Telecommunications
Group project

MICA project : Matlab implementation of a cardiologist assistant

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Introduction

The aim of the MICA project (Matlab Implementation of a Cardiologist Assistant) was to create an intuitive application that could be used by cardiologists during medical examination. The application is used by providing previously acquired electrocardiograms. The following key features were sought :

- **Display of an electrocardiogram (ECG)** : the application is capable of displaying an ECG on precise intervals and truncate the signal according to the user's choice
- **Analysis of ECG** : the assistant detects and displays PQRST[1] waves and corresponding intervals. In addition to the graphs, useful statistics are calculated and displayed (such as BPM rate).
- **Detection of pathologies** : a global analysis of the signal warns the doctor of potential illnesses. Nevertheless, the application is an assistant therefore it should not replace medical opinion but only assist cardiologists while taking precautions
- **Data export** : the cardiologist is able to export the selected part of the signal but also the result of the analysis that contains the automatic detection report. A personal typed report can also be attached. These functions enables to offer his examination to another specialist.

Algorithms are discussed in section 1 and the details of the application in section 2.

[1]PQRST : these are specific defined in relation to the hearbeat

1 Used algorithms and back-end details

1.1 Detection of P, QRS and T waves

The Pan Tompkins algorithm developped in 1985 by its creators, was used to detect R waves and QS locations.[1]

1.1.1 R wave detection

This algorithm can be sliced into six main steps as shown in Figure 1. Processing is based on the detection of sudden variations in signal amplitude. These very sharp variations allows a robust analysis to be made.[2].

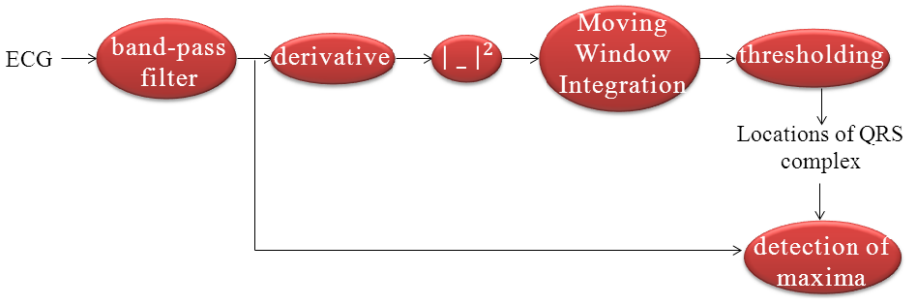

Figure 1: Pan and Tomkins algorithm

R waves have a maximum energy in the 5 - 15 Hz band. For this reason a band-pass filter was required to reduce noise present outside of this band. A band-pass filter is a combination of a low-pass filter and a high-pass filter. The transfer function of the low-pass (H_1) and the transfer function (H_2) were given by :

$$H_1(Z) = \frac{(1 - Z^{-6})^2}{(1 - Z^{-1})^2} \tag{1}$$

$$H_2(Z) = \frac{-1 - 32Z^{-16} - 32Z^{-17} + Z^{-32}}{1 - Z^{-1}} \tag{2}$$

The low-pass filter delays the signal by 6 samples. Whereas the high-pass filter does not have a constant group delay, but it has an average a delay of 16 samples. A consequence of this band-pass filtering was the increasing amplitude of the ECG signal.

The QRS complex is brief and has a high amplitude, consequently its derivative has high maximum values clearly recognisable by peaks. A five-point differentiation filter was used to provide the QRS complex slope information. The transfer function of the derivative filter is given by :

$$H_3(Z) = \frac{1}{8T_s}(-Z^{-2} - 2Z^{-1} + 2Z^1 + Z^2) \tag{3}$$

The group delay of this filter is zero. However, by making the filter causal, a group delay of 2 samples was created. Properties of previously filters are detailed in Figure 3.

Then, the signal was squared to intensify the local extrema and a moving-window integration was required to obtain a unique maximum for each complex. The equation used was :

$$s_{MWI}(n) = \frac{1}{N} \sum_{i=0}^{N-1} s_{sq}(n-i) \tag{4}$$

Notations are :

- s_{sq} the samples of the ECG after the squaring step
- s_{MWI} the output of the moving-window integration and N the window integration size

It requires that N was adapted to the average width of the QRS complex. If the window was too wide, T waves would have interfered. On the contrary, if the window was too small, multiple P waves would have been obtained. Therefore the window integration size was determined with the average width of a QRS complex (0.15/2 s). The equation below was established to obtain a width N in number of samples:

$$N = 0.15 * F_s - 1 \tag{5}$$

The 1-offset enabled the delay to be an entire value which simplified later calculations. This delay was compensated by adding the offset :

$$delay_{MWI} = \frac{N-1}{2} \tag{6}$$

The thresholding step consisted in researching maxima without taking into consideration the excessive low maxima which could be generated by T waves or noise. The threshold was obtained by calculating the average of the signal obtained previously. Figure 2 illustrates the result of the process.

Thanks to the previous step, the locations of QRS complexes were defined. Finally, R waves were found by detecting the maxima-positions in each QRS complex.

1.1.2 Q and S wave detection

Once the R waves were located, Q waves were defined as the first minimum between the beginning of the QRS complex and the R wave location. Similarly, S waves were defined as the minimum between the R wave location and the end of the QRS complex.

However, locations of QRS waves were delayed by the Pan and Tompkins algorithm. To obtain wave locations in the patient ECG time frame, a delay-compensation was necessary (this delay was called delay_PT in the Matlab code and was equal to 37 samples). Figure 5 illustrates the QRS detection on the signal egc_normal_1.m.

1.1.3 P and T wave detection

P and T waves can be detected by using the locations of the R waves. The R-R interval was considered.

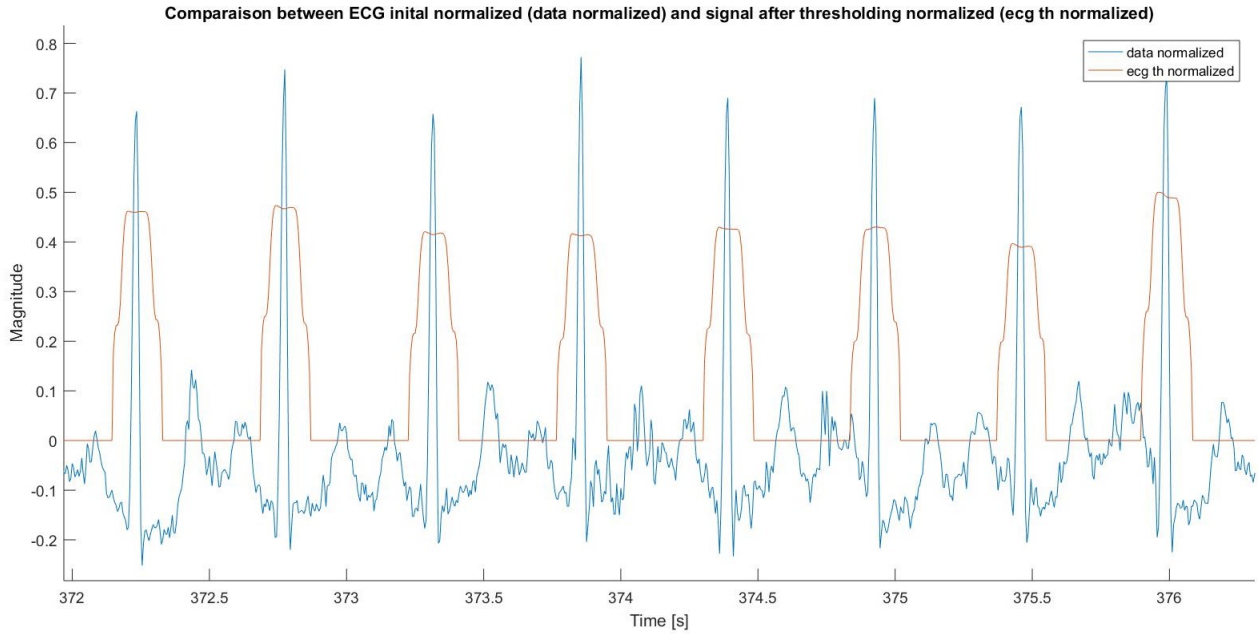

Figure 2: Time comparison between ECG and signal after threshold

Filter	Nature	Type	Group delay (samples)	Stability	Phase
H_1	Low-pass	IIR	5	No	Linear
H_2	Hight-pass	IIR	15	No	No linear
H_3	5-point differentiation	FIR	2	Yes	Linear

Figure 3: H Filter properties

To detect the T and P waves, a three-step processing was used (based on [3]). The first step consisted of filtering the EGC signal with a differentiator. This filter allowed maxima to be revealed. The transfer function was given by :

$$G_1(Z) = 1 - Z^{-6} \tag{7}$$

The group delay of the differentiator was 3 samples. The second step was to use a low-pass filter to reduce noise and to smooth the curve. This filter used the following transfer function and had a group delay of 3.5 but a round was used to obtain an entire delay : 4 samples.

$$G_2(Z) = \frac{1 - Z^{-8}}{1 - Z^{-1}} \tag{8}$$

The properties of previous filters are detailed in Figure 4.

In order to compare positions between the filtering signal and the ECG, the ECG signal was delayed. Then, for each R wave :

- between 0.2 and 0.7 times the R-R interval after the R peak, one of the signal zero-crossings has to be tagged as T wave location. For this reason, the maximum of the previous positions was used on the ECG to determine the T wave.

Filter	Nature	Type	Group delay (samples)	Stability	Phase
G_1	Differentiator	FIR	2	Yes	Linear
G_2	Low-pass	IIR	3,5	No	Linear

Figure 4: G Filter properties

- based on the same method, the Q wave was detected between 0.1 and 0.25 times of the R-R interval before the R peak.

Different intervals were used. They were established to avoid detecting waves that do not match.

Finally, to obtain T and Q wave locations on the ECG signal, the delay had been removed. The P,Q,R,S and T wave locations are displayed in the Figure 5 below :

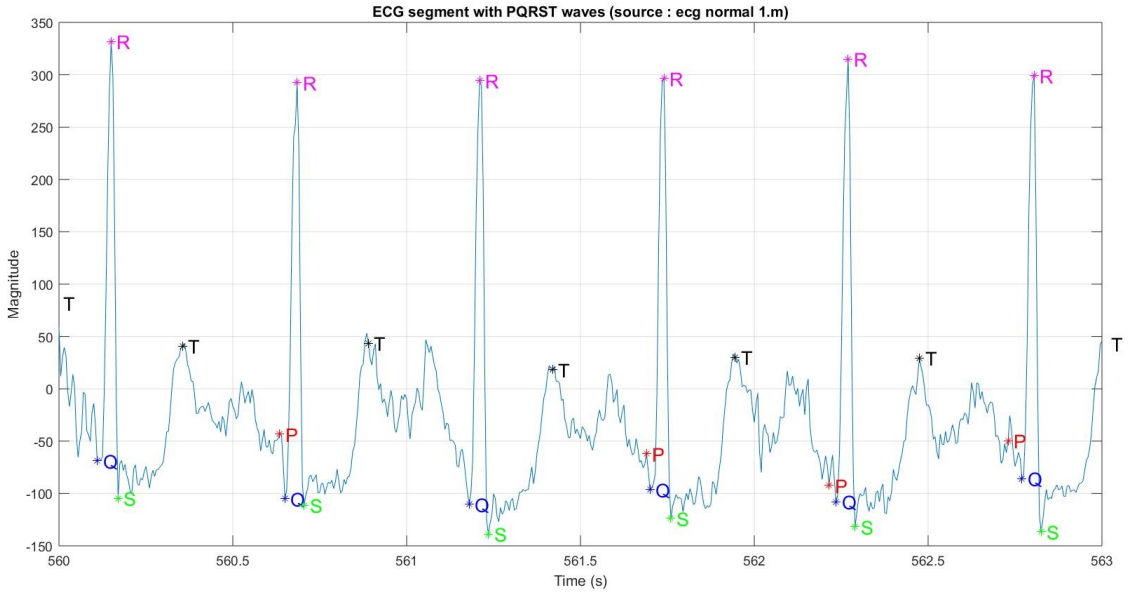

Figure 5: Locations of PQRST waves in a random segment

1.2 Automatic identification of cardiac pathologies

1.2.1 Tachycardia / Bradicardia

Tachycardia and Bradicardia pathology detection were based on the inspection of the cardiac rhythm. To establish the cardiac rhythm in an ECG, the mean of all R-R occurrences was used. The R-R interval was defined as : $\Delta_n = t_{n+1} - t_N$ where t_n was the position of the n-th R peak. Therefore, the cardiac rhythm estimated in a signal of N R peaks was calculated by the following equation:

$$\text{cardiac rhythm estimated} = \frac{1}{N}\sum_{n=0}^{N-1}\Delta_n \tag{9}$$

Once the cardiac rhythm was estimated, the detection was performed due to the table Figure 8 (page 10).

1.2.2 Ectopic beat

Ectopic beats, also called Premature Ventricular Contraction (PVC) were detected after comparison to a threshold ϵ. This detection was realized on 2 R-R intervals that was respectively preceeding and following the heartbeat. After calculating R-R intervals of the ECG, the threshold was calculated as follows :

$$\epsilon|_{time} = \textit{Limit length QRS complex} - \textit{Normal length QRS complex} \tag{10}$$

where the limit length of QRS complex was set at 0.12ms and the normal length QRS complex was set at 0.8ms Those values were extracted from medical reports ([2], [4].

Then, those average lengths were converted into a threshold as given by the equation:

$$\epsilon|_{sample} = \epsilon|_{time}.F_s \tag{11}$$

To obtain the number of PVC detected, the following equation was verified for each R-R interval :

$$|\Delta_n - \Delta_{n-1}| \geq \epsilon \tag{12}$$

and the PVC counter was increment if the criteria of detection was respected.

2 Graphical application (front-end)

The ergonomics of the application was optimised to be conveniently usable but still provide detailed reports. The graphical interface was divided into three tabs in which the user can navigate at his convenience :

- Signal importation
- Setting analysis parameters
- Analysis results

2.1 Signal importation

This tab was implemented as the welcome page. The "Load from file" button was developed in order to open a dialog window for file selection. Then the values of interest were extracted from file and checked to ensure that the given file format is usable.

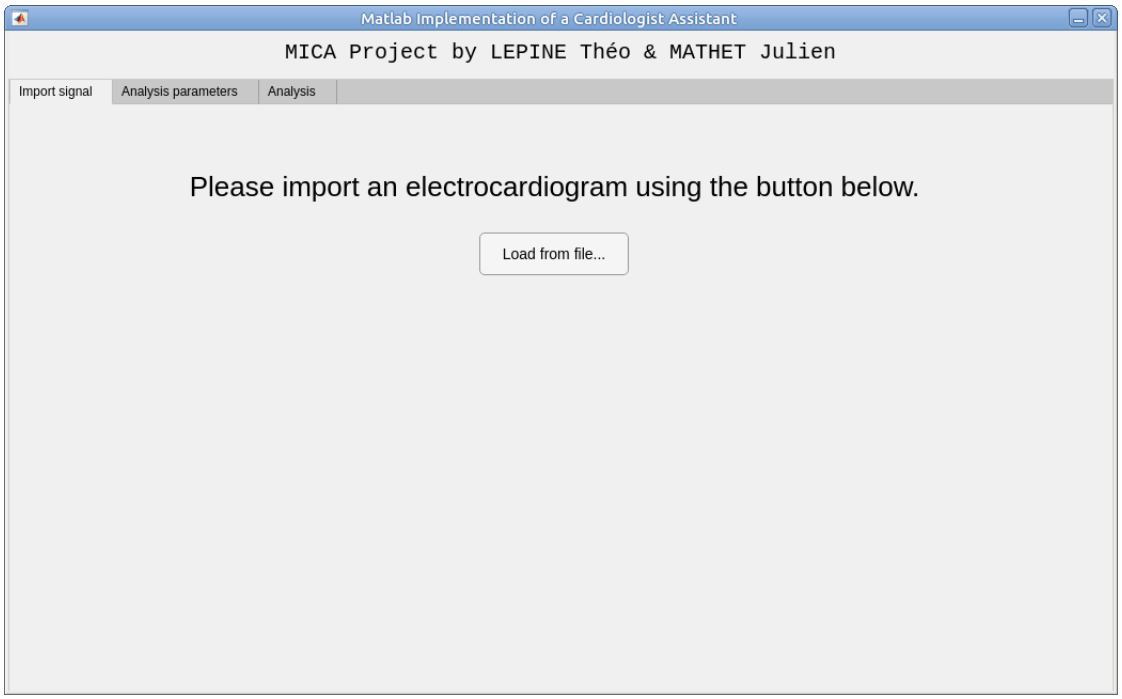

Figure 6: Screenshot of the signal importation tab

The unwary user is notified by an error dialog box.

2.2 Analysis parameters

The objectives of this tab were to offer a pleasant and graphical module to select the interval of analysis. This issue is crucial because it is often annoying to find an appropriate window.

The solution was designed by using cursors for lower and upper limits. Those cursors were placed below the graphics and have the same time axis as the plotted signal. In this

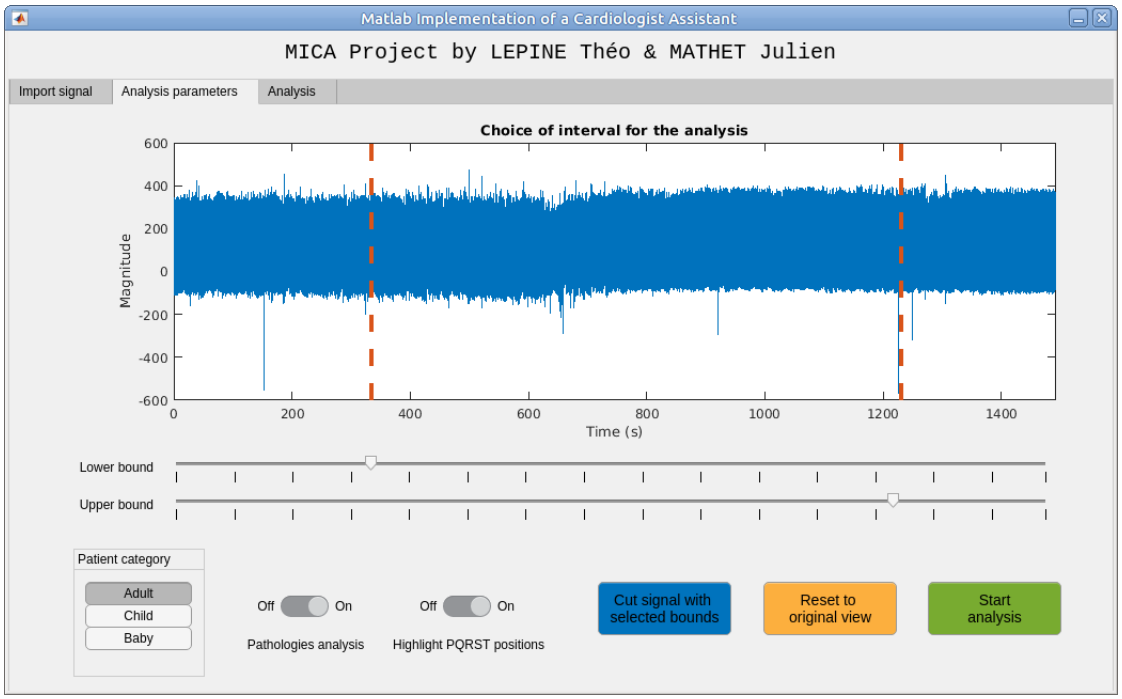

Figure 7: Screenshot of analysis parameters tab

way, when the user wants to restrict the interval, he can simply drag-and-drop the cursor. Delimiters were also added to instantly indicate the selected interval.

The blue button was also added to provide an easy solution for re-sizing. Due to the "Cut signal" function, the ECG can be restricted multiple times in order to analyse a very precise part of the original signal. Nevertheless, the cardiologist can restore the original signal by pressing the orange "Reset" button.

In the lower left corner, the doctor is able to provide information on his patient like his age group. This characteristic is used to provide a more accurate pathology prediction by selecting more precise intervals for tachychardia and bradychardia detection depending on the age. Used intervals are given in Table 8, according to data collected from **??**.

The cardiologist was also asked for the desired functionalities displayed in the analysis result tab.

2.3 Results of analysis

The final tab was created to clearly reveal potential key points that requires cardiologist attention. Thanks to colorful graphical feedback, pathology detection results were reported according to three different levels :

- **Green light** : everything seemed to be clear, doctor confirmation is suggested
- **Orange light** : a disease has been detected but this could be a false positive as the occurance is close to the upper limits detection
- **Red light** : an alarming situation is detected and requires doctor's attention

Statistics were also calculated to assist in the interpretation of graphs.

An export module is also available to issue a detailed report containing doctor's interpretation and automated analysis.

Patient category	Cardiac rhythm	Tolerance level / Pathology
Adult	[0; 60[	Dangerous bradycardia
	[60; 80[	Suspicious bradycardia
	[80; 100[	Clear
	[100; 120[	Suspicious tachycardia
	[120; +∞[	Dangerous tachycardia
Child	[0; 62[	Dangerous bradycardia
	[62; 96[	Suspicious bradycardia
	[96; 116[	Clear
	[116; 151[	Suspicious tachycardia
	[151; +∞[	Dangerous tachycardia
Baby	[0; 106[	Dangerous bradycardia
	[106; 136[	Suspicious bradycardia
	[136; 156[	Clear
	[156; 186[	Suspicious tachycardia
	[186; +∞[	Dangerous tachycardia

Figure 8: Decision table of bradychardia / tachycardia according to patient category and cardiac rhythm

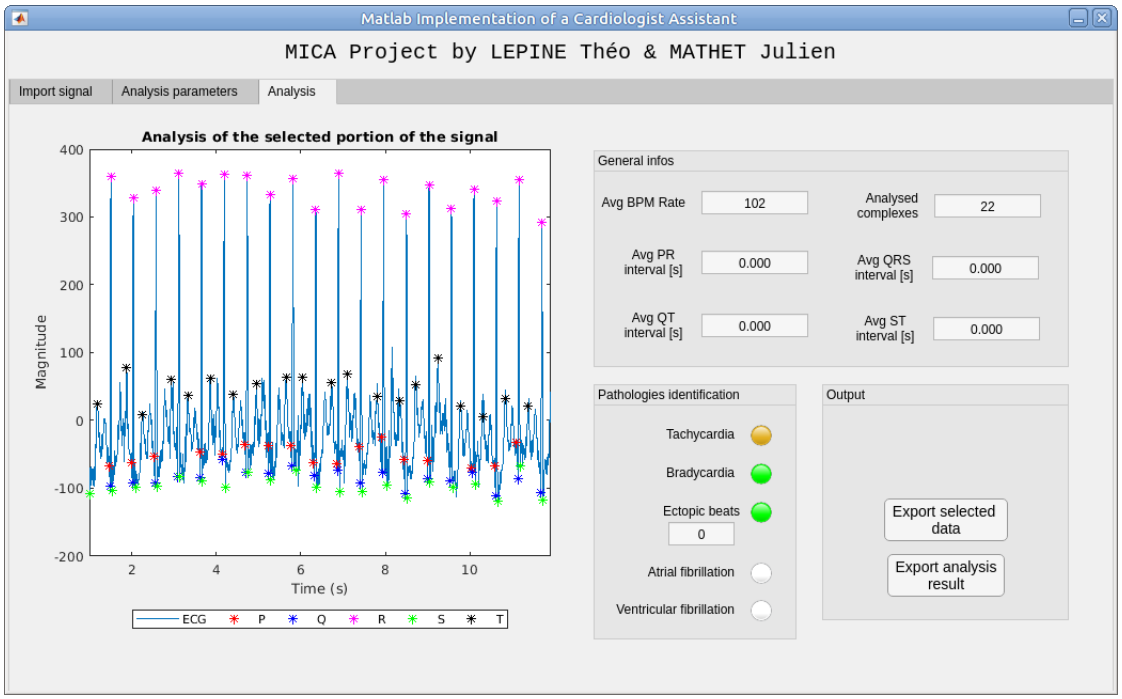

Figure 9: Screenshot of the analysis result

Conclusion

The proprieties of an electrocardiogram can efficiently be extracted using the Pan and Tompkins algorithm. It enables the pathology estimation to be obtained. The possible improvements increase the number of detected pathologies, optimise the analysis to increase its robustness and integrate other external data (like blood pressure) to create a wider automated diagnosis.

The application can also help a cardiologist avoid medical errors and improve his efficiency. The current program is an assistant but it could lead to fully automated diagnoses based on techniques developed in this project. The user friendly interface is adapted for cardiologist, but it could be reusable for general use with minor changes.

References

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