

Introduction to robotics

2nd lab

If you are reading this in PDF format, keep in mind that animations do no work. You can find the google doc version here, with animations and latest updates:

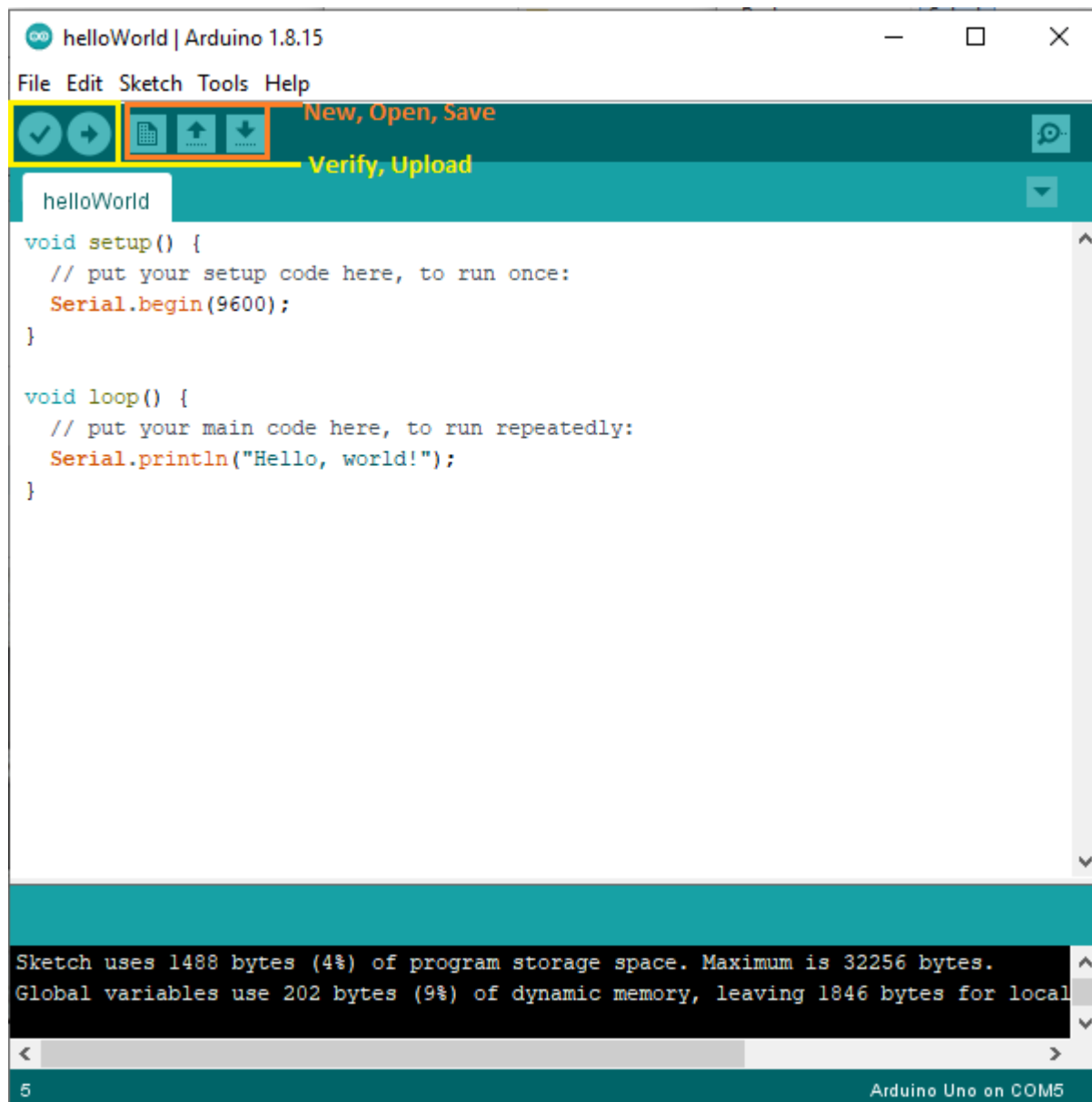
<https://docs.google.com/document/d/1Z9ofnWpoNjrwOyd1u8emjRYhxn1rN7hxqrLACGZc3B/edit?usp=sharing>

First of all, **get your kits**.

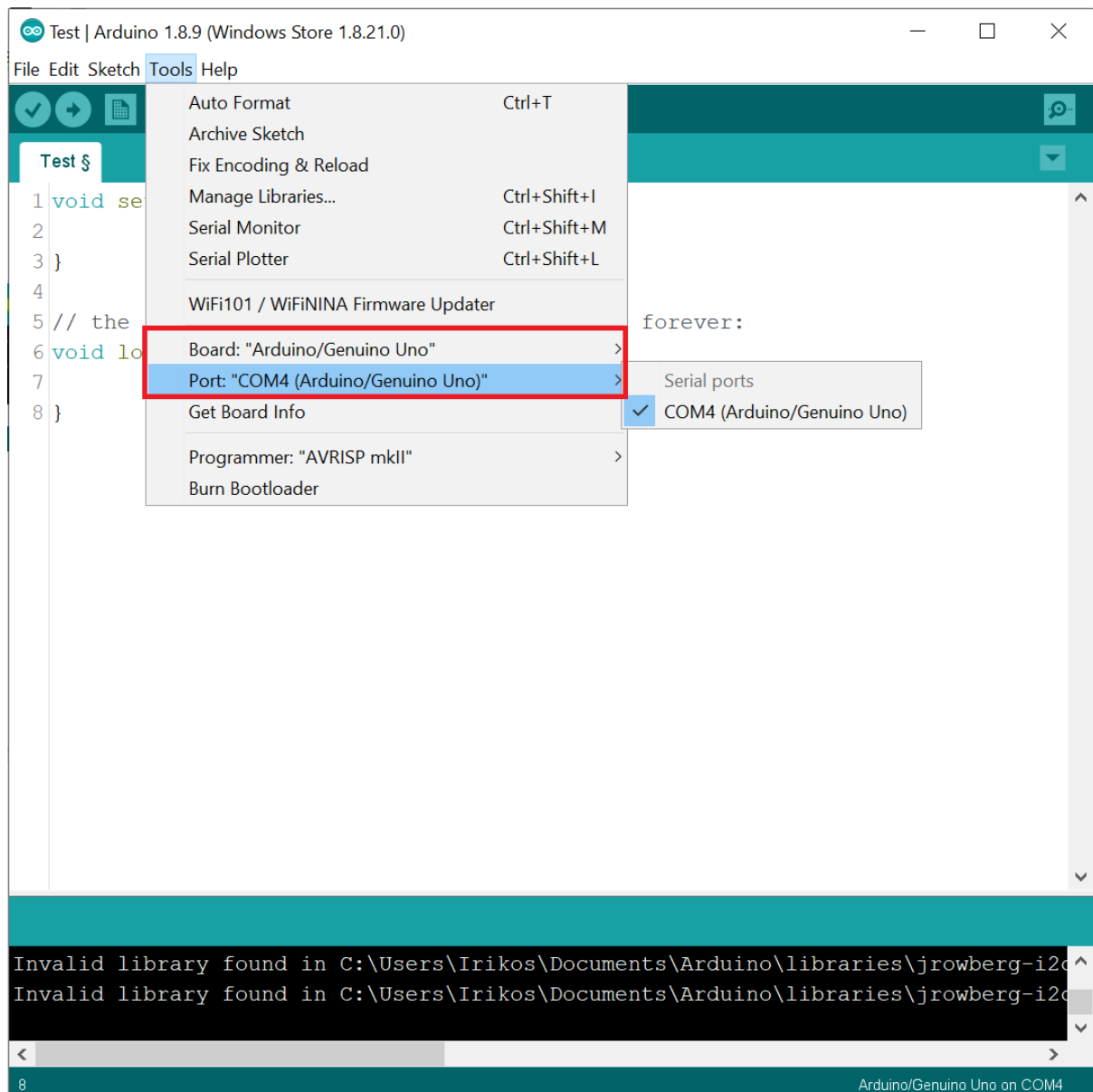
1. Arduino IDE

Learn the Arduino IDE interface.





Obs: Don't forget to check if the port is selected!

**Tips:**

- opening serial monitor **RESTARTS** your program
- uploading also verifies your code, no need to verify and (re)upload when doing small changes
- when uploading, one of the most common error sources is **not having the right port selected**. Make sure you have the right board and port selected. This can change even if the arduino loses power for a brief second
- If you have problems finding the arduino port, **run Arduino IDE as administrator (sudo in linux)**

2. Blinking led no. 13.

```
void setup() {  
  // initialize digital pin LED_BUILTIN as an output.  
  pinMode(LED_BUILTIN, OUTPUT);  
}  
  
// the loop function runs over and over again forever  
void loop() {  
  digitalWrite(LED_BUILTIN, HIGH); // turn the LED on (HIGH is the  
  voltage level)  
  delay(1000);                     // wait for a second  
  digitalWrite(LED_BUILTIN, LOW);  // turn the LED off by making the  
  voltage LOW  
  delay(1000);                     // wait for a second  
}
```

Source: <https://docs.arduino.cc/built-in-examples/basics/Blink>

Questions:

1. What's with the delay?
-
2. What happens if we change only one? Does it matter which one?
-
3. What happens if we remove it?
-
4. What is LED_BUILTIN?
-

The built in examples are helpful, but do not get into the habit of opening them from File -> Examples in the Arduino IDE. Instead, go to <https://docs.arduino.cc/built-in-examples/>, understand the schematic and the code, then go to the IDE and write it yourself. The built in examples code can be confusing due to lots of comments and they also cover the basics of Arduino programming which you should master. **There's a big difference between understanding how it's done and actually doing it yourself. Illusion of mastery is a real thing.**

Remember, LED_BUILTIN is actually an arduino constant for the number 13. You can easily replace LED_BUILTIN with the number 13. It is, however, bad practice to write the number of the pin directly. Still, since we will be using the PIN no. 13 for other purposes besides controlling an LED, it's best to create our own variable. (do that now)

```
const int ledPin = 13;

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

void loop() {
  // put your main code here, to run repeatedly:
  digitalWrite(ledPin, HIGH);
  delay(1000);
  digitalWrite(ledPin, LOW);
  delay(1000);
}
```

Questions:

1. Although we'll leave it like that, what's a potential problem in the naming of "ledPin"?
—
2. What's another coding style mistake?
—
3. Why "const int" and not int?
—

Code naming schemes sometimes require inspiration. Pay attention to your project specifications. For example, when building a stoplight that has 3 LEDs of fixed colors, it is reasonable to name your led pins *redLedPin*, *yellowLedPin* and *greenLedPin* as you'll always need these 3 colors in the project. However, if you are just blinking a random LED where the color doesn't matter anymore, you need to find another source of inspiration for the name. Naming it *redLedPin*, because you chose a red LED leaves no room for portability and requires code intervention when changing the color of the LED.

Now, as we've talked and as you can see, the built in led is actually connected to pin 13. So let's add an led to pin 13 as well.

For this, we'll need 3 items:

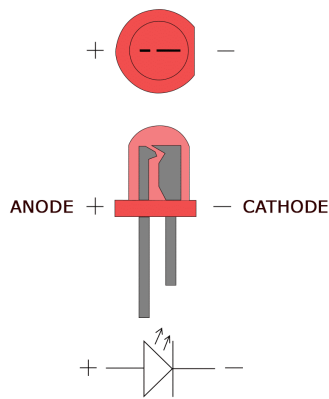
- a LED (**green or maybe yellow. Blue and white ones are the brightest and can hurt your eyes**)
- a breadboard
- a 220 ohm resistor (330 works as well)

Take them all out.

Let's recap the course a bit:

Questions:

- What's a LED?
- Which one is + and which one is - and how do you recognize them? How are they called?
- What's a breadboard and how does it work?
- What's a resistor?



A light-emitting diode (LED) is a semiconductor light source that emits light when current flows through it. Electrons in the semiconductor recombine with electron holes, releasing energy in the form of photons. The color of the light (corresponding to the energy of the photons) is determined by the energy required for electrons to cross the band gap of the semiconductor.

Interesting facts: Unlike a laser, the light emitted from an LED is neither spectrally coherent nor even highly monochromatic. However its spectrum is sufficiently narrow that it appears to the human eye as a pure (saturated) color.



Resistors are electrical components used to limit current in a circuit. They are passive components, meaning they only consume power (and can't generate it). The resistor's resistance limits the flow of electrons through a circuit.

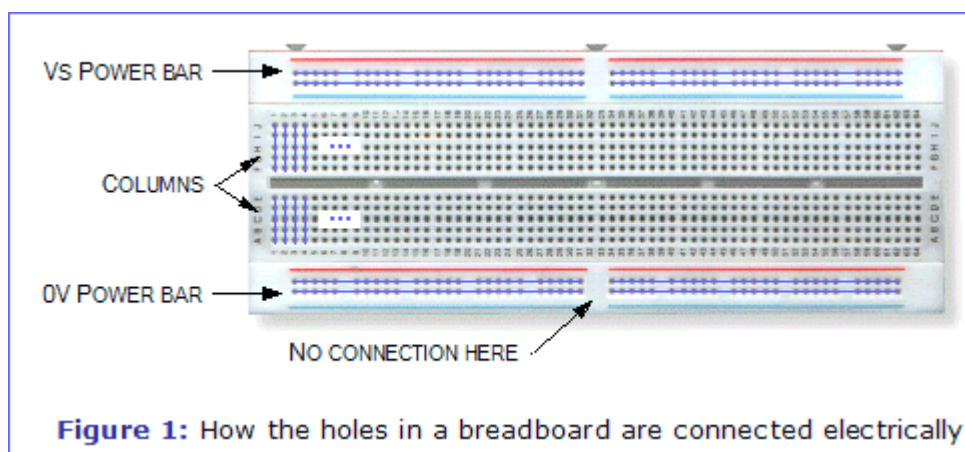
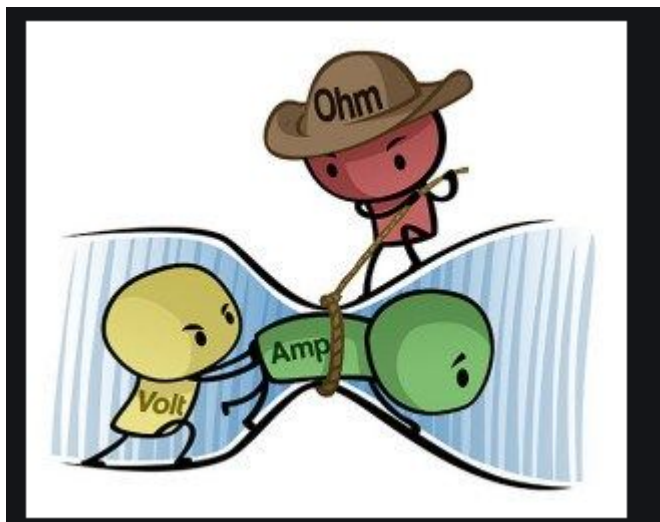
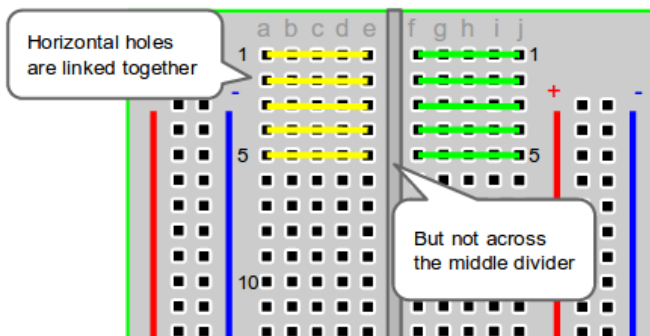


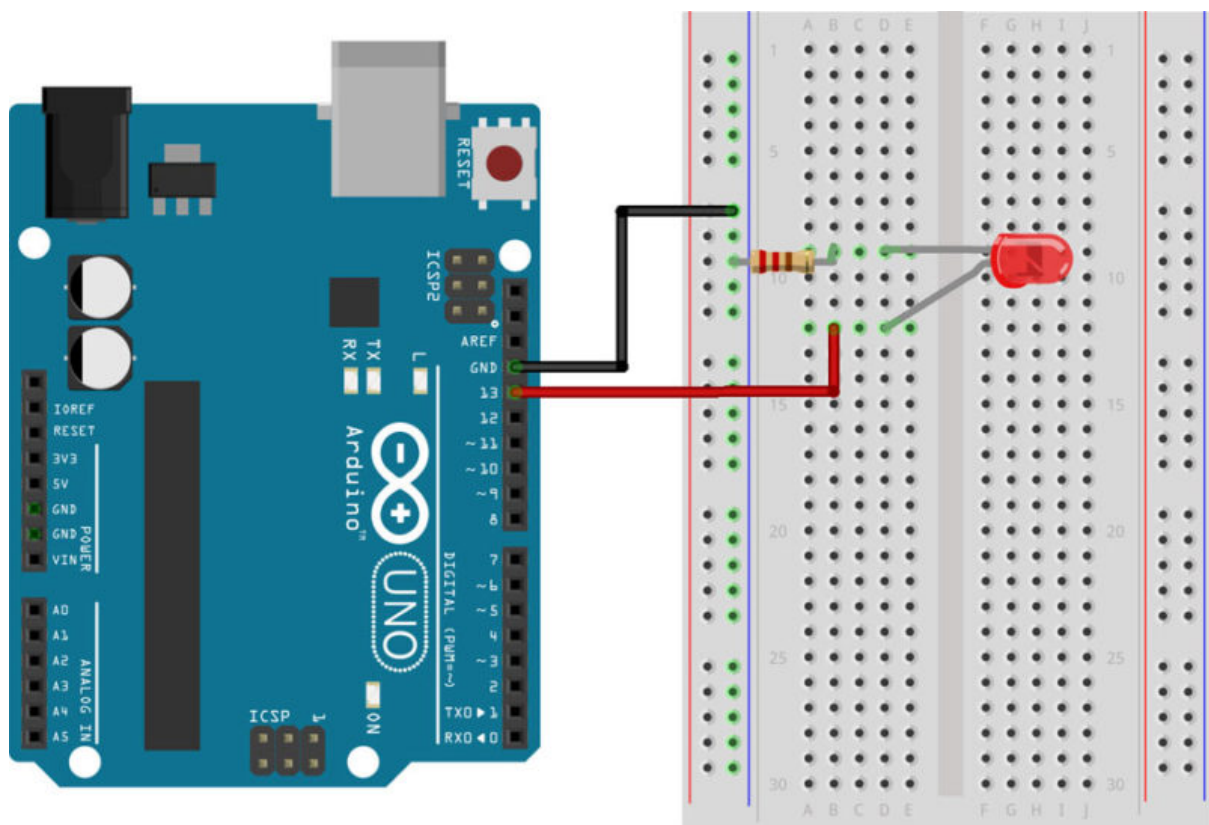
Figure 1: How the holes in a breadboard are connected electrically



Using the same code, let's add the LED. We can add the resistor to both the GND or the 13 PIN.

When possible, follow the **wires color scheme**:

- **BLACK** for **GND** (dark colors if not available)
- **RED** for **POWER** (3.3V / 5V / VIN) (bright colors if not available)
- **Bright Colored** for read and write signal (use red when none available and black only as a last option)
- We know it is not always possible to respect this due to lack of wires, but the first rule is **NOT USE BLACK FOR POWER OR RED FOR GND!**



ATTENTION! Do not look directly perpendicular to the tip of the LED and do not look too much at the LED. It can and will affect your eyes - take this seriously!

3. Blink without delay (home exercise)

The example above works well, but mostly because it's simple. Can you identify a problem with it?

The `delay()` function pauses the program for the amount of time specified as a parameter. While it is easy to create a blinking LED with the **`delay()`** function and many sketches use short delays for such tasks as switch debouncing, the use of `delay()` in a sketch has significant drawbacks. No other reading of sensors, mathematical calculations, or pin manipulation can go on during the delay function, so in effect, it brings most other activity to a halt. More knowledgeable programmers usually avoid the use of **`delay()`** for timing of events longer than 10's of milliseconds unless the Arduino sketch is very simple.

But there's a better way.

"An analogy would be warming up a pizza in your microwave, and also waiting for some important email. You put the pizza in the microwave and set it for 10 minutes. The analogy to using `delay()` would be to sit in front of the microwave watching the timer count down from 10 minutes until the timer reaches zero. If the important email arrives during this time you will miss it.

What you would do in real life would be to turn on the pizza, and then check your email, and then maybe do something else (that doesn't take too long!) and every so often you will come back to the microwave to see if the timer has reached zero, indicating that your pizza is done." (source: arduino.cc)

```
const int ledPin = 13;
int ledState = LOW; // could be bool

// Generally, you should use "unsigned long" for variables that hold
// time
// The value will quickly become too large for an int to store
unsigned long previousMillis = 0;
const long interval = 1000; // interval at which to blink
(milliseconds)

void setup() {
  pinMode(ledPin, OUTPUT);
}

void loop() {
  // TODO: WRITE CODE
}
```


Millis() returns the number of milliseconds passed since the Arduino board began running the current program. This number will overflow (go back to zero) after approximately 50 days.

```
unsigned long time;

void setup() {
  Serial.begin(9600);
}
void loop() {
  Serial.print("Time: ");
  time = millis();

  Serial.println(time); //prints time since program started
}
```

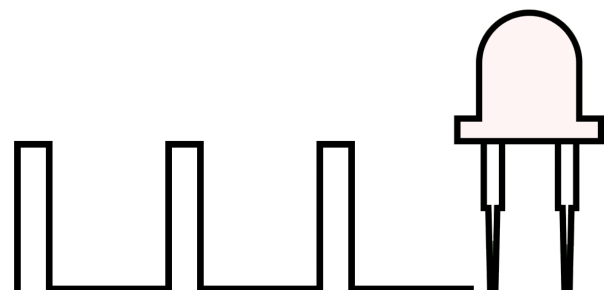
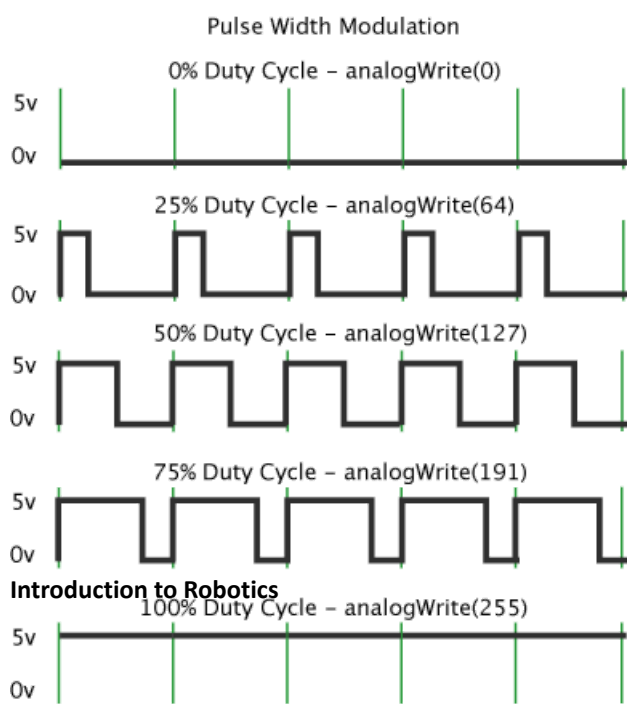
When checking Serial Monitor, check the “Check timestamp” for this example. What do you notice?

4. Fading an LED

Now that we know how to turn a light (LED) on and off, let's see how we can choose the intensity of the light as well.

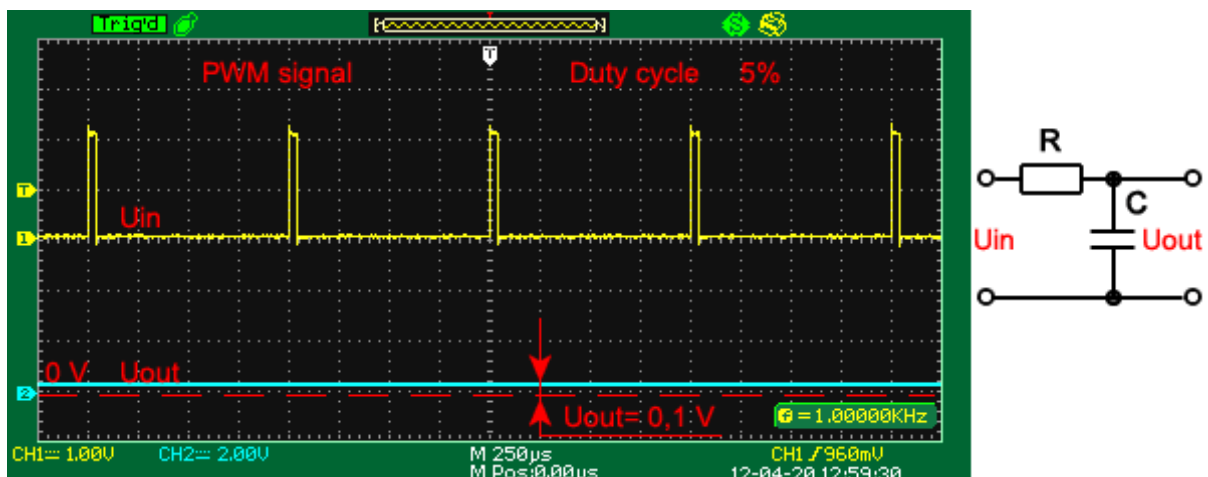
As you might remember from the course, the LED is a good example of a component that can be used both as a **digitalOutput** and an **analogOutput**. Basically, the intensity of the LED when using **digitalWrite(ledPin, HIGH) = analogWrite(ledPin, 255)**, but you can set the LED value anywhere between 0 and 255.

Let's recap the course a bit: PWM (pulse-width modulation) is a technique for getting analog results with digital means.



In practice, we use an RC low pass filter to convert the square wave into a continuous

analog voltage (azzurro line in the gif below)



That being said, let's change the code and play a bit with the LED intensity. Since 255 is maximum, let's change it to 200.

```
const int ledPin = 13;

void setup() {
  pinMode(ledPin, OUTPUT);
}

void loop() {
  analogWrite(ledPin, 128);
}
```

What do we notice? What if we change the value to 127?

Questions:

1. Why did it turn off?
-
2. Why didn't it fade?
-

Ok, so always remember that the PINS that can use PWM and on which you can use analogWrite are the ones with ~ (3, 5, 6, 9, 10, 11)

So, let's change it to **digital pin 9 (D9)** and try again. After we have connected the **ANODE (+)** wire to D9, we can easily see the advantage of keeping the pinNumber in a variable. In the code, we only have to change the **ledPin** value once, instead of changing it both in setup (pinMode) and in loop (analogWrite)

```
const int ledPin = 9;

void setup() {
  pinMode(ledPin, OUTPUT);
}

void loop() {
  analogWrite(ledPin, 200); // change it to more values and test it's
                           // limits: 200, 128, 127, 100, 10 etc
}
```

Now let's fade it on and off.
Let's write the code together.

```
const int ledPin = 9; // the PWM pin the LED is attached to
int brightness = 0;    // how bright the LED is
int fadeAmount = 5;    // how many units to fade the LED by

// the setup routine runs once when you press reset:
void setup() {
  // declare pin 9 to be an output:
  pinMode(led, OUTPUT);
}

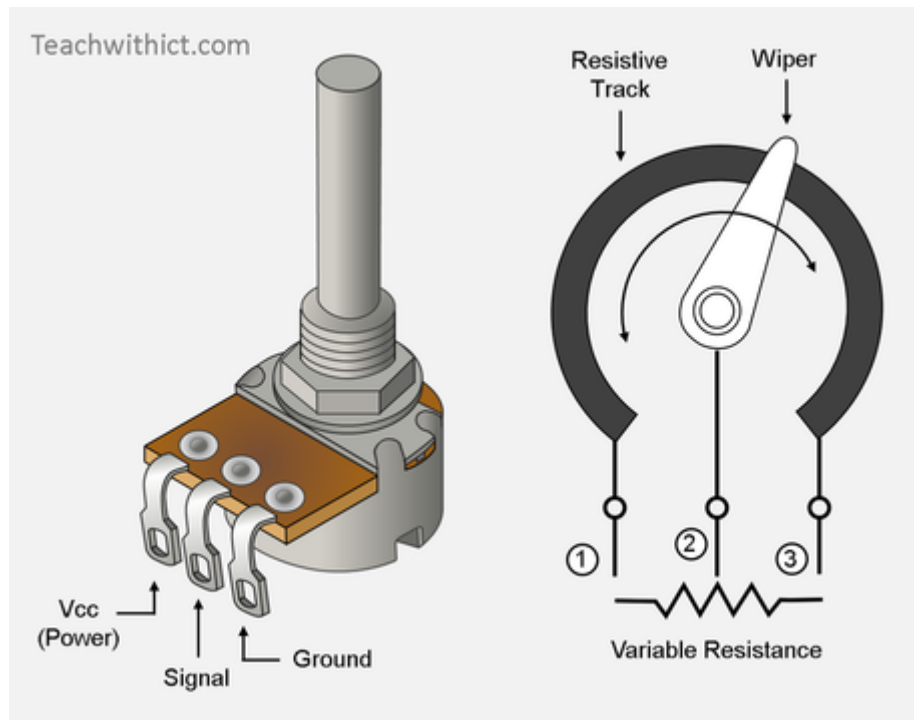
// the loop routine runs over and over again forever:
void loop() {
  // TODO: WRITE CODE
}
```

Source: <https://www.arduino.cc/en/Tutorial/Fade>

5. Reading and printing a potentiometer value

Controlling the LED intensity is great, but changing the value and re-uploading the code is not practical. Let's add a component which we can use to control the LED intensity.

Meet the potentiometer:



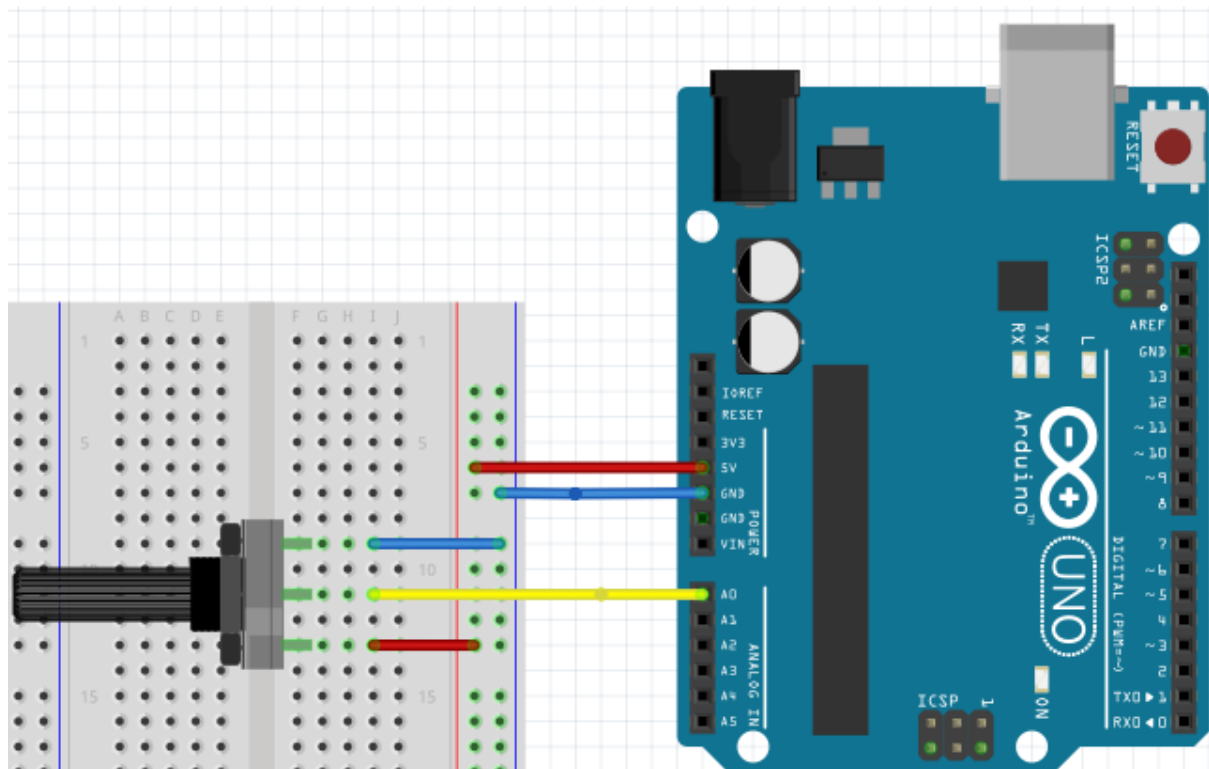
A potentiometer is a simple knob that provides a variable resistance, which we can read into the Arduino board as an analog value.

Let's connect the potentiometer to the board as follows:

- the outermost pins go to **5V** and **GND**
- the middle pin goes to **A0**

```
const int potPin = A0;
int potValue = 0;

void setup() {
  // initialize serial communication at 9600 bits per second:
  Serial.begin(9600);
}
// the loop routine runs over and over again forever:
void loop() {
  // TODO: WRITE CODE
}
```



This is the example from <https://www.arduino.cc/en/Tutorial/AnalogReadSerial>, but slightly modified.

Questions:

1. **Q:** Why do we use **const int** for pins but **int** for values?

-

Run the program and open **Serial Monitor**.

On the bottom right, you will see **9600 baud**.

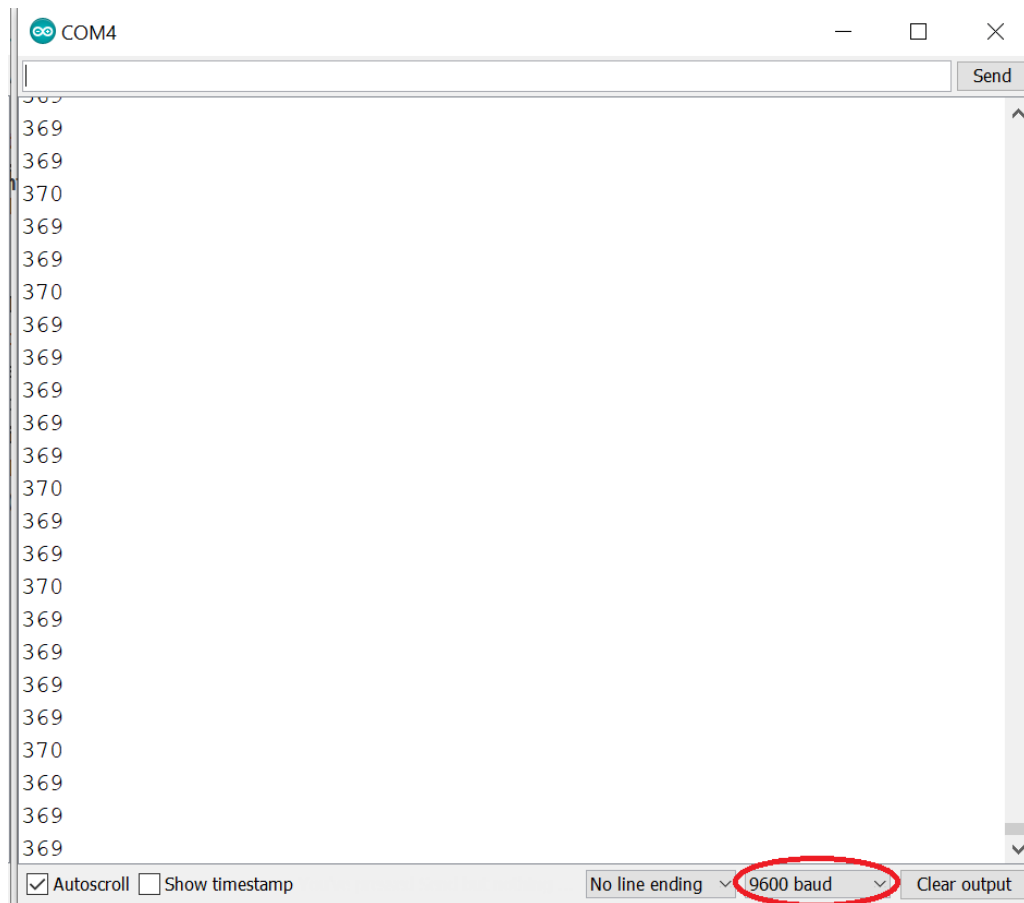
The **baud rate** is the **rate** at which information is transferred in a communication channel. In the serial port context, "9600 **baud**" means that the serial port is capable of transferring a maximum of 9600 bits per second.

At baud rates above 76,800, the cable length will need to be reduced. The higher the baud rate, the more sensitive the cable becomes to the quality of installation, such as how much of the wire is untwisted around each device.

Long story short, the number in `Serial.begin(9600)` must be the same as the baud rate.

Q: What do you think will happen if we change the baud rate in the serial monitor? Why does this happen?

-



6. Reading the analog voltage

The microcontroller of the board has a circuit inside called an analog-to-digital converter or **ADC** that reads this changing voltage and converts it to a number between 0 and 1023. When the shaft is turned all the way in one direction, there are 0 volts going to the pin, and the input value is 0. When the shaft is turned all the way in the opposite direction, there are 5 volts going to the pin and the input value is 1023. In between, `analogRead()` returns a number between 0 and 1023 that is proportional to the amount of voltage being applied to the pin.

Therefore, we can calculate the voltage read on the **potPin** by adding one line.

```
float voltage = potValue * (5.0 / 1023.0);
```

So, our program should look like this:

```
const int potPin = A0;

int potValue = 0;
float voltage = 0;

void setup() {
  // initialize serial communication at 9600 bits per second:
  Serial.begin(9600);
}

// the loop routine runs over and over again forever:
void loop() {
  // TODO: WRITE CODE TOGETHER
}
```

Source: <https://docs.arduino.cc/built-in-examples/basics/ReadAnalogVoltage>

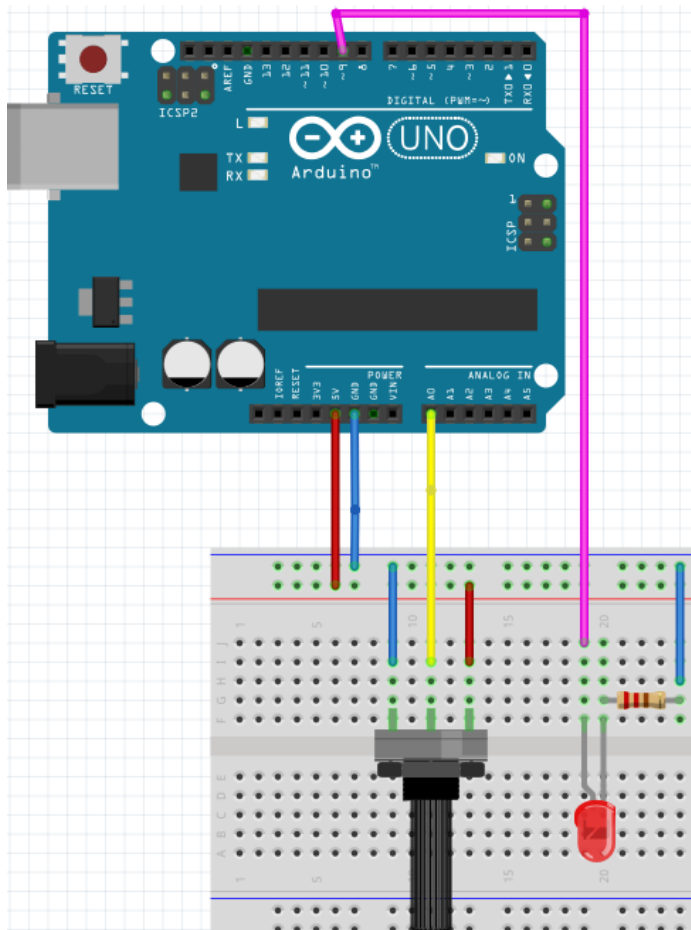
Let's recap the lab a bit:

- we connected a **LED** to **D9**, which also has a ~
- we used `analogWrite(ledPin, ledValue)`, with `ledValue = 0..255` to set the intensity of the LED

Now, let's use the potentiometer to control the intensity of the LED.

7. Fading an LED with the potentiometer (home exercise)

For this, we need to read the **potValue**, store it in a variable and write that variable to the LED.



The idea is simple, we have an analogInput and need to control an analogOutput with it

```
const int potPin = A0;
const int ledPin = 9;
// global variables are initialized to 0 by default
int potValue;

void setup() {
  pinMode(potPin, INPUT);
  pinMode(ledPin, OUTPUT);
}

void loop() {
  potValue = analogRead(potPin);
  analogWrite(ledPin, potValue); // TODO: finish code
}
```


Source: <https://docs.arduino.cc/built-in-examples/analog/AnalogInOutSerial>

Do that, see what happens.

Questions:

1. Why does it behave in this way?

-

2. How can we fix it?

-

```
const int potPin = A0;
const int ledPin = 9;

int potValue = 0;
int ledValue = 0;

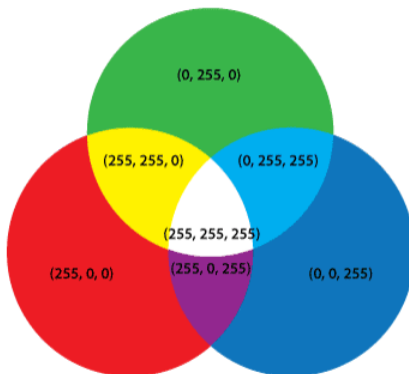
void setup() {
  pinMode(potPin, INPUT);
  pinMode(ledPin, OUTPUT);
}

void loop() {
  potValue = analogRead(potPin);
  ledValue = // TODO: finish code
  // ledValue = potValue / 4; // this works just as well
  analogWrite(ledPin, ledValue);
}
```

Extra exercise, for home: connect the LED (which goes to **D9**) to the middle pin of the potentiometer. As you can see, it controls the fade, much in the same way Arduino did. We did not need an Arduino to do this, as it is a simple exercise. However, with the help of Arduino we can increase the complexity of the project using the code, while keeping the complexity of the hardware fairly low.

8. Controlling a RGB LED

These LEDs have three tiny LEDs of 3 primary colors (**red, green and blue**) where a terminal is common for all. Some have common positive terminal (anode) and some have common negative terminal (cathode). When different voltages are applied to different LEDs, they make a mixture and produce several thousands of colors.

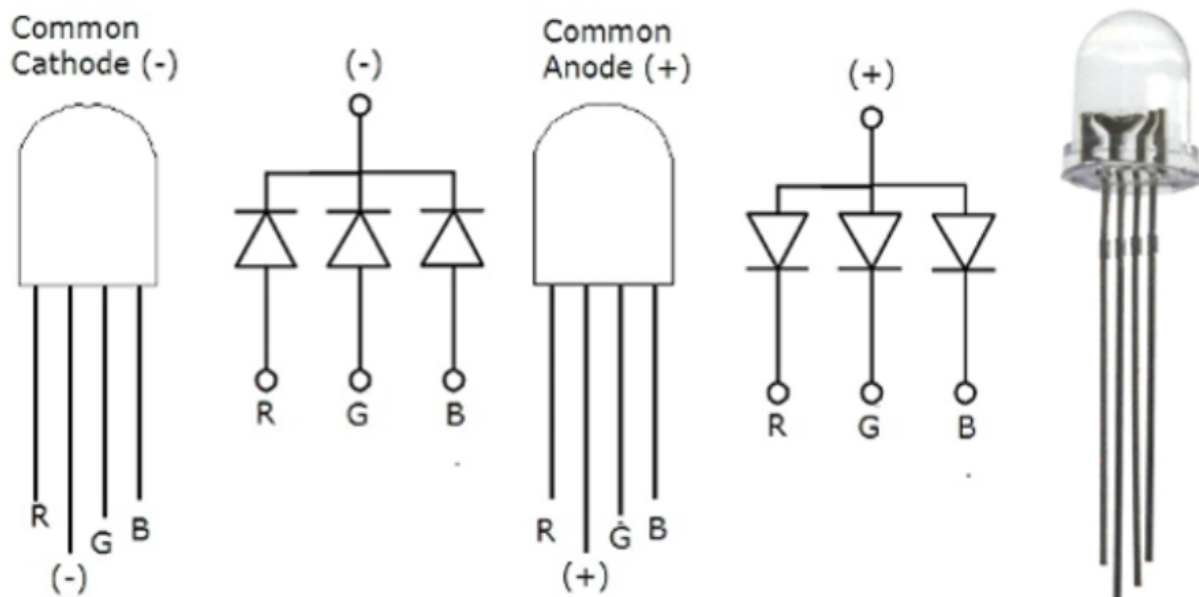


There are actually two types of RGB LEDs; the common cathode one and common anode one.

With a **common anode** you connect the anode to the +5v and each individual LED to a resistor each. Connect that resistor to an output pin.

Then a write LOW to that pin will turn the LED on and a HIGH will turn it off. This is called **current sinking**.

With a **common cathode** you connect the cathode to ground and connect each LED's anode through a resistor to the output pin. Then a HIGH turns it on. This is called **current sourcing**.

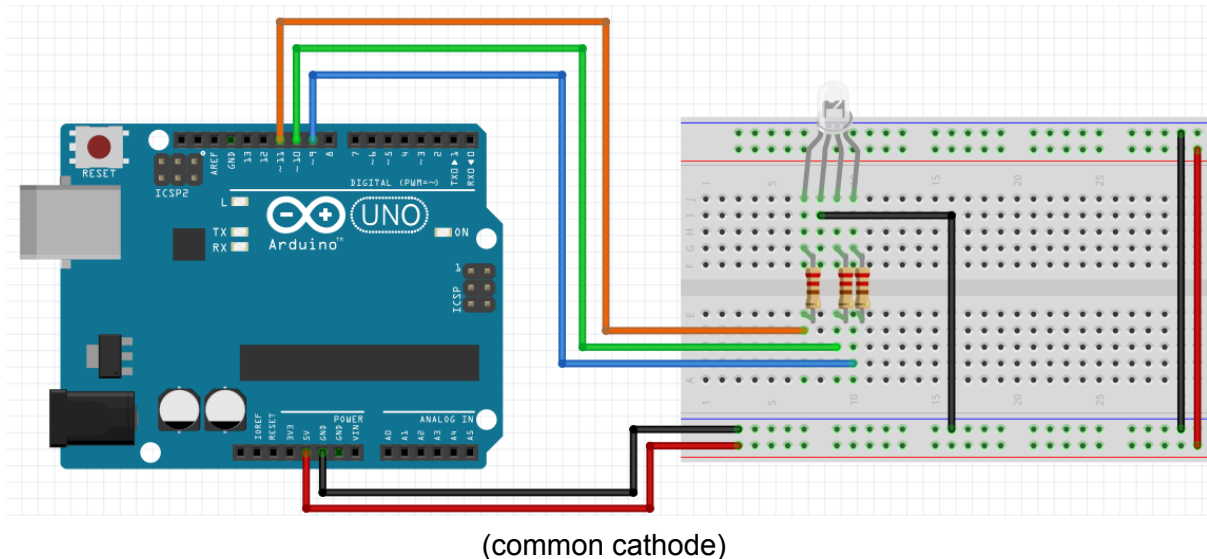


To check if you have a common cathode or common anode you can use a multimeter. Set it to diode and first use - **on the long pin** and + **on a small one**. If it lights up, it's a common **cathode**. If not, use + **on the long pin** and - **on a small one**; if it lights up now, then it's a common **anode**.

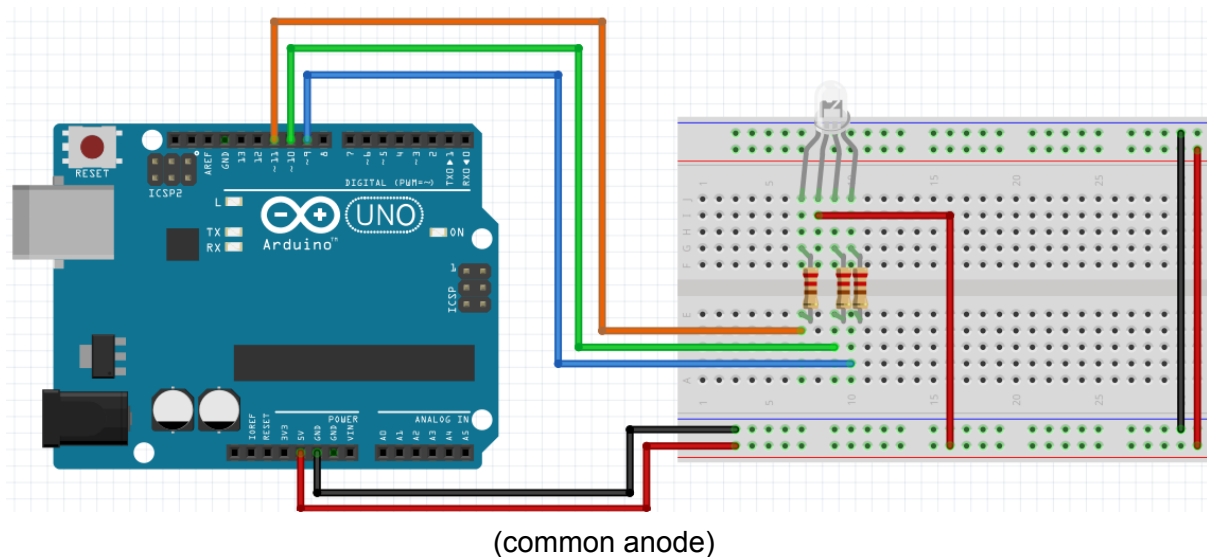
Either way, after finding out which type you have (most likely common cathode), keep the long pin and keep switching between the smaller ones with the multimeter, in order to change between **R** - Red, **G** - Green and **B** - Blue

Which one do you have?

8.a Common Cathode



8.b Common Anode



The main difference that you will encounter is that you need to connect the cathode to GND in common cathode configuration and the anode to 5V in common anode configuration. Then, in the code, the values work in the opposite way. For common cathode, 255 is the maximum brightness and 0 is minimum, while for common anode 255 is minimum and 0 is maximum. Check the link for a detailed explanation.

<https://www.hackster.io/techmirtz/using-common-cathode-and-common-anode-rgb-led-with-arduino-7f3aa9>

```
const int redPin = 11;
const int greenPin = 10;
const int bluePin = 9;

void setup() {
  pinMode(redPin, OUTPUT);
  pinMode(greenPin, OUTPUT);
  pinMode(bluePin, OUTPUT);
  Serial.begin(9600);
}

void loop() {
  // play with LOW and HIGH on each of them. Change the pinValues to match
  // the colors if they don't
  digitalWrite(redPin, HIGH);
  digitalWrite(greenPin, HIGH);
  digitalWrite(bluePin, HIGH);
}
```

However, using digitalWrite only gives us a small fraction of the possible colors combination. Let's switch to analogWrite instead.

```
const int redPin = 11;
const int greenPin = 10;
const int bluePin = 9;

void setup() {
  pinMode(redPin, OUTPUT);
  pinMode(greenPin, OUTPUT);
  pinMode(bluePin, OUTPUT);
  Serial.begin(9600);
}

void loop() {
  // play with LOW and HIGH on each of them. Change the pinValues to match
  // the colors if they don't
  analogWrite(redPin, 133);
  analogWrite(greenPin, 244);
  analogWrite(bluePin, 13);
}
```

Even better, let's create a function to simplify using it.

```
const int redPin = 11;
const int greenPin = 10;
const int bluePin = 9;
bool commonAnode = false;

void setup() {
  pinMode(redPin, OUTPUT);
  pinMode(greenPin, OUTPUT);
  pinMode(bluePin, OUTPUT);
  Serial.begin(9600);
}

void loop() {
  setColor(255, 0, 0); // red
  delay(1000);
  setColor(0, 255, 0); // green
  delay(1000);
  setColor(0, 0, 255); // blue
  delay(1000);
  setColor(255, 255, 0); // yellow
  delay(1000);
  setColor(255, 0, 255); // purple
  delay(1000);
  setColor(0, 255, 255); // acqua
  delay(1000);
}

void setColor(int redValue, int greenValue, int blueValue) {
  // TODO: WRITE CODE
}
```