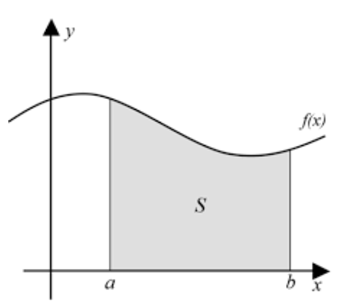
Measuring the Energy Use of a Computer Program:

An Introduction and Application of Riemann Sums

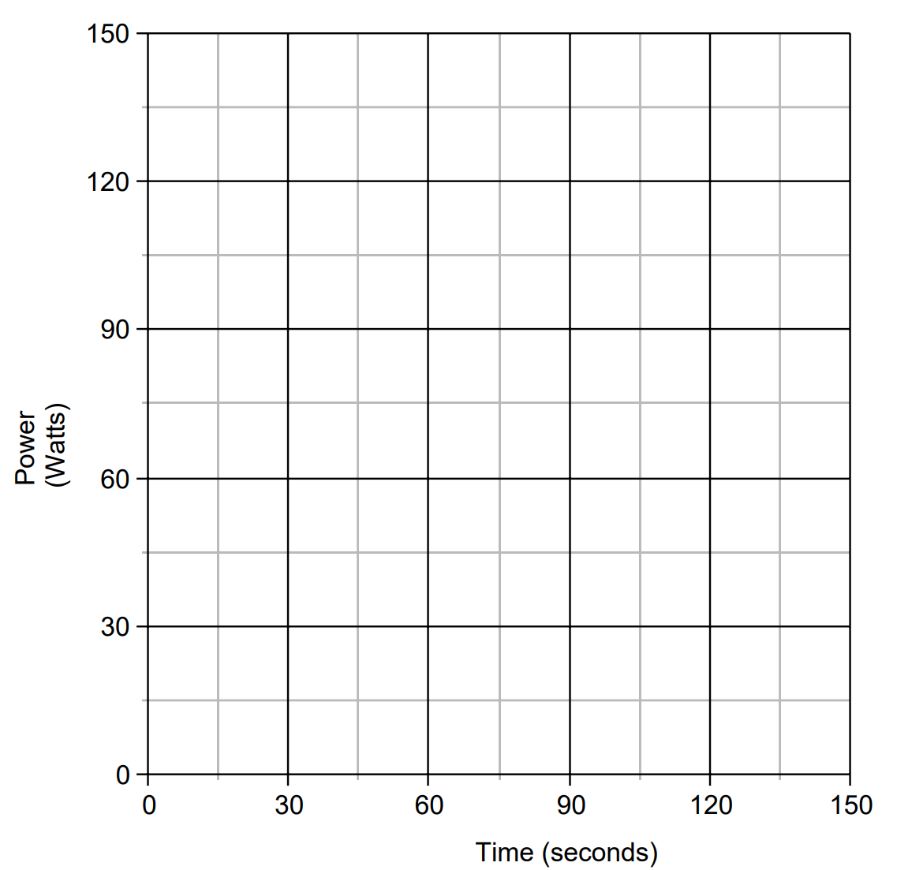


 In Calculus, one fundamental problem is to find the area under a curve. This area can be very informative and provides the solutions to many important problems. If your equation is representing a rate and you plot it against time, the area under the curve will represent a total. For example, suppose you have a person walking a constant 10 meters per second. After 12 seconds, the person has walked 120 meters. This can be applied to many situations beyond speed and distance traveled though. In physics, we often measure the power that something is using in Watts (W). Watts is a rate that is measuring how much energy, in Joules (J), something uses per second. For example, a 23 W lightbulb uses 23 J of energy every second.

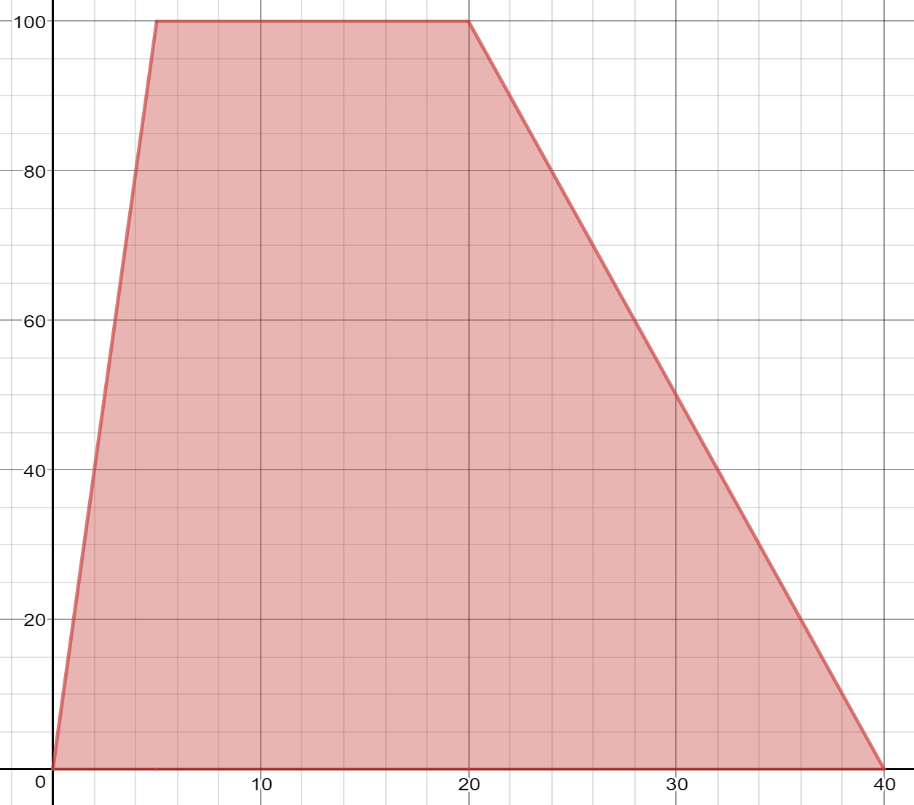
seconds

m/s

Total Distance Traveled = 10 m/s x 12 s = 120 m

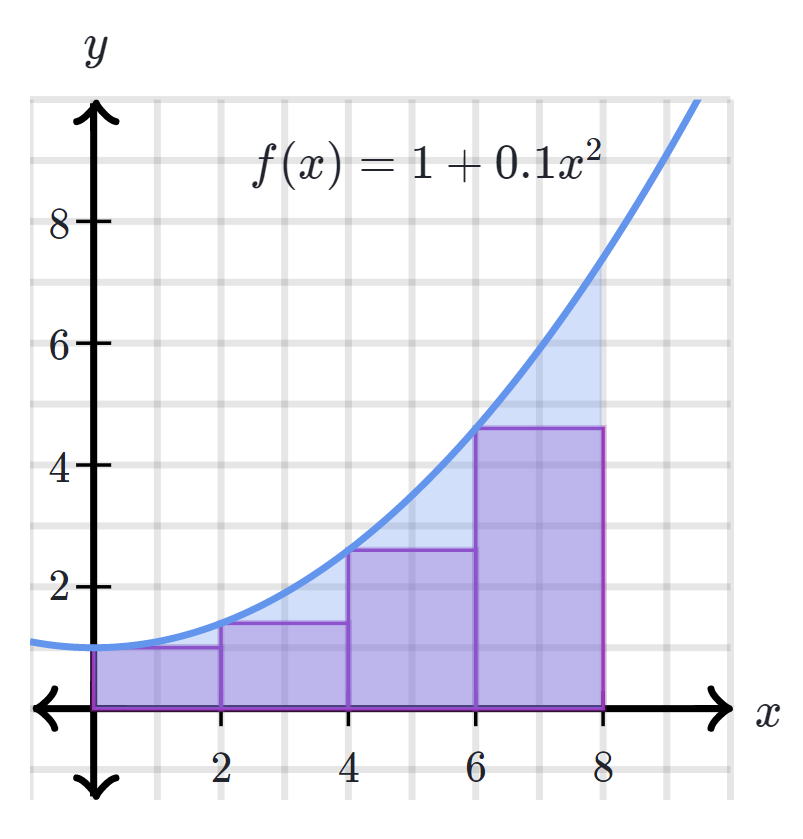
1. How much energy (In J) does a 120 W lightbulb use in two minutes? Draw a graph to explain how you found your answer.

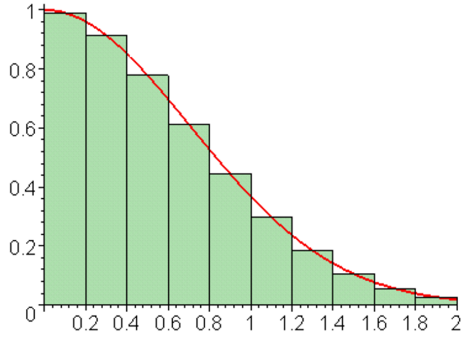
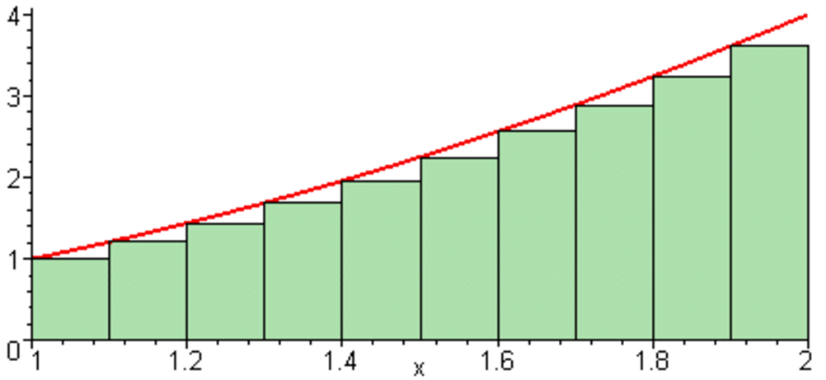
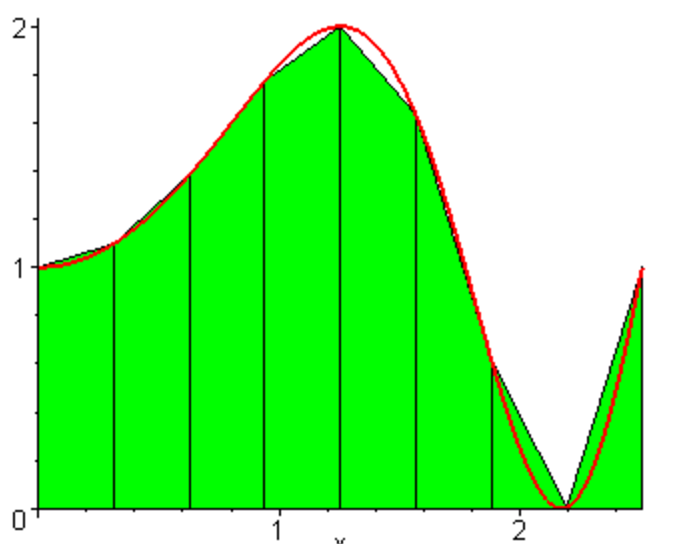
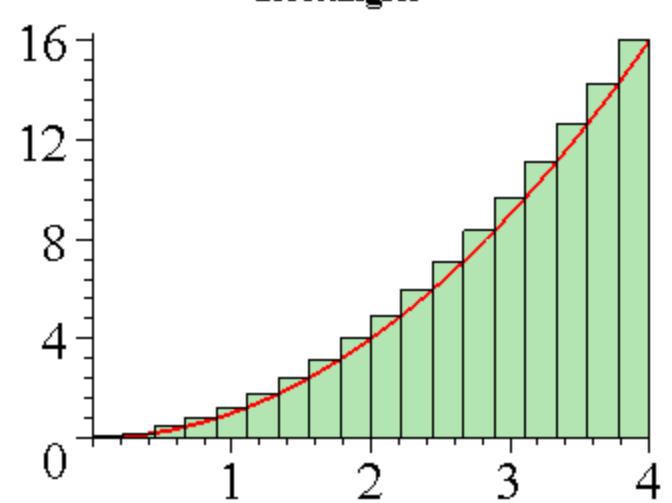
Hopefully, what we have done so far has seemed easy. However, what happens if you have a dimmable lightbulb and quickly brighten the bulb from being off up to 100 W in 5 seconds, leave it on for 15 seconds, and then slowly turn it back off over 20 seconds?

1. Determine how much energy was used in this situation.

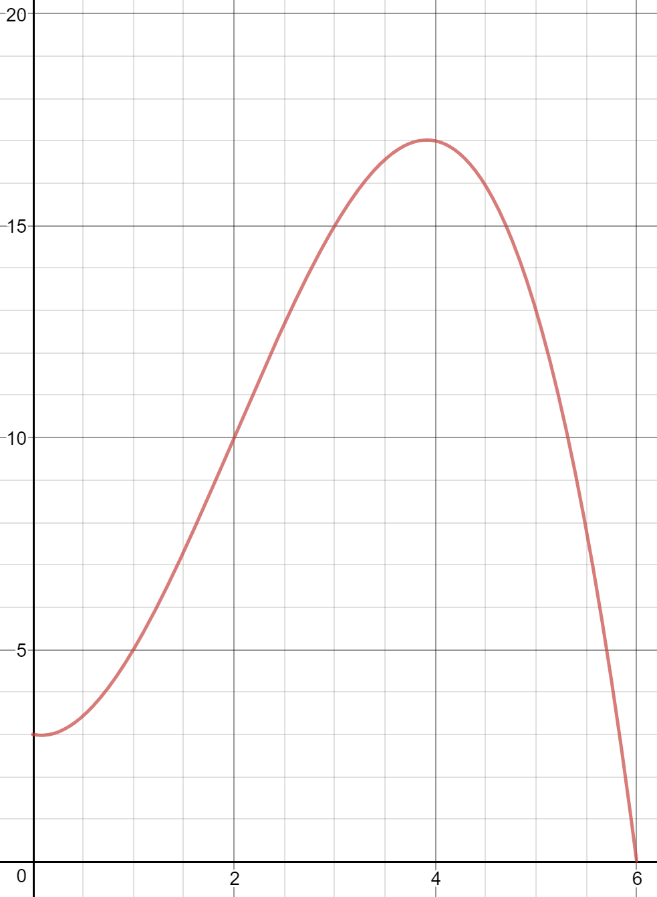
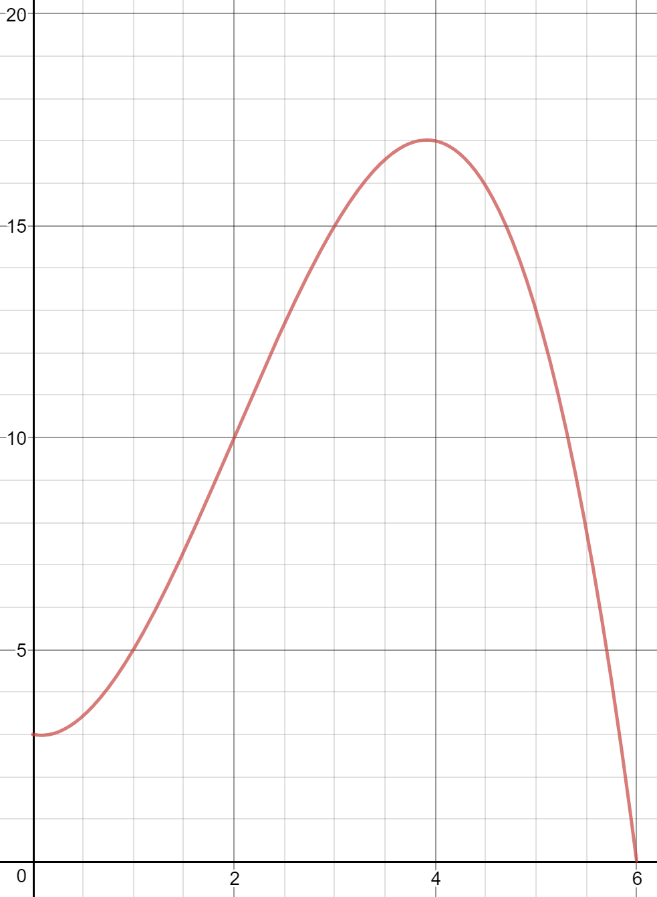
Power (W)

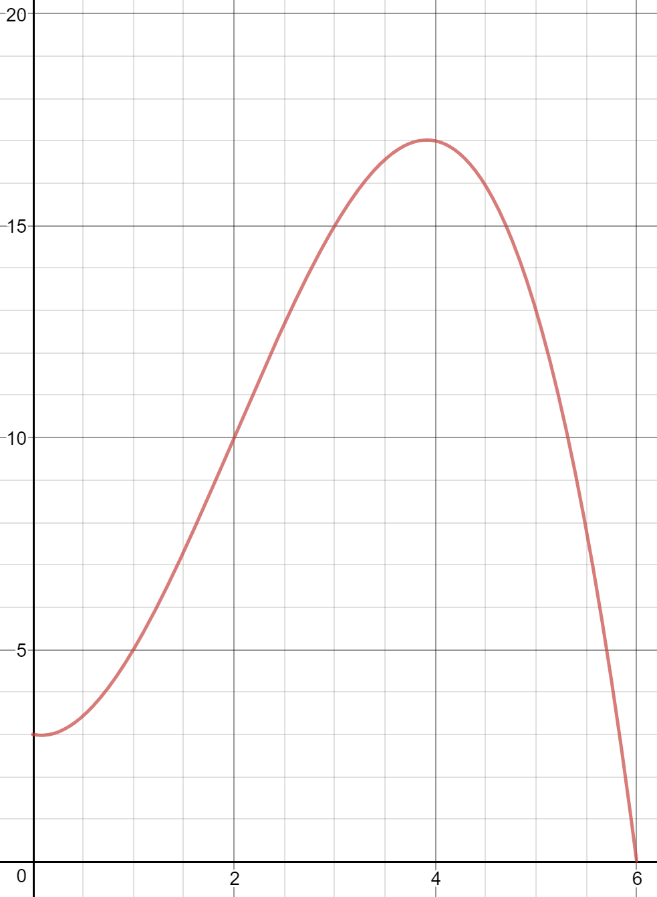
seconds

Being able to split up the area into smaller shapes is an important concept, and in fact is the foundation of Riemann Sums and Integrals. Most likely, in the shape above, you chose to split the shape into three parts, two triangles and one rectangle. A Riemann Sum is a method of splitting up the area under a curve using many rectangles. It is useful to find the area under a curve, especially when you are dealing with lines that are not straight. An example is shown to the left. This Riemann Sum is called a left sum, because the rectangles touch the curve on their left upper corner. It is possible to create other types of Riemann sums as well, such as right sums, middle sums, and trapezoidal sums. Try to match each of these other types of Riemann Sums to the three examples that follow.

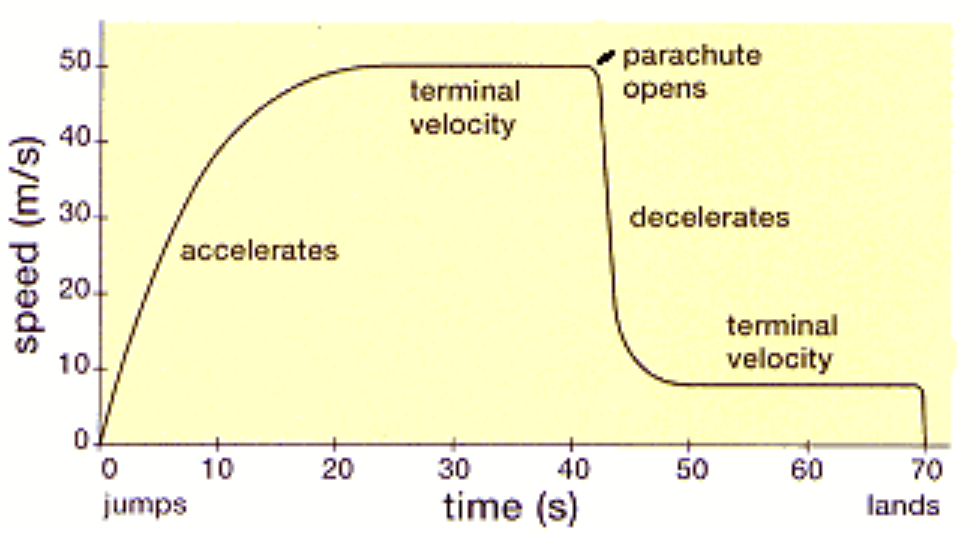
1. Match the graphs to the following types of Riemann Sum:
   1. Left Sum
   2. Right Sum
   3. Middle Sum
   4. Trapezoidal Sum

As you use more and more rectangles, the approximation that they give you of the area under the curve becomes better and better. An integral in Calculus is defined using infinite rectangles under the curve. Limits are involved, and we will work on that later.

1. Perform a left Riemann Sum on the following Graph with rectangles that have a width of 2.
2. Perform another Riemann sum on the same graph, this time doing a right sum with rectangles that have a width of one unit.
3. Perform one more Riemann Sum on this graph. Use a left sum again, but this time have your rectangles be 0.5 units wide.



1. Do you think your answers are accurate? Justify your answer.
2. Which answer do you think is the most accurate? Justify your answer.
3. What do you think the true area under this curve is?
4. Determine the height that the following parachutist jumped from. The graph represents his vertical speed as a function of time. Remember, performing a Reimann sum will help you to find this distance.

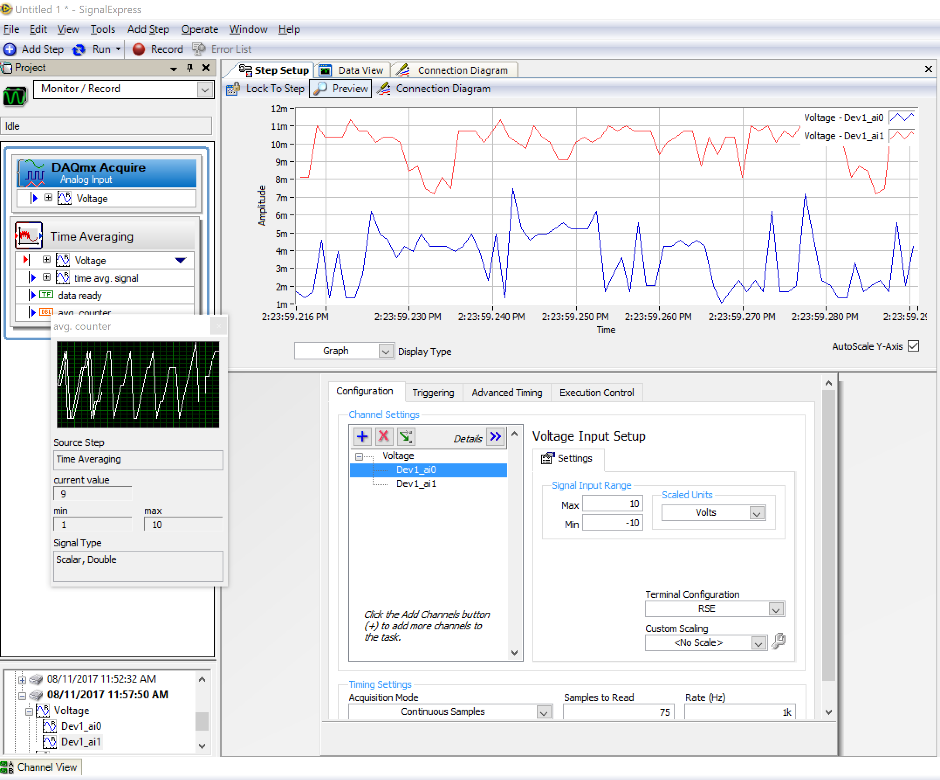


Now, we will take what we have learned about Reimann Sums and apply it to some research that is taking place on computers. Computer chips have been getting smaller and more powerful at an exponential rate. However, now, they are nearing a physical limit where it will soon be impossible to make them smaller than they already are. Because of this, research is currently being done to find new ways of computing that does not use the traditional computer chip, but instead takes advantage of different phenomena that are described in physics. Two examples of these are making “computer chips” out of magnets or out of oscillators. It is possible to use the physics behind these things to craft a computer of sorts. Now, to see if the research is producing results, one measurement that is done is to figure out how much energy it takes to solve certain problems. This is done by measuring how much power a computer is drawing while running a program at the CPU and the GPU.

One method of doing this is using software. There are options that exist that will allow you to measure the power consumption, as well as other data, related to the CPU or GPU while a program is running. One downside is that you have to run two separate programs – one for the CPU and one for the GPU. This usually necessitates running a program multiple times, sometimes while measuring the CPU, sometimes while measuring the GPU. The other drawback is that they are not as accurate, having a slower sampling rate (How often they take measurements) and drawing some power to run themselves.

The second method involves using hardware. This requires you to put current clamps on the CPU and GPU and measuring the current that flows to them. Then, using some physics, it is possible to calculate the power draw for the CPU and GPU since the voltage of your wires is known. While more accurate, it requires you to open your computer and to have a second computer to run a data acquisition program. It is also much more expensive. But, because this is the method used for superior research, it is what we will use.

Oftentimes to test computers abilities, programs called benchmarks are used. These programs push a computer to use its full capabilities and represent a higher-level program being run on a computer. Since we are in high school, it seems appropriate to use a benchmarking program for games. We will be using free versions of Unigine’s benchmarking platforms Heaven and Superposition.

In order to record the energy being used by the computer, we will be using current clamps tied into a National Instruments Data Acquisition unit. Then, using National Instrument’s Signal Express software, we are able to record the currents being used by the GPU and CPU. Here is a screenshot of that software. This software also allows for recorded data to be exported to Excel.

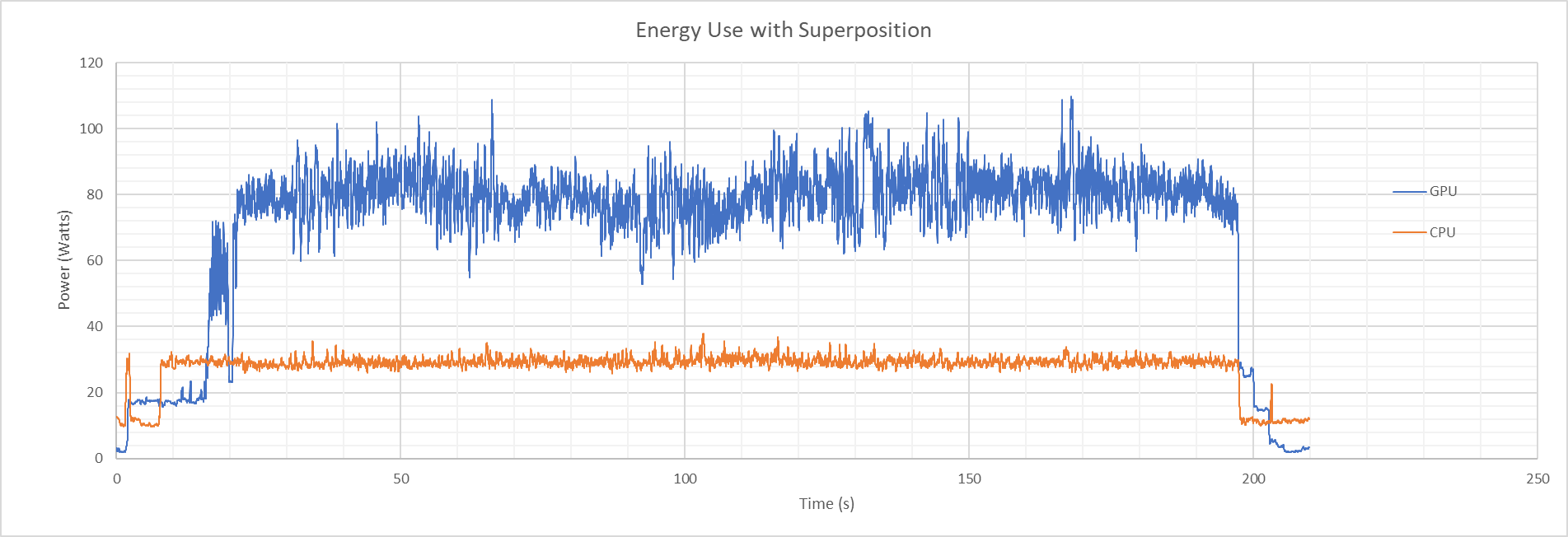
The superposition benchmarking software was run at the 1080p Medium setting and data was recorded and exported to Excel. At this point, a few modifications were done to it. First, the current clamps actually send signals to the Signal Express software in Voltages. These need to be converted into current based on the setting of the clamps, and then multiplied by the 12 V running through the wires to the CPU and GPU. (Remember from Physics, P=IV) This will give us a result in Watts. Because the data is very noisy, a .2 second rolling average was used in plotting the data that you will see.

Program

Closes

Benchmark

Ends



Benchmark

Begins

Program

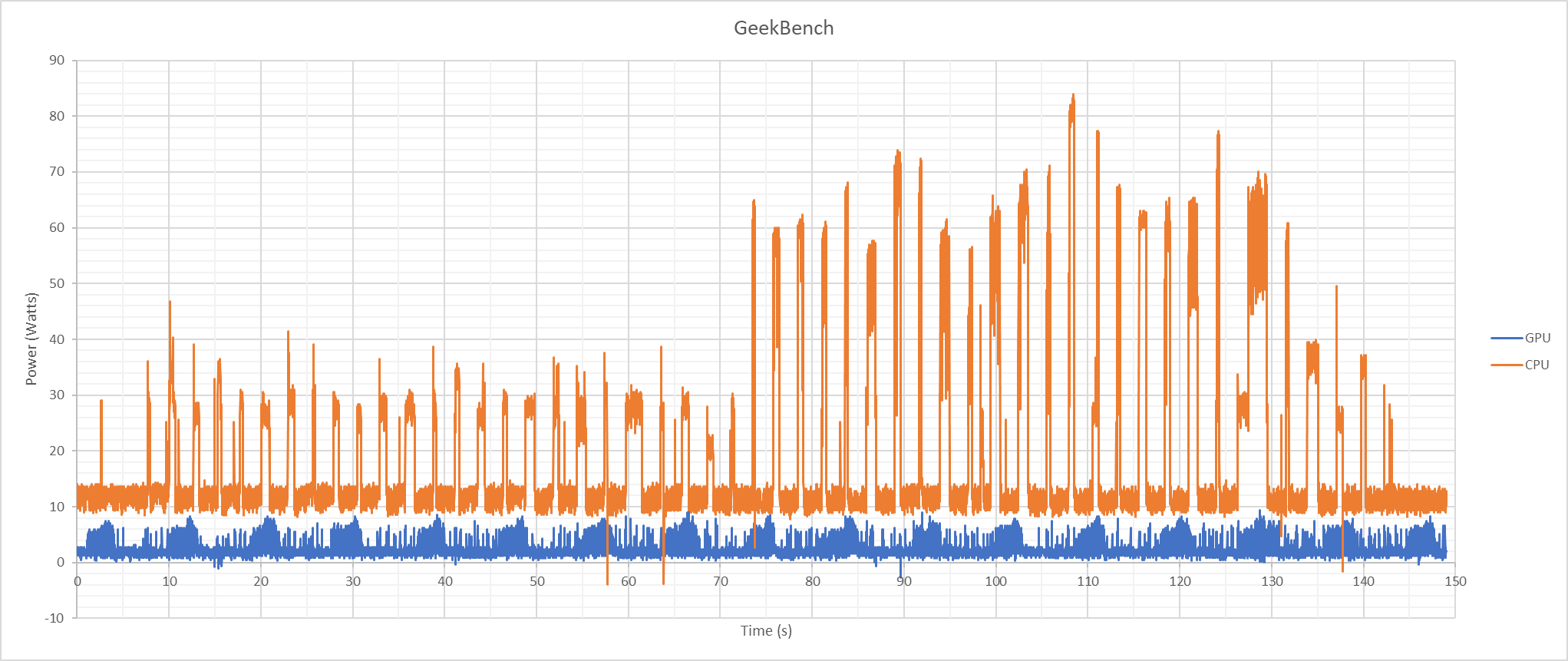
Opens



1. Use Riemann Sums to calculate the total energy use during the benchmark by the CPU. Show your work.
2. Use Riemann Sums to calculate the total energy use during the benchmark by the GPU. Show your work.
3. Combine your two answers to get the total energy used by the computer to run this program.

Here is another benchmarking program called Geekbench. Unlike Superposition, Geekbench is meant to benchmark the CPU. At the beginning, only one of the four cores of the CPU is used. The second half of the test uses all 4 of the cores.

This benchmark is made up of many smaller benchmarks. What property of the graph demonstrates this?





1. Use Riemann Sums to calculate the total energy use during the benchmark by the CPU. Show your work.
2. Use Riemann Sums to calculate the total energy use during the benchmark by the GPU. Show your work.
3. Combine your two answers to get the total energy used by the computer to run this program.