EXERCISES – BIOLOGICAL SIGNALS

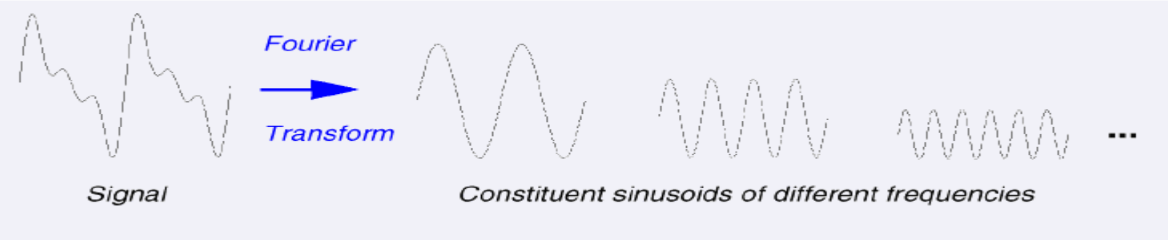
Exercise 12 - SS 2014 – Michel Kana

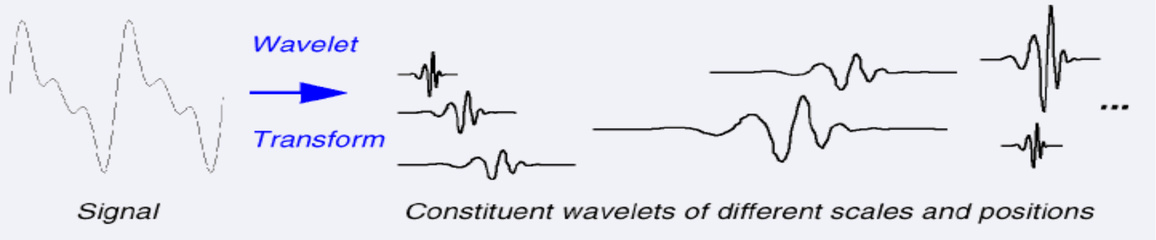
What will we do today?

1. **Introduction to Wavelet Transform**
2. **Heart rate variability with Wavelet Transform**
3. **Summary**

Fourier Transform vs. Wavelet Transform

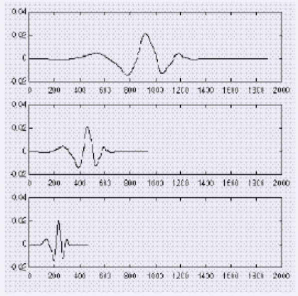
- Fourier analysis represents a signal as either a function of time or frequency, but not both.
- Like sines and cosines in Fourier analysis, wavelets are used as basis functions in representing other functions.
- Wavelets are waveform of limited duration that has an average value of zero.
- Wavelets are located in both frequency (via dilation) and time (via translation) domains.





Wavelets

- Wavelets are generated from a single basic wavelet $\psi(t)$ called mother wavelet as follows: $\psi_{a,b}\,(t) = \frac{1}{\sqrt{a}}\psi(\frac{t-b}{a})$, where b is the shift-coefficient and a is the scale coefficient.

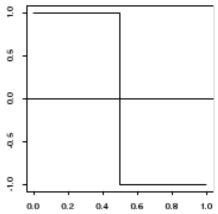


$$f_{(t)} = \Psi(t) \;\; ; \;\; a = 1$$

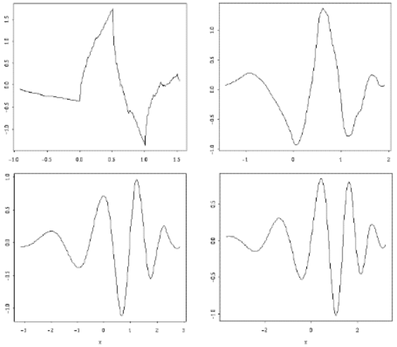
$$f_{(t)} = \Psi(2t) \;\; ; \;\; a = 1/2$$

$$f_{(t)} = \Psi(4t) \;\; ; \;\; a = 1/4$$

- Prominent examples are the Haar and Daubechies wavelets



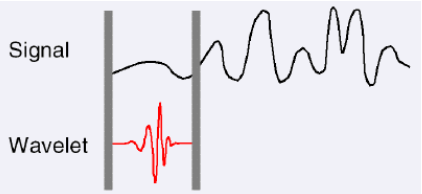
Haar wavelet



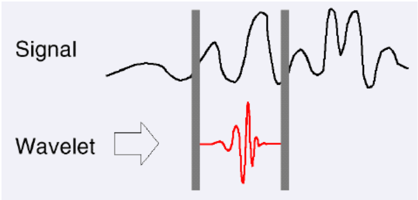
Daubechies wavelets

The Wavelets Transform

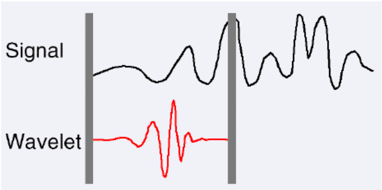
- Wavelet Transform is the representation of a signal $f(t)$ as a linear combination of wavelet basis functions: $f(t) = c_0\varphi(t) + \sum_{a,b} c_{a,b}\psi_{a,b}$
- A wavelet basis consists of a father wavelet $\varphi(t)$ that represents the smooth baseline trend and a mother wavelet $\psi_{a,b}$ that is dilated and shifted to construct different levels of detail.
- The wavelet basis functions are chosen according to the signal being approximated.



Step1: take a wavelet and correlate it with a section of the signal



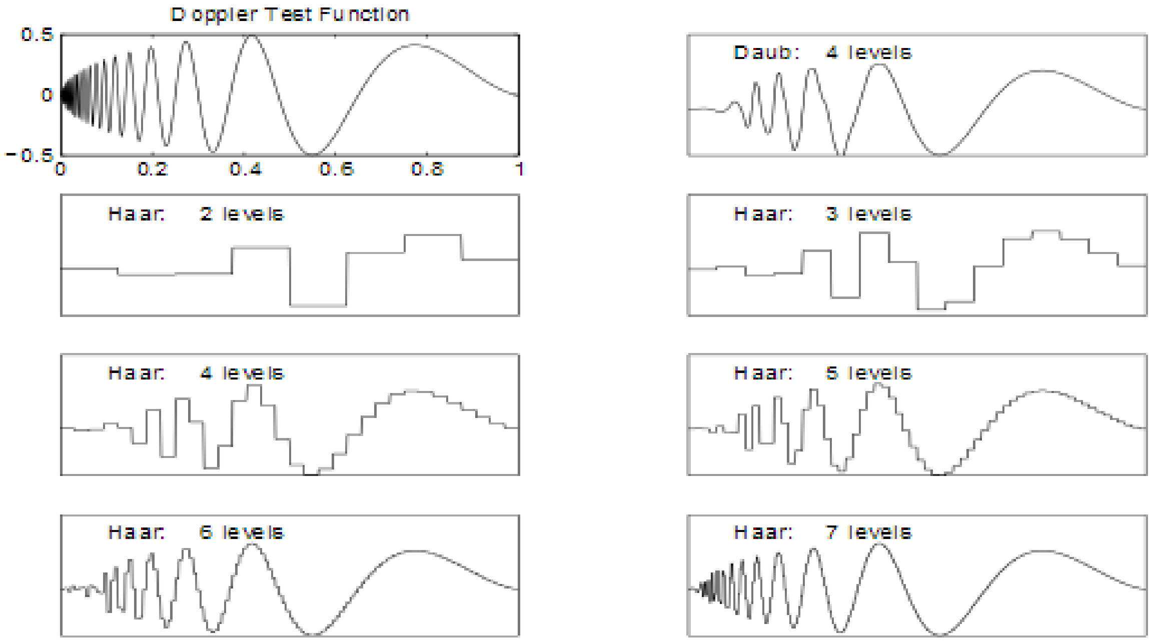
Step2: shift the wavelet to the right and repeat step 1 until the whole signal is covered



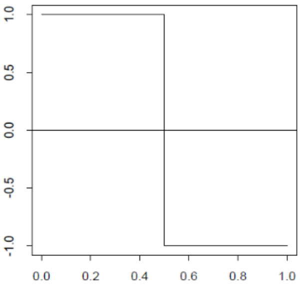
Step3: scale (stretch) the wavelet and repeat steps 1 and 2

Example of wavelet transform

$$f(t) = t(1-t)\sin\left(\frac{2.1\pi}{t+0.05}\right)$$



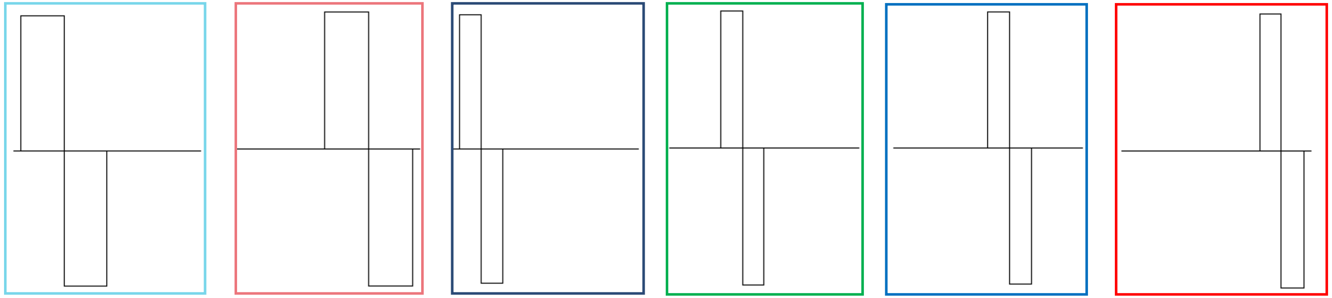
Example of wavelet transform

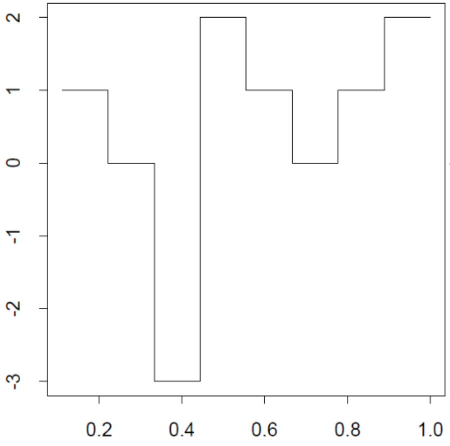


Haar wavelet

shift

scale





$$f = \frac{1}{2}\phi - \frac{1}{2}\psi_{00} + \frac{1}{2\sqrt{2}}\psi_{10} - \frac{1}{2\sqrt{2}}\psi_{11} + \frac{1}{4}\psi_{20} - \frac{5}{4}\psi_{21} + \frac{1}{4}\psi_{22} - \frac{1}{4}\psi_{23}$$

$$\phi(x) = \mathbf{1}(0 \leq x < 1)$$

The Wavelet Transform in Matlab

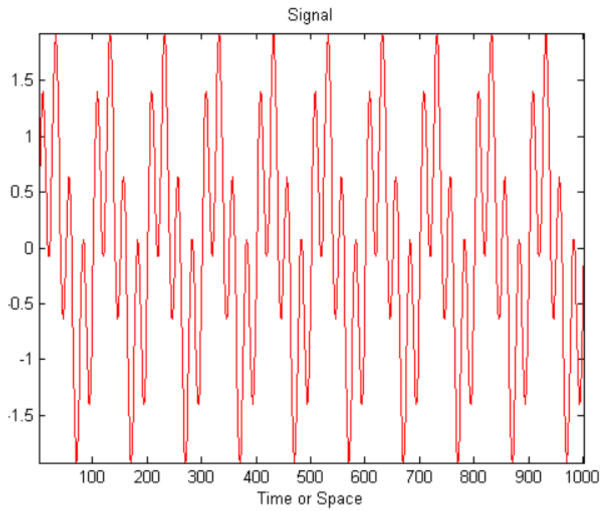
Consider the following data x with two component frequencies components

10 Hz component

40 Hz component

Sample frequency (Hz)

```
F1 = 10;
F2 = 40;
Fs = 1000;
t = 0:1/Fs:1;
x = sin(2*pi*t*F1) + sin(2*pi*t*F2);
clf; plot(x,'r');
axis tight
title('Signal');
xlabel('Time or Space')
```



The Wavelet Transform in Matlab

The scalogram is a visual method of displaying a spectrum of frequencies over time.
There are 3 axes: x representing time, y representing scale, and z representing wavelet coefficient value

Wavelet name

scales

```
wname = 'gaus4';
scales = 1:1:128;
TAB_Sca2Frq = scal2frq(scales,wname,1/Fs);
[~,idxSca_1] = min(abs(TAB_Sca2Frq-F1));
Sca_1 = scales(idxSca_1)
[~,idxSca_2] = min(abs(TAB_Sca2Frq-F2));
Sca_2 = scales(idxSca_2)
```

table of scales and frequencies

Scale for frequency F1

Scale for frequency F2

Using the function scal2freq, we compute the correspondence table of scales and frequencies for the **gaus4** wavelet.
Then, we find the scales corresponding to the frequencies **F1 = 10** and **F2 = 40**.

The Wavelet Transform in Matlab

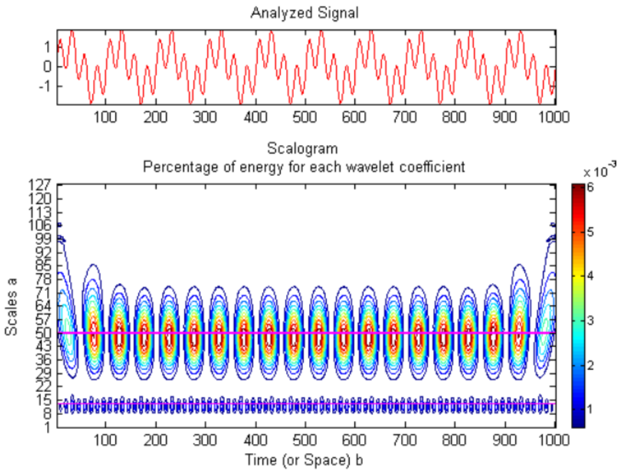
coefs = cwt(x,scales,'*wname*‘,’scalCNT’) computes the continuous wavelet transform (CWT) coefficients of the real-valued signal x at real, positive scales, using wavelet *'wname'* and displays a contour representation of the scalogram

```
clf;
coefs = cwt(x,scales,wname,'scalCNT');
hold on
plot([1 size(coefs,2)],[Sca_1 Sca_1],'Color','m','LineWidth',2);
plot([1 size(coefs,2)],[Sca_2 Sca_2],'Color','m','LineWidth',1);
```

Wavelet coefficients

Highlight frequency component F1

Highlight frequency component F2



The Wavelet Transform in Matlab

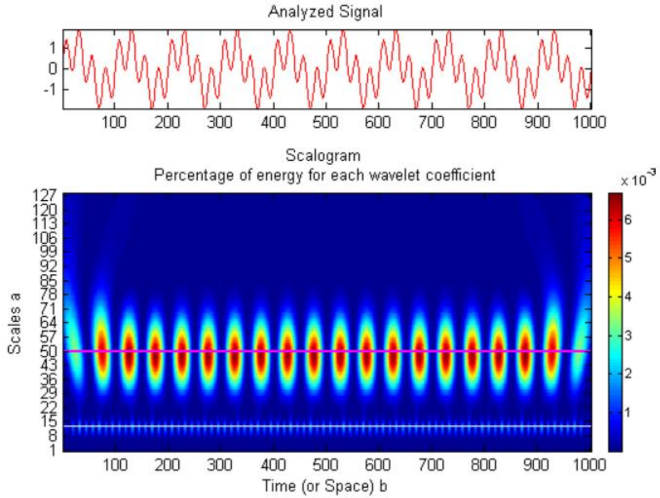
wscalogram('image',coefs,'scales',scales,'ydata',x) computes the scalogram SC which represents the percentage of energy for each coefficient.

```
clf;
wscalogram('image',coefs,'scales',scales,'ydata',x);
hold on
plot([1 size(coefs,2)],[Sca_1 Sca_1],'Color','m','LineWidth',2);
plot([1 size(coefs,2)],[Sca_2 Sca_2],'Color','w','LineWidth',1);
```

Wavelet scalogram

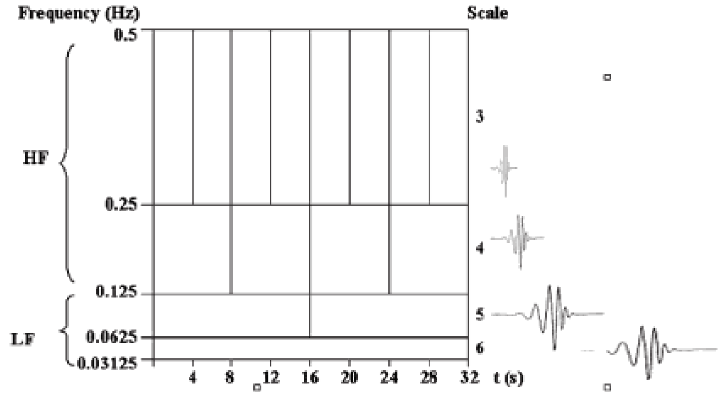
Highlight frequency component F1

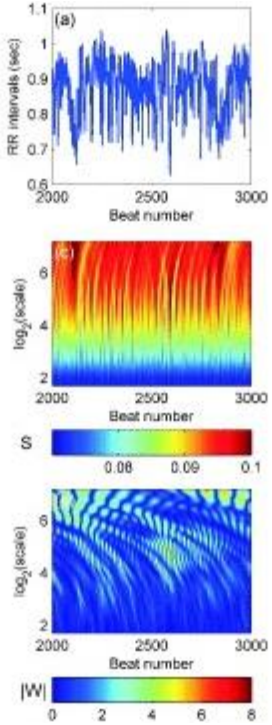
Highlight frequency component F2



Heart rate variability with Wavelets Transform

- Discrete WT can be performed using a Daubechies 4 wavelet with 6 logarithmically progressing scales
  - scale 1 and 2 correspond to 0.5-2 Hz
  - scales 3 and 4 correspond approximately to HF (0.125 –0.5 Hz)
  - scales 5 and 6 correspond to LF (0.03125 – 0.125 Hz).





http://www.mathworks.com/help/wavelet/examples/wavelet-scalogram-using-1d-wavelet-analysis.html

Exercice 1: RR Interval measurement with BIOPAC

- **Biopac MP35 measurement system**
  - ECG is recorded using Biopac SS2L wires plugged in the first channel.
- **Biopac Student Lab PRO software**
  - The acquisition is set up at a sampling rate of *200 Hz*.
  - Analog Channel CH1 should have the preset ECG (.5 - 35 Hz).
  - Calculation Channel C1 should have the preset ECG – RR Interval

Heart Rate Variability with Matlab

- Importing RR intervals from Biopac into Matlab
  - File -> Save as text

Resample from 200 Hz to 4 Hz

```
Fs = 4;
x = resample (RR, Fs, 200)
clf; plot(x,'r');
axis tight
title('Signal');
xlabel('Time or Space')
```

Heart Rate Variability with Matlab

Wavelet name

scales

```
wname = 'gaus4';
scales = 1:1:128;
TAB_Sca2Frq = scal2frq(scales,wname,1/Fs);
LF = (0.15-0.04)/2;
HF = (0.4-0.15)/2;
[~,idxSca_1] = min(abs(TAB_Sca2Frq-LF));
Sca_1 = scales(idxSca_1)
[~,idxSca_2] = min(abs(TAB_Sca2Frq-HF));
Sca_2 = scales(idxSca_2)
```

table of scales and frequencies

Scale for LF frequency 0.04 – 0.15 Hz

Scale for HF frequency 0.15 – 0.4 Hz

Heart Rate Variability with Matlab

```
clf;
coefs = cwt(x,scales,wname,'scalCNT');
hold on
plot([1 size(coefs,2)],[Sca_1 Sca_1],'Color','m','LineWidth',2);
plot([1 size(coefs,2)],[Sca_2 Sca_2],'Color','m','LineWidth',1);
```

Wavelet coefficients

Highlight LF frequency component

Highlight frequency HF component

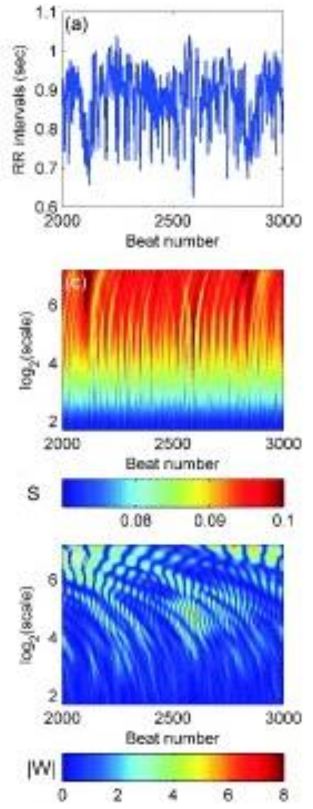
Heart Rate Variability with Matlab

```
clf;
wscalogram('image',coefs,'scales',scales,'ydata',x);
hold on
plot([1 size(coefs,2)],[Sca_1 Sca_1],'Color','m','LineWidth',2);
plot([1 size(coefs,2)],[Sca_2 Sca_2],'Color','w','LineWidth',1);
```

Wavelet scalogram

Highlight LF frequency component

Highlight HF frequency component



Exercice 2: HRV with wavelet transform during breathe holding

- **Procedure**
  - Subject is instrumented for ECG measurement with Biopac.
  - Take a couple minutes relaxation before the experiment
  - Perform a 1 min recording in a sitting position while breathing normally.
  - Perform another recording while the subject *exhales and empties the lungs; then immediately holds breathing as long as possible.*
  - Perform another 1 min recording while breathing normally
- **Evaluation**
  - Export the data from BSL Pro as txt File (Edit →Clipboard →Copy Wave Data).
  - Import the data into Matlab using tdfread or csvread
  - Estimate the total power of each frequency band (LF and HF) using Matlab wavelet transform functions: cwt, waveinfo, scal2frq, wscalogram.
    - Reveal the change in the power of HF component over the time

Exercice 3: HRV with wavelet transform during active standing

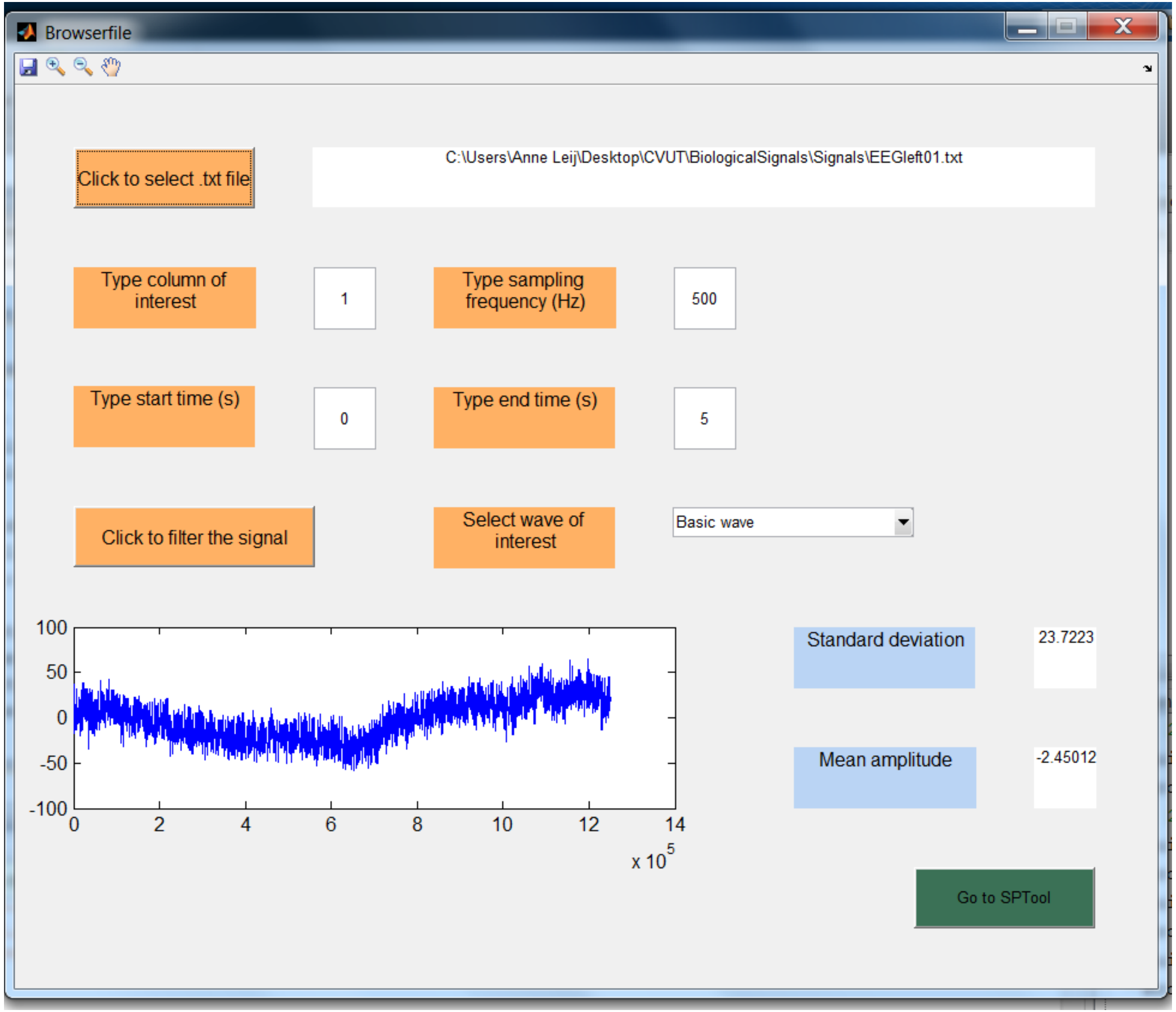
- **Procedure**
  - Subject is instrumented for ECG measurement with Biopac.
  - Perform a 1 min recording in a sitting position.
  - Perform another 1 min recording while the subject *actively stands up from the sitting position.*
  - Perform a 1 min recording in a sitting position.
- **Evaluation**
  - Export the data from BSL Pro as txt File (Edit →Clipboard →Copy Wave Data).
  - Import the data into Matlab using tdfread or csvread
  - Estimate the total power of each frequency band (LF and HF) using Matlab wavelet transform functions: cwt, waveinfo, scal2frq, wscalogram.
    - Reveal the change in the power of HF and LF components over the time

Team Projects

- **Project 1: Cardiovascular Signal Analyzer**
  - Digital filtering of a raw PPG signal
  - Extraction of PH (pulse height) and PP (peak-to-peak) values from a filtered PPG signal
  - MAP estimation using PH
  - Fourier transform of PP intervals and estimation of HF and LF
  - Implementation in Matlab, if possible with an interactive GUI
    - User should be able to import the raw signal import from a Biopac text export
    - User should be able to enter the sampling frequency, signal type (ECG or PPG or both) and channel numbers
    - User should be able to filter the raw signal
    - User should be able to execute PP, PH, MAP, LF, HF computation
    - User should be able to display plots of the raw signal for a given start and end timestamp
    - User should be able to display plots of PP, PH, MAP over the time for a given start and end timestamp and display the value of LF and HF

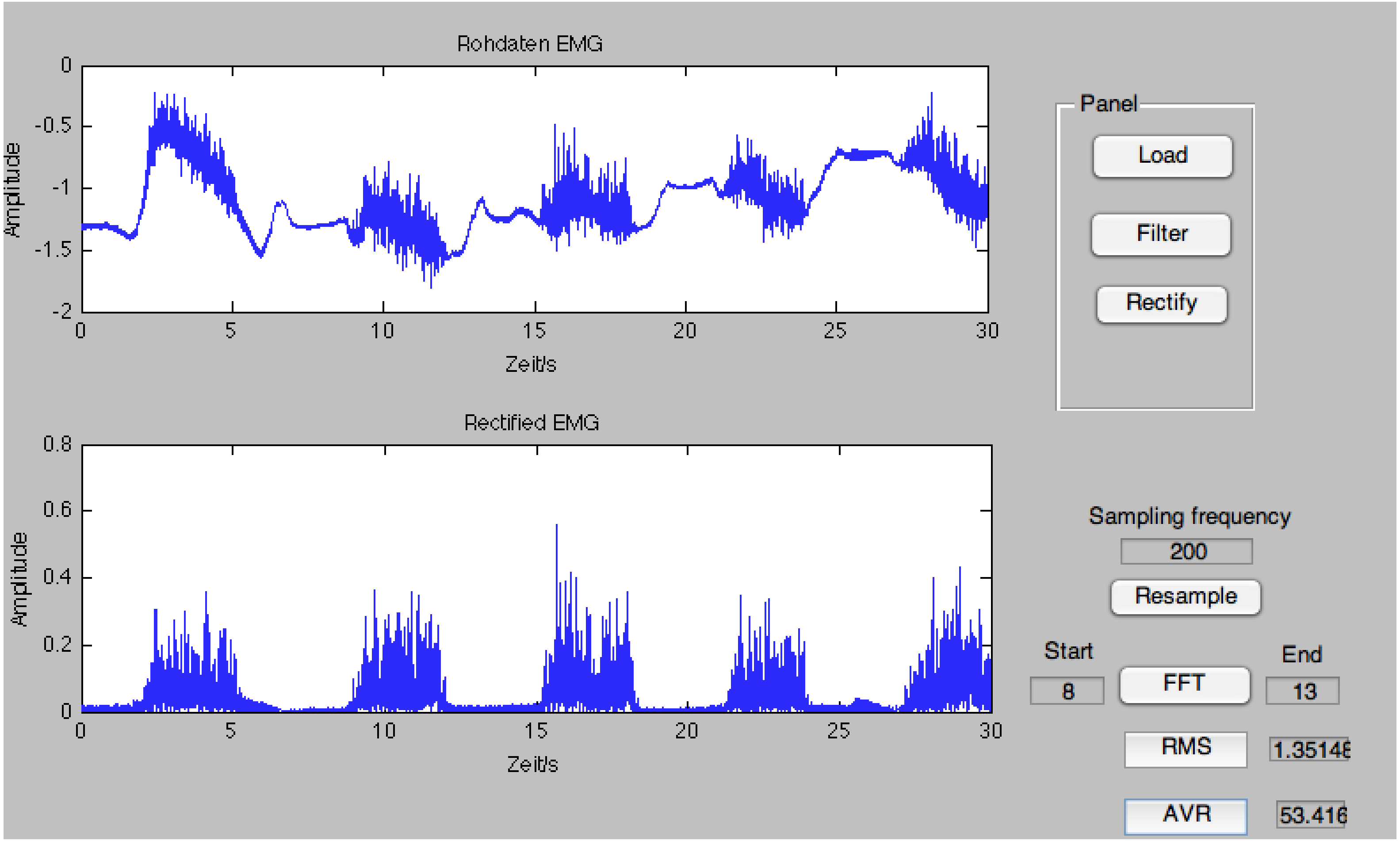
Team Projects

- **Project 2: Nervous Activity Analyzer**
  - Digital filtering of a raw EEG signal
  - Extraction of alpha, beta, theta, delta waves from a filtered EEG signal
  - Computation of STD, AVG and CC
  - Implementation in Matlab, if possible with an interactive GUI
    - User should be able to import the raw signal import from a Biopac text export
    - User should be able to enter the sampling frequency
    - User should be able to filter the raw signal
    - User should be able to execute alpha, beta wave, theta, delta wave computation using Fourier or Wavelet transform or digital filtering
    - User should be able to execute STD, AVG, CC computation
    - User should be able to display plots of the raw signal for a given start and end timestamp
    - User should be able to display plots of alpha, beta wave, theta, delta waves over the time for a given start and end timestamp and display the values for STD, AVG and CC


Browserfile
Click to select .txt file
C:\Users\Anne Leij\Desktop\CVUT\BiologicalSignals\Signals\EEGleft01.txt
Type column of interest
1
Type sampling frequency (Hz)
500
Type start time (s)
0
Type end time (s)
5
Click to filter the signal
Select wave of interest
Basic wave
100
50
0
-50
-100
0
2
4
6
8
10
12
14
x 10^5
Standard deviation
23.7223
Mean amplitude
-2.45012
Go to SPTool

Team Projects

- **Project 3: Muscle Activity Analyzer**
  - Digital filtering of a raw EMG signal
  - Computation of rectified EMG from a filtered EMG signal
  - Computation of the spectrum of the filtered EMG signal using Fourier transform
  - Computation of RMS, ARV
  - Implementation in Matlab, if possible with an interactive GUI
    - User should be able to import the raw signal import from a Biopac text export
    - User should be able to enter the sampling frequency
    - User should be able to filter the raw signal
    - User should be able to execute rectified EMG computation
    - User should be able to execute Fourier transform of the rectified EMG for a given start and end timestamp
    - User should be able to execute RMS, ARV computation for a given start and end timestamp
    - User should be able to display plots of the raw EMG, rectified EMG, EMG Fourier transform for a given start and end timestamp
    - User should be able to display the values for RMS, ARV for a given start and end timestamp


Rohdaten EMG
Amplitude
Zeit/s
Panel
Load
Filter
Rectify
Rectified EMG
Amplitude
Zeit/s
Sampling frequency
200
Resample
Start
8
FFT
End
13
RMS
1.35148
AVR
53.416