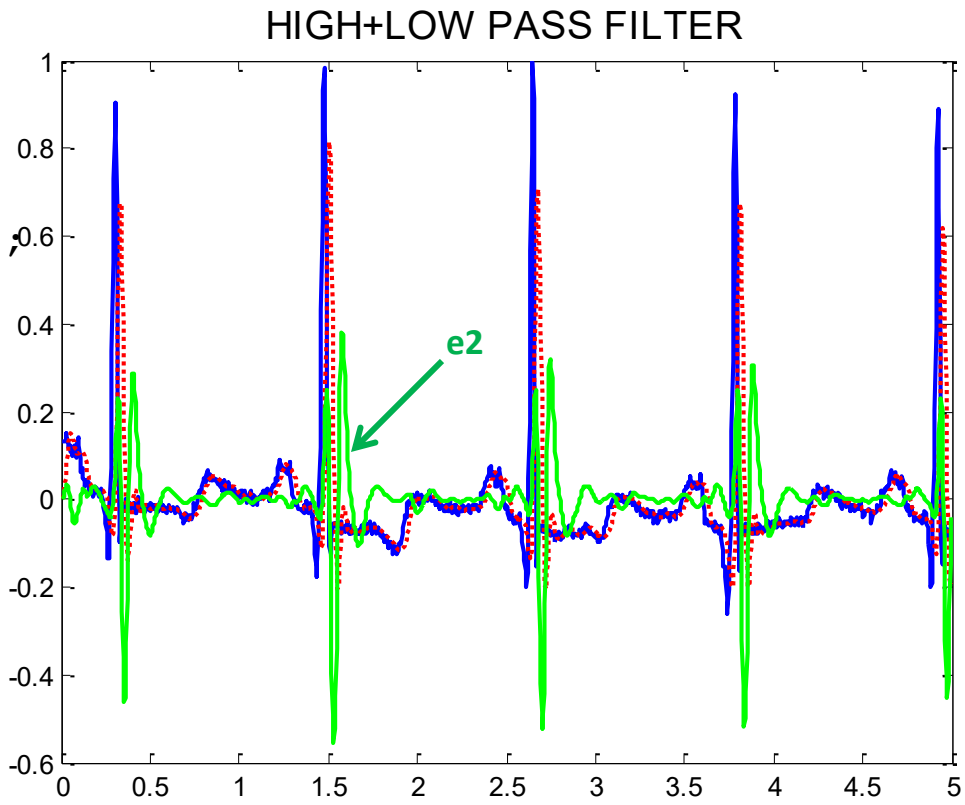
```
order = 4;
wc = 25;
fc = wc / (0.5 * fs);
[b, a]=butter(order, fc);
e1 = filter (b, a, ECG);
```



Example Matlab

- 1. High pass filter (wc = 5)

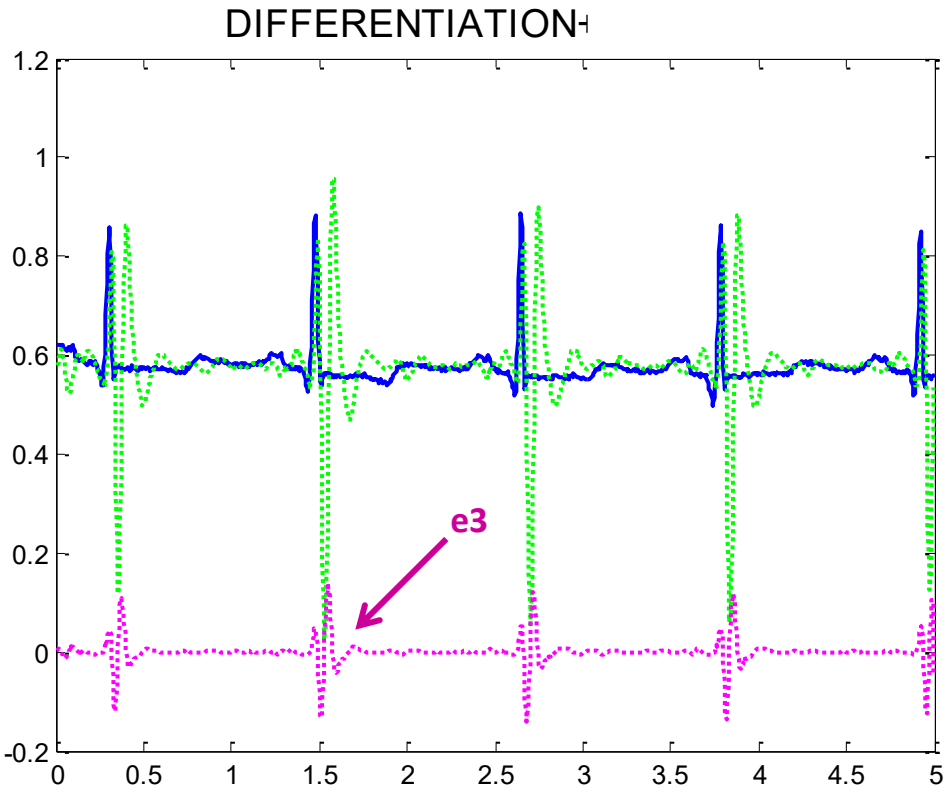
```
order = 4;
wc = 5;
fc = wc / (0.5 * fs);
[b,a] = butter(order fc,'High');
e2 = filter (b, a, e1);
```



Example Matlab

- **2. Differentiation + potentiation (square)**

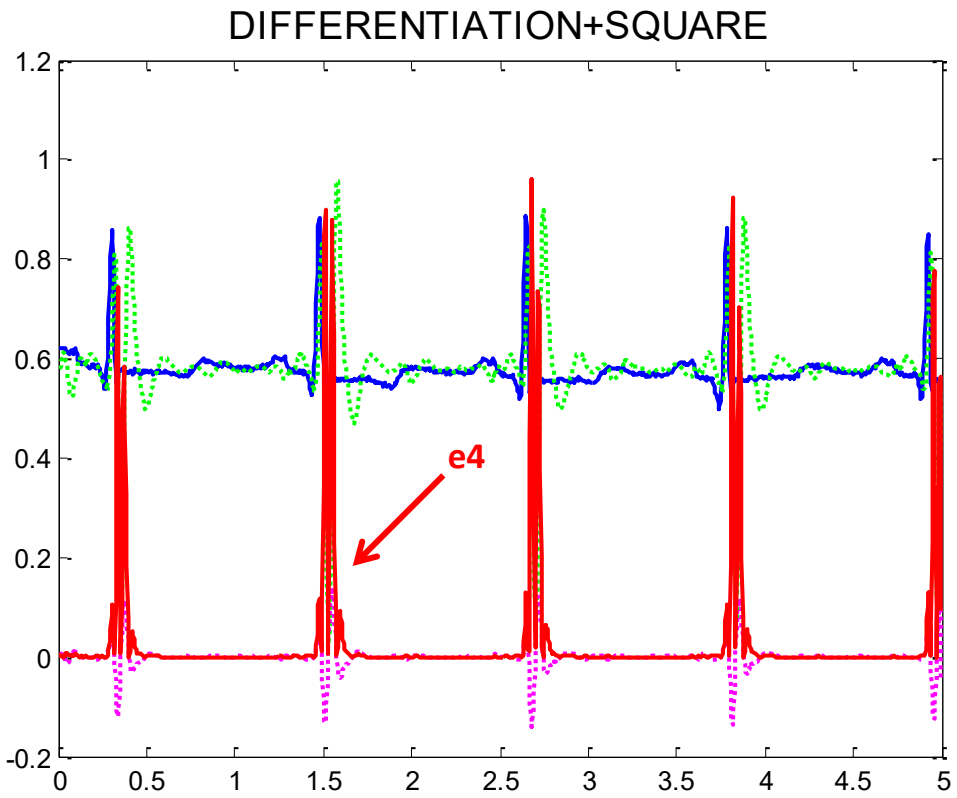
```
e3 = diff(e2);
e4 = e3.^2;
```



Example Matlab

- **2. Differentiation + potentiation (square)**

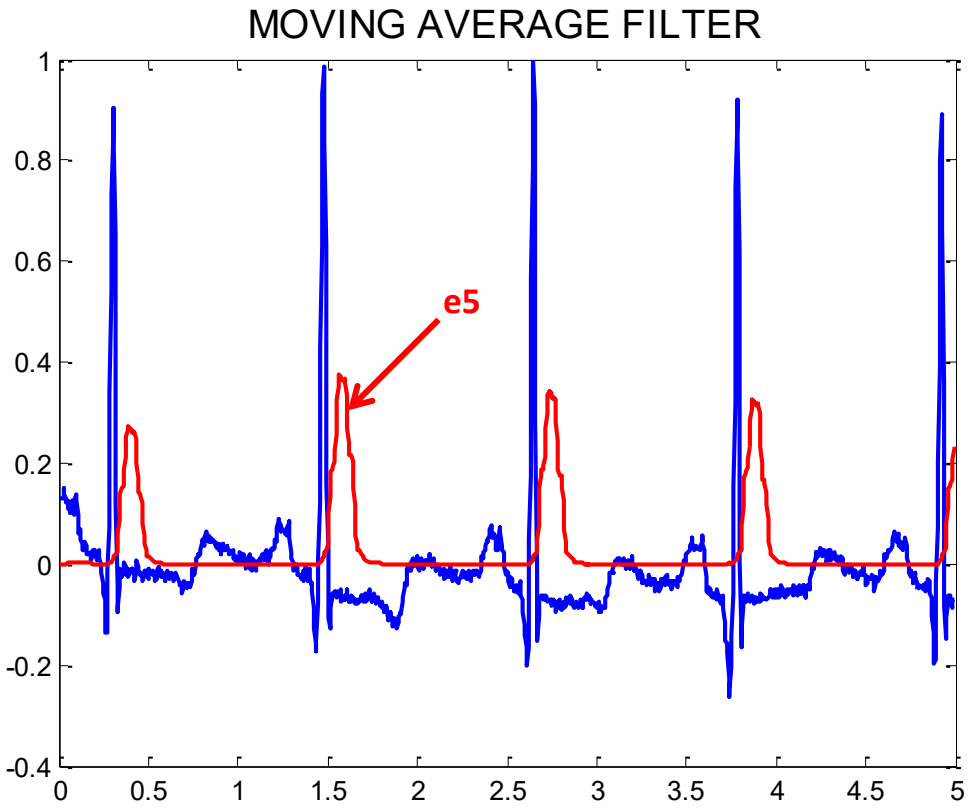
```
e3 = diff(e2);
e4 = e3.^2;
```



Example Matlab

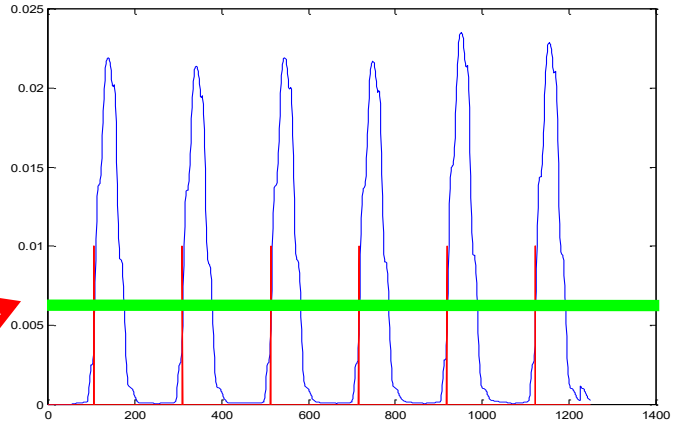
- **3. Moving Average**

```
timeWindow = 0.2;
b  = (1/N)*ones (1, N);
a  = 1;
e5 = filter (b, a, e4);
```



Example Matlab

- **Hypotheses / parameters**



  - **Threshold** (Thresholds)

```
threshold = 0.7 * mean (e5)
```

  - Additional rules

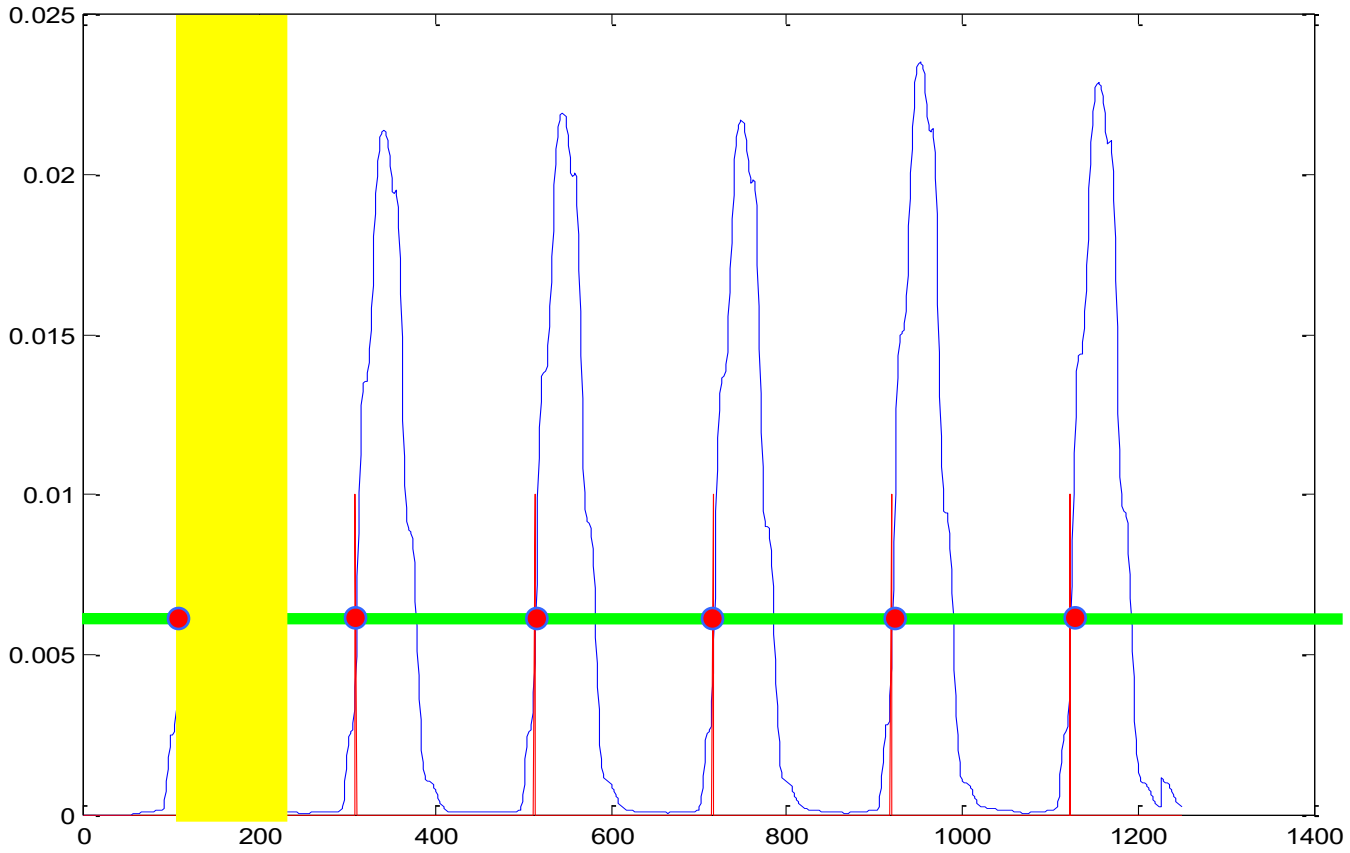
    From a physiological perspective it is impossible that a peak occurs before a certain time interval

```
pause = 0.3 seconds
```

Example Matlab

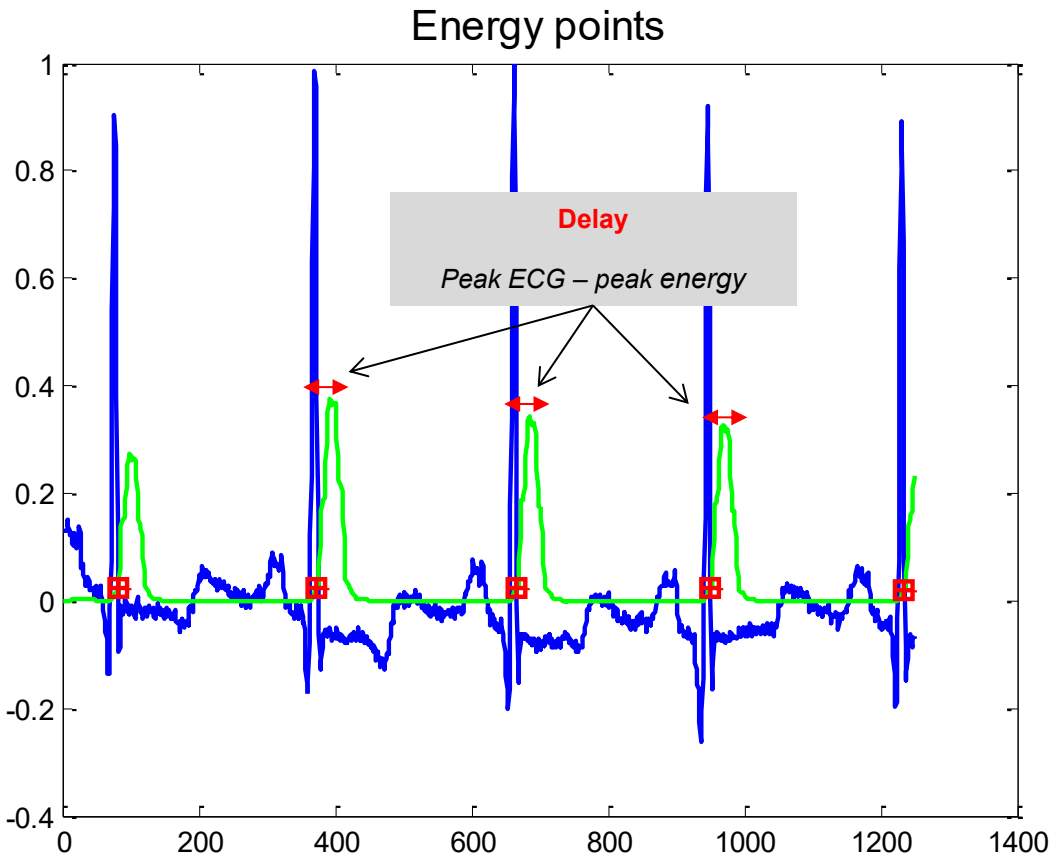
- **Energy and detection threshold**

Threshold



Example Matlab

- **ECG / Signal energy**
  - Note the **delay**!
  - Due to signal processing



Example Matlab

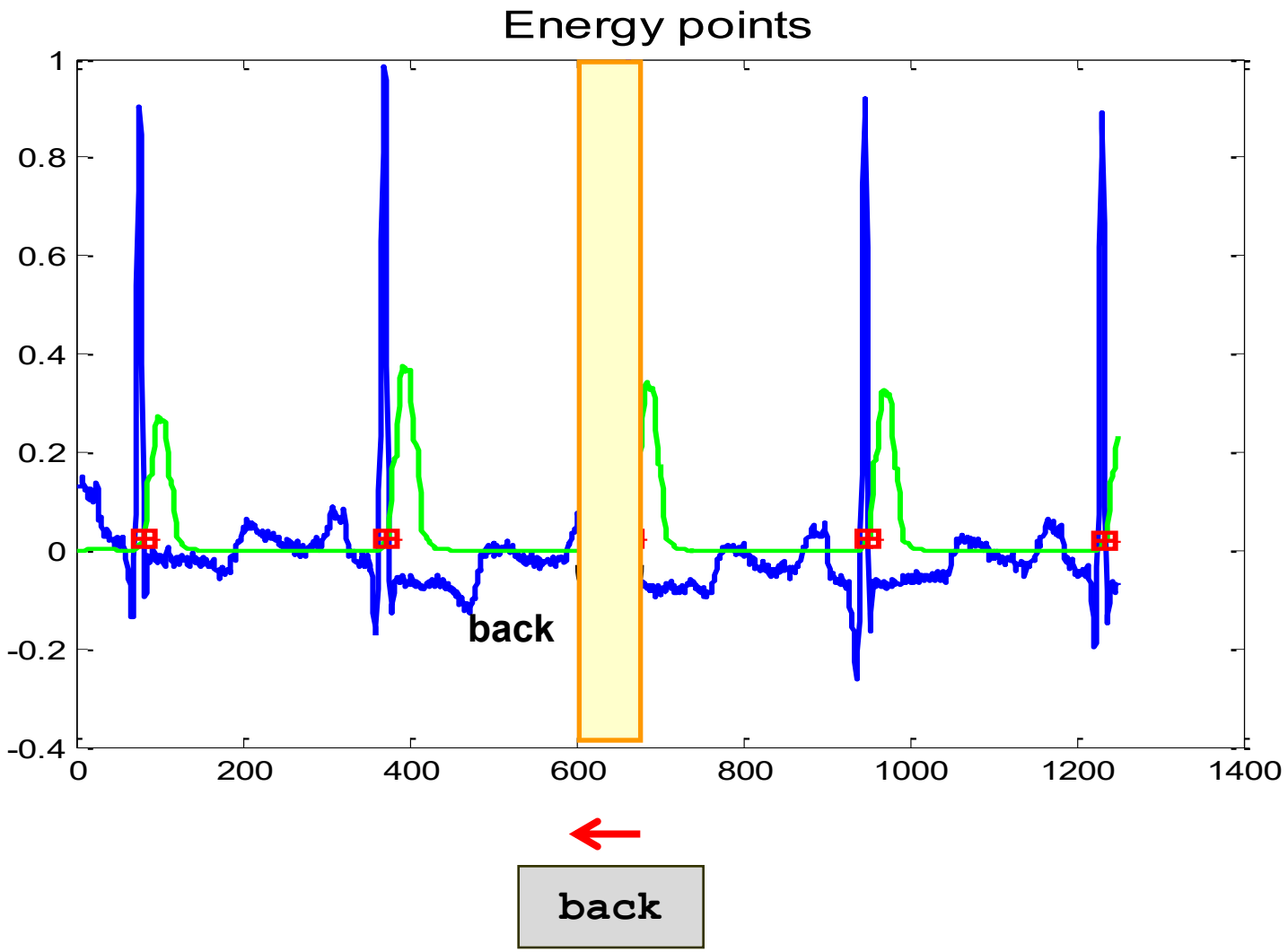
Implication - Back search

- Filters necessarily introduce delays in the signal processing process
- Once detected the peak energy (in power signal) we need to **search the QRS peak in the original ECG** – considering a range of time before the energy peak

```
back = 0.2 seconds
```

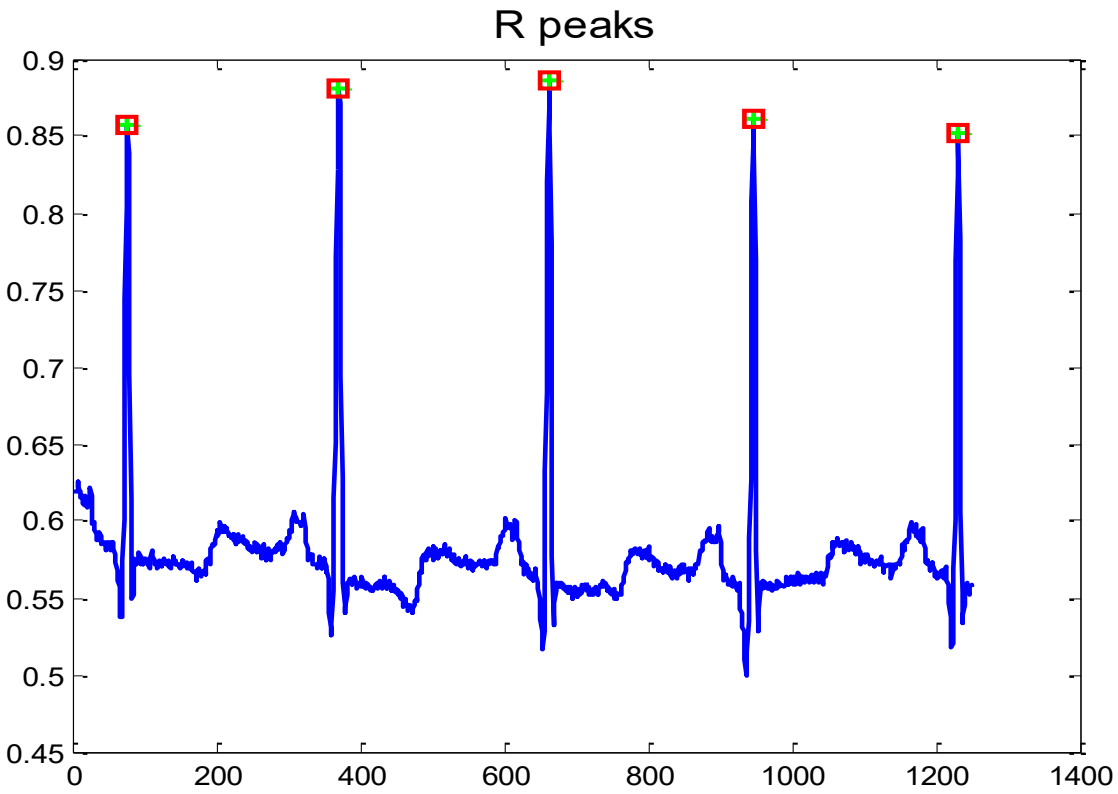
- Alternative: use of ***filtfilt(.) matlab function*** insted ***filter(.)***

Example Matlab



Example Matlab

- **Finally**
  - **Beats / min =?**
  - ***online***: Average of the last R peaks (typically around last 5 or 7 beats)



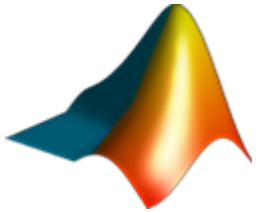
2. R peak detection - segmentation

- TP – final goal

```
>> qrsdetection

================================================
----------- Duration : 15 seconds
----------- Num beats: 15

----------- beats/min: 60
================================================
>>
```

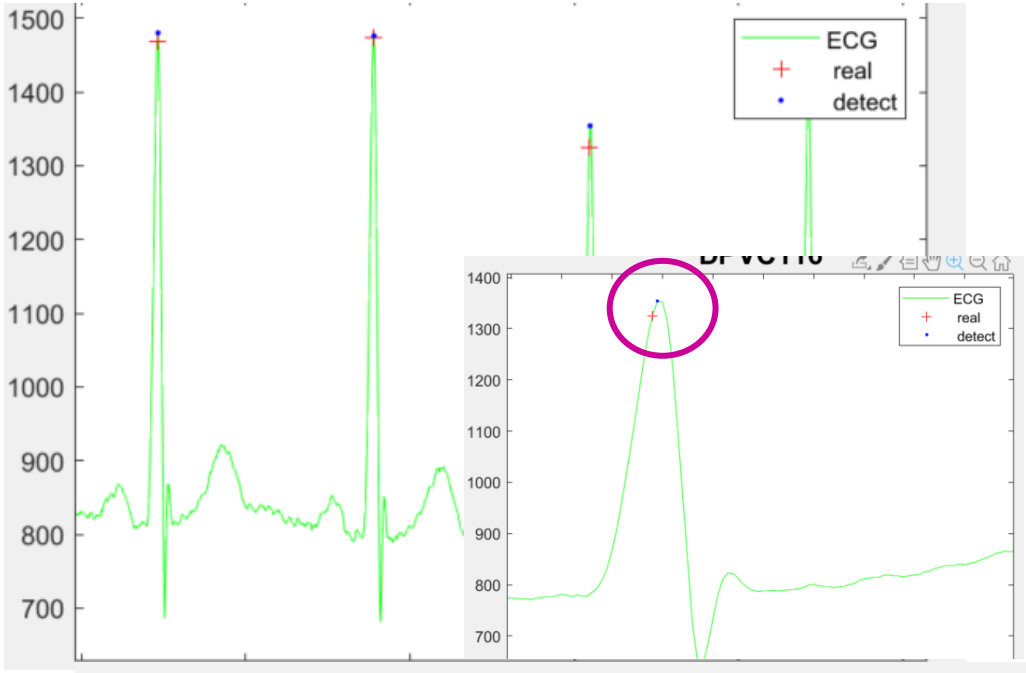


++ main_ecgRpeak.m

Data sets

- **Data (Ecg's)**
  - Collected in the first class

- **DATPVC (250 Hz)**
  - DAT.ecg - signal
  - DAT.ind - R peaks indexes



Consider a tolerance !

10 points ??

- **Validation**
  - **TP** true positive - peak correctly detected
  - **FP** false positive - peak identified incorrectly
  - **FN** false negative - peak not identified
  - **TN** **- no sense !!!**

++ main_RpeakAverage.m

Modifications/adaptations

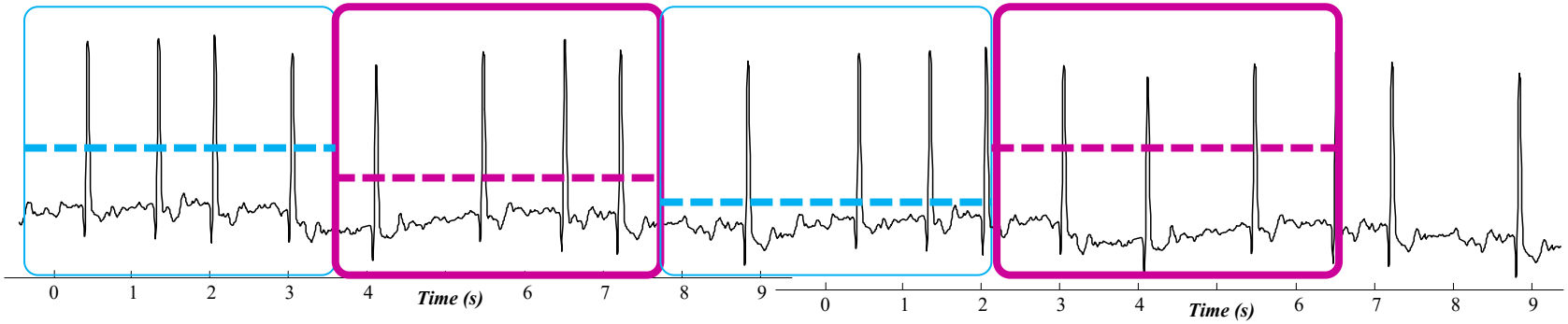
- Several algorithms (thousands!) have been developed based on the detection of energy.

- The fundamental difference between them ?
  - In specific parameters (filters, …)
  - Mainly in determining the Limiar (Threshold)
    - The original algorithm (Pan & Tompkins) considers an adaptive thresholds !

2. R peak

Improvements

- Threshold can be computed considering N beats instead of all signal
- Sliding window approach



Other ideas ??

- **Fell free to propose /test new ideas !**

2. R peak detection - segmentation

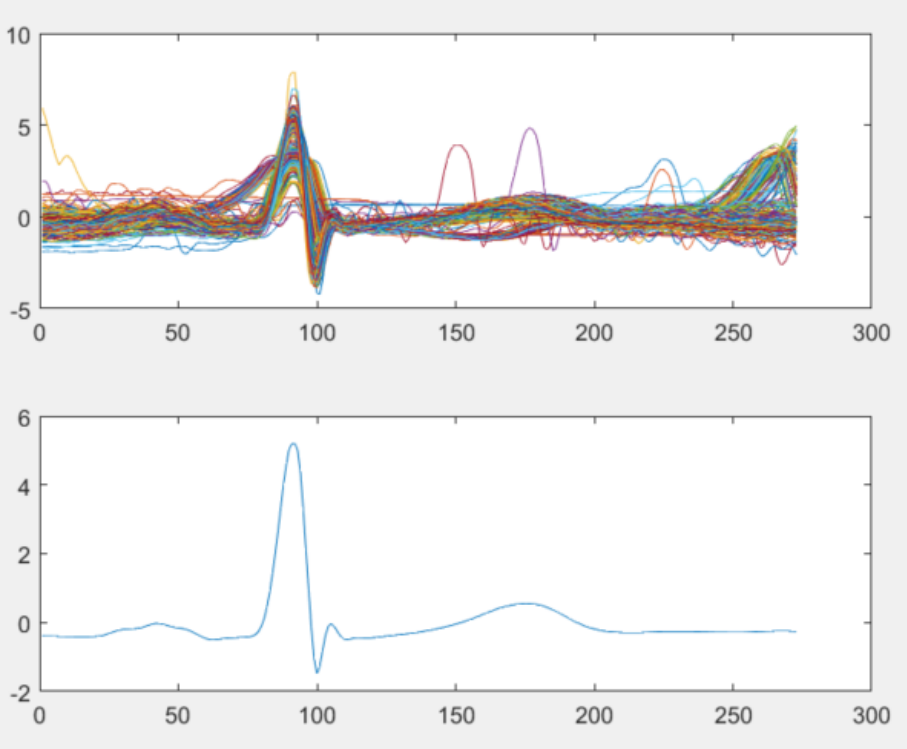
- **R peak detection**
  - Physiology
  - Detect R peaks – segmentation of ECG beats
  - Pan and Tompkins algorithms

- **Average beat**
  - **Normalization process**

2. Average beat

Estimate the average beat from a signal

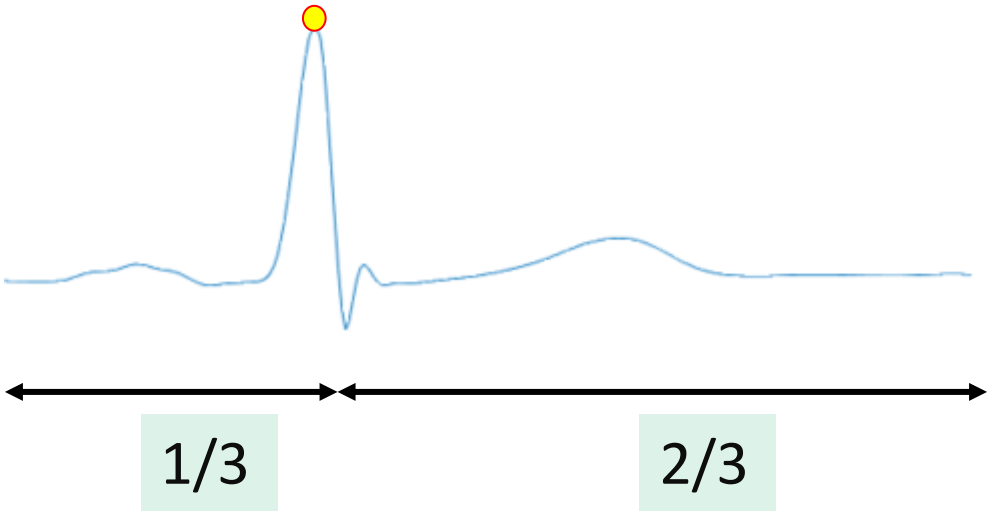
- 1. Synchronization of all beats
  - **Using R peak**
- 2. Normalization
  - ***Duration***
  - ***Amplitude***
- 3. Average



2. Average beat

Estimate the average beat from each signal

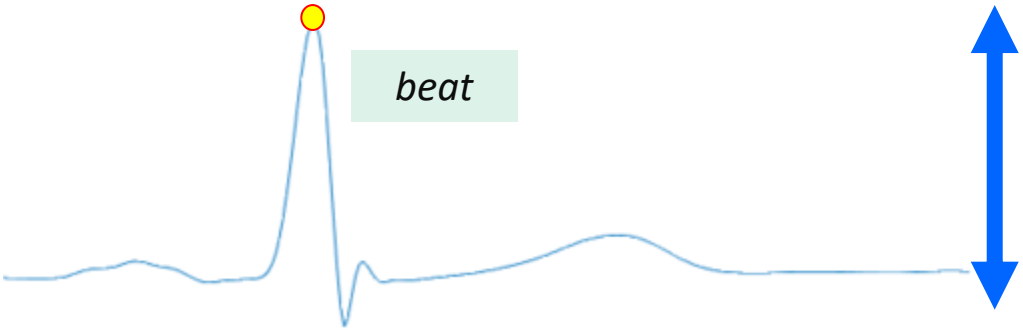
- 1. Synchronization – R peak
- 2. Normalization
  - ***Same duration = mean of all beats duration (computed for all signal)***
  - *1/3 auricular activity*
  - *2/3 ventricular activity*



2. Average beat

- **Estimate the average beat of an individual from a signal**
  - 1. Synchronization – R peak
  - 2. Normalization
    - ***Amplitude***

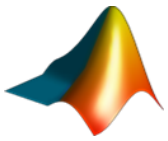
```
mean(beat) = 0
std(beat)  = 1
```



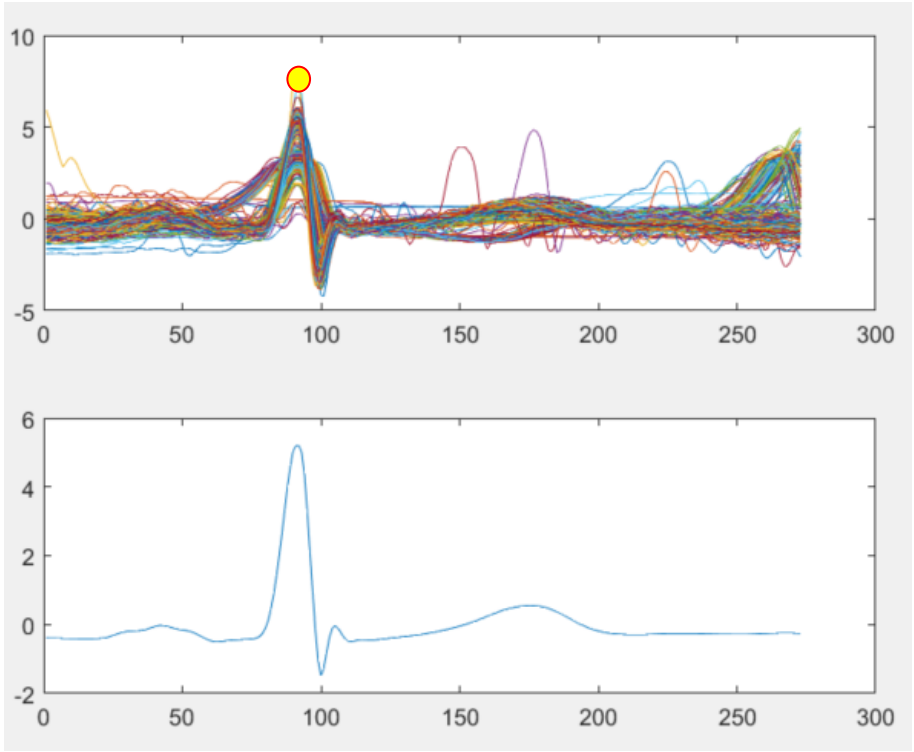
2. Average beat

- **Estimate the average beat of an individual from a signal**
  - 3. Average of all normalized beats

average



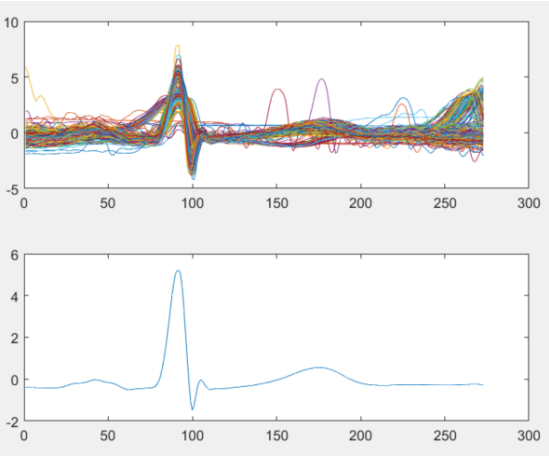
++ main_RpeakAverage.m



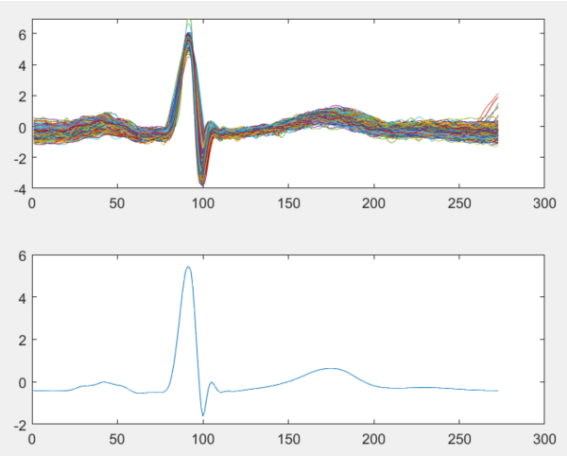
Improvements

- Iterative process
- Consider only the beats that are "more similar" with the average

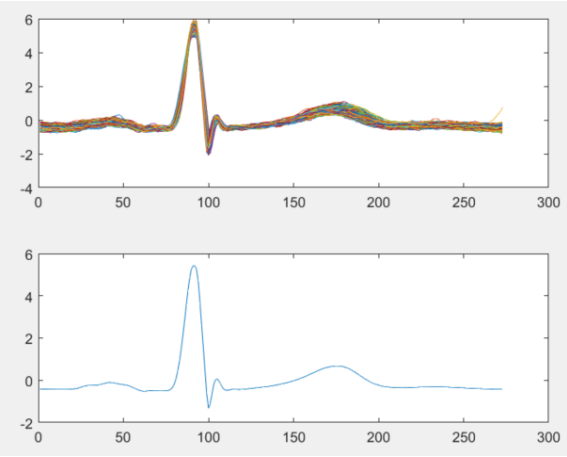
1st iteration



2nd iteration



3rd iteration

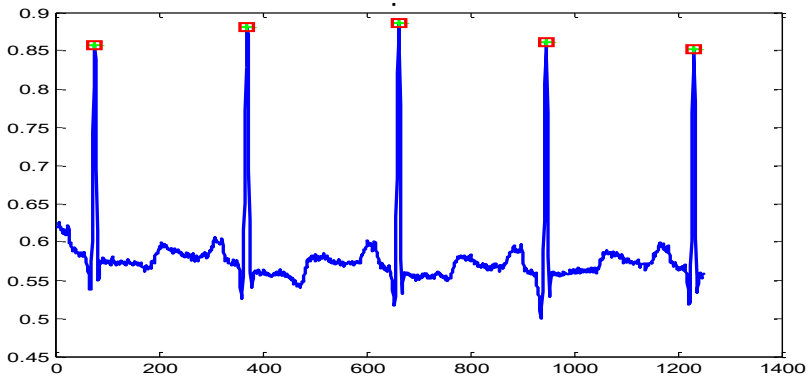


Other ideas ??

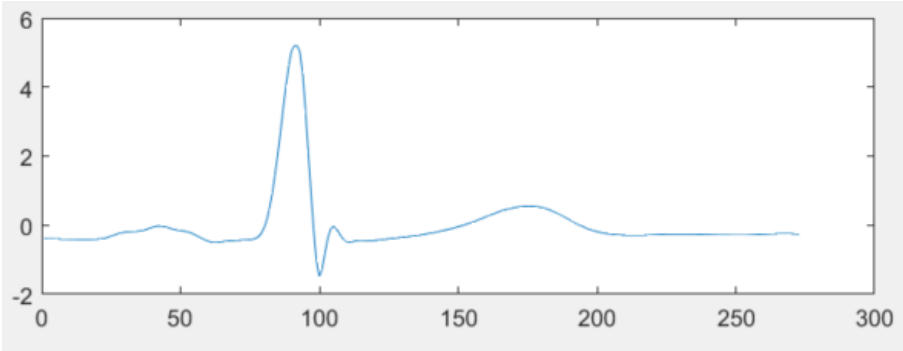
- **Fell free to propose /test new ideas !**

Conclusions

- **1. R peak**
  - Compute Rpeaks / heart beat
  - Validate with DATPVC



- **2. Average beat**



- **NO SUBMISSION / EVALUATION**

  This work will be used in the arrhythmias