Chapter 1

Introduction to the Arduino and Computer Control

In PH250 we have a goal of getting our computers to talk to our physics experiments (see the course syllabus). This comes in two forms. One is to have the computer control the experiment. For example, we could have the computer turn on our apparatus, or turn it off. The second form is having the experimental device provide data to the computer that we can later analyze. In both cases, we need a piece of electronics that goes between the experimental measuring devices and the computer. These electronic pieces are often called Data Acquisition (DAQ) boards. There are many different forms of DAQ's. They can cost anywhere from a few dollars to many thousands of dollars.

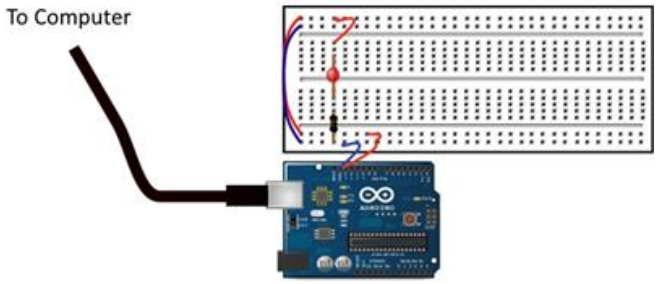
We will use a DAQ developed for learning. It is low cost because it's developers placed the plans for it in the open-source world so that no one would get royalties (including themselves) for the design. Thus board manufacturer's pay less, so we pay less. It is low cost, but not low quality. They named their DAQ "Arduino."

The Arduino is fragile, like all DAQ's. We will need to be careful with our Arduino's. They will be destroyed by putting too large a voltage (something we will discuss as we go) or electrical current (also something you will study in PH220) into the input pins. They also can be destroyed by being dropped or squashed, so some caution is warranted.

Let's start our study of computer control by controlling something simple with our Arduino DAQ. Earlier we though about turning an apparatus on or off. We can practice doing this with any device. While it might be exciting to try this with a nuclear reactor, it will be easier (and safer!) to start off simple. Let's turn on and off Light Emitting Diode (LED) lights.

1.1 First Computer Control: LED blink (Step-by-step)

Your instructor will provide you with a light emitting diode (LED) light, a resistor, some wires, and a prototyping board. This last item helps hold the other things in place so we can make electricity go through them. Here is what we will build for our light blinking experience:



You are probably familiar with words like "voltage" and "current" even though you have not yet studied these in PH220. You have been plugging in things for many years now. And so you know that "voltage" has something to do with electrical energy. That is enough for now. Our voltage source is just a source of energy to make our circuits work.

A resistor is kind of what it sounds like. It tries to stop or slow down the electricity in the circuit. The LED is just a circuit element that lights up when electricity goes through it. You see them on computers and cell phones as indicators that something has happened.

Let's assemble our system one step at a time.

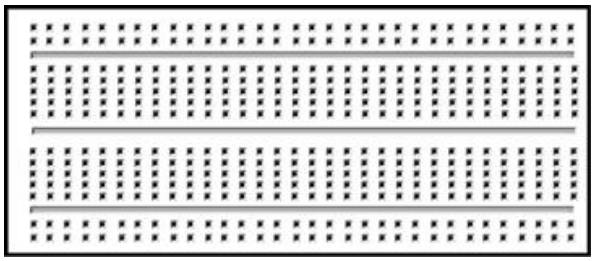
1.1.1 Prototyping boards

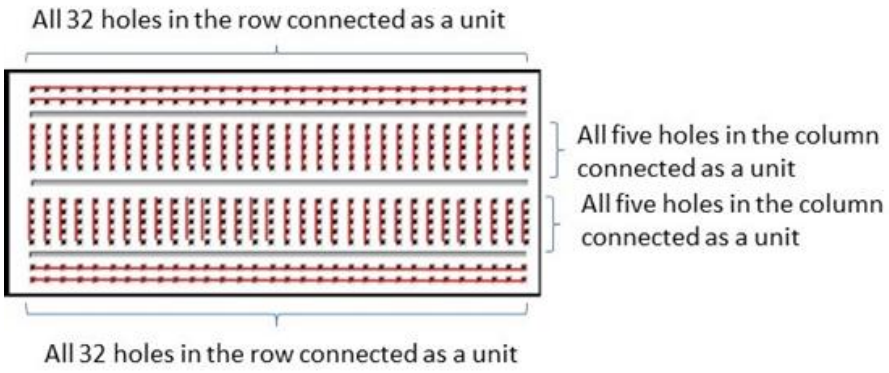
Let's start with your prototyping board.

You might notice that the LED and the resistor in the diagram seems to be stuck in some strange board full of holes. This is our prototyping board. You should have one in your Arduino kit. Your instuctor will have several that you can borrow if you need another one.

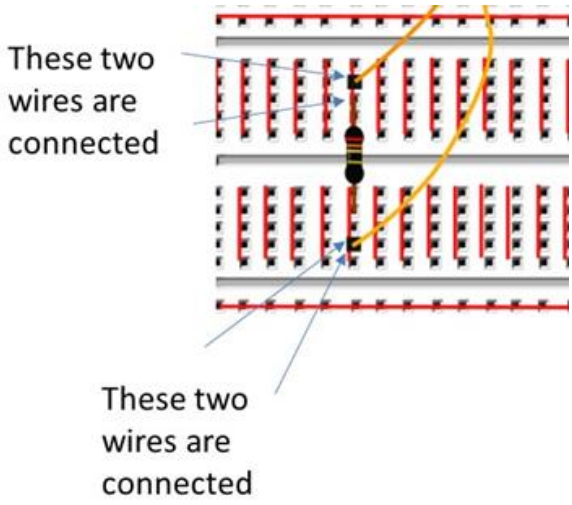
We will connect a lot of electrical wires together. We have devices to make this job easier. Our porototyping board is one of these. They are officially called prototyping boards, but you might hear them called proto-boards, or even "breadboards." They are designed to allow you to put an electronic element on the board and then connect other things to that element. The boards look like this.

Notice that in the center of the board there are sets of five holes. Under the board surface, these holes are connected together as shown by the red lines in the next figure. Any wire that goes in one of the connected holes is therefore





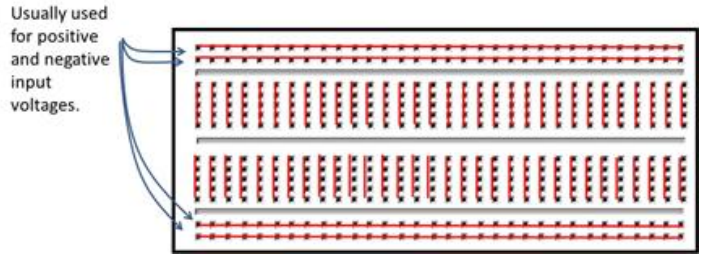
connected to any other wire that goes in the set of five connected holes. So you can connect up to four other wires to the first wire. In the next figure, you can see an example of a resistor that is placed on the proto-board and is connected to two yellow wires. Notice that each end of the resistor is connected to a wire



by placing the end of the resistor in one of a set of five connected holes and

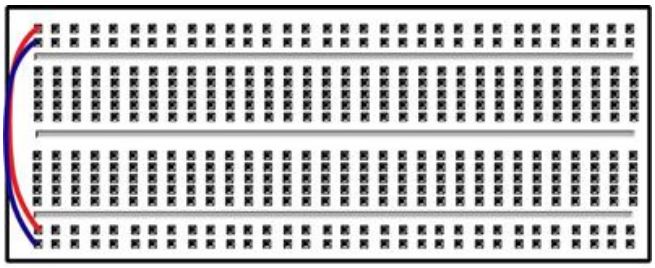
by placing a wire in another of the set of five connected holes. This would be a silly circuit to build. There is no connection to a source of electrical energy. But this gives the idea of how the prototyping board works.

There are also two long rows of holes on the side of the proto-board. These are usually all connected along the whole row. Not all proto-boards are alike



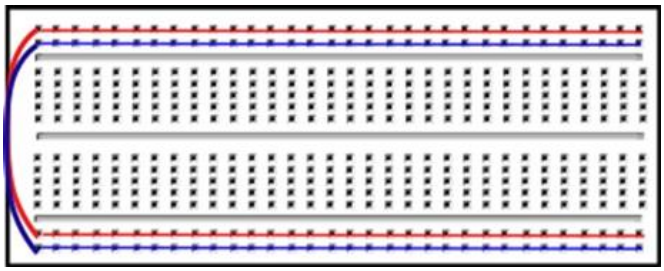
when it comes to these long rows. But most are connected along the whole row. These long rows are often used as a convenient way to make input power available all along the whole board. Of course, once you know how the board is wired underneath, you can use the connections any way that is consistant with that design. We could skip using proto-boards and just connect everything with wires and alligator clips. But proto-boards often make holding everything in place much easier.

In today's lab experience, let's start by using the long rows as a place for electrical energy to be used. We have long rows on the top and bottom of the proto-board. For our first experience, we will use just 0V and +5V. Let's make these voltages available on both the top and the bottom of the board by wiring the two sets of rows together. Looking at our wiring diagram for the inside

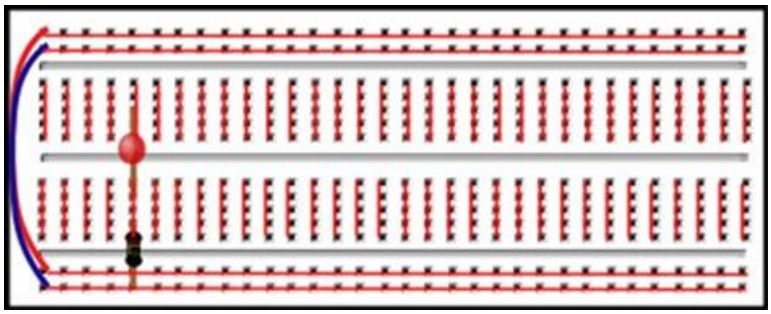


of the proto-board we can see that how the top row and the second from the bottom row have been connected with a wire (it is red if you are reading this in color) and the second from the top and the bottom row are also wired together (the wire is blue if you are seeing this in color). And we know that these entire rows are wired underneath. Some proto-boards even have red and blue lines to indicate that these rows can be used for electrical power. Some of ours do.

Next let's add our LED light and our resistor. Notice that the LED spans the gap between the top and the bottom of the board.



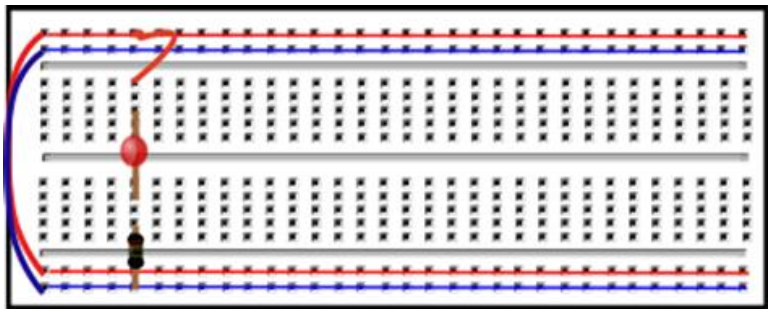
In the next figure I have included our red connection lines so we can keep in mind which parts of the proto-board are connected underneath.



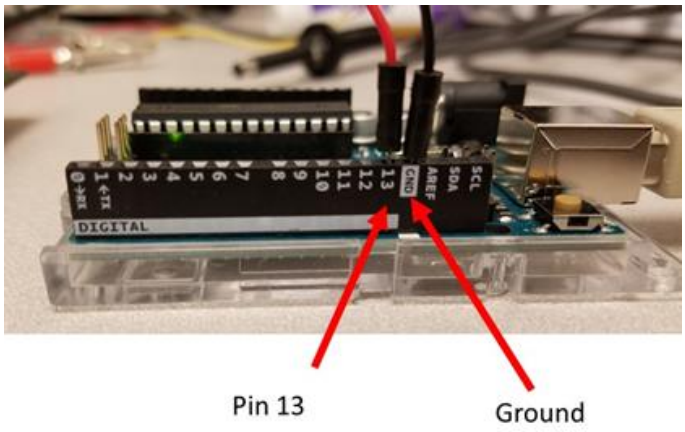
We placed one LED light wire in one column. On the other side of the board we place the other wire. The wires that come out of an electronic device are often called "leads" and I will use this term. So one LED lead goes in a group of five holes on one side of the board and the other lead goes into a group of five hole on the other side of the board. If you look closely, you will see that one side of your LED is flat. The lead on the flat side should be toward the bottom (toward our 0V connection that we will make). LED lights only work one direction. So when using LED's, if they don't work, turn them around.

Notice that the way we have done this one LED lead and one resistor lead are connected in one group of five holes. The resistor is connected to the very bottom row. The top of the LED is not connected to anything yet. It is in a set of five holes that are connected together, but we need another wire to connect

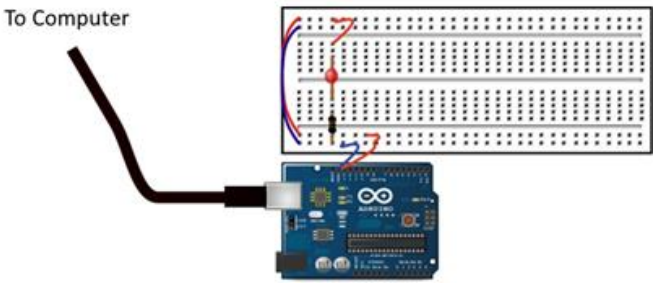
the top of the LED to the +5V. Let's choose the top of our power rows to be +5V and add the wire to connect the LED.



Now we can wire our light to our Arduino. This will take two wires. One should be wired to pin13. The pin numbers are given on the side of the wiring areas. This pin 13 is a digital output. That means it will either have 5V or it



will have 0V. The 5V will be our "on" value that could turn on an instrument. In our case it will turn on our LED light. The 0V is the "off" value. When pin 13 has a value of 0V our light will go off. We know that voltage is related to electrical energy. We will study voltage more next week. But for now we need to know that voltage is a comparison. So we need to know "5V compared to what?" We compare to the voltage of the ground. This is literal. Most buildings have a large copper rod pounded into the ground. All of the plugs in the building have one of their three wires connected to this rod. Thus they are all "grounded." This is our reference. Our computer is connected to a plug so it is grounded. Our Arduino is connected to the computer so it is grounded. And one of our pins is a connection to the ground. It is marked "GND." This will be our 0V. So we need to connect pin 13 and the GND pin to our +5V and our 0V rows on our proto-board. The next figure shows one way to do this.



We now have hour "hardware" built for blinking a light. But we need to give instructions to our Arduino that tells it what to do with pin 13 and pin GND so our light will blink. Our Arduino has a small computer on board, and we need a computer program to be uploaded to the Arduino for this small computer to run. We will write and upload that program next.

1.1.2 LED light blink Sketch

You wrote computer programs in Python in PH150. Our Arduino programs are similar. They have loops and mathematical statements. There are some differences as well. Our Arduino programs have special code "objects" for controlling our Arduino. Most Arduino programs are very short. We just need instructions to tell the Arduino what to turn on, turn off, or what data to collect. For today's lab, we just need to address the digital output pins.

Let me introduce the commands we will use. Each digital output has a number. The code defines a variable of type integer (int) and sets it equal to the pin number. That pin can be HIGH or LOW with HIGH = +5V and LOW = 0V. Each digital pin needs to be set up for output or input. This is done with a pinMode statement:

```
pinMode(ledPin, OUTPUT)
```

The variable ledPin is the pin number (for us 13). And the key word "OUTPUT" sets up our pin 13 to turn things on or off.

To set the pin to HIGH use a digitalWrite command

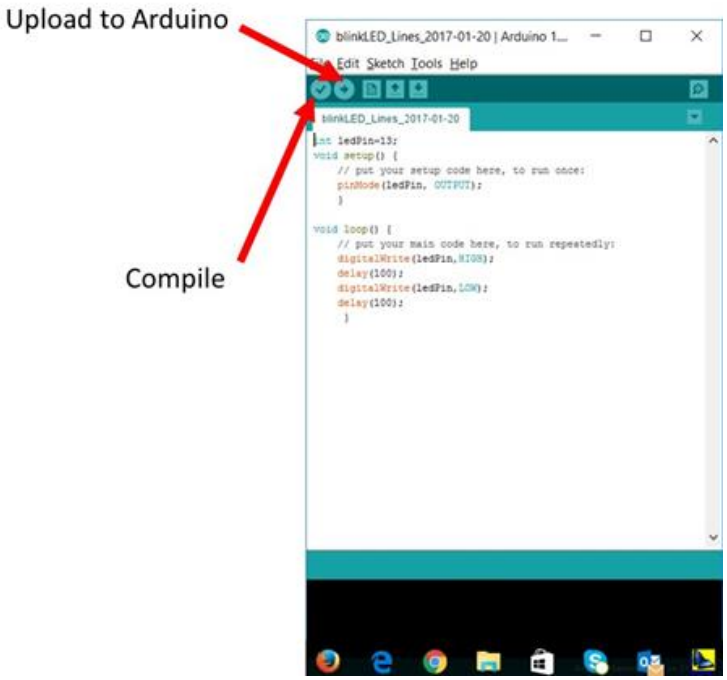
```
digitalWrite(ledPin,HIGH);
```

and finally, to let the light be on for a while, use a delay command where the delay time is given in milliseconds (ms)

```
delay(100);
```

These would not be normal Python commands. They are part of a specific code library for use in making things with Arduino's.

We have a special development environment for programing our Arduino as well. It looks like this. We will need to install this development environment.



To do so we go to https://www.arduino.cc/en/Guide/HomePage and choose to instal the Arduino IDE for your computer. IDE stands for "integrated development environment." This is the environment that you see in the last figure. It has two unusual buttons on its toolbar. One is the "compile" button. When you used Python in PH150, you could run your code by pushing on a green arrow button in most development environments. If you used Jupyter scripts, they also had a function to run your code. But our Arduino is not big enough to be able to run code this way. We need to convert our human-understandable code that looks mostly like Python into a digital format that the Arduino can understand. The compile button does this. As the code is converted, the Arduino software looks for errors in the code. If there are errors, it will tell you at this point. This is different than Python which only told you about errors as the code ran. But remember we don't want to run our program on our computer. We want it to run on our Arduino. So this check is good before we send the translated code to the Arduino.

We also need a way to send our code to our Arduino and that is what the upload to Arduino button does. Once the code is compiled without errors, connect the USB cable to the Arduino and push the upload button.

There are also some syntax differences between the Arduino computer language and Python. If you have taken CS124 or know the "C" language, you will recognize some of these changes.

- Everything in a function needs to be in curly braces { }

- Indenting is a good idea, but not required
- comments can be started with two slashes //
- every line needs a semicolon at the end;

1.1.3 Arduino LED light blink sketch (program)

We are ready to write code to blink our LED light. Here is an example code. We write this code right in the Arduino development environment main window.

```
/////////////////////////////////////////////////////////
//Arduino Sketch to blink one LED light
//   Written by Brother Lines
//  (place your name here in your code)
//   Feb 6, 2017
//
//   Define our Arduino Variables
//      We will call pin 13 "ledPin"
/////////////////////////////////////////////////////////
int ledPin=13;

/////////////////////////////////////////////////////////
// Arduino setup function comes next
//    Every Arduino sketch needs a setup function
//    We will set up our ledPin (pin 13) as an output pin
void setup() {
 // put your setup code here, to run once to set up:
 pinMode(ledPin, OUTPUT);
 }

/////////////////////////////////////////////////////////
// Arduino loop function
//    Every Arduino sketch has a loop function
//    This is where we put what we want the Arduino to do
//    The Arduino will do whatever is in the loop function
//    until the Arduino is unplugged.

void loop() {
 // put your main code here, to run repeatedly:
 // turn on the LED
 digitalWrite(ledPin,HIGH);

 // leave in on for 100ms
 delay(100);

 // turn off the LED
```

```
 digitalWrite(ledPin,LOW);

 // leave in off for 100ms
 delay(100);
 }
////////////////////////////////////////////////////////////
////////////////////////////////////////////////////////////
```

Notice that we used a lot of comments. There are only ten lines that are actually required to make the sketch run.

```
int ledPin=13;
void setup() {
 pinMode(ledPin, OUTPUT);
 }
void loop() {
 digitalWrite(ledPin,HIGH);
 delay(100);
 digitalWrite(ledPin,LOW);
 delay(100);
 }
```

The comments are not required for the sketch to work, but they help us remember what we did later. In our class, **comments are required for full credit**. So don't leave out the comments. In fact, you can add any comments that might help you remember why the code works.

Also notice that Arduino programs are called "sketches." Most of the commands are special Arduino commands. And luckily, they make sense when we read them. Try it out. Type in this sketch including the comments and compile and upload it to your Arduino. If all goes well, the LED light will begin to blink. If all did go well, go on to the next section. If it did not, call over an instructor.

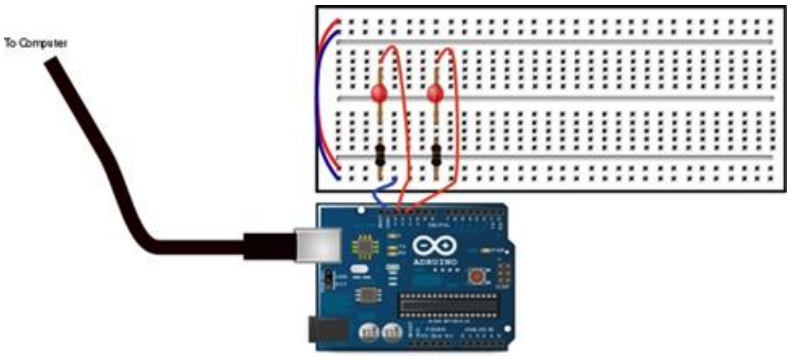
Save your sketch and maybe take a photo of your hardware set up. Place both in your lab notebook along with notes on how you got it to work. We will build on this sketch, so spend some time documenting what you did in your lab notebook so you can refer to it later.

1.2 Second Computer Control: Two LED blink

Now let's see if we can apply what we have learned. Let's change our hardware so that it has two LED lights. Most of the hardware setup will be the same. But We will wire them to two Arduino pins, say 12 and 13 (along with GND of course) and have them blink, but blink independently.

We will have to abandon our nice +5V top row as our connection to pin 13 because we need two pins, 12 and 13. The two pins must work independently. In fact, let's have one LED on when the other is off.

This is why we can't wire both LED lights to the top row and wire the top row to pin 13 as we did last time. That would make both lights blink at once, but would not let one be off and the other on. Instead, let's wire the top lead of one LED directly to pin 13 of our Arduino, and let's wire the top lead of the other LED to pin 12. The two resistors can share a connection to the GND pin, so let's keep using the 0V bottom row of the proto-board. Your hardware should look something like this.



We will need to modify our sketch (save the old one first so you have a separate copy for reference). Here is a suggestion of what the new sketch might look like.

```
////////////////////////////////////////////////////////
//Arduino Sketch to blink one LED light
//   Written by Brother Lines
//   Feb 6, 2017
//
//   Define our Arduino Variables
//      We will call pin 13 "ledPin1"
//      We will call pin 12 "ledPin2"
////////////////////////////////////////////////////////
int ledPin1=13;
int ledPin2=12;

////////////////////////////////////////////////////////
void setup() {
 // put your setup code here, to run once:
 // set both pins to OUTPUT
 pinMode(ledPin1, OUTPUT);
 pinMode(ledPin2, OUTPUT);
 }

////////////////////////////////////////////////////////
void loop() {
```

```
 // put your main code here, to run repeatedly:
 // turn on one LED and turn off the other
 digitalWrite(ledPin1,HIGH);
 digitalWrite(ledPin2,LOW);
 // wait
 delay(100);
 // now switch so the first LED is off
 // and the second is on
 digitalWrite(ledPin1,LOW);
 digitalWrite(ledPin2,HIGH);
 // wait
 delay(100);
 }
//////////////////////////////////////////////////////////
//////////////////////////////////////////////////////////
```

Again save your sketch and maybe take a photo of your hardware set up. Place both in your lab notebook along with notes on how you got it to work. Make sure others at your table are able to get their setup to work.

1.3 Third Computer Control: Two LED blink using math

Let's leave our hardware alone in the two LED setup from the last section. And let's make the LED's blink the same way. But this time, let's calculate when they should be on or off. Why would we do this? Because sometimes in computer control of experiments we need to turn something on or off based on a calculation. You may have your computer watching to make sure the experiment doesn't get too hot or cold. The Arduino can bring in temperature information, but you would have to write the code to tell it to turn off the heater when your experiments gets to hot and to turn it on when it gets too cold. This could be done with a mathematical comparison. We will use such a comparison in the next sketch.

Suppose we want to know if a number is even or odd. Even numbers are evenly divisible by 2. We could divide a number by 2 and see if the remainder is zero. Our Arduino language has a good set of mathematical functions. The remainder function is a "%" sign. For example

$$\begin{aligned} 3\%2 &= 1 \\ 6\%2 &= 0 \end{aligned}$$

Let's have one light turn on if a number is even, then switch to the other light if the number is odd.

In our code we will introduce a variable, i, that we will increment (add one to) every time the loop runs. So the first time the Arduino loop runs it will be

zero (even) and the next time 1 (odd) and the next time 2 (even) and the next time 3 (odd) and so on. If you studied Python you would call such a variable an "integer" and might even know to call it a "loop counter."

In our Arduino sketch we will test to see if i is even in an if-statement. If-statements go like this

```
 if (test condition ) {
   do something;
 }
 else {
   do something else;
 }
```

Notice that the parts of the if-statement need curly braces. Our condition to test is

```
i % 2 == 0
```

Note that there are two equals signs. That makes it a test for equality rather than an assignment. So we will have an if-statement like this

```
if (i % 2 == 0 ) {
 digitalWrite(ledPin1,HIGH);
 digitalWrite(ledPin2,LOW);
 delay(1000);
 }
 else {
 digitalWrite(ledPin1,LOW);
 digitalWrite(ledPin2,HIGH);
 delay(1000);
 }
```

One last addition, our Arduino language has a shortcut for the statement

```
i=i+1
```

It is simply

```
i++
```

We will use this to make i increase by one each time the loop runs. The whole code might look like this.

```
//////////////////////////////////////////////////////
// code to blink two LED's using a mathematical expression
// to determine when they should light. Note that the
// Arduino code is closer to C++ than python.
//////////////////////////////////////////////////////
int ledPin1=13;
int ledPin2=12;
```

```
int i=0;

//////////////////////////////////////////////////////
void setup() {
 // put your setup code here, to run once:
 pinMode(ledPin1, OUTPUT);
 pinMode(ledPin2, OUTPUT);
 }

//////////////////////////////////////////////////////
void loop() {
 // put your main code here, to run repeatedly:
 // if the integer, i, is even light one light,
 // if odd light the other light
 if (i % 2 == 0 ) {
    digitalWrite(ledPin1,HIGH);
    digitalWrite(ledPin2,LOW);
    delay(1000);
 }
 else {
    digitalWrite(ledPin1,LOW);
    digitalWrite(ledPin2,HIGH);
    delay(1000);
 }
 i++;
 }
//////////////////////////////////////////////////////
//////////////////////////////////////////////////////
```

Again save your sketch. You should probably say in your lab notebook that you used the previous hardware setup. You might want to describe in your lab notebook how the mathematical algorithm works.

1.4 Fourth Computer Control: Two LED blink in the Fibonacci sequence

Suppose instead of LED lights we had large radio transmitters. And suppose we were part of the Search for Extra-Terrestrial Intelligence (SETI). We wish to send a message to any intelligent life that they would understand. Intelligent life probably would be able to do mathematics and would understand how mathematics occurs in nature. One sequence of numbers that occurs over and over again in nature was discovered by Fibonacci. Let's blink our LED lights (representing those powerful radio transmitters) in the Fibonacci sequence.

We need to know now to calculate the Fibonacci sequence. One method is

to know that the sequence goes like this

$$0, 1, 1, 2, 3, 5, 8 \ldots$$

and that we can find the next number in the sequence by choosing $f_1 = 0$ first, then $f_2 = 1$ then using the formula

$$f(x-1) \ + \ f(x-2)$$

Let's see that this works. For the first of the sequence, we just write the 0. For the second we just write the 1. Then for the third

$$\begin{aligned} f_3 &= f_2 + f_1 \\ &= 1 + 0 \\ &= 1 \end{aligned}$$

So far so good. Let's try the next in the sequence

$$\begin{aligned} f_4 &= f_3 + f_2 \\ &= 1 + 1 \\ &= 2 \end{aligned}$$

Again it worked. For the next one

$$\begin{aligned} f_5 &= f_4 + f_3 \\ &= 2 + 1 \\ &= 3 \end{aligned}$$

and though we won't prove it, it works for every member of the sequence. See if you can figure out how to write this code. An example is given below, but see if you can figure out what the code should be.

This example is a much more complex version of a mathematical based computer control.

```
//////////////////////////////////////////////////////////
// code to blink two LED's using a mathematical expression
// to determine when they should light. Note that the
// Arduino code is closer to C++ than python.
//////////////////////////////////////////////////////////
int ledPin1=13;
int ledPin2=12;
int i=0; //loop counter

//////////////////////////////////////////////////////////
int fib_count=0; // number of blinks based on Fibonacci
int i_max=10; // maximum Fibonacci number before
 // starting over
```

```
////////////////////////////////////////////////////////
void setup() {
 // put your setup code here, to run once:
 pinMode(ledPin1, OUTPUT);
 pinMode(ledPin2, OUTPUT);
 }

int fib(int x) {
 // calculates the Fibonacci sequence using recursion
 if (x==0)
    return 0;
 if (x==1)
   return 1;
   return fib(x-1) + fib(x-2);
 }

////////////////////////////////////////////////////////
void loop() {
 // put your main code here, to run repeatedly:
 // blink the LED's with the number of blinks being
 // the Fibonacci sequence.
 fib_count=fib(i);
 if (i % 2 == 0 ) {
   // turn off one light
   digitalWrite(ledPin2,LOW);
   // now blink the second light fib_count times
   for (int n=0; n<fib_count; n++) {
      digitalWrite(ledPin1,HIGH);
      delay(100);
      digitalWrite(ledPin1,LOW);
      delay(100);
   }
 }
 else {
   // turn off the other light
   digitalWrite(ledPin1,LOW);
   // now blink the first light fib_count times
   for (int n=0; n<fib_count ; n++) {
      digitalWrite(ledPin2,HIGH);
      delay(100);
      digitalWrite(ledPin2,LOW);
      delay(100);
   }
 }
 // increment i
```

```
 i++;
 // limit our blinks to the first i_max Fibonacci numbers
 if (i>i_max) i=0;
 }
}
//////////////////////////////////////////////////////////
//////////////////////////////////////////////////////////
```

Again save your sketch. You should probably say in your lab notebook that you used the previous hardware setup. You really should describe in your lab notebook how the mathematical algorithm works.

For next week, you should read the lab before coming to class. So your assignment is to read Lab 2.