BME 313 Bioinstrumentation

Fall 2021

Laboratory #4 – ECG

Team Lakers

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November 15, 2021

Introduction

The main objective of this lab experiment is to understand how an electrocardiogram (ECG) works by creating an electrocardiogram using a circuit and sensors on the body. An ECG is a method that is used to collect electrical signal data that originated from the heart. Electrodes are placed on the body and collect signals based on the depolarization and repolarization of the atrium and ventricles of the heart. The human heart has four chambers: right atrium, left atrium, right ventricle, and left ventricle as seen in **Figure 1.** The blood first starts in the right atrium of the heart. When the atrium contracts, it pushes the blood into the right ventricle through the tricuspid valve (Mayo Clinic). The cardiac cells depolarize which is shown through a wave called the P wave on a ECG as seen in **Figure 2**. When the ventricles contract and push the blood to the pulmonary artery through the pulmonary valve, these cardiac cells depolarize and can be seen on an ECG as a "QRS" wave. When the ventricle relaxes, it is shown on the ECG as a T wave. The atrium will also relax (before ventricular contraction), but it is not seen on the ECG since the signal from the ventricles is so large and overshadows the atrial relaxation signal. Understanding the electrical activity, volume, and pressure in the left ventricle is pertinent in understanding how an ECG works because it can explain how the blood is pushed around the heart. After the blood fills into the left ventricle from the left atrium, there is high ventricular pressure which closes the mitral valve (Klabunde, 2017). At this time, the volume in the ventricle is constant since there is no blood movement. When the pressure builds in surpasses the aortic pressure, the aortic valve will open allowing the blood to exit the heart. This causes a depolarization of the cardiac cells which is shown on the ECG as a QRS wave, as previously mentioned.

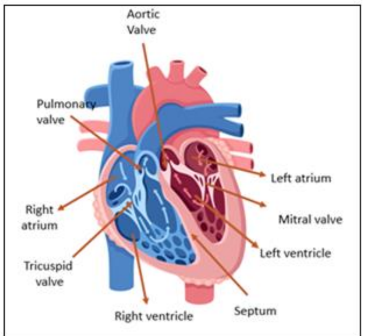

Figure 1. Parts of the Heart. Diagram of a human heart with the individual parts labelled

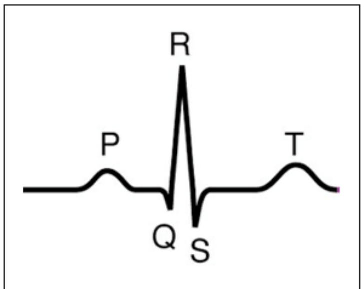

Figure 2. PQRST Sequence. ECG wave showing the electrical activity of the heart

Being able to read an ECG rhythm is very important because it can tell the condition of someone's heart. For example, multiple p waves in heart rhythm could indicate a 1st, 2nd, or 3rd degree heart block. Jagged peaks of QRS waves could indicate that there is a bundle branch block. Furthermore, the ability to read in ECG could help you understand if someone is having a lethal rhythm which could lead to death. These rhythms can include ventricular tachycardia, ventricular fibrillation, and even asystole, which means there is no cardiac signal detected (Lafferty, 2018). Because the heart and lungs are connected, breathing can affect the heart rate. When someone hyperventilates, their breathing becomes very rapid, and their heart rate increases. The physiological basis behind the heart rate change is due to the change in carbon dioxide. During hyperventilation, carbon dioxide levels lower which means the pH of the blood increases. The body exhibits a physiological response by stimulating the sympathetic nervous system which increases the heart rate. Looking at the heart itself, the SA node stimulates an electrical signal to the atria more often which leads lead to an increase in the beats per minute of the sinus rhythm shown in an ECG.

In this lab experiment, we are creating a circuit that will allow us to read an ECG using electrodes on the body, a high pass filter, low pass filter, non-inverting operational amplifier, and inverting operational amplifier. An application of this that can be used in bioinstrumentation is a portable heart monitor that has wireless electrodes on a patient's chest. This is a viable application because it will allow a patient to walk freely without having wires and could allow them to monitor their heart at home. Another application of this could be used in a research setting. For example, a scientist may introduce a visual stimulus and may want to understand what a person's heart does in response. An EKG would allow the researcher to map out the cardiac response in response to the original stimulus.

Methods and Materials

Theoretical

The procedure of this lab experiment can be broken into four parts: the inverting op amp, the high pass filter, the non-inverting op amp, and the low pass filter. **Figure 3** shows the entire configuration of the circuit board set up and is broken into board different parts based on color. The blue indicates the inverting op amp, the teal color indicates the high pass filter, the orange indicates the non-inverting op amp, and the purple represents the low pass filter. In the first section, an electrode is placed on both legs and a single arm of a team member. The student is connected to the inverting op amp using electrodes which detect the electrical signals and input them into the op amp to amplify the signal. An AD260 op amp is used for the inverting op amp with a10 kΩ resistor. To gauge the amount of gain, **Equation 1** was used. In the second portion of the experiment, a high pass filter is used to zero out the first turn inverting op amp. The resistor used was a 5.6 kΩ resistor and the capacitor used was a 1000 µF capacitor. In the third part, a non-inverting op amp amplifies the signal taken from the high pass filter. A 741 op amp was used for the non-inverting op amp 1 kΩ and 10 kΩ resistor. **Equation 2** was used to calculate the gain from the non-inverting op amp. In the fourth and final stage a low pass filter is used to remove noise from the signal so that there is no artifact displayed in the cardiac rhythm. The resistor used was a 1kΩ resistor and a capacitor with a value of 1µF.

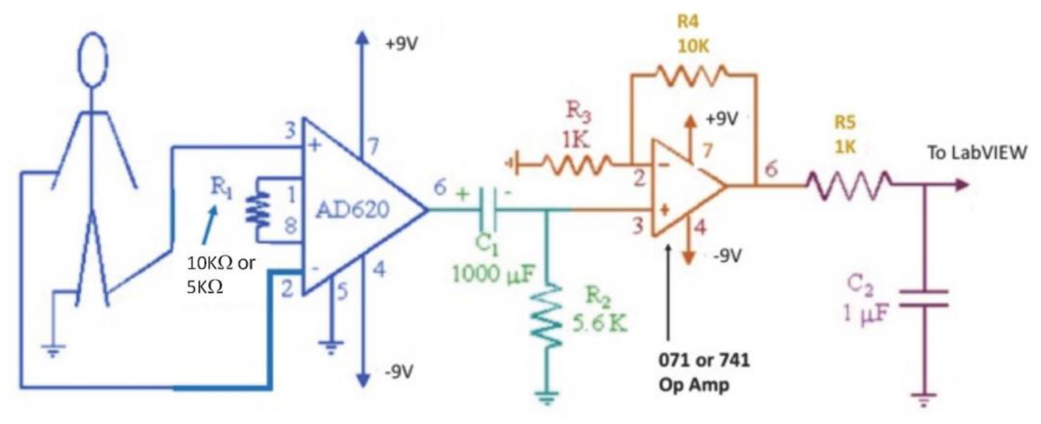

Figure 3. Theoretical drawing of complete ECG circuit. The circuit consists of four parts (separated by color) and uses a 741 op amp, AD620 op amp, two 9-volt batteries, two 10kΩ resistors, 5.6kΩ resistor, 1kΩ resistor, 1000µF capacitor, and 1µF capacitor.

$$Inverting\ Gain\ = \frac{49.4\ k\Omega}{R_G} + 1$$

Equation 1: Used to calculate the gain of the inverting operational amplifier.

$$Non - Inverting\ Gain\ = \frac{V_{out}}{V_{in}} = 1 + \frac{R_f}{R_{in}}$$

Equation 2: Used to calculate the gain of the inverting operational amplifier.

An inverting and non-inverting op amp were used in this experiment. For the inverting op amp, the AD260 op amp was used while a 741 op amp was used for the inverting op amp as seen in **Figure 4 and Figure 5.** The nominal resistance values were taken while the resistor ends were placed in both Pin 1 and Pin 8 of the AD260 op amp. While the rest of the pins are consistent between the two op amps, Pin 5 is different. Pin 5 in AD260 is a reference point for the output. Special attention should be given to Pin 2 and Pin 3 of the AD260 op amp and 741 op amp. On the AD260 op amp, the input is directed into Pin 2 which makes it an inverting op amp. In the 741 op amp, the input is directed into Pin 3 which makes it a non-inverting op amp.

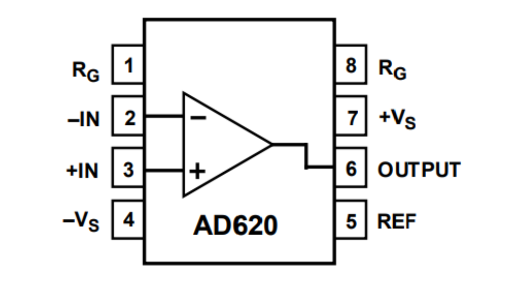

Figure 4. AD 260 Operational Amplifier. The diagram shows the pin configuration for the AD260 op amp.

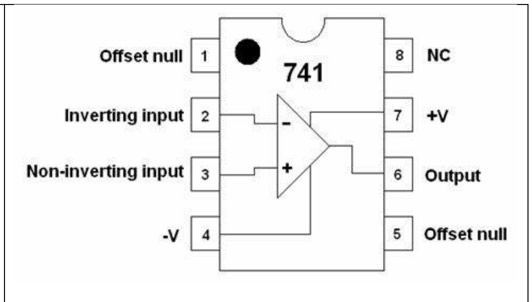

Figure 5. 741 Operational Amplifier. The diagram shows the pin configuration for the 741 op amp.

Experimental

The experimental portion of this lab was done using a breadboard that was connected to LabVIEW using a NI USB-6008 DAQ Card. The LabVIEW front panel and block diagram, **Figure 6,** are shown below to highlight that the output rate, points per cycle, offset, and amplitude were manipulated to display the cardiac rhythm.

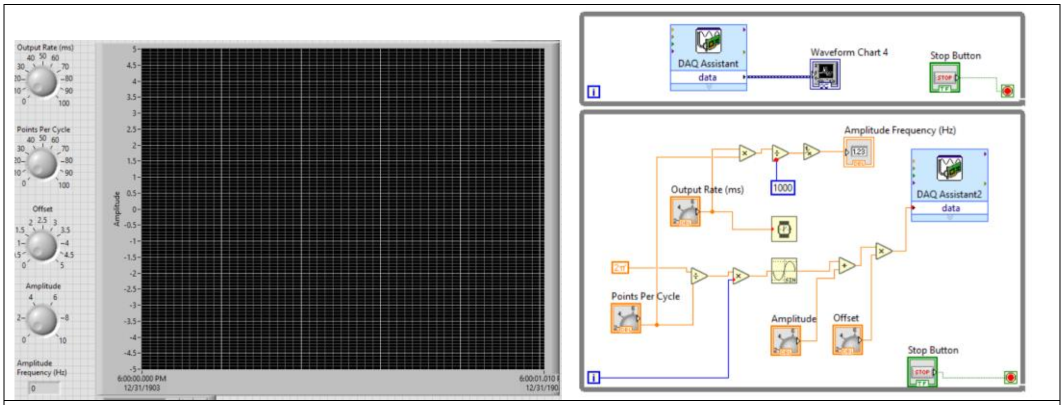

Figure 6. LabVIEW Front Panel and Block Diagram. The front panel (left) depicts the various dials that can be manipulated such as the output rate, points per cycle, offset, and amplitude. The block diagram (right) shows how the code layout of how the sine wave is generated.

The breadboard was connected to the DAQ assistant and two 9V batteries. The inverting op amp was created by placing a 10kΩ resistor in Pin 1 and Pin 8 as seen in **Figure 7.** A jumper wire was connected from AO1 of the DAQ card to Pin 2 to input the signal. Next, a high pass filter was created by placing a 1000 µF capacitor into the breadboard with one end in Pin 6 and was followed by a 5.6kΩ resistor which had one leg placed in the blue (ground) rail. The signal was outputted to the succeeding 741 op amp by placing a wire between the capacitor and resistor to Pin 3 of the 741 op amp. The non-inverting op amp was created after this by placing a

10kΩ resistor (R_f) in Pin 6 with its other leg in the blue (ground) rail, placing the 1kΩ resistor (R_{in}) below it, any by grounding Pin 2 by placing a wire between the two resistors. From Pin 6, a wire connected the op amp to the low pass filter. The low pass filter was configured by placing a 1kΩ resistor, then placing a 1μF capacitor with one leg in ground. Using alligator clips, each 9V battery was connected to the breadboard. The first battery had was connected to the positive terminal while the other was connected to the ground terminal. The second battery was connected to the positive terminal between the wires that connected to Pin 7 of both op amps. The first battery was connected the negative terminal between the wires that were connected to Pin 4 of both op amps.

To understand the difference between the theoretical and experimental gain values, **Equation 3** was used to calculate this difference. **Equation 4** was used to calculate the heart rate for the student subject by using the number of peaks in the rhythm and dividing that by the time difference. This was used to calculate both the resting and hyperventilating heart rates.

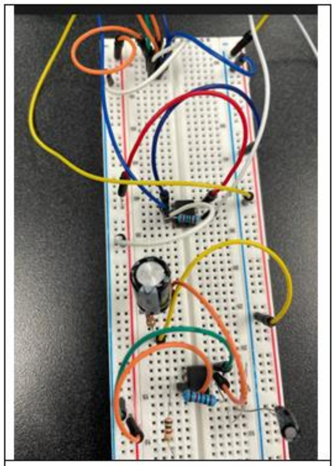

Figure 7. ECG breadboard. This image depicts the circuit created to make the ECG in this experiment. It uses a 741 op amp, AD620 op amp, two 9-volt batteries, two 10kΩ resistors, 5.6kΩ resistor, 1kΩ resistor, 1000μF capacitor, and 1μF capacitor.

$$Percent\ Difference\ (\%) = \frac{|A-B|}{\frac{(A+B)}{2}} \times 100$$

Equation 3: Used to calculate the percent difference between the theoretical and experimental values.

$$Heart\ Rate = \frac{Heart\ Rate\ (bpm)}{Time\ (min)} \Rightarrow \frac{Number\ \ of\ peaks}{Time\ Difference\ (s)} \times \frac{60\ sec}{1\ min}$$

Equation 4: Used to calculate the heart rate from the experimental results shown on LabVIEW.

Results

The data from both the theoretical and experimental portions of this laboratory experiment are displayed below.

Table 1: Resistor, Gain, and Battery Voltage values for the inverting, AD620 instrumentation amplifier.

	R_G Value (kΩ)	Gain	Voltage of Battery 1 (V)	Voltage of Battery 2 (V)
Nominal Values	10	5.94	9	9
Measured Values	9.75	6.10	8.58	8.41
Percent Difference (%)	2.5	2.69	1.68	6.44

Above in **Table 1** we recorded the R values, Gain and Battery voltage of the non-inverting apparatus. Using what we know to be the normal values we constructed the percent difference based on what was measured. The nominal values are all based on the values that the components are expected to give as stated directly on them.

Table 2: Resistor, Gain, and Battery Voltage values for the non-inverting, 741 operational amplifier.

	R_{in} Value (kΩ)	R_f Value (kΩ)	Gain	Voltage of Battery 1 (V)	Voltage of Battery 2 (V)
Nominal Values	1.0	10	11	9	9
Measured Values	0.96	9.81	11.31	8.79	8.52
Percent Difference (%)	4.0	1.9	2.81	2.33	5.33

In **Table 2** a similar process was done but the percent difference is higher in this table. We calculated a 4 percent in the "R_{in}" column and 11.31 in the "Gain" column. This shows some problems in possible areas of calculations, measuring or reading of the graph.

Table 3: Observed and LabVIEW calculated resting and hyperventilating heart rate values for each team member.

	Observed		**LabVIEW Calculated**	
	Resting Heart Rate (bpm)	**Hyperventilating Heart Rate (bpm)**	**Resting Heart Rate (bpm)**	**Hyperventilating Heart Rate (bpm)**
Kyla	64	96	76	90
Codey	76	90	72	86

Table 3, we took the individual heart rates of both Codey and Kyla. Resting and hyperventilating are shown with hyperventilating being a much higher rate than resting. Observed and LabVIEW Calculated show to have close values to each other. Though, in the LabVIEW there are some small changes.

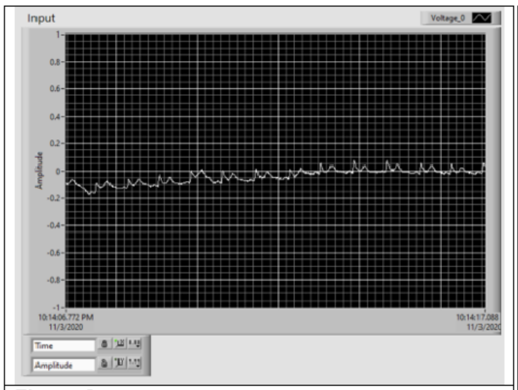

Figure 8. LabVIEW front panel of the resting heart rate. The signal data shown depicts the heart rhythm of the student when she was breathing normally.

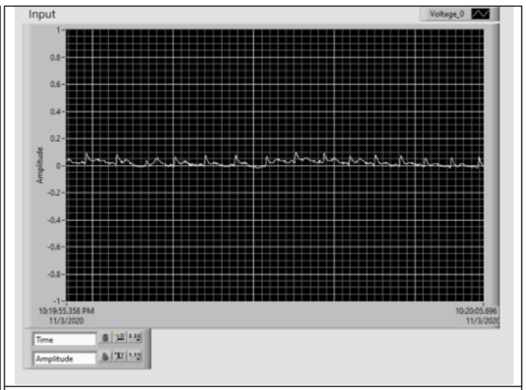

Figure 9. LabVIEW front panel of the hyperventilating heart rate. The signal data shown depicts the heart rhythm of the student when she was hyperventilating.

The experimental heart rates were calculated using the circuit created in the experimental portion of the experiment and are shown in Table 4. **Figures 8 and 9** and **Equation 4** were used to calculate these heart rates through the number of peaks and time difference in the graphs.

Table 4: Number of peaks and time differences for both resting and hyperventilating heart rate calculated from the LabVIEW display.

	Resting Heart Rate		**Hyperventilating Heart Rate**	
	Number of Peaks (beats)	**Time Difference (s)**	**Number of Peaks (beats)**	**Time Difference (s)**
Kyla	14	11	15	10
Codey	18	15	20	14

The values in **Table 4** show values from resting and hyperventilating heart rates but calculating number of peaks during the recording and the time difference. The number of peaks increased during hyperventilating, but the time difference decreased.

Table 5: Resting and hyperventilating heart values from the students of the BME 313 class.

Student Name	**Resting Heart Rate (bpm)**	**Hyperventilation Heart Rate (bpm)**
Yancey Williams, II	55	56
Alec Witt	80	96
Victoria Purdy	84	60
Chloe Demellier	84	84
Kevin Sun	75	79
Shervin Shams	60	75
Megan Saalwaechter	79	80
Sam Wilcox	90	105
Peyton Clark	88	80
Molly Matthews	89	74
Elizabeth Simpson	84	96
Maaike Priest	81	97
Amber Stone	84	96
Shalarria Cooper	72	84
Ethan Custis	70	86
Rachel Matthews	60	72
Bailey Anderson	60	72
Ashley Kimbel	72	84
Han Jing	84	96

Charles Lipscomb	108	108
Javier Dominguez	72	96
Richard Menendez	96	120
Cade Pair	71	86
Gio Esposito	72	84
Krishna Josyula	96	96
Arushi Kotru	96	120
Mykala Prior	96	96
Sommer Dorrough	84	108
Lulu Smith	48	72
Ksenia Klochkova	60	84
Christoper Morgan	84	100
Nicole Bentley	72	72
Jasmine El Mubaid	96	120
Faith Muriuki	72	96
Lidya Canturk	72	96
Achintya	72	84
Erica Schilling	96	96
Ethan Dunkin	70	90
Kyla Gabriel	64	96
Rachel Lewis	72	84
Olivia Lerille	71	98
Codey Dunson	76	90

Above is a table that was gained by gathering all resting and hyperventilating from the entire classroom. **Table 5**, for the most part has some small changes but overall has a similar trend compared to our group's data. Some data points are abnormally low and does not increase much during hyperventilation.

Table 6: Statistical analysis of the BME 313 student heart rates.

	Mean		Standard Deviation		
P-Value from T-test	**Resting Heart Rate (bpm)**	**Hyperventilating Heart Rate (bpm)**	**Resting Heart Rate (bpm)**	**Hyperventilating Heart Rate (bpm)**	**Both Heart Rates**
$7.98e^{-8}$	78.02	90.43	12.78	19.41	17.13

Table 6 shows the average of all the students' heart rates at resting and hyperventilating. It also shows our calculations of standard deviations for both. These deviations are very high and show that the heart rate across all the students varied widely. Large deviations found here are okay to some extent as different people will have different resting and hyperventilating rates naturally.

Discussion

The computational results, found in LabView, are not exactly the values found as nominal values or the values to be expected during this exercise. The results given in the computational section were not far off from our recorded data. Since we are pulling data from a graph it is alright to see some small variation in the data since it is harder to interpret the values.

The human error that comes with interpreting the data and the imperfect equipment. In our case, it is probably due to the resister and Operational Amplifier not being completely true to their stated. Also In LabVIEW, there were gaps in the axes data points. Decimal integers may be difficult to read through an interface like this, so the user must make some assumptions based off the position of the wave chart. Since there are somethings that cannot be controlled, we use the best techniques we can in order to measure the proper values and anticipate causes of error in the data. With the help of multiple measurements and rational thinking we picked out data that best represented what was shown in LabVIEW.

In the experiment, we put together the circuit configured with both a high-pass and a low-pass as well as two op amps in order to convert analog signal from the subject to a recognizable pulse signal. In the "AD620 instrumentation amplifier" table, **Table 2**, it can be seen that the values measured are within acceptable bounds except the highest percent difference which had a 11.31% deviation. This is a large alteration compared to the expected value, it is important to know that this could be a cause of improper measuring procedure or faulty component. Also in **Table 1**, we calculated a gain that was almost exactly the expected gain that was predicted to occur before the experiment. As for the data from **Table 3**, this table depicts the Observed, LabVIEW data, instead of the nominal data. The percent difference when looking at LabVIEW values is not much greater in this table. The error that stems from this section is like due to the difficulties that come from reading graphs and having to estimate in between values. Since our measurements are so similar in this exercise it is probably correct to state that the data collected is an accurate representation of a proper output.

We also got data from the whole class. We conducted an 'Unpaired' T-test which means the samples taken are independent from each other. We can then use the test to see if the two means we calculated differ by a significant amount. We used Excel's 'TTEST' command to calculate this value. If the test showed to be too large then we would have reason to doubt the data gathered as we may have obtained the calculations by chance, but shown in **Table 6** the p-value is very small reading just $7.98e^{-8}$. In **Table 5,** most students in the table are within normal bounds, but there are some that do not follow the same trend. While this is unexpected, it is still close to the expected values, so it is likely to be just a measuring error. The subject 'Yancey' starts at a very low 55 BPM and only increase by one while hyperventilating. It is likely that the sensor may have not been properly secured which led to inaccurate experimental data. In **Table 1**, unlike in **Table 2** the gain is the expected value when reading the LabVIEW data, but it may be due to troubles in reading the graph and trying to find data points on the wave to a precise point that caused the data to be altered some in the experiment.

Commented [KG1]: Dr. Berry said we should include a discussion of our statistical analysis procedure. "Describe the basis for your use of the t-test to seek statistical significance. Show theoretical calculations and measured values."

The percent error found for the experiment only went up to a max of 11.31%. This level of error may be considered fairly high for most data points, so more evaluations may be done in order to determine a more precise value. If the experiment were to be redone, it would be important to minimize this amount of error by reducing user errors during the procedure by double checking measurements and looking at the deviation in components used to see if they need replacing. Since alterations in the values caused by faulty components cannot be helped, we would likely take up more refined measuring techniques.

Conclusion

In this lab, we gained the knowledge and ability to create a heart sensor using an Operational Amplifier which is a major component. Also, both high-pass and low-pass filters are utilized in heart sensors as well as inverting and non-inverting functions of the Operational Amplifier. We take note of the rate of the pulse and how it changes over time. We found that hyperventilation caused heart rate to increase in most cases. This is caused by a change in the CO_2 percentage within the blood of the subject. CO_2 contributes to the acidity levels of the blood and thus changes the pH level in the subject. Sympathetic signals are sent to the brain in order to increase heart rate in an attempt to adjust the pH level to the proper state. Knowing how to create devices like heart rate sensors and learning why physiological occurrences, like changing heart rates, happen is important for in the biomedical engineering field.

References

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