

# IoT Product Design and Coding Bootcamp

Brian Rashap, Ph.D.

15-MAR-2021



# IoT Fun



# Introduction



# Brian Rashap, Ph.D.

- Proud husband of Krista and father of Shelby (22) and Ethan (18)
- Electrical Engineer with 25 years industrial experience
- High School track coach
- Hobbies: running, cycling, reading, spending time with family





# Cecilia Castillo, Assistant

- Software Engineer with over 25 years experience in government and commercial applications development, teaching, and mentoring.
- Side gig teaching robotics and technology to homeschool students.
- Enjoy rock climbing, bicycling, reading, gardening.





# Introductions

## INTRODUCTIONS



# Class Rules

- Respect each other. Help each other.
- Ask questions.
- Be on time (let us know via Slack if you won't be here)
- Keep your workspace and the classroom neat and tidy.
- If you are struggling, let me, Susan, or Esteban know. We are here to HELP!



# Grading

Class assignments will total 1000 points. You will need to earn at least 750 total points and at least 225 points on your Capstone to graduate.

- ① IoT assignments + Lab Notebooks: 300 pts
- ② Fusion 360 assignments: 100 pts
- ③ Weekly quizzes: 100 pts
- ④ Midterm Projects: Smart Room Controller/Plant Watering System: 200 pts
- ⑤ Team Capstone Project: 300 pts

More information will be provided later today on how assignments are turned in.

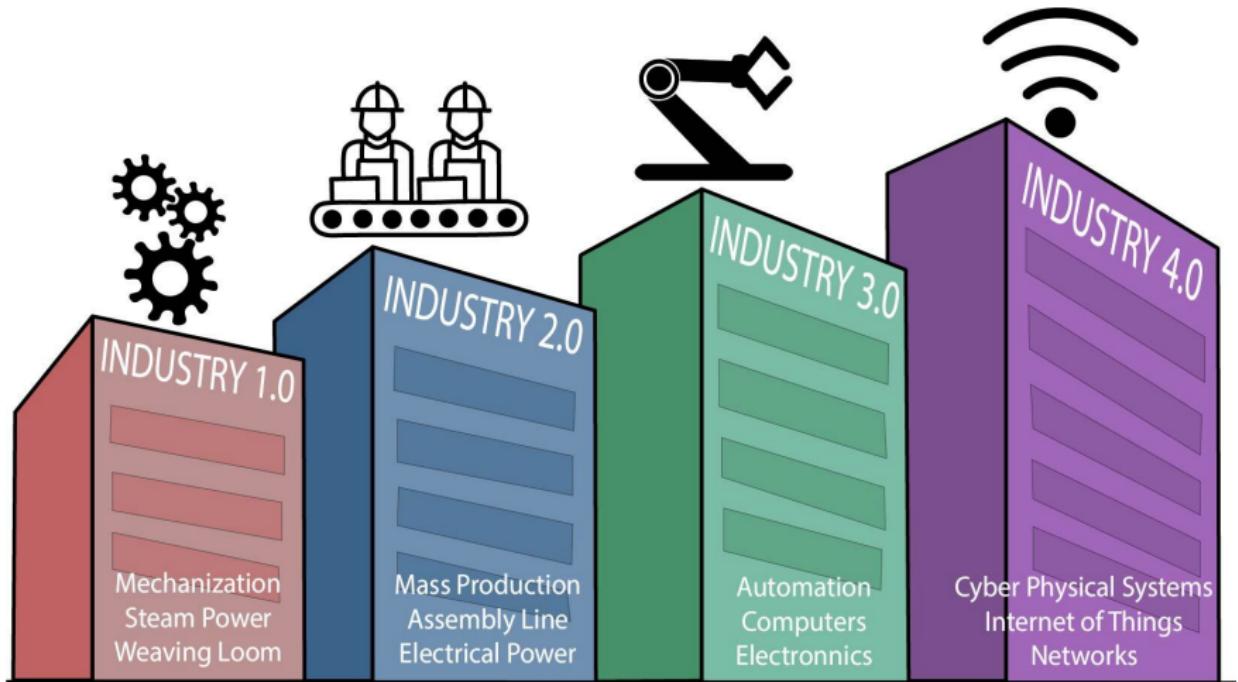


# Credit for Prior Learning (CPL)

Approved for CPL	
CIS 1605	Internet of Things
CIS 1275	Introduction to C++
BCIS 1110	Fundamentals of Information Literacy and Systems
BUSA 1130	Business Professionalism
BUSA 1198	Project Management Fundamentals
CSIS 1151	Intro to Programming for Non-Majors of CS*
* CSIS 1151 credit requires appropriate math prerequisites	

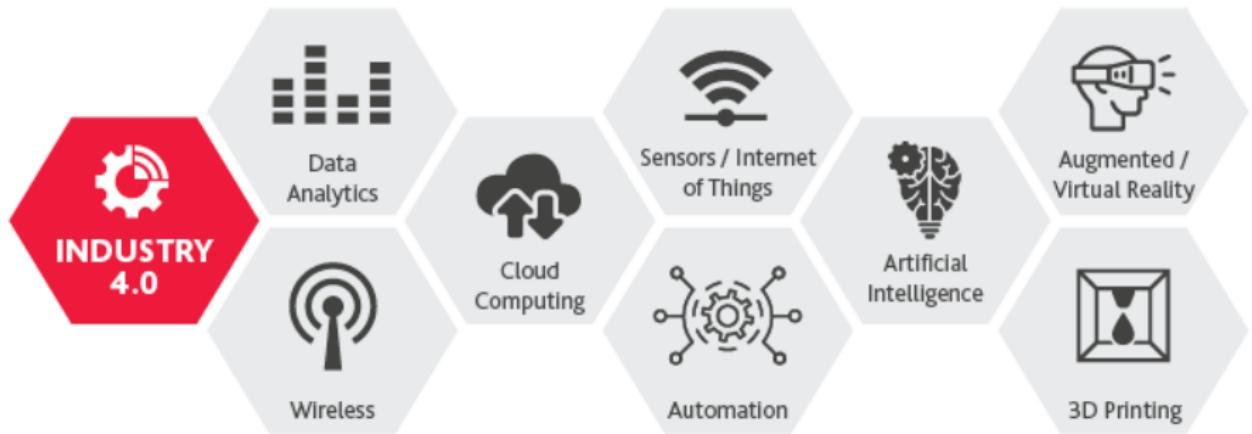


# Evolution of Industry





# Components of Industry 4.0





# IoT and Data Science



**AI:** Data-based learning



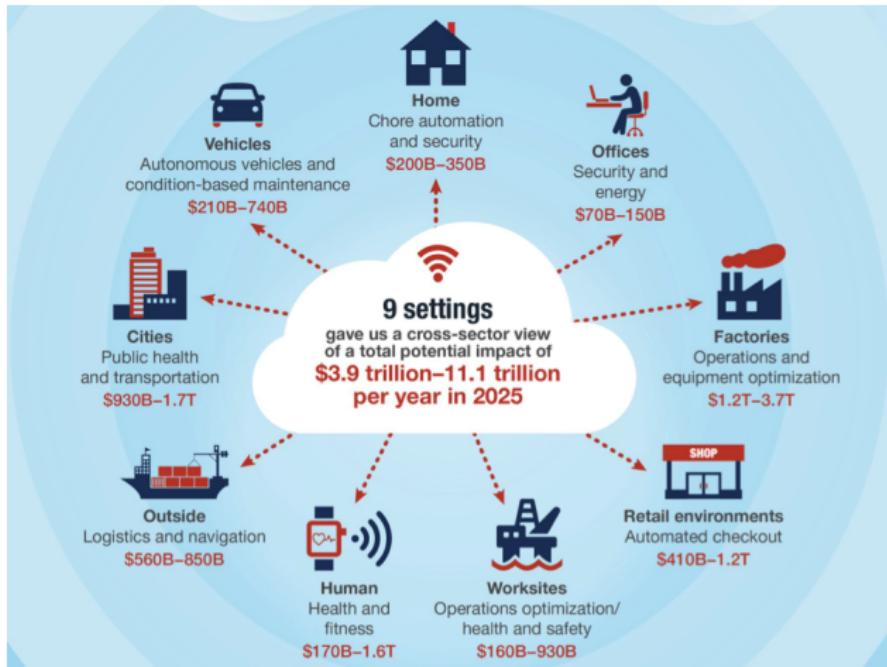
**Big Data:** Capture, storage, analysis of data



**IOT:** Data Collection through IoT



# IoT 2025



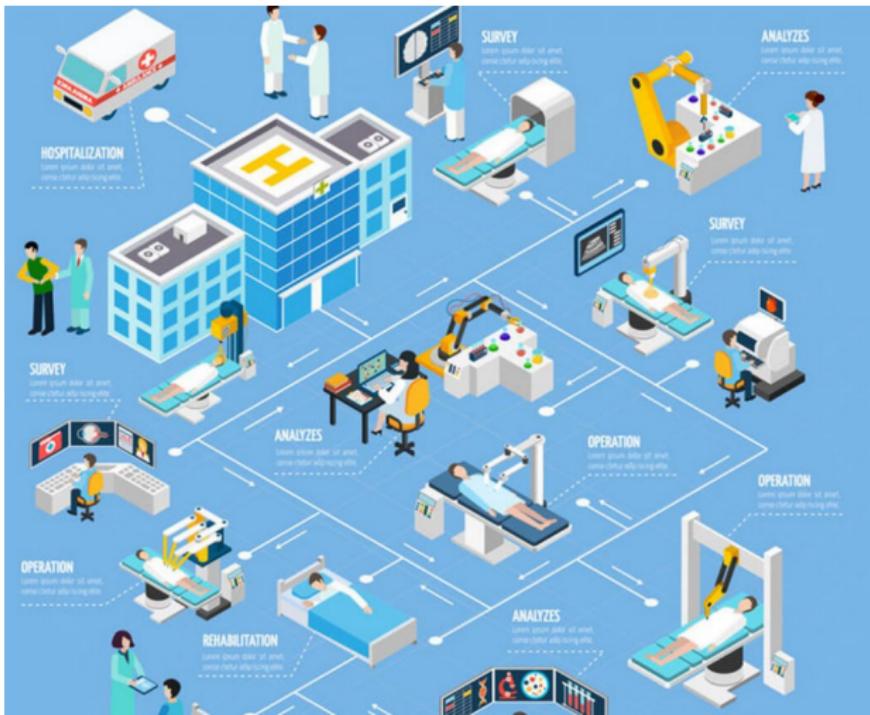


# Smart Facilities





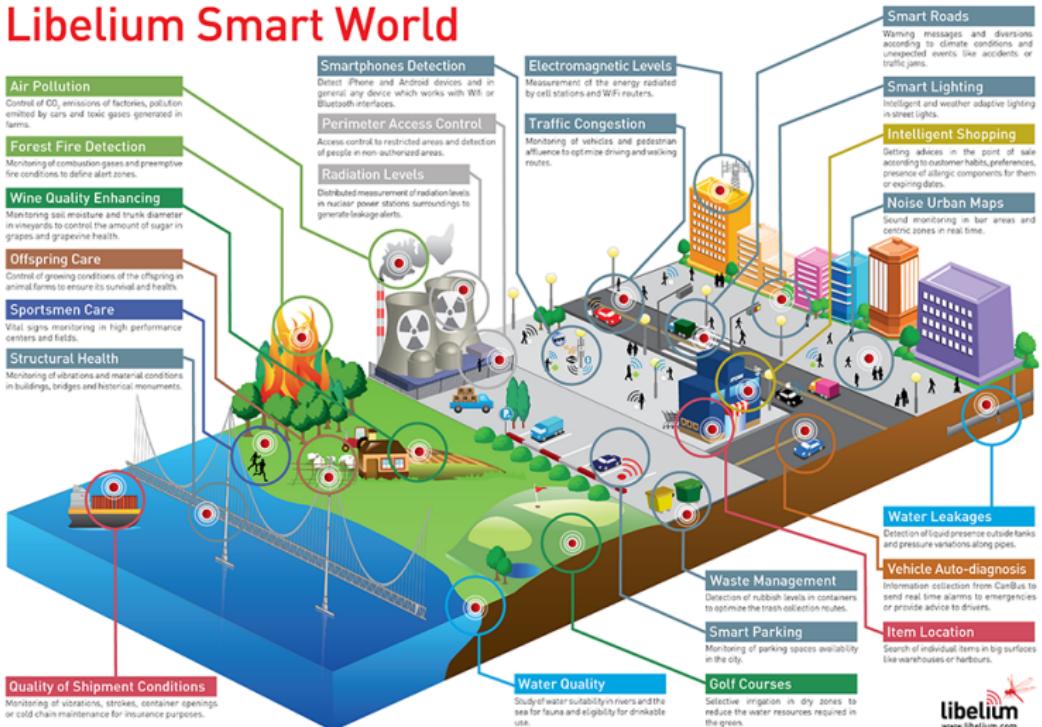
# Healthcare 2025





# Smart World

## Libelium Smart World



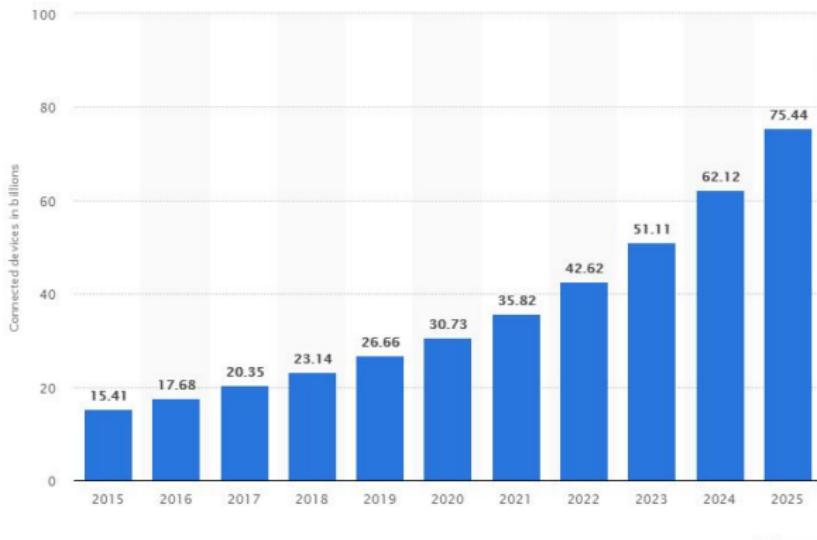


# And Out of This World





# IoT Growth



© Statista

## How ubiquitous is the Internet of Things?

- There are approximately 31 billion IoT devices today.
- 127 new IoT devices are connected to the internet every SECOND.
- This morning, 1,828,800 IoT devices will be added to the internet.



# Let's Begin Our Journey





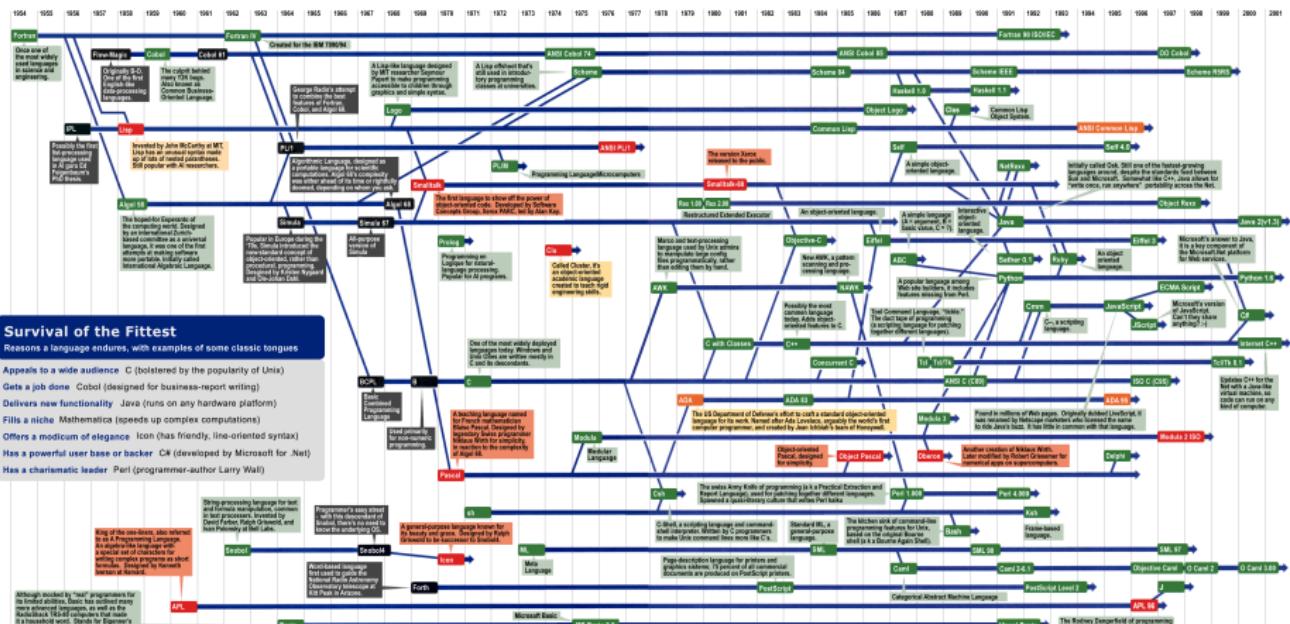
# Computer Languages

# Mother Tongues

## Tracing the roots of computer languages through the ages

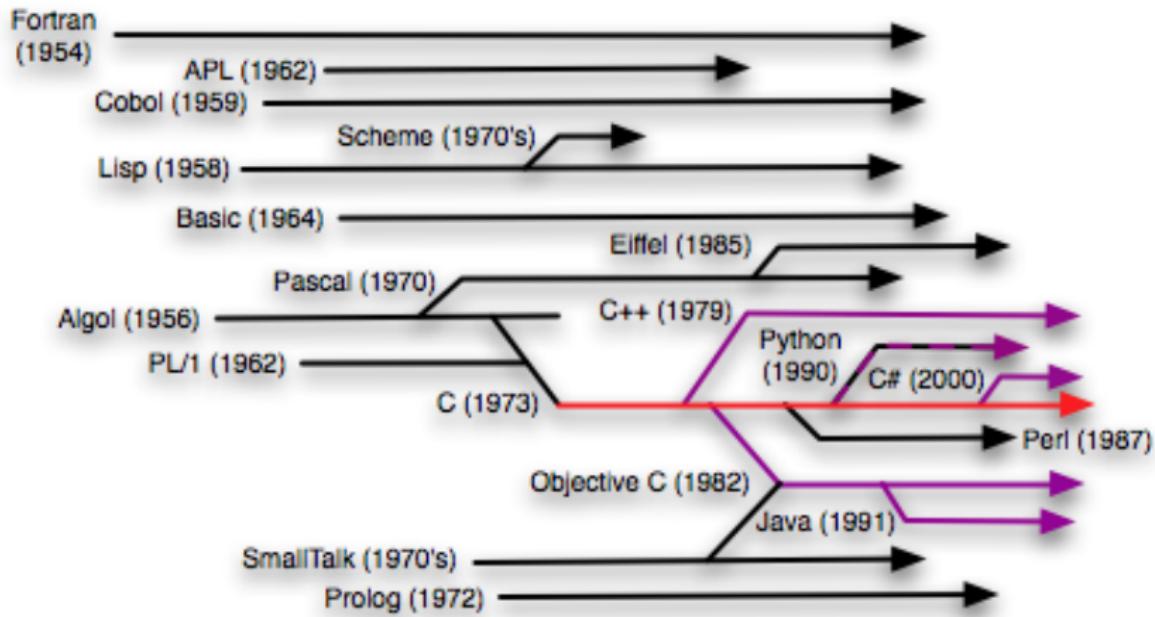
Just like half of the world's spoken tongues, most of the 2,305-plus computer programming languages are either endangered or extinct. As powerhouses C/C++, Visual Basic, Cobol, Java and other modern sources code dominate our systems, hundreds of older languages are running out of life.

**Code-karate** Garry Booch, Rational Software's chief scientist, is working with the Computer History Museum in Silicon Valley to record and, in some cases, maintain writings by leading new compilers so our ever-changing hardware can grok the code. Why bother? "They tell us about the state of software practice, the minds of their inventors, and the technical, social, and economic forces that shaped history at the time," Booch explains. "It'll provide the foundation for computer history, and it'll give historians and programmers a better appreciation of what was brilliant, and what was an utter failure." Here's a peek at the strongest branches of programming's family tree. For a more exhaustive rundown, check out the Language List at [HTTP://WWW.informatics.uni-freiburg.de/Java/melchanc/fst.html](http://WWW.informatics.uni-freiburg.de/Java/melchanc/fst.html). —Michael Mendano





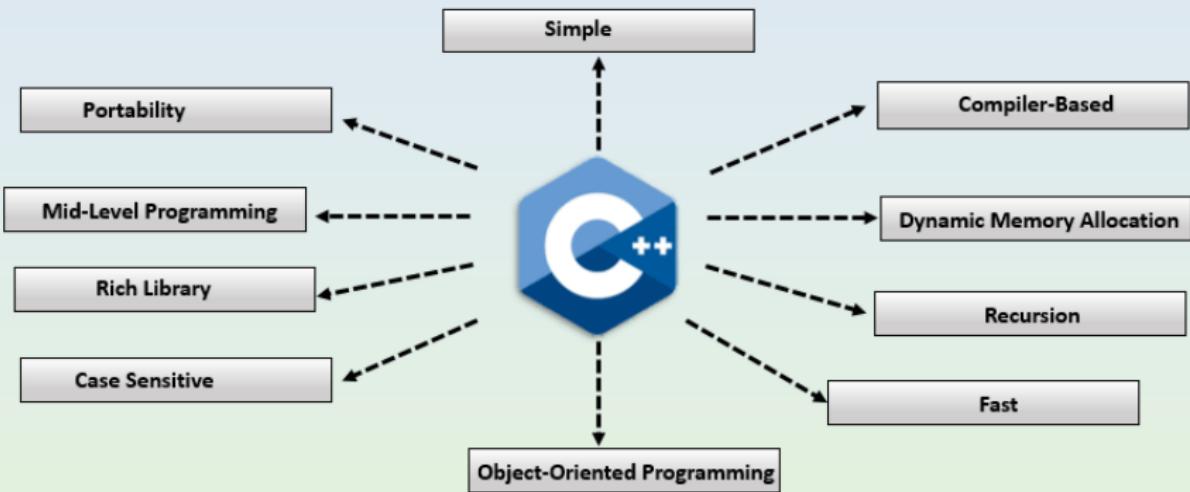
# Computer Languages





# Why C++

## Features of C++



[www.educba.com](http://www.educba.com)



# CLI vs GUI

```
[root@localhost ~]# cd /var  
[root@localhost var]# ls -la  
total 72  
drwxr-xr-x. 18 root root 4096 Jul 30 22:43 .  
drwxr-xr-x. 23 root root 4096 Sep 14 20:42 ..  
drwxr-xr-x. 2 root root 4096 May 14 00:15 account  
drwxr-xr-x. 11 root root 4096 Jul 31 22:26 cache  
drwxr-xr-x. 3 root root 4096 May 18 16:03 db  
drwxr-xr-x. 3 root root 4096 May 18 16:03 empty  
drwxr-xr-x. 2 root root 4096 May 18 16:03 games  
drwxrwx-T. 2 root gdm 4096 Jun 2 18:39 pdfs  
drwxr-xr-x. 38 root root 4096 May 18 16:03  
drwxr-xr-x. 2 root root 4096 May 18 16:03 log  
drwxr-xr-x. 2 root root 4096 May 18 16:03 private  
drwxr-xr-x. 2 root root 4096 Jul 1 22:11 repodata  
lrwxrwxrwx. 1 root root 6 May 14 00:12 run -> run  
drwxr-xr-x. 14 root root 4096 May 18 16:03 spool  
drwxrwxrwt. 4 root root 4096 Sep 12 23:58 tmp  
drwxr-xr-x. 2 root root 4096 May 18 16:03 yp  
[root@localhost var]# yum search wiki  
No matches found.  
[root@localhost var]#
```



# VS

Start





# Command Line Interface - Basic Navigation

The Command Line Interface (CLI) will allow us to directly navigate the computers operating system. We will use:

- macOS or Linux: Terminal
- Windows: PowerShell

The following commands will work on all three system, except where noted below. macOS and Linux are case-sensitive, Windows is not.

- `pwd`: Show the present working directory.
- `ls`: To get the list of all the files or folders.
- `cd`: Used to change the directory.
- `du`: Show disk usage. (not available in PowerShell).
- `man`: Used to show the manual of any command.



# Command Line Interface - File and Directory Manipulation

- **mkdir:** Used to create a directory if it does not already exist. It accepts directory name as input parameter.
- **rmdir:** It is used to delete a directory if it is empty.
- **cp:** This command will copy the files and directories from source path to destination path. It can copy a file/directory with new name to the destination path. It accepts source file/directory and destination file/directory.
- **mv:** Used to move the files or directories. This command is similar to the cp command but it deletes a copy of the file or directory from the source path.
- **rm:** Used to remove files or directories.
- **touch:** Used to create or update a file. (PowerShell New-Item).



# Command Line Interface - Displaying the file contents

- cat: It is generally used to concatenate files. It gives the output on the standard output.
- more: It is a filter for paging through text one screenful at a time.

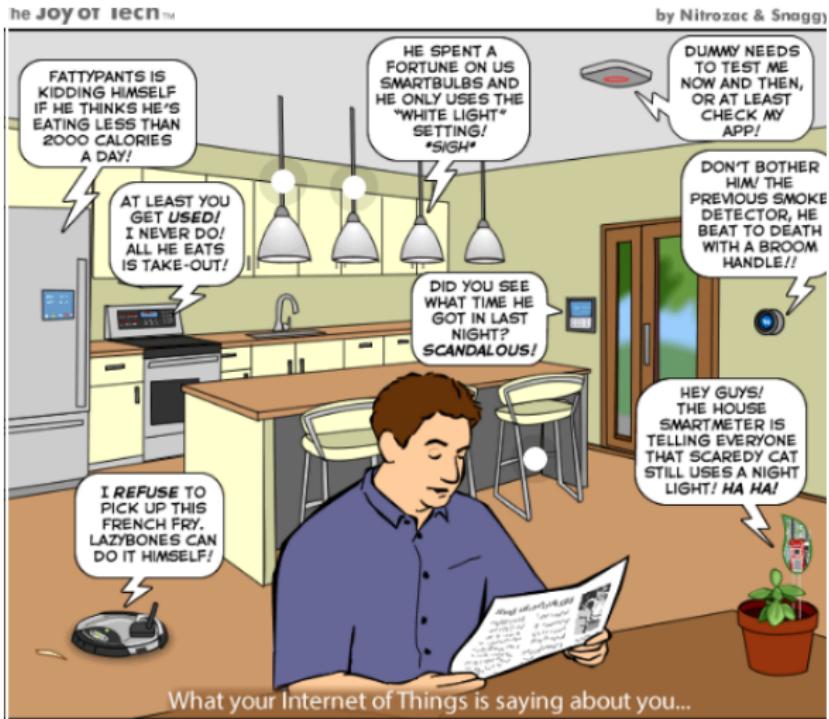
The below commands are not available in PowerShell:

- less: It is used for viewing files instead of opening the file. Similar to the "more" command but it allows backward as well as forward movement.
- head: Used to print the first N lines of a file. It accepts N as input and the default value of N is 10.
- tail: Used to print the last N-1 lines of a file. It accepts N as input and the default value of N is 10.

On all systems, commands can be "piped" together: ls | more <file>



# IoT Fun



# Smart Room Controller

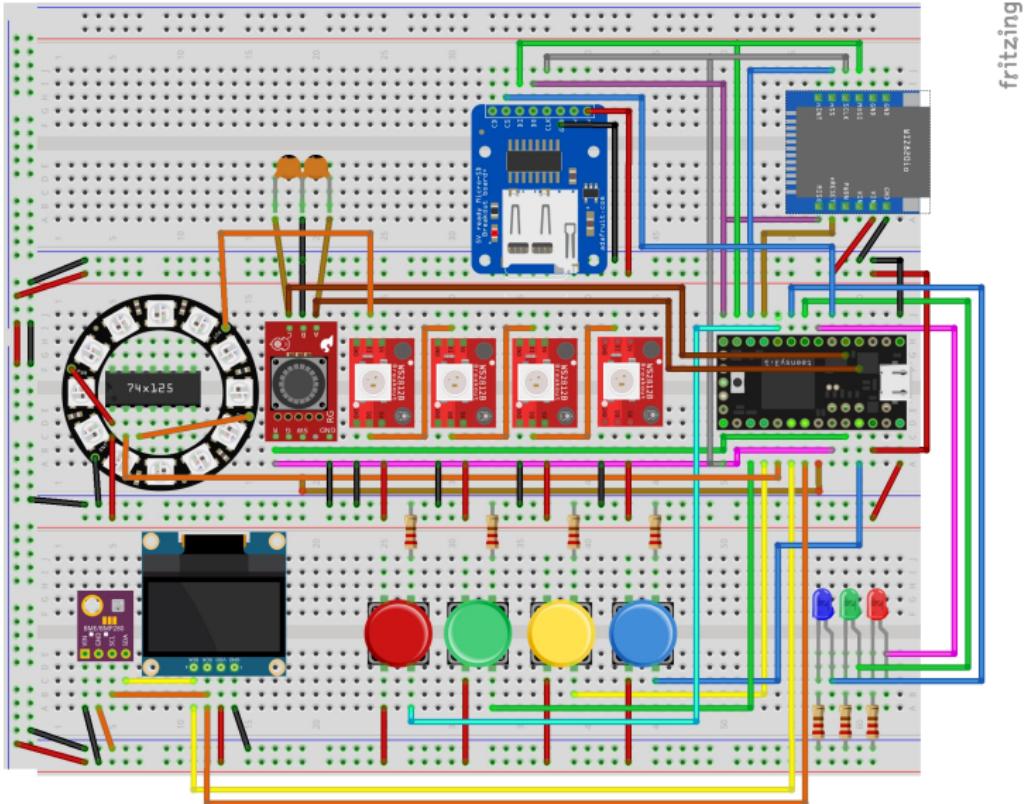


# Our First Microcontroller





# Smart Room Controller

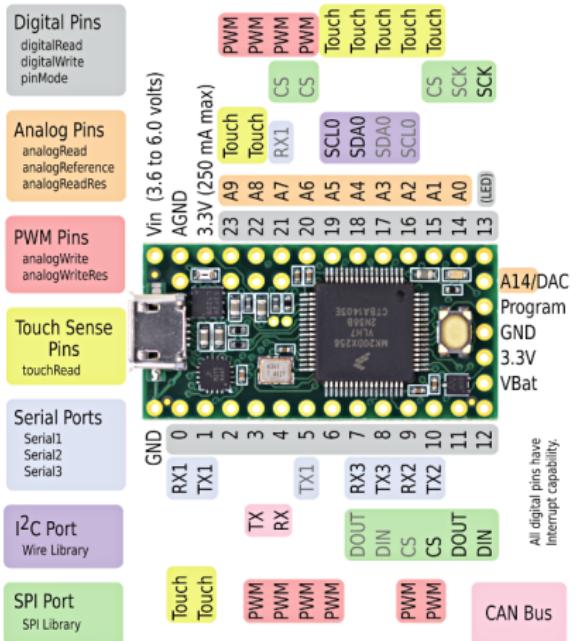


fritzing



# Teensy 3.2

- Cortex-M4 72MHz (overclocked to 96 MHz)
- 34 GPIO pins
- 3.3V and 5.0V operating voltages
- 500mA of available power with USB





# Arduino IDE for Teensy

We are going to start off using the Arduino IDE<sup>1</sup>. The Arduino IDE is programmed essentially using C++ code, but makes the compiling and loading onto the microcontroller simpler.

We begin by installing the Arduino IDE (Skip this step if on Mac):  
*<https://www.arduino.cc/en/main/software>*

Then, we install the Teensyduino add-on:

*[https://www.pjrc.com/teensy/td\\_download.html](https://www.pjrc.com/teensy/td_download.html)*

---

<sup>1</sup>An IDE, or Integrated Development Environment, enables programmers to consolidate the different aspects of writing a computer program.



# Other Software

## ① Git

- <https://git-scm.com/downloads>

## ② Fritzing

- IoT Bootcamp Teams Site

## ③ Drawio

- <https://app.diagrams.net/>

## ④ Fusion 360

- Instructional Videos - Teams Site

## ⑤ Formlab's Preform

- <https://formlabs.com/software/>

## ⑥ Ultimaker's Cura

- <https://ultimaker.com/software/ultimaker-cura>



# GITHUB Simplified

```
1 // In PowerShell go to ./Documents/<yourname>
2 // Get a repository that already exists and pull
   it into your local machine
3 git clone <URL of repository>
4
5 // From the repository directory, get updates
6 git pull
7
8 // Send your changes up to the repository
9 git add .
10 git commit -m "<comment>"
11 git push
12
13 // You may get asked to enter your GIT username
14 git config --global user.email "you@example.com"
```



# GITHUB First Clone

ddc-iot-classroom-2

Accept the assignment —

L01\_HelloWorld

Once you accept this assignment, you will be granted access to the `l01-helloworld-brashap` repository in the `ddc-iot` organization on GitHub.

Accept this assignment



You're ready to go!

You accepted the assignment, `L01_HelloWorld`.

Your assignment repository has been created:

<https://github.com/ddc-iot/l01-helloworld-brashap>

```
1 brian:~$ cd Documents/
2 brian:Documents$ mkdir IoT
3 brian:Documents$ cd IoT
4 brian:IoT$ git clone https://github.com/ddc-iot/L01_helloWorld-brashap
5 Cloning into 'L01_helloWorld'...
6 Username for 'https://github.com': brashap
7 Password for 'https://brashap@github.com':
8 remote: Enumerating objects: 4, done.
9 remote: Counting objects: 100% (4/4), done.
10 remote: Compressing objects: 100% (3/3), done.
11 remote: Total 4 (delta 0), reused 4 (delta 0), pack-reused 0
12 Unpacking objects: 100% (4/4), 321 bytes | 53.00 KiB/s, done.
```

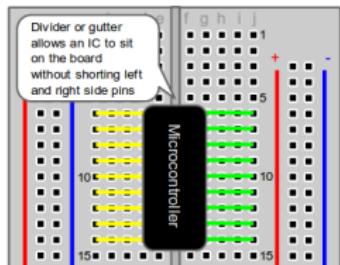
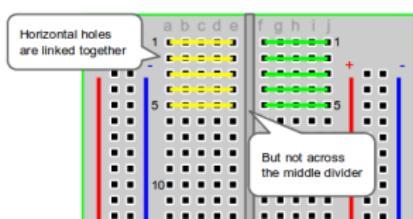
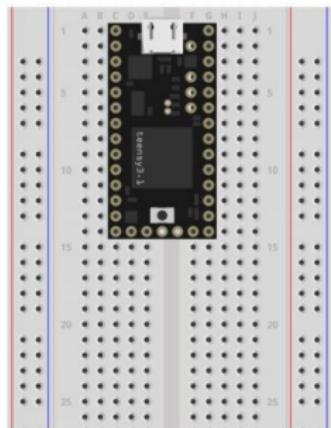
Second Clone: [https://github.com/ddc-iot/class\\_slides](https://github.com/ddc-iot/class_slides)

# L01\_HelloWorld

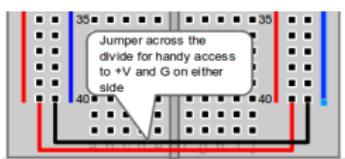
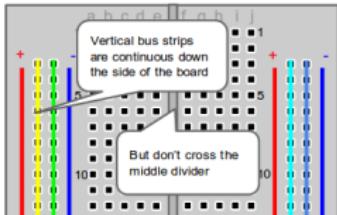


# Teensy on Breadboard

## Horizontal Rows



## Vertical Columns





# Basic Structure of Arduino Sketch

```
1 // the "header" is used for GLOBALS
2
3 void setup() {
4     // code in setup() runs once
5     // it is used to initialize objects,
6     // begin processes, and set variables
7     pinMode(13, OUTPUT);    //set Pin 13 as an Output
8 }
9
10 void loop() {
11     // functionality of your code
12     // this loops indefinitely
13 }
```



# Class Assignments

- ① Lab Notebook - flow chart
- ② Lab Notebook - schematic
- ③ Fritzing breadboard layout
- ④ Arduino code with comments

```
1  /*
2   * Project:      Title of Project
3   * Description: Description of Project
4   * Author:       Your Name
5   * Date:        Today's Date
6   */
7
8 // Single Line Comments
```



# Hello World in some of the 603+ Coding Languages

## Fortran

```
c      Hello world in Fortran
      PROGRAM HELLO
      WRITE (*,100)
      STOP
100 FORMAT ('Hello world! ' /)
      END
```

## C (K&R)

```
/* Hello world in c, K&R-style */
main()
{
    puts("Hello world!");
    return 0;
}
```

## Python 2

```
# Hello world in python_2
print "Hello world"
```

## Assembler (Intel)

```
; Hello world for intel Assembler (MSDOS)
mov ax,cs
mov ds,ax
mov ah,9
mov dx, offset Hello
int 21h
xor ax,ax
int 21h
```

```
Hello:
db "Hello world!",13,10,"$"
```

## Powershell

```
# Hello World in Microsoft Powershell
'Hello world!'
```

## LabVIEW

LabVIEW 7.1  
Hello World!

## LaTeX

```
% Hello world! in LaTeX
\documentclass{article}
\begin{document}
Hello world!
\end{document}
```

## Unix Shell

```
# Hello world for the unix shells (sh, ksh, csh, zsh, bash, fish, xonsh, ...)
echo Hello world
```

## Lisp-Emacs

```
(defun hello-world()
  "Display the string hello world."
  (interactive)
  (message "hello world"))
```

## BASIC

```
10 REM Hello world in BASIC
20 PRINT "Hello world!"
```

## C++

```
// Hello world in C++ (pre-ISO)
#include <iostream.h>
main()
{
    cout << "Hello world!" << endl;
    return 0;
}
```

## Perl

```
# Hello world in perl
print "Hello world!\n";
```

## Python 3

```
# Hello world in Python_3
print("Hello world")
```

## Pascal

```
{Hello world in pascal}
program Helloworld(output);
begin
    writeln('Hello world!');
end.
```

## MATLAB

```
% Hello world in MATLAB.
disp('Hello world');
```

## HTML

```
<HTML>
<!-- Hello world in HTML -->
<HEAD>
<TITLE>Hello world!</TITLE>
</HEAD>
<BODY>
Hello world!
</BODY>
</HTML>
```

## Postscript

```
% Hello World in Postscript
%PS
/Palatino-Roman findfont
100 scalefont
setFont
100 100 moveto
(Hello world!) show
showpage
```



# Assignment L01\_01\_HelloWorld



We will write our first program together as a class, using:

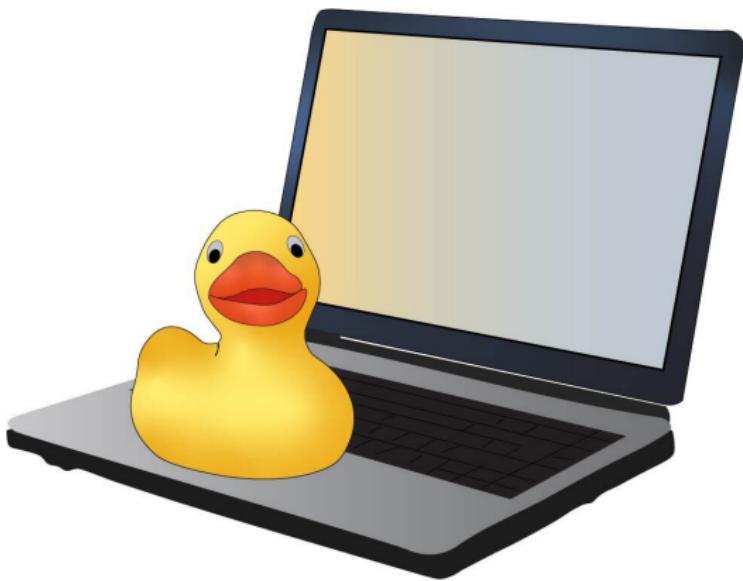
- `pinMode(pin,mode)`
- `digitalWrite(pin,state)`
- `delay(delay_time)`

How fast can you make it blink and still see it blinking?

# L02\_HelloLED



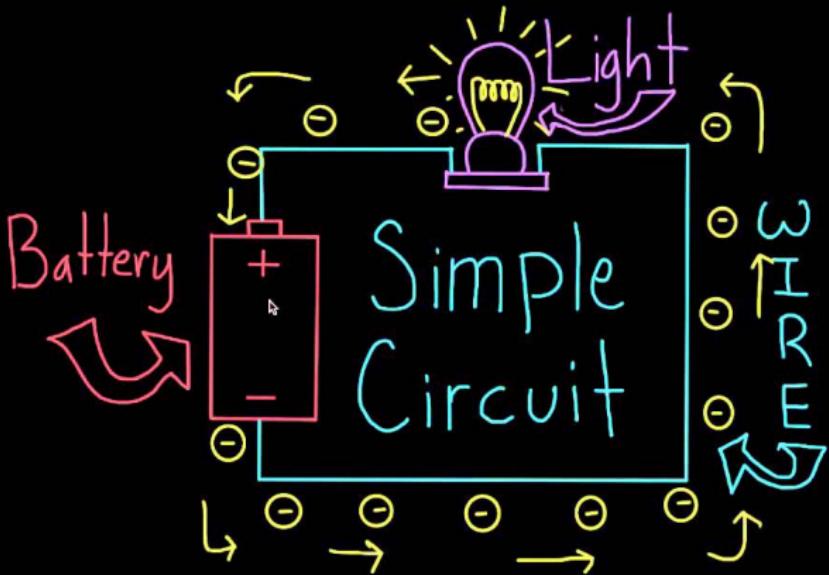
# Rubber Ducking - An Odd but Brilliant Tool



Rubber ducking is simply a method of debugging code. Programmers carry around a rubber duck with them, When they get stuck, they explain their code line-by-line to the rubber duck.

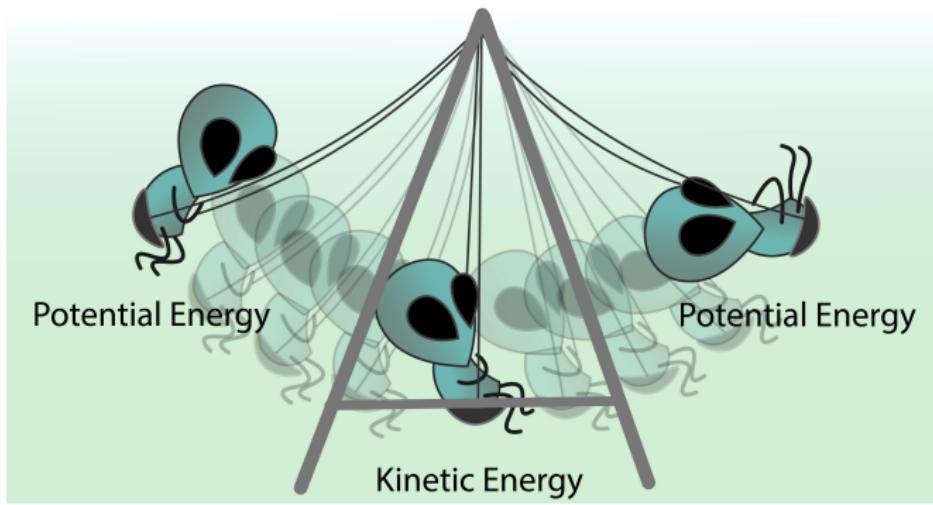


# Introduction to Electrical Circuits





# Energy



- Kinetic Energy - energy of motion
- Potential Energy - energy stored in an object

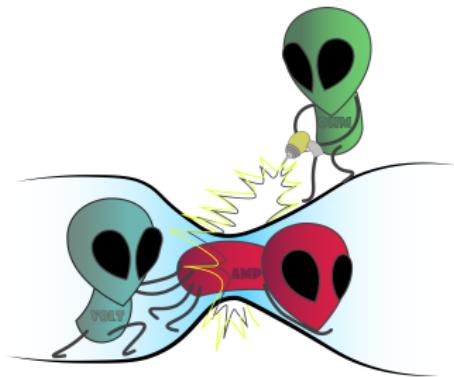
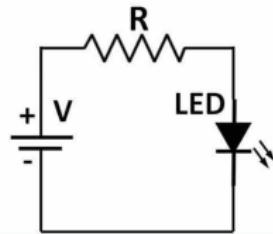


# Ohm's Law

Georg Ohm (16 March 1789 – 6 July 1854) was a German physicist and mathematician. As a school teacher, Ohm began his research with the new electrochemical cell, invented by Italian scientist Alessandro Volta. Ohm found that there is a direct proportionality between the potential difference (voltage) applied across a conductor and the resultant electric current. This relationship is known as Ohm's law:

## Ohm's Law

$$V = I * R$$





# Resistor Color Bands

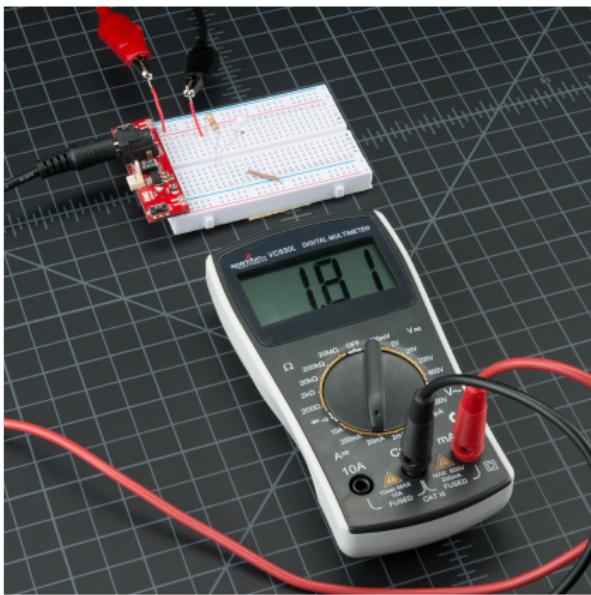
**4-Band-Code**

COLOR	1 <sup>ST</sup> BAND	2 <sup>ND</sup> BAND	3 <sup>RD</sup> BAND	MULTIPLIER	TOLERANCE
Black	0	0	0	1Ω	
Brown	1	1	1	10Ω	± 1% (F)
Red	2	2	2	100Ω	± 2% (G)
Orange	3	3	3	1KΩ	
Yellow	4	4	4	10KΩ	
Green	5	5	5	100KΩ	± 0.5% (D)
Blue	6	6	6	1MΩ	± 0.25% (C)
Violet	7	7	7	10MΩ	± 0.10% (B)
Grey	8	8	8	100MΩ	± 0.05%
White	9	9	9	1GΩ	
Gold				0.1Ω	± 5% (J)
Silver				0.01Ω	± 10% (K)

**5-Band-Code**

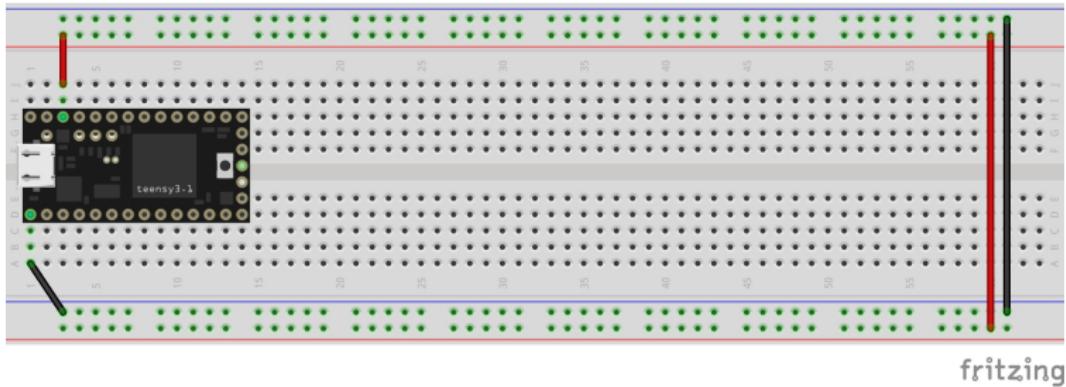


# Measuring Voltage, Current, and Resistance





# Power from the Teensy 3.2

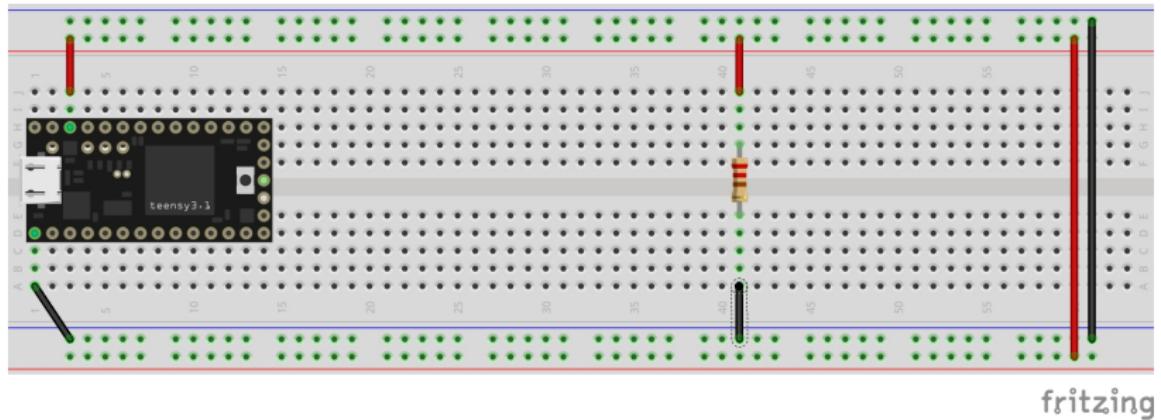


The Teensy 3.2 has three pins related to power:

- 3.3V: 250mA of power to be used for most hardware
- $V_{in}$ : 5V from the USB cable to power 5V hardware
- GND: The ground pin to close the electrical loop



# One Resistor



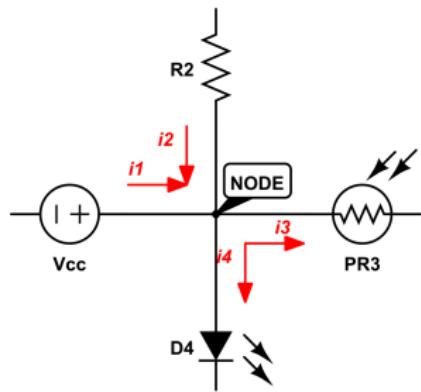
Using your multimeter, measure the voltage "across" and current "through" the resistor.



# Kirchhoff's First Law

Gustav Robert Kirchhoff (12 March 1824 – 17 October 1887) was a German physicist who contributed to the fundamental understanding of electrical circuits. His first law:

In an electrical circuit, the sum of currents flowing into that node is equal to the sum of currents flowing out of that node

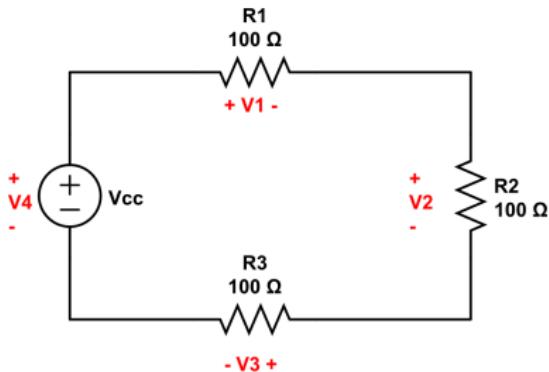


$$i_1 + i_2 = i_3 + i_4$$



# Kirchhoff's Second Law

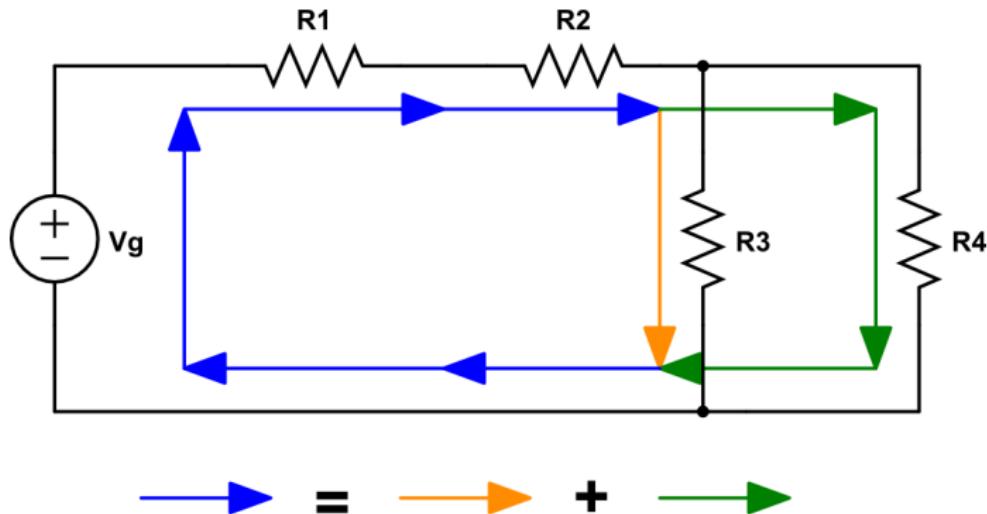
The directed sum of the potential differences (voltages) around any closed loop is zero.



$$V4 - (V1 + V2 + V3) = 0$$

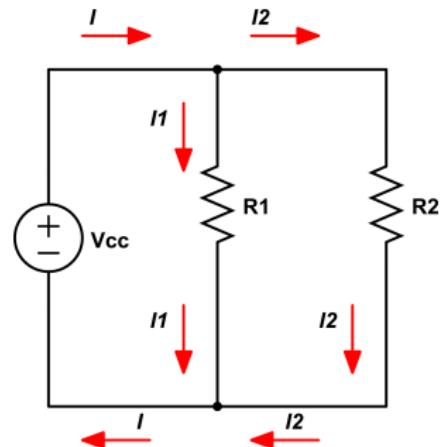
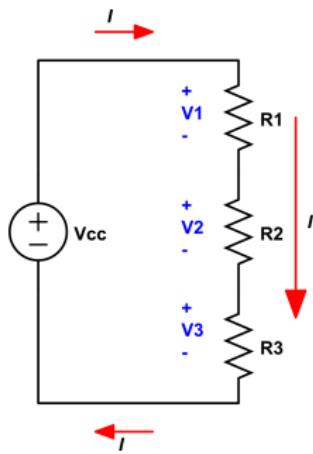


# Resistors in Series and Parallel





# Resistors in Series and Parallel

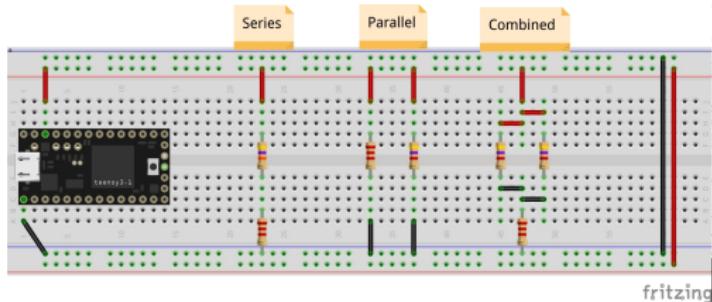


$$R_{eq} = R_1 + R_2$$

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$



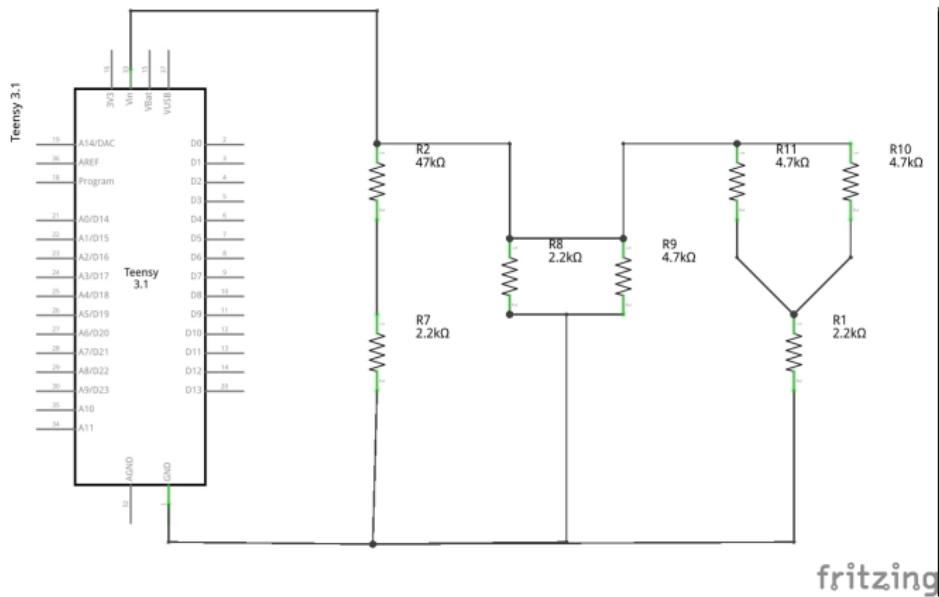
# Assignment: L02\_00\_Resistors



- In your lab notebook, draw the circuit diagrams
  - ① Series:  $4.7\text{k}\Omega$  and  $2.2\text{k}\Omega$
  - ② Parallel:  $4.7\text{k}\Omega$  and  $2.2\text{k}\Omega$
  - ③ Combined: Two  $4.7\text{k}\Omega$  in series with  $2.2\text{k}\Omega$
- Calculate the combined resistance and the voltage at each node, as well as the current through each component.
- Create Fritzing diagram
- Build (**one at a time**) on your breadboard and test your calculations with a multimeter.



# Schematics in Fritzing



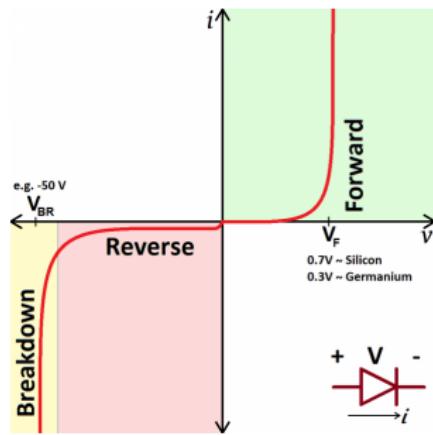
In Fritzing, go to the Schematic tab and layout your resistors.

**NOTE:** The schematic for the Teensy does not match it's physical layout.



# Diodes

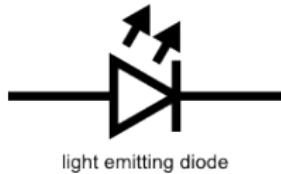
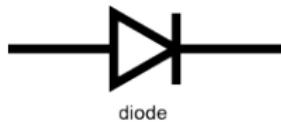
The key function of a diode is to control the direction of current-flow. Current passing through a diode can only go in one direction, called the forward direction. Current trying to flow the reverse direction is blocked.





# Light Emitting Diodes

LEDs (that's "ell-ee-dees") are a particular type of diode that convert electrical energy into light.



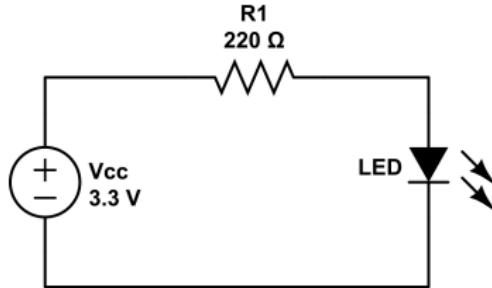


# Current Limiting Resistors

As a LED has very little resistance, when it is connected directly to a power supply, the current draw will exceed its specs and it will burn out.

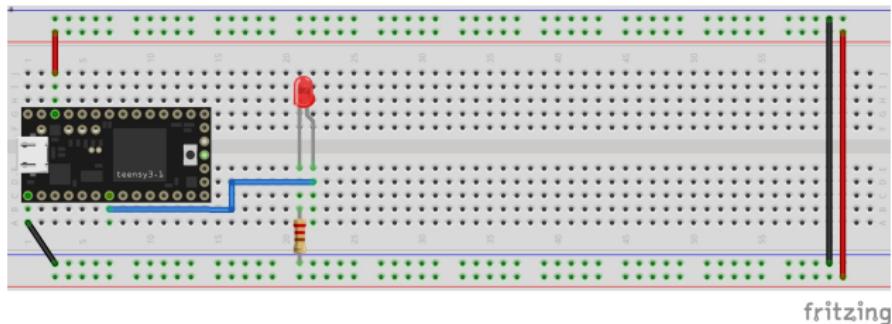
$$V_{pp} - V_{LED} = IR \implies R \geq \frac{V_{pp} - V_{LED}}{I_{max}}$$

For a 3.3V power supply, a 0.43V across the LED, and a max current of 100mA, the resistor needs to be greater than  $29\Omega$ .





# Assignment L02\_01\_helloLED

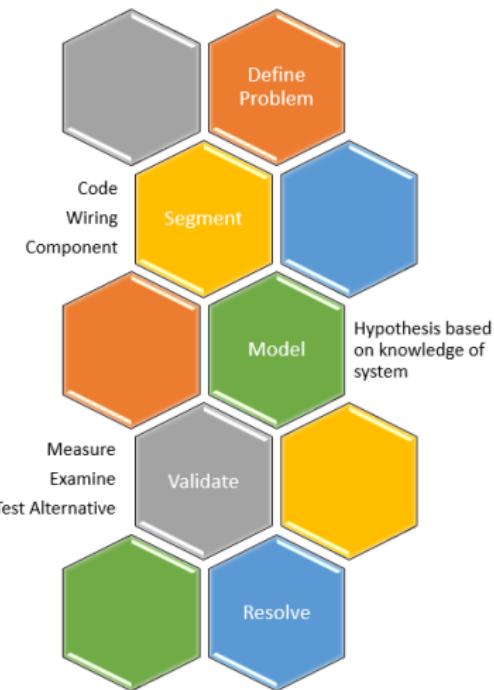


- Using Pin 5 as an output and the appropriate current limiting resistor, blink the LED once per second.
- Measure the voltage at both leads of the LED and record in your notebook.
- Change the resistor to  $1k\Omega$  and then  $10k\Omega$ . What happens to the brightness? Measure the voltage and current in each case. Record in your notebook.

**REMEMBER:** Lab notebook, Fritzing, breadboard, then code



# Model Based Troubleshooting





# Constants and Variables

It is often useful to give a name to something that will be used repeatedly in the code. They can be constants or variables:

- A Constant is a declaration that does not change throughout the code. For example a the pin that an LED is attached to.
- A Variable is a declaration that changes as the code processes. For example, a counter or index.

The use of Constants and Variables has several advantages:

- It improves readability by assigning names to items.
- Items can be changed by changing a single declaration.
- It allows the code to do math.

The first two Data Types that we will be using:

- **int**: an Integer between  $\pm 2,147,483,648$ .
- **float**: a Floating point number with 7-digits precision.



## Constants and Variables Example

```
1 const int LEDPIN = 5;
2 const int LEDDELAY = 1000;
3 int i;
4
5 void setup() {
6     pinMode(LEDPIN, OUTPUT); //set LEDPIN as Output
7     i = 100;
8 }
9 void loop() {
10    digitalWrite(LEDPIN, HIGH);
11    delay(LEDDelay);
12    digitalWrite(LEDPIN, LOW);
13    delay(LEDDelay+i);
14    i = i + 100;
15 }
```



# Assignment L02\_02\_helloLEDvar



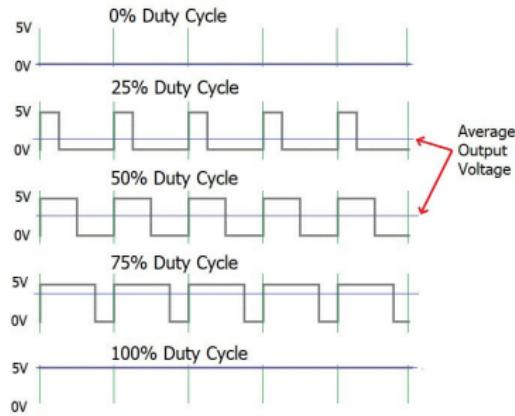
- Convert L02\_01\_helloLED with constants and/or variables.



# Pulse Width Modulation

## Software Configurable:

- Digital Input: High/Low (3.3V/0V)
- Digital Output: High/Low (3.3V/0V)
- Analog Input: 0V to 3.3V
- Analog Output: 0V to 3.3V PWM





# Assignment L02\_03\_helloLEDanalog



Use `analogWrite` to change the brightness of the LED, using values:

- 255
- 63
- 171
- 16

Measure the voltage with your multimeter at each value.

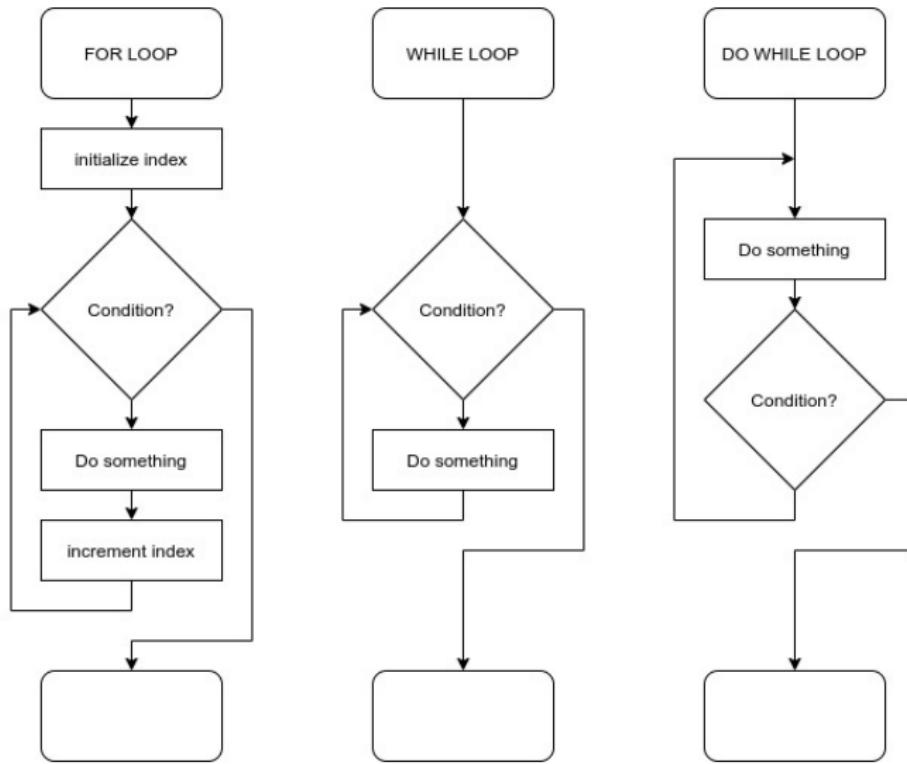


# Flowcharts

Symbol	Name	Function
	Process	Indicates any type of internal operation inside the Processor or Memory
	input/output	Used for any Input / Output (I/O) operation. Indicates that the computer is to obtain data or output results
	Decision	Used to ask a question that can be answered in a binary format (Yes/No, True/False)
	Connector	Allows the flowchart to be drawn without intersecting lines or without a reverse flow.
	Predefined Process	Used to invoke a subroutine or an Interrupt program.
	Terminal	Indicates the starting or ending of the program, process, or interrupt program
	Flow Lines	Shows direction of flow.



# Loops





# FOR Loop syntax

```
1 // FOR loop syntax
2 for (initialization; condition; increment) {
3     // statement(s);
4 }
5
6 // EXAMPLE
7 for (j=0; j <= 255; j++) {
8     analogWrite(LEDPIN, j);
9 }
```



# WHILE loop syntax

```
1 // WHILE loop syntax
2 while (condition) {
3     // statement(s)
4 }
5
6
7 // EXAMPLE
8 while (button == HIGH) {
9     digitalWrite(LEDPIN, HIGH);
10 } //continue this loop until button is released
```



# For vs While Loops

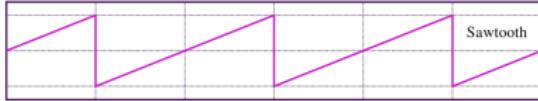
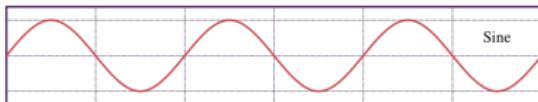
## For VS While Loop

Comparison Chart

For Loop	While Loop
The for loop is used for definite loops when the number of iterations is known.	The while loop is used when the number of iterations is not known.
For loops can have their counter variables declared in the declaration itself.	There is no built-in loop control variable with a while loop.
This is preferable when we know exactly how many times the loop will be repeated.	The while loop will continue to run infinite number of times until the condition is met.
The loop iterates infinite number of times if the condition is not specified.	If the condition is not specified, it shows a compilation error.



# Assignment L02\_04\_helloLEDtri



Using a FOR Loop, have the LEDs follow a Triangle Wave function from off to full brightness with a period of 10 seconds.



# While or Do While





# Number Systems

Decimal

92<sub>10</sub>

Digits: 0,1,2,3,4,5,6,7,8,9

Binary

01011100<sub>2</sub>

Digits: 0,1

Hexadecimal

5C<sub>16</sub>

Digits: 0,1,2,3,4,5,6,7,8,9,A,B,C,D,E,F

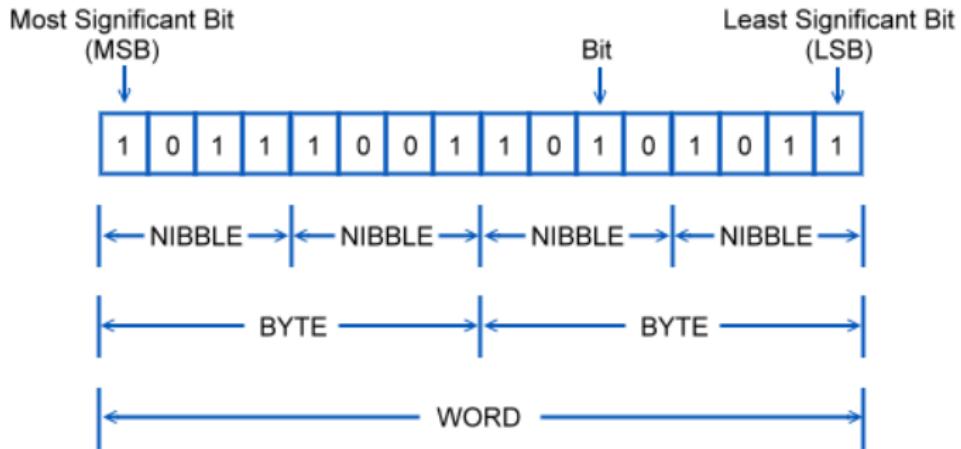
Octal

34<sub>8</sub>

Digits: 0,1,2,3,4,5,6,7



# Bits, Nibbles, Bytes, and Words





# Data Types: Numbers

Data Type	8-bit AVR systems (Arduino Uno)				32-bit ARM systems (Teensy 3.2)		
	bytes	range (signed)	range (unsigned)	bytes	range (signed)	range (unsigned)	
char	1	-128 to 127	0 to 255	1	-128 to 127	0 to 255	
short	2	+/- 32,767	0 to 65,353	2	+/- 32,767	0 to 65,353	
int	2	+/- 32,767	0 to 65,353	4	+/- 2,147,483,648	0 - 4,294,967,295	
long	4	+/- 2,147,483,648	0 - 4,294,967,295	4	+/- 2,147,483,648	0 - 4,294,967,295	
long long	8	+/- 9,223,372,036,854,770,000	0 to 18,446,744,073,709,551,615	8	+/- 9,223,372,036,854,770,000	0 to 18,446,744,073,709,551,615	
float	4	3.4E +/- 38 (7 digits)	n/a	4	3.4E +/- 38 (7 digits)	n/a	
double	4	3.4E +/- 38 (7 digits)	n/a	8	1.7E +/- 308 (15 digits)	n/a	
long double	8	1.7E +/- 308 (15 digits)	n/a	8	1.7E +/- 308 (15 digits)	n/a	
Unambiguous							
uint8_t	1	n/a	0 to 255	1	n/a	0 to 255	
int8_t	1	-128 to 127	n/a	1	-128 to 127	n/a	
uint16_t	2	n/a	0 to 65,353	2	n/a	0 to 65,353	
int16_t	2	+/- 32,767	n/a	2	+/- 32,767	n/a	
uint32_t	4	n/a	0 - 4,294,967,295	4	n/a	0 - 4,294,967,295	
int32_t	4	+/- 2,147,483,648	n/a	4	+/- 2,147,483,648	n/a	

There are  $7.5 \times 10^{18}$  grains of sand on Earth. A long long integer and the floating point numbers are larger than this.



# Math Warning and Type Casting

Be cognizant of the data type when performing math operations.

```
1 int x = 3;
2 int y = 2;
3 float yf = 2.0;
4 float z;
5
6 //int divided by an int returns an int
7 z = x/y;                      // z = 1.0
8 z = x/yf;                     // z = 1.5
9 z = x / 2;                     // z = 1.0
10 z = x / 2.0;                  // z = 1.5
11
12 //type casting used to change datatype
13 z = (float) x / (float) y;    // z = 1.5
14 z = x / (float) y;           // z = 1.5
15
16 z = (int) (x / yf);         // z = 1.0
17 y = x / yf;                 // y = 1
```

Type Casting is a way to ensure that you are correctly moving between datatypes.



## Header Files

A header file is a file with the extension .h which contains C function declarations and macro definitions to be shared between several source files. There are two types of header files: those that the programmer writes and those that come with the compiler.

Both the user and system header files are included using the preprocessing directive #include. It has the following two forms:

- `#include <file.h>` for system header files.
- `#include "file.h"` for user created header files in the directory that contains the current code.

An example is the math.h header that defines various mathematical functions.

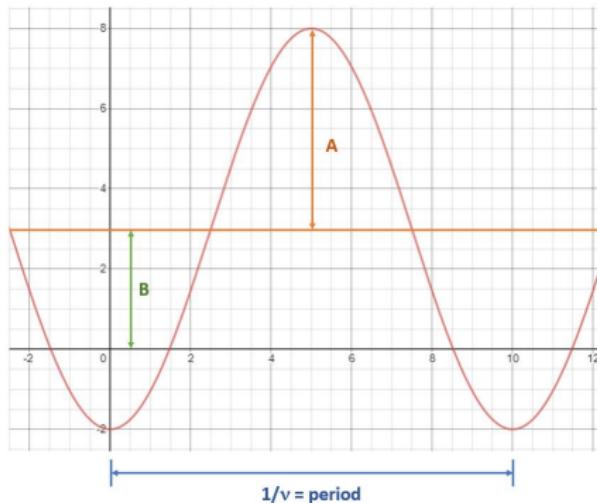


# Basic Structure of Arduino Sketch Revisited

```
1 #include <math.h>          // include header files
2 const int LEDPIN = 5;      // declare constants
3 float Vout;                // declare variables
4 float n;
5
6 void setup() {              // runs once
7     pinMode(LEDPIN, OUTPUT); // system settings
8     n = 0;                  // set variables
9 }
10
11 void loop() {               // loops indefinitely
12     Vout = sin(2*PI*n);
13     n = n+0.01;
14 }
```



# Sine Waves

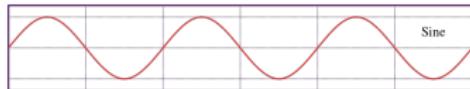


$$y = A * \sin(2 * \pi * \nu * t) + B$$

where  $A$  = amplitude,  $B$  = offset,  $\nu$  = frequency =  $\frac{1}{\text{period}}$ ,  
and  $t$  = time in seconds.



## Assignment L02\_05\_helloLEDsin



Use a `sin()` function to vary brightness of your LED.

- Use `math.h`.
- Function `sin` takes a double as an input and returns a double.
- Set the period to 5 seconds.

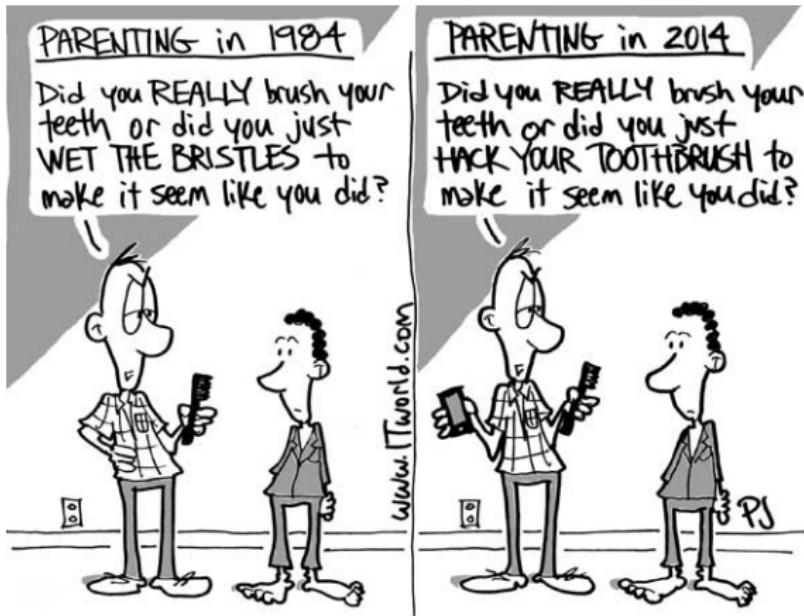
The function `millis()` returns milliseconds since Teensy has been powered on. For the sine equation, use  $t = \text{millis}() / 1000.0$ .

Why is adding the decimal after 1000 important?

# L03.Buttons



# IoT Fun





# Displaying to the Screen: The Serial Monitor

```
1 void setup() {  
2  
3 // Enable Serial Monitor  
4 Serial.begin (9600);  
5 while (!Serial); // wait for Serial monitor  
6 Serial.println ("Ready to Go");  
7 }  
8  
9 void loop() {  
10 for (i=0; i <=13; i++){  
11 Serial.print(i);  
12 delay(printDelay);  
13 }  
14 }
```



# Print Statements

- ① Serial.print() prints data to the monitor through the serial port as human-readable text:
  - Serial.print('N') prints: N
  - Serial.print("Hello World") prints: Hello World
  - Serial.print(78) prints: 78
  - Serial.print(3.141592) prints 3.14
  - Serial.print(3.141592,5) prints 3.14159
- ② Serial.println() displays the print() followed by a carriage return (\r) or newline (\n).
- ③ Serial.printf() displays a formatted print.



# Format Specifiers Statements

**ControlString**

```
printf("a = %d\nb = %d\n", a, b);
      ^          ^          ^          ^
      1st Line  2nd Line  New Line  New Line
           ↑       ↑
           arg1    arg2
```

specifier	Output	Example
d or i	Signed decimal integer	392
u	Unsigned decimal integer	7235
o	Unsigned octal	610
x	Unsigned hexadecimal integer	7F8
X	Unsigned hexadecimal integer (uppercase)	7FA
f	Decimal floating point, lowercase	392.65
F	Decimal floating point, uppercase	392.65
e	Scientific notation (mantissa/exponent), lowercase	3.9265e+2
E	Scientific notation (mantissa/exponent), uppercase	3.9265E+2
g	Use the shortest representation: %e or %f	392.65
G	Use the shortest representation: %E or %F	392.65
a	Hexadecimal floating point, lowercase	-0xc.90feP-2
A	Hexadecimal floating point, uppercase	-0XC.90FEPE-2
c	Character	a
s	String of characters	sample
p	Pointer address	b8000000
n	Nothing printed. The corresponding argument must be a pointer to a signed int. The number of characters written so far is stored in the pointed location.	
%	A % followed by another % character will write a single % to the stream.	%

```
1 int count = 42;
2 float value = 3.14159;
3 Serial.printf("Print an integer %i and a float %0.4f\n",count,value);
4
5 \\ Output: Print an integer 42 and a float 3.1415
```



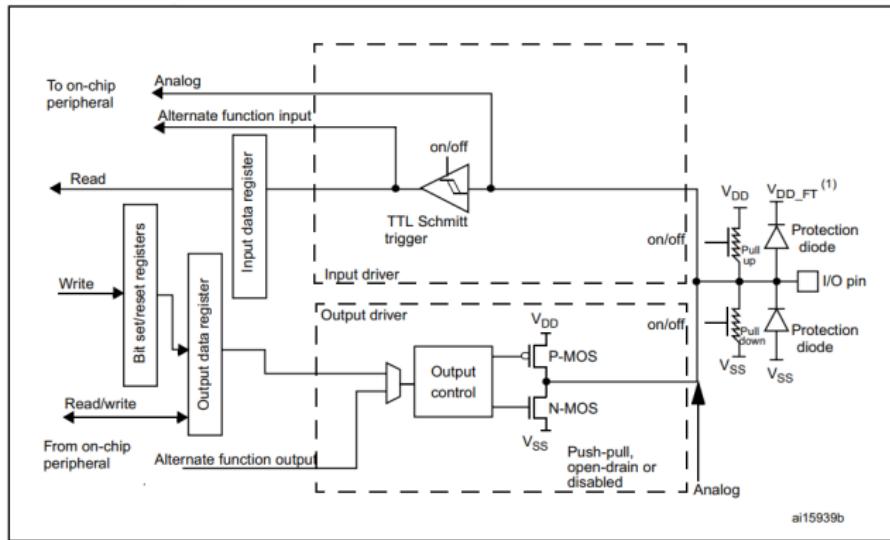
# Assignment L03\_00\_SerialMonitor



- ① Print Hello World to your monitor screen.
- ② Next, display to the screen a count from 0 to 13, separated by commas, three times by using:
  - Serial.print();
  - Serial.println();
  - Serial.printf();



# One Pin - Many Functions



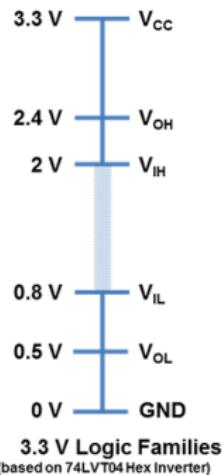
ai15939b

Software Programmable: Input or Output and Digital or Analog.



# Digital Input/Output

Digital electronics rely on binary logic to store, process, and transmit data or information. Binary Logic refers to one of two states – ON or OFF. This is commonly translated as a binary 1 or binary 0. A binary 1 is also referred to as a HIGH signal and a binary 0 is referred to as a LOW signal.

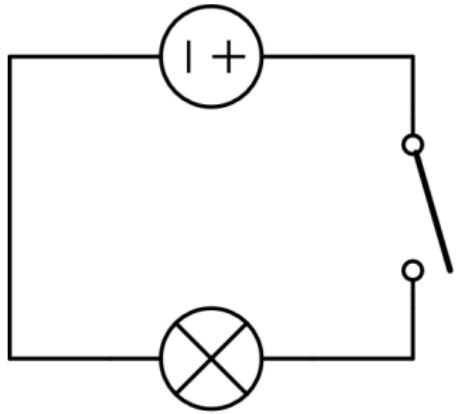


- `digitalWrite(pin,value);`
- `inputValue = digitalRead(pin);`

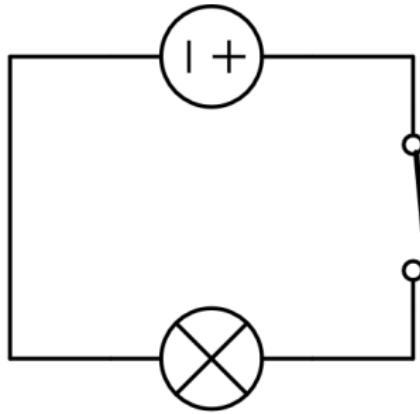
where, value equals HIGH or LOW.



# Switches



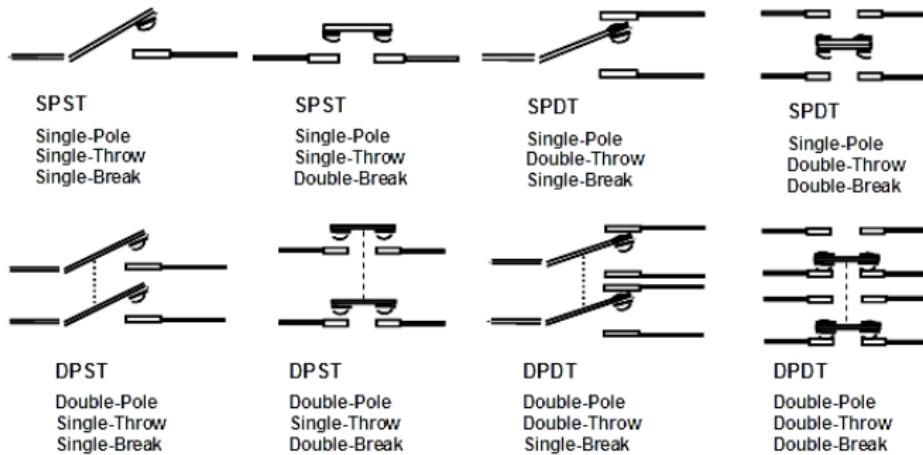
Lamp Off



Lamp On

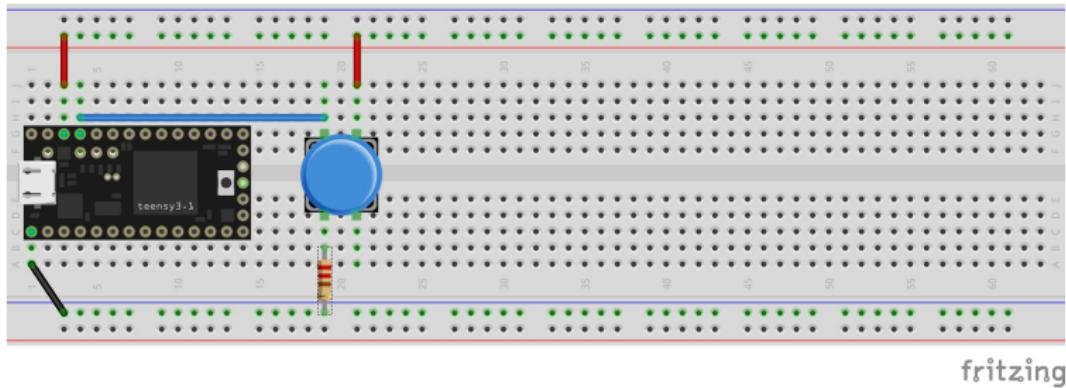


# Types of Switches





# Our First Button and Pull Down Resistors



fritzing

Wait - why is there a resistor connected to ground?



# Assignment: Buttons



- Labbook: draw circuit
- Fritzing diagram
- Wire your circuit
- Write the code

Connect a button to Pin 23 and a multimeter to measure the voltage at the pin. Using `digitalRead()`:

## ① L03\_01\_button

- Print button state to the screen.
- Remove the resistor, how does this affect the button state and the voltage.
- Replace the pull-down resistor with a pull-up. How does the logic change?

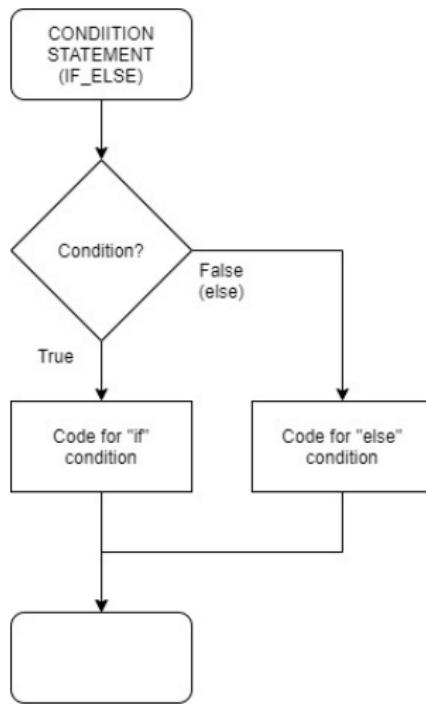
- Not pressed: 3.3V
- Pressed: GND

## ② L03\_02\_button\_input\_pullup

- Remove the pull-up resistor
- Implement:  
`pinMode(pin,INPUT_PULLUP);`



# IF-ELSE Statements



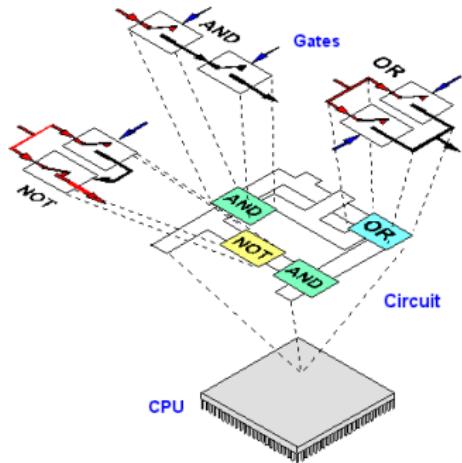


# IF-ELSE Statements

```
1 // IF statement SYNTAX
2 if (condition) {
3     //statement(s)
4 }
5 else {
6     // else statement(s)
7 }
8
9 // EXAMPLE
10 if (buttonState) {
11     Serial.printf("Button is pressed \n");
12 }
13 else {
14     Serial.printf("Button is not pressed \n");
15 }
```



# Data Types: Boolean and Boolean Logic



Boolean datatype (bool)  
holds either a TRUE or  
FALSE

Boolean Logic Operations (condition statements)

- ① NOT (!): true if operand is false and visa-versa
  - $x = !x$
- ② AND (&&): true if both operands are true
  - $z = x \&\& y$
- ③ OR (||): true if either operand is true
  - $z = x || y$

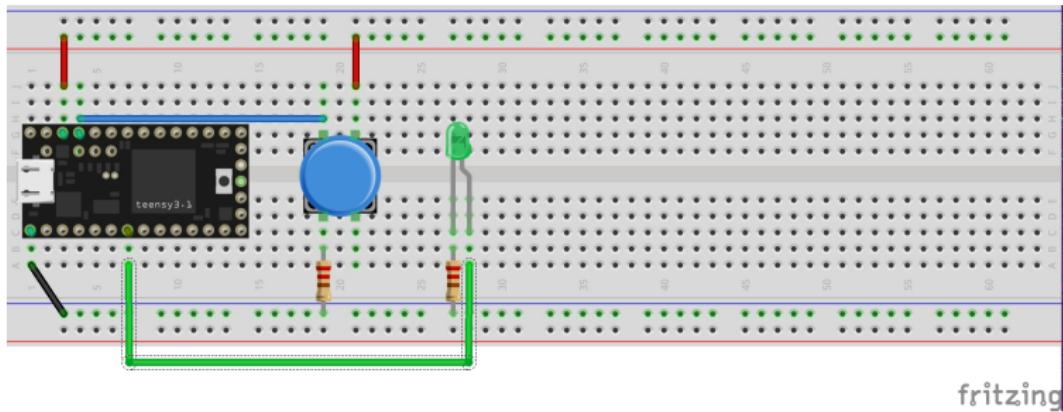


# Boolean Logic In Action

```
1 bool x;
2 bool buttonState1, buttonState2;
3 int y, z;
4
5 x = !x;           // invert x
6
7 if (!x) {        // if x is false
8     // do something
9 }
10
11 // LOGICAL AND: if both pins are pressed
12 buttonState1 = digitalRead(PIN1);
13 buttonState2 = digitalRead(PIN2);
14 if ((buttonState1) && (buttonState2) {
15     // do something
16 }
17
18 // LOGICAL OR: if either value is greater than zero
19 if (y > 0 || z > 0) {
20     // do something
21 }
```



## Button and LED





# Assignment: Buttons and LEDs



## ① L03\_03\_buttonLED

- Add an LED to Pin 5 and use the button to turn the LED on and off.
- Also, print button state to the screen

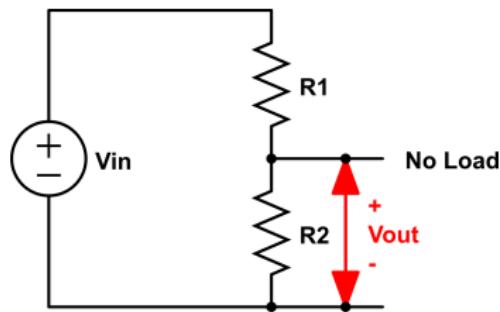
## ② L03\_04\_twobuttonLED

- Add a second button (Pin 16) and LED (Pin 6)
- Have each button control one LED
- Also, print button states to the screen

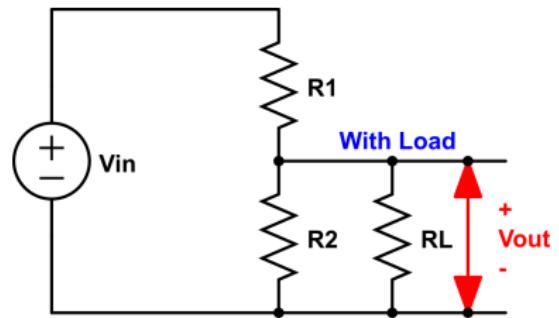


# Resistors in Series and Parallel

Open Circuit Behavior



Behavior Under Load

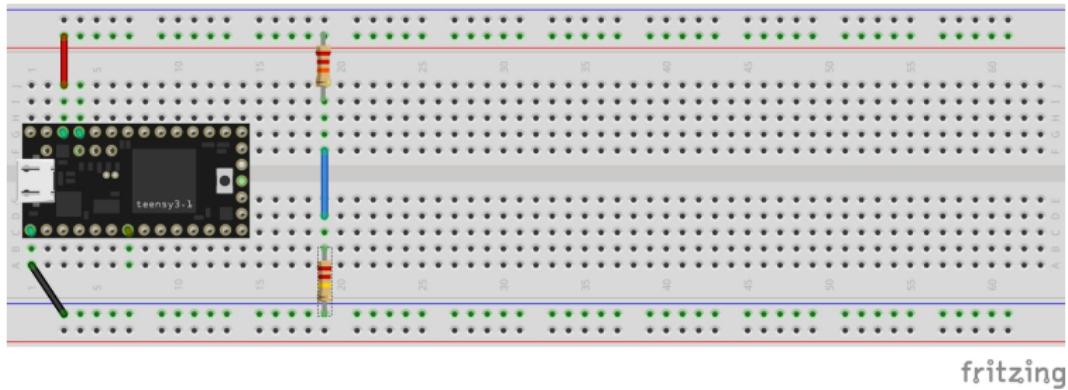


$$V_{out} = V_{in} \frac{IR_2}{I(R_1+R_2)} = \frac{R_2}{R_1+R_2} V_{in}$$

$$V_{out} = \frac{R_2 \parallel R_L}{R_1 + R_2 \parallel R_L} V_{in}$$



# Voltage Dividing

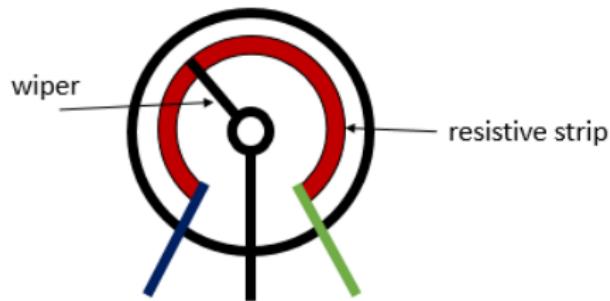


We are just using the Teensy to provide Power and GND.

- Use various combinations of resistors between  $1\text{k}\Omega$  and  $22\text{k}\Omega$ .
- Calculate the Series resistance and the voltage between the two resistors in your Lab Notebook.
- Measure with your multimeter and compare.



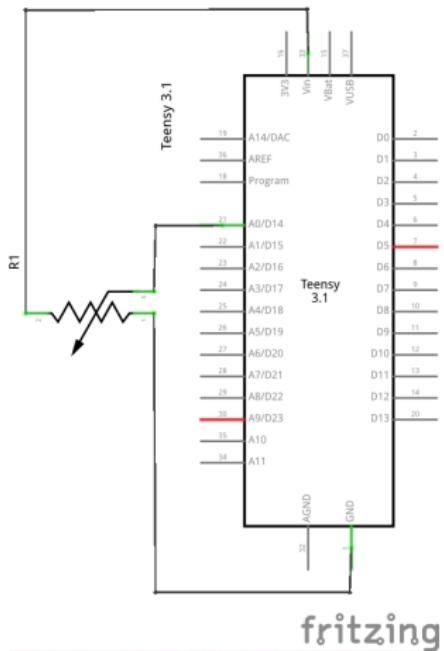
# Potentiometer - Variable Resistor



A potentiometer has 3 pins. Two terminals (the blue and green) are connected to a resistive element and the third terminal (the black one) is connected to an adjustable wiper.



# Assignment L03\_05\_AnalogInput



- 1 Utilize `analogRead()` to measure analog input across potentiometer (voltage divider) using Pin 14.
- 2 Determine the range of the `analogRead` across the entire range of the potentiometer.



# Anatomy of a Function

## Anatomy of a function in C / C++

Datatype of data returned,  
any C datatype (int, float, bool, etc.)

"void" if nothing is to be returned

Function Name

```
int myMultiplyFunction(int x, int y) {
```

Parameters passed to  
function, any C datatype

```
    int result;
```

```
    Result = x * y;  
    Return result;
```

Return statement,  
datatype matches declaration

```
}
```

Curly braces required



# Types of Variables

```
1 void setup() {  
2     x = 1;  
3 }  
4 void loop() {  
5     x = addx();  
6 }  
7 int addx() {  
8     int y;  
9     static int z;  
10  
11     y = y + x;  
12     z = z + x;  
13     return y;  
14 }
```

## ① Global Variables

- Accessible throughout the program and all functions.

## ② Local Variables

- Accessible only in the function
- Created when function is called, destroyed when function is returned.

## ③ Static Local Variables

- Accessible only in the function
- Maintains value across multiple calls of a function.
- Destroyed only when program is terminated.

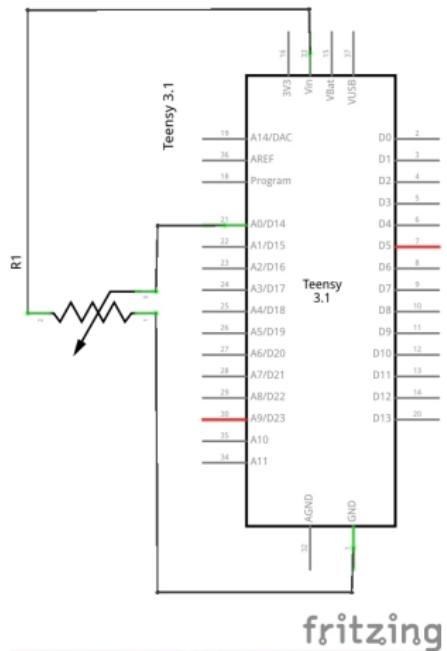


# Basic Structure of Arduino Sketch Revisited

```
1 int num, doubleNum;
2
3
4 void setup() {
5     Serial.begin(9600);    // Turn on Serial Monitor
6     while(!Serial);        // Wait for Serial Monitor to be running
7     num = 1;                // Initialize num;
8 }
9
10 void loop() {
11     doubleNum = twotimes(num); // call the funciton twotimes
12     num = doubleNum;
13     Serial.printf("The number is now %i \n", num);
14     Serial.printf("The number in HEX is 0x%X \n", num);
15     delay(1000);
16 }
17
18 int twotimes(int number) {
19     int answer;            // declare answer as a local variable
20     answer = 2 * number;
21     return answer;
22 }
```



# Assignment L03\_05\_AnalogInput Revisited



- ① Modify your code by adding a function, `in2volts()`, that converts the analog input value to voltage.
- ② Print both the raw `analogInput` and the associated voltage to your screen.

# L04\_oneButton



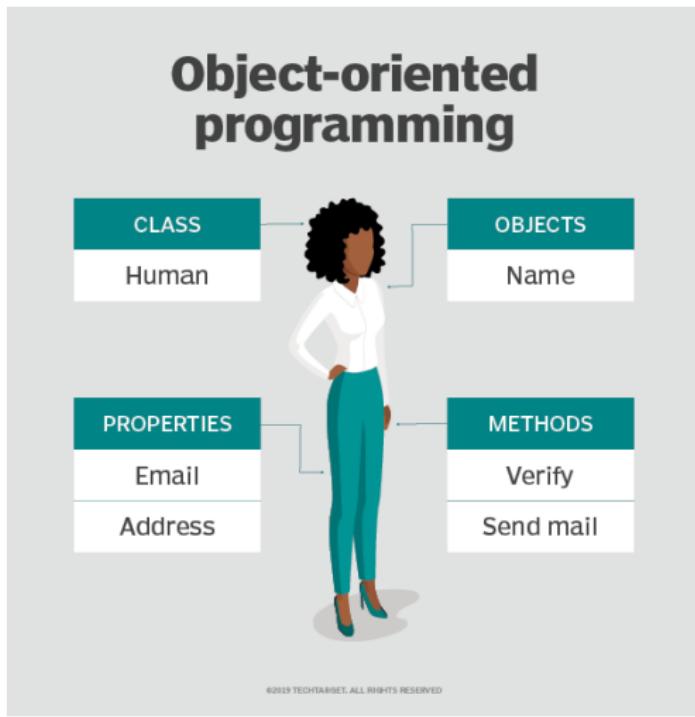
# IoT Humor



*"I remember when you could only lose a chess game to a supercomputer."*

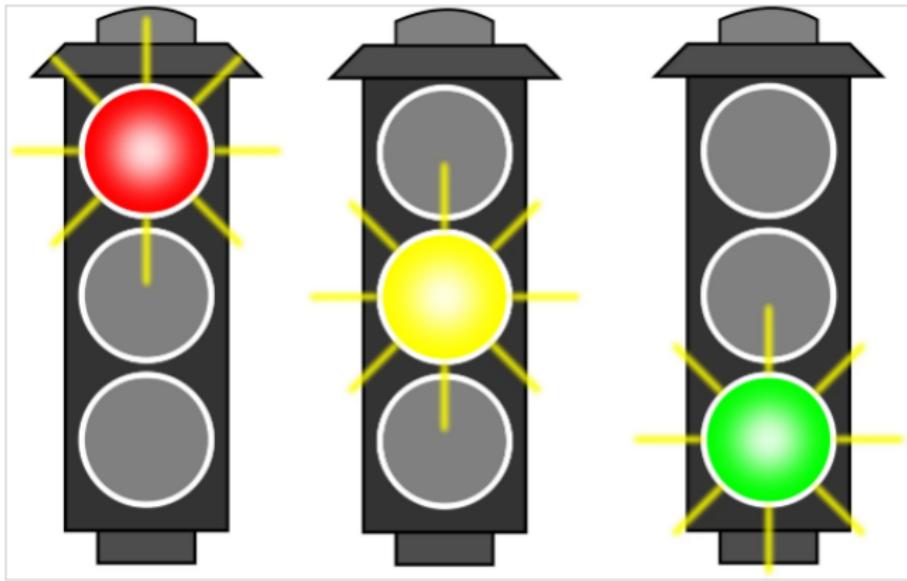


# Objects





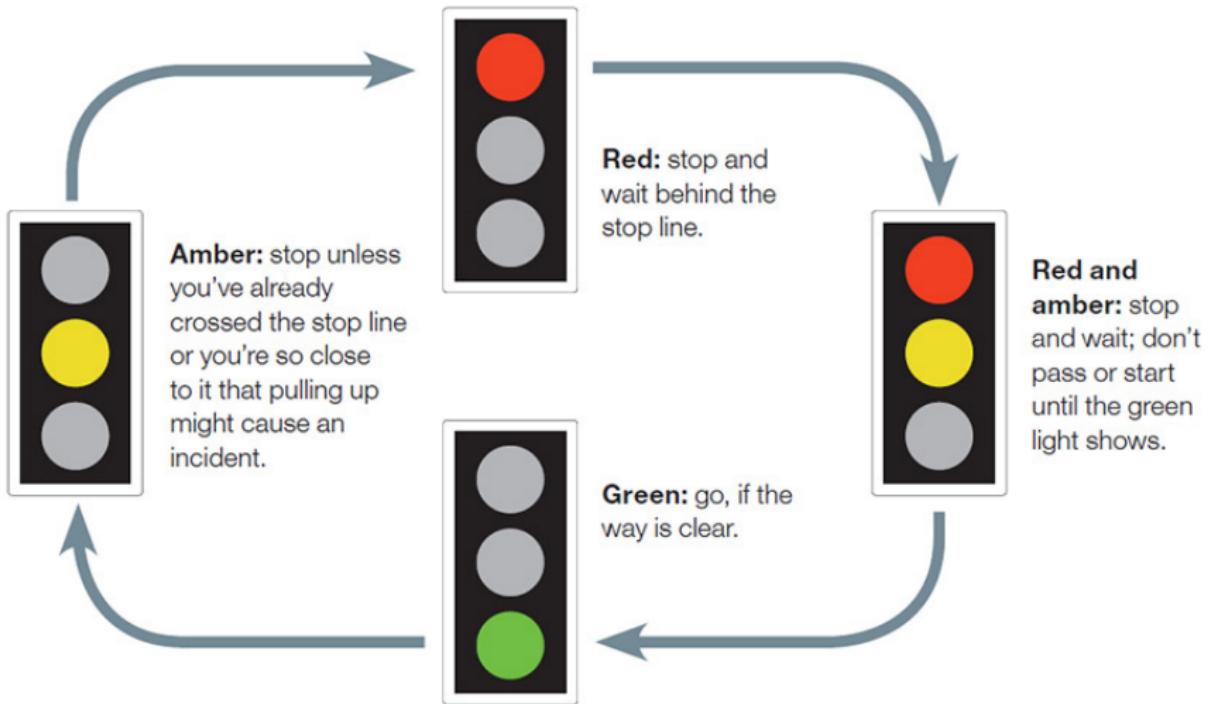
# Traffic Light



Let's use the traffic light to build our own Objects



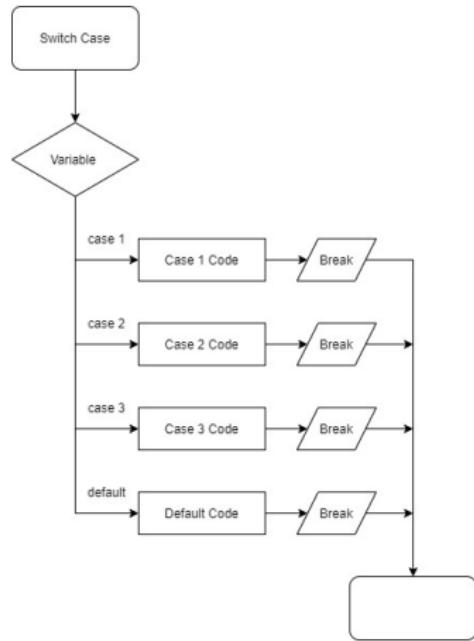
# State Machine - Traffic Lights, British Style





# SWITCH...CASE syntax - multiple IFs

```
// SWITCH...CASE syntax
switch (variable) {
    case constant1:
        // statements
        break;
    case constant2:
        // statements
        break;
    case constant3:
        // statements
        break;
    default:
        // statements
        break;
}
```



The variable is compared to the constants and the applicable code is called. If variable doesn't match any of the constants, then the default case is called.



## Enumeration (enum)

The C-language has a user defined datatype, enum, which allows the user to create a variable with various names for each of its states.

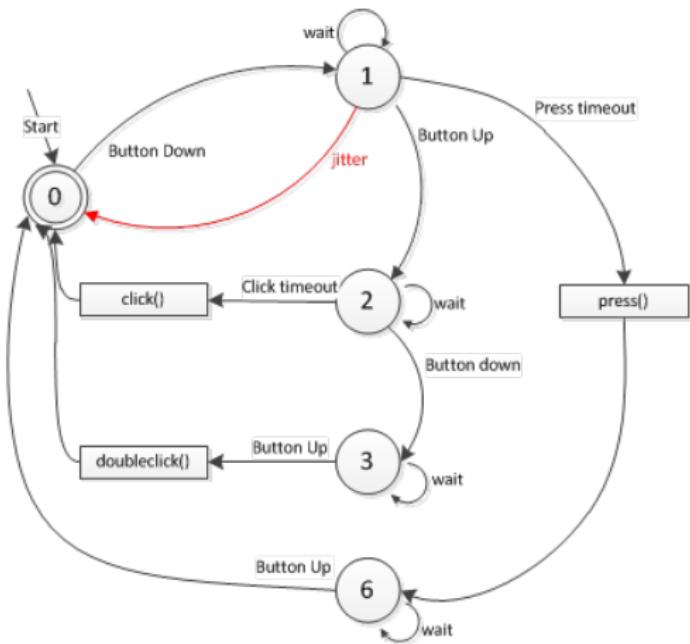
- Within the enum declaration descriptive tags are used
- Then the compiler assigns the tags an integer value.

```
1 // Datatype State: the four traffic light states
2 enum State{
3     GREEN,
4     YELLOW ,
5     RED ,
6     RED_YELLOW
7 };    //note the ; after the }
```

The compiler treats enum as your personal variable type. For example, the enum variable (e.g., State) can now be used within switch...case statements.



# OneButton Library



The `tick()` method checks the input pin for a single click, double click or long press situation.



# Basic Structure of Arduino Sketch - Revisited

```
1 // the "header" is used for GLOBALS
2 #include <OneButton.h>           // system library files
3 #include "TrafficLight.h"        // local library files
4
5 OneButton button1(23, false);    // define objects
6
7 const int GREENLED = 23;        // declare global constants
8 bool greenState;               // declare global variables
9
10 // setup() is used for code that runs once at the beginning
11 void setup() {
12     Serial.begin(9600);          // begin processes
13     pinMode(GREENLED, OUTPUT);   // define input/output modes
14     button1.attachClick(click);  // initialize objects
15     greenState = false;         // set variables
16 }
17
18 // loop() is used for code that runs continuously
19 void loop() {
20     tick();
21     digitalWrite(GREENLED, greenState);
22 }
23
24 // user defined functions
25 void click() {
26     greenState = !greenState;
27 }
```



# OneButton Declarations

```
1 #include <OneButton.h>
2 OneButton button1(pin, activeLOW, pullUP);
3 void setup() {
4     button1.attachClick(click1);
5     button1.attachDoubleClick(doubleClick1);
6     button1.attachLongPressStart(longPressStart1);
7     button1.attachLongPressStop(longPressStop1);
8     button1.attachDuringLongPress(longPress1);
9     button1.setClickTicks(250);
10    button1.setPressTicks(2000);
11 }
```

OneButton parameters (not variables):

- pin: the pin the button is connected to.
- activeLOW: "true" means input LOW when button pressed.
- pullUP: "true" is INPUT\_PULLUP pinMode.



# Using OneButton

```
1
2 void loop() {
3     button1.tick(); // check the state of the button
4 }
5
6 void click1() {
7     Serial.println("Hi, my name is Brian.");
8 }
9
10 void doubleClick1() {
11     Serial.println("Hope your day is going well.");
12 }
```



# Assignment: OneButton



- Notebook: flowchart
- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

## ① L04\_01\_oneButton

- Use OneButton libary and button on Pin 23.
- Click() - toggle bool variable buttonState.
- doubleClick() - toggle bool variable blinker.

## ② L04\_02\_oneButtonLED

- Single Click: toggle LED on/off using buttonState variable.
- Double Click: when LED is on, toggle between solid and rapidly blinking (50ms) using blinker variable.
- What happens if blinking is made slower (try > 1 second)?

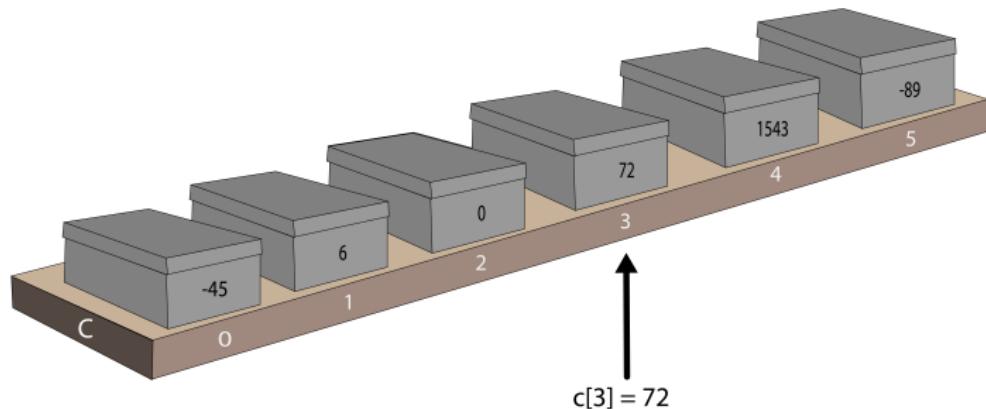


# Avoiding Delays

```
1 void loop() {  
2     //run constantly  
3     currentTime = millis();  
4  
5     //run once per second  
6     if((currentTime - lastSecond) > 1000) {  
7         Serial.print(".");  
8         lastSecond = millis();  
9     }  
10  
11    //run once per minute  
12    if((currentTime - lastMinute) > 60000) {  
13        Serial.println();  
14        Serial.println("Minute");  
15        lastMinute = millis();  
16    }
```



# Arrays



- Syntax: datatype var[ ] = {element 1, element 2, element 3};
- Example: int c[] = -45, 6, 8, 72, 1543, -89



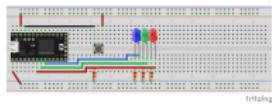
# Using Arrays

```
1 int myInts[6];
2 int myPins[] = {2, 4, 8, 3, 6};
3 int mySensVals[6] = {2, 4, -8, 3, 2};
4 char message[6] = "hello";
5
6 void loop() {
7     mySensVals[0] = 10; //assign value to array
8     x = mySensVals[4]; //retrieve value from array
9     for (i = 0; i < 5; i = i + 1) {
10         Serial.println(myPins[i]);
11     }
12 }
```

**NOTE:** The array index starts at 0 (not 1).



# Assignment: OneButton



- Notebook: flowchart
- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

## ① L04\_04\_oneButtonArray

- Use 3 LEDs and one Button
- Single Click - toggle current LED on/off
- Double Click - using an array, select the next LED
- Long Press (start) - light up the three LEDs in sequence
- Long Press (end) - light up the three LEDs in reverse order



# String datatype and Serial Read

- We can enter input via the Serial.Monitor using the String class.
- The String class acts like a datatype.
- And, it also allows methods, such as `toInt()`

```
1 String input;
2 int value;
3
4 void setup() {
5   Serial.begin(9600);
6 }
7
8 void loop() {
9   input = "";
10  while(input=="") {
11    input = Serial.readStringUntil('\n');
12  }
13  value = input.toInt();
14  Serial.printf("The number you entered is %i \n",value);
15 }
```



# Assignment: Serial Read



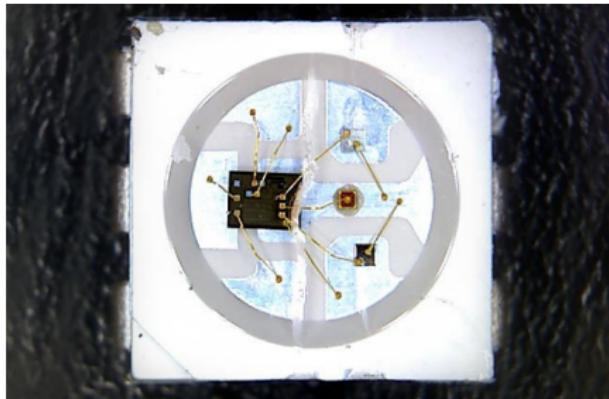
## ① L04\_05\_timer - Create a Stop Watch and Countdown Timer

- Click for start and stop
- Double Click to switch between Stop Watch and Timer. In Timer mode, prompt the user on the Serial Monitor to enter the time to countdown from.

# L05\_NeoPixels



# NeoPixels

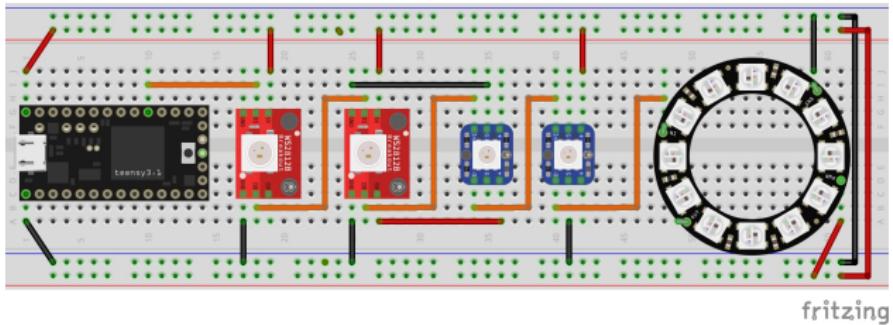


NeoPixels are:

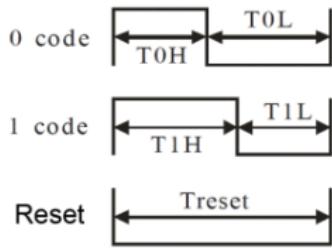
- Addressable RGB LEDs based on the WS2812 (or WS2811) LED/drivers.
- They come as individual pixels, in strips, in matrices, rings, etc.
- They can be programmed via your microcontroller to create a wide array of effects and animations.



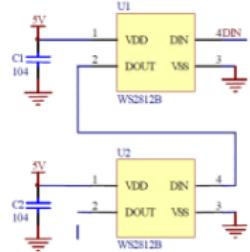
# NeoPixel Programming



WS2812 Protocol



LED-Chain





# Using NeoPixel Class and Methods

```
1 #include <Adafruit_NeoPixel.h>
2
3 const int LED_PIN = 17;      // Pin the NeoPixels are connected to
4 const int LED_COUNT = 16;    // Total number of NeoPixels
5
6 Adafruit_NeoPixel pixel(LED_COUNT, LED_PIN, NEO_GRB + NEO_KHZ800); //declare object
7 /* Argument 1 = Number of pixels
8 * Argument 2 = GPIO pin number
9 * Argument 3 = Pixel type flags, add together:
10 *   Use:
11 *     NEO_GRB      Pixels are wired for GRB bitstream (most NeoPixel products)
12 *     NEO_KHZ800   800 KHz bitstream (WS2812)
13 *   Other options for Argument 3:
14 *     NEO_KHZ400   400 KHz (WS2811)
15 *     NEO_RGB      Pixels are wired for RGB bitstream (v1)
16 *     NEO_RGBW     Pixels are wired for RGBW bitstream
17 */
18 void setup() {
19   pixel.begin();
20   pixel.show(); //initialize all off
21 }
22
23 void loop() {                                //n is the pixel number being set
24   pixel.setPixelColor(n, red, green, blue); //red,green,blue = 0 - 255
25   pixel.setPixelColor(n, color);           //hex code 0x000000 - 0xFFFFFFFF
26   pixel.fill(color, first, count);
27   pixel.setBrightness(bri)                // 0 - 255
28   pixel.show();                          //nothing changes until show()
29   pixel.clear();                         //even clear() needs a show()
30   pixel.show();
31 }
```



# Where do global header files go?

The screenshot shows a Windows File Explorer window with the following details:

- Path:** This PC > Local Disk (C:) > Users > IoT\_Instructor > Documents > Arduino > libraries
- File Explorer ribbon:** Home, Share, View, File (selected), Clipboard, Organize, New, Open, Select.
- Left sidebar:** Quick access, Desktop, Downloads, Documents, Pictures, IoT, class\_slides, instructor\_guide, Messages, Workflow, Creative Cloud Files, OneDrive, This PC, 3D Objects, Desktop, Documents, Downloads, Music, Pictures, Videos.
- Table:** A list of folders in the "libraries" directory.

Name	Date modified	Type
ACROBOTIC_SSD1306	3/11/2020 1:45 PM	File folder
Adafruit_ADXL343	3/3/2020 9:27 AM	File folder
Adafruit_BME280_Library	3/3/2020 9:27 AM	File folder
Adafruit_BusIO	7/20/2020 2:00 PM	File folder
Adafruit_GFX_Library	7/20/2020 2:00 PM	File folder
Adafruit_NeoPixel	10/12/2020 10:17 AM	File folder
Adafruit_PWM_Servo_Driver_Library	8/3/2020 10:09 AM	File folder
Adafruit_SSD1306	7/20/2020 2:00 PM	File folder
Adafruit_Unified_Sensor	3/3/2020 9:27 AM	File folder
colors	3/5/2020 11:23 AM	File folder
DS1307RTC	8/3/2020 3:12 PM	File folder
Grove_-_Air_quality_sensor	7/31/2020 1:25 PM	File folder
hue	7/22/2020 10:23 AM	File folder
hue2	8/3/2020 2:23 PM	File folder
mac	3/12/2020 12:45 PM	File folder
OLED_SSD1306_Chart	8/3/2020 12:15 PM	File folder
OneButton	3/3/2020 9:26 AM	File folder
RTC	8/3/2020 3:12 PM	File folder
RTClib_by_NeoR0N	8/3/2020 9:41 AM	File folder
wemo	7/16/2020 7:48 AM	File folder
wemoObj	7/20/2020 10:21 AM	File folder
readme	2/18/2020 9:32 AM	Text Document
		1 KB



# Generating Random Numbers

```
1  /*
2   * The random() generates pseudo-random numbers.
3   *     random(min,max)
4   *     random(max)      //assumes min = 0
5   * returns a number between min and max-1
6   */
7
8   // print a random number from 0 to 299
9   randNumber = random(300);
10  Serial.println(randNumber);
11
12 // print a random number from 10 to 19
13 randNumber = random(10, 20);
14 Serial.println(randNumber);
```



# Assignment: NeoPixels



- Notebook: flowchart
- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

## ① L05\_01\_neoPixel

- With a FOR loop, light up 4 pixels and ring. Small delay between pixels.

## ② L05\_02\_colorHeader

- Implement a header file that contains the pixel colors.

## ③ L05\_03\_neoStrip, use setPixelColor() to implement functions:

- Send a pixel of a random color down and back on the strip
- Light the strip up as a rainbow
- Send a pair of Maize and Blue lights down the strip.

## ④ L05\_04\_pixelFill

- Light up 7 segments of different colors using the fill() method

# L06\_Encoders



# IoT Humor

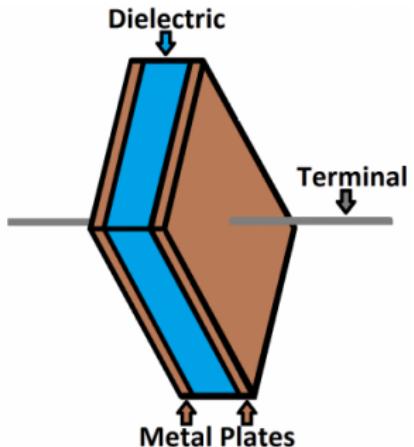




# Capacitors

A capacitor is created out of two metal plates and an insulating material called a dielectric. The metal plates are placed very close to each other, in parallel, but the dielectric sits between them to make sure they don't touch.

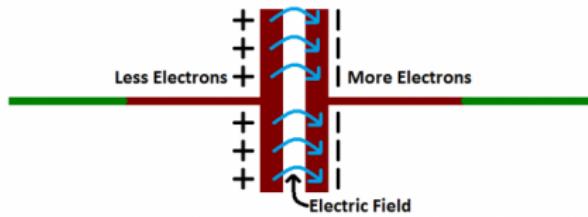
- The dielectric can be made out of all sorts of insulating materials: paper, glass, rubber, ceramic, plastic, or anything that will impede the flow of current.
- The plates are made of a conductive material: aluminum, tantalum, silver, or other metals.





# Capacitors

When current flows into a capacitor, the charges get "stuck" on the plates because they can not get past the insulating dielectric. Electrons build up on one of the plates, and it becomes overall negatively charged. The large amount of negative charges pushes away like charges on the other plate, making it positively charged.

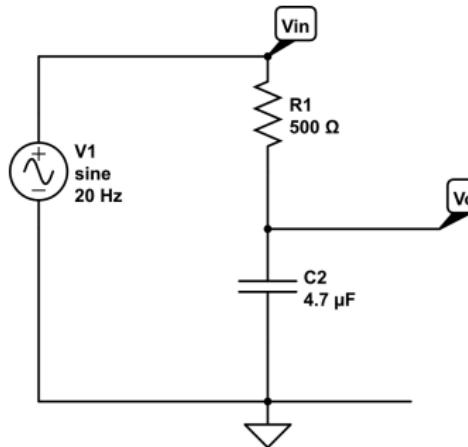


The stationary charges on these plates create an electric field, which influences electric potential energy and voltage. When charges group together on a capacitor like this, the cap is storing electric energy just as a battery might store chemical energy.



# Low Pass Filter - cutoff frequency $f_c$

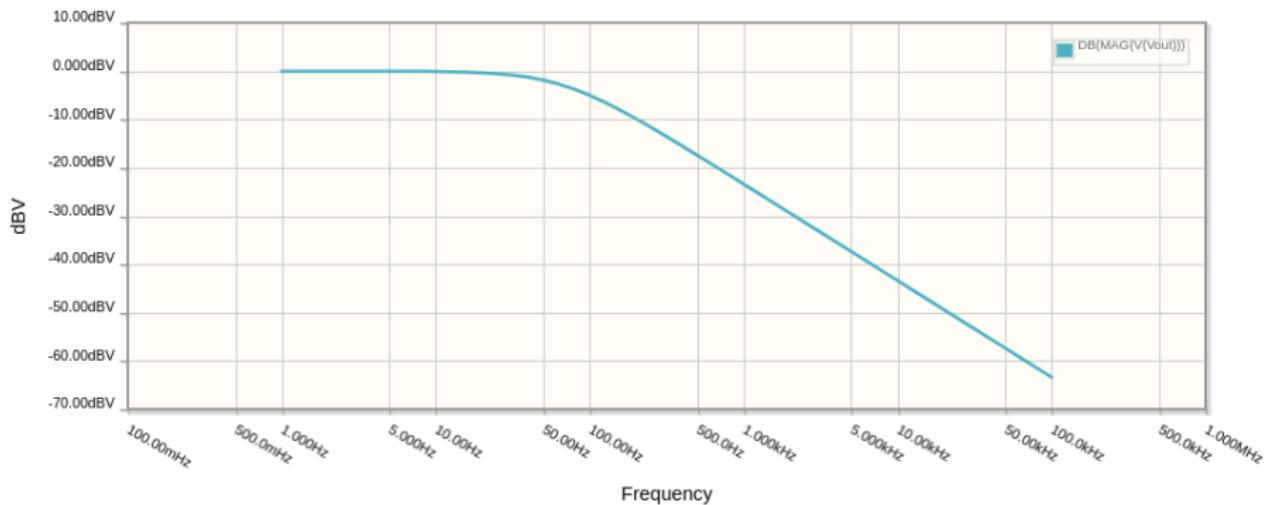
- At low frequencies, there is plenty of time for the capacitor to charge up to practically the same voltage as the input voltage.
- At high frequencies, the capacitor only has time to charge up a small amount before the input switches direction. The output goes up and down only a small fraction of the amount the input goes up and down. At double the frequency, there's only time for it to charge up half the amount.



$$f_c = \frac{1}{2\pi\tau} = \frac{1}{2\pi RC}$$



# Low Pass Filter Response



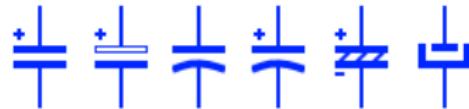
$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(500)(4.7 \times 10^{-6})} = 67.5678 \text{ Hz}$$



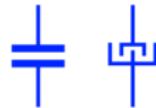
# Capacitors - does it matter how they are placed

- Some types of capacitors (electrolytic and tantalum) are polarized (they have + and - terminals). This is due to how the dielectric film has been deposited, the reverse polarity leads to degradation of the dielectric.
- Other capacitors (ceramic and film) do not have a polarity and can be installed in either direction.

Polarized Electrolytic Capacitor

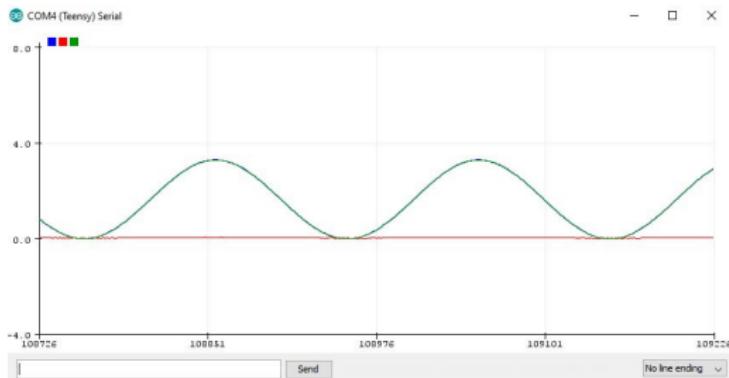


Generic Capacitor





# Serial Plotter



It can give you visualizations of variables in real-time. This is super useful for visualizing data, troubleshooting your code, and visualizing your variables as waveforms.

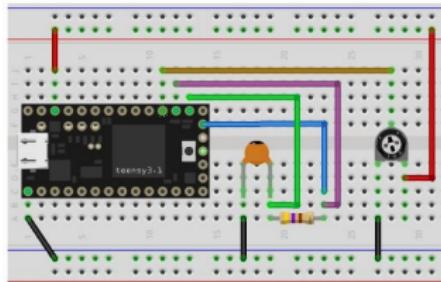
Data is plotted using `Serial.printf()` with the data separated by commas.  
For example:

- `Serial.printf("%i , %i, %0.3f \n",data1,data2,data3);`



# Assignment: Low Pass Filters

## ① L06\_00\_lowPass

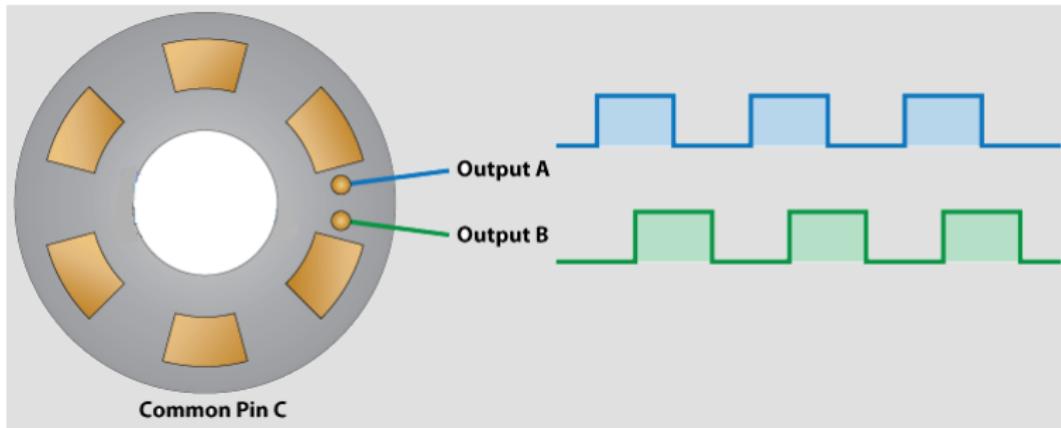


- Notebook:  
schematic
- Fritzing diagram
- Wire your circuit
- Write the code

- Connect a potentiometer to an Analog Input. Use it to vary a frequency ( $\nu$ ) from 0 to 500 Hz.
- Create code that generates a sine wave of frequency  $\nu$ :  $\sin(2\pi\nu t)$
- Create a low pass filter with  $f_c \approx 67\text{Hz}$
- Connect the ADC output (A14) to the input to the filter and to an Analog Input.
- Connect the output of the filter to another Analog Input
- Using the Serial Plotter, the frequency and both inputs.
- Record in your notebook how the signals change when  $\nu$  is varied.

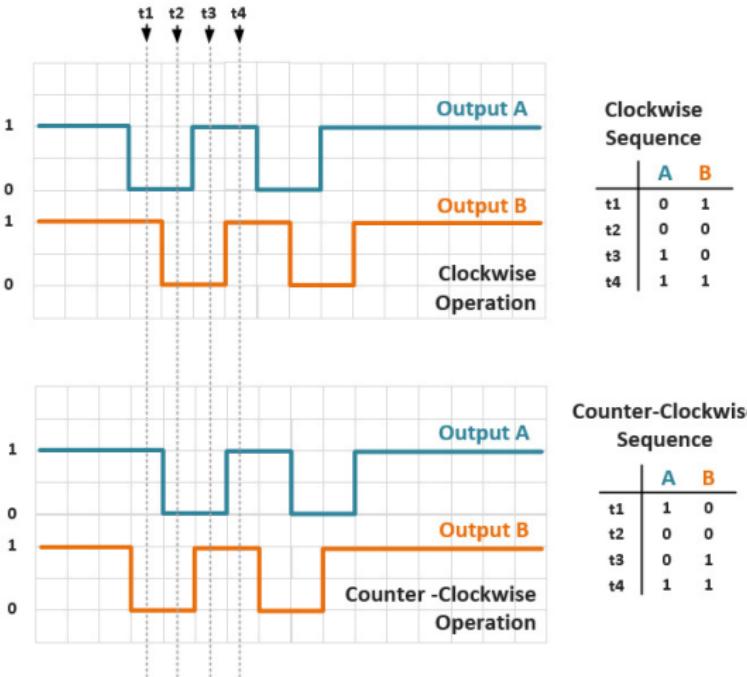


# Encoders





# Encoders



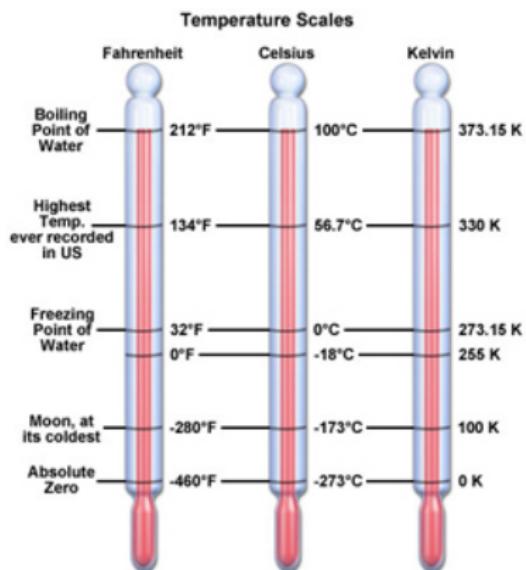


# The Encoder Class

```
1 #include <Encoder.h>
2 Encoder myEnc(pinA, pinB);
3
4 void setup() {
5 }
6
7 void loop() {
8     // read encoder position
9     position = myEnc.read();
10
11    // set encoder to a position
12    myEnc.write(maxPos);
13 }
```



# Mapping (or Converting)



Mapping is the conversion from one set of units to another. For example converting from Celsius to Fahrenheit:

$$Temp(^{\circ}F) = \frac{9}{5} * Temp(^{\circ}C) + 32$$

C++ provides us with a function to do this mapping:

```
newVal = map(value, fromLow, fromHigh, toLow, toHigh);
```

For example:

```
tempF = map(tempC,0,100,32,212);
```



# Assignment: Encoders



- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

## ① L06\_01\_encoder

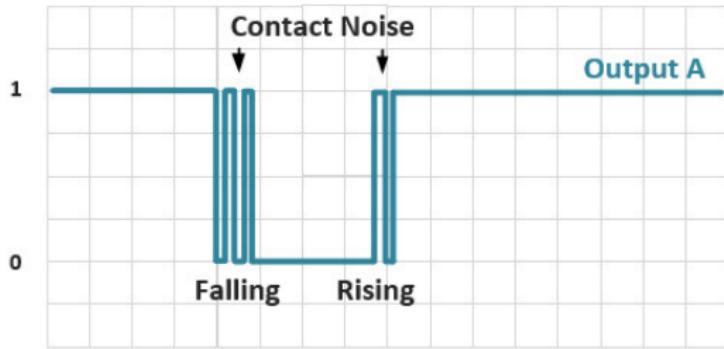
- Display the encoder position to the screen
- What do you notice about the encoder position as you turn it slowly?

## ② L06\_02\_NeoPixel

- The encoder has 96 positions. Map the encoder input to 16 NeoPixels.
- Bound the input, so the mapped range from 0 to 15.
- What is the difference in performance if you bind the input vs the mapped range?
- Use the encoder to light up the four NeoPixels and the ring.

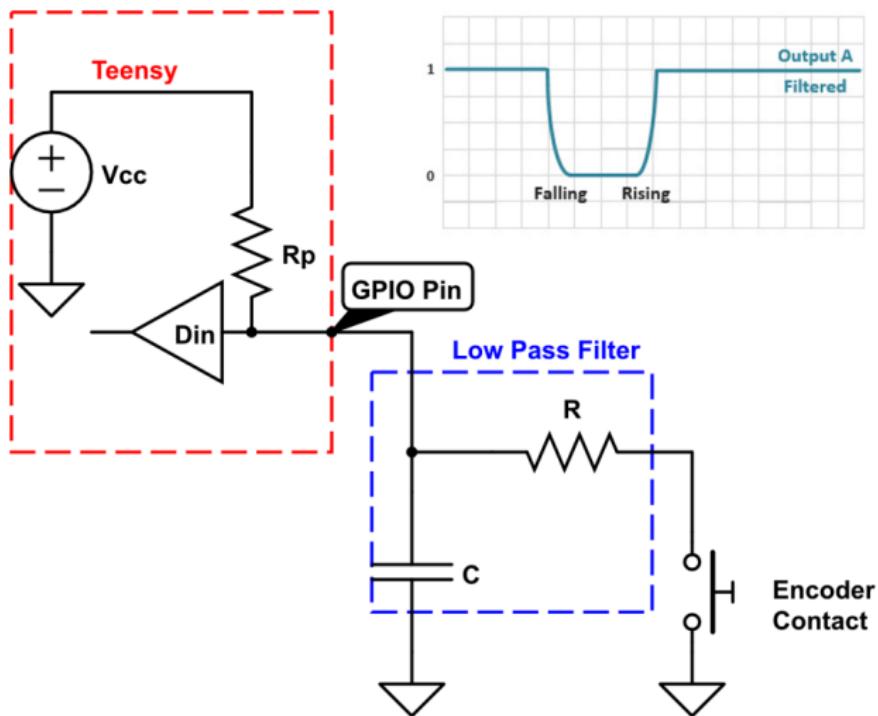


# Encoder Jitter





# Encoder - Low Pass Filter





# Assignment: Encoders



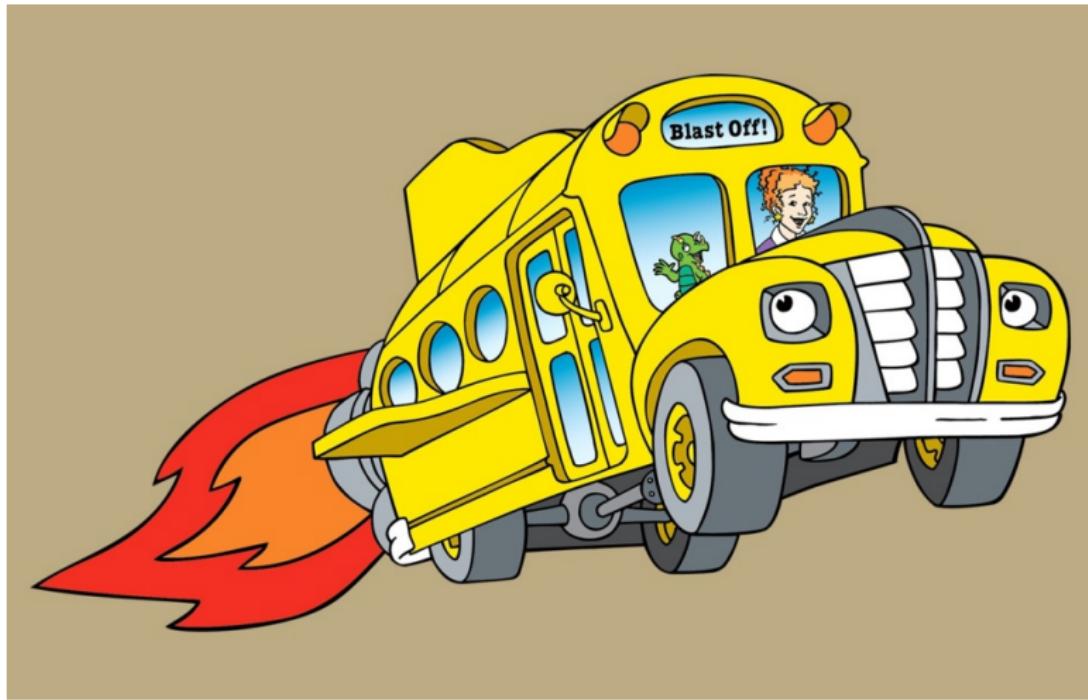
- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

- ① L06\_03\_encoder\_switch
  - Connect the encoder switch and LEDs
  - Use the switch to turn on/off the NeoPixels.
  - Set encoder LED to red for off and green for on.
  - Disable turning the encoder when off.
- ② L06\_04\_rainbow1
  - Without OneButton: Use a button to cycle the NeoPixel ring colors through the colors of the rainbow. (i.e., one color change each time button is pressed).
- ③ L06\_05\_rainbow2
  - With OneButton: Have it continuously cycle (i.e, while pressed colors change every one second).

# L07\_SPI

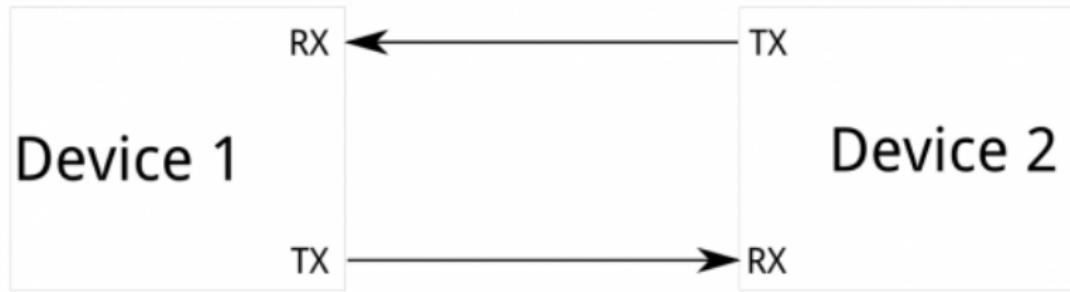


# Buses and Interfaces





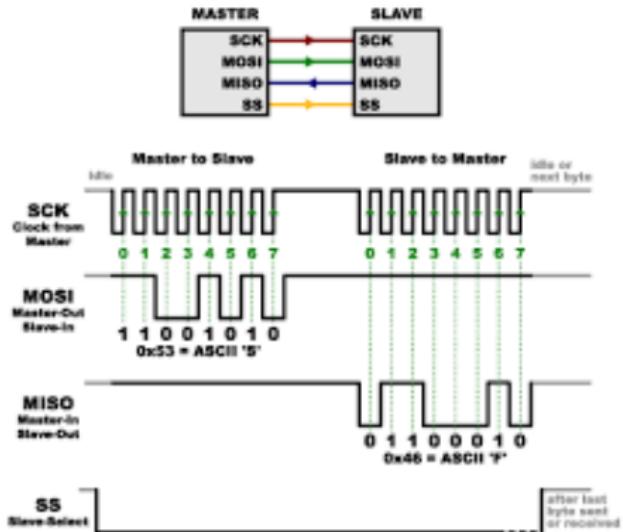
# UART



Universal Asynchronous Receiver/Transmitter



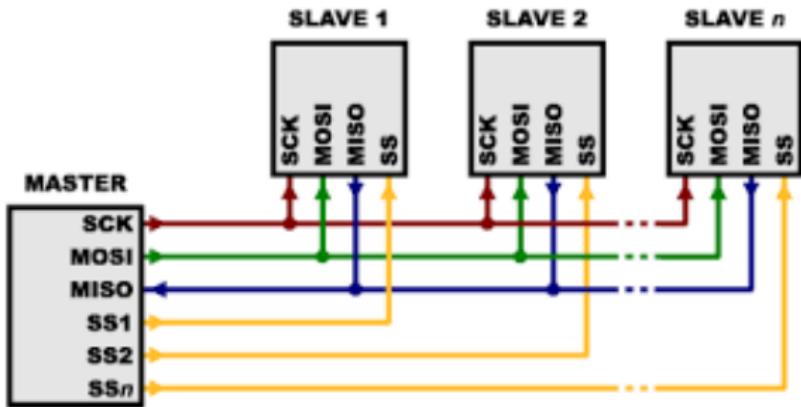
# Serial Peripheral Interface



- Master Out, Slave In (MOSI) connects to Data In
- Master In, Slave Out (MISO) connects to Data Out



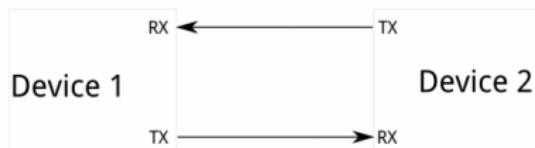
# Serial Peripheral Interface



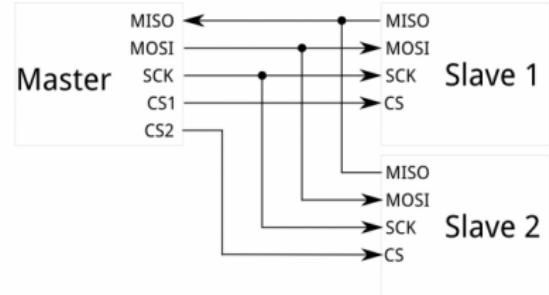


# Serial +/−

## UART



## SPI





# Assignment: L07\_01\_dataLogger



- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

- ➊ The starter code details the pin assignments for SPI, use these for your schematic and Fritzing.
- ➋ Modify the starter code to:
  - Read two inputs:
    - ➌ The value of the encoder (unbounded)
    - ➍ A potentiometer connected to Pin 22.
  - Write to  $\mu$ SD Card a timestamp (in millis()) and the two input values every 5 seconds.

# L08\_Ethernet



# The Internet





# IP Addresses

- When a device joins the network it is given an internet address.
    - static or dynamic
  - IPv4 (32-bit) - 4.2 billion
  - IPv6 (128-bit) -  $340 * 10^{27}$  (quadrilliard)
  - In Powershell: ipconfig /all
  - In Terminal (MAC/Linux): ifconfig

IPy4 address in dotted-decimal notation

172 . 16 . 254 . 1

↓      ↓      ↓      ↓

10101100.00010000.11111110.00000001

8 bits

32 bits (4 bytes)

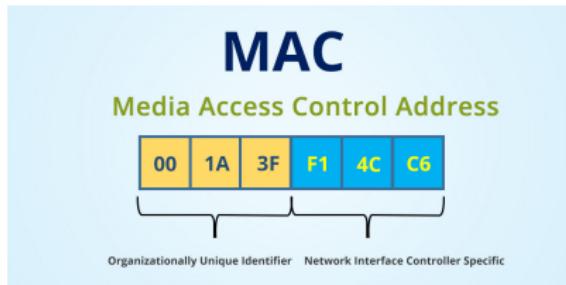
An IPv6 address (in hexadecimal)

2001:0DB8:AC10:FE01:0000:0000:0000:0000

2001:0DB8:AC10:FE01:: Zeroes can be omitted



# MAC Address



A MAC Address is a unique 6-byte (48-bit) address that is usually permanently burned into a network interface card (NIC) and uniquely identifies the device on an Ethernet-based network. The uniqueness of MAC addresses is ensured by IEEE.

If you are creating your own MAC address, the 2's place bit of the first byte, the "locally administered bit" should be set. The 1's place bit, the "globally administered" bit must be off.

Therefore, `xA-xx-xx-xx-xx-xx` is valid, while `x7-xx-xx-xx-xx-xx` is not.



# Assignment: Wemo



- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

Add the Ethernet (CS=10) to your breadboard along with a button in Pin 23.

## ① L08\_00\_EthernetTest

- Create your own mac.h MAC Address.

## ② L08\_01\_Wemo

- From the wemo.h library determine how the functions are called.
- Create code to turn on/off multiple Wemo Outlets in the classroom.

## ③ L08\_02\_Wemo\_Timer

- Create timer that turns off a Wemo 10 secs after you push "off" button without using delay()

## ④ L08\_03\_Wemo\_Object

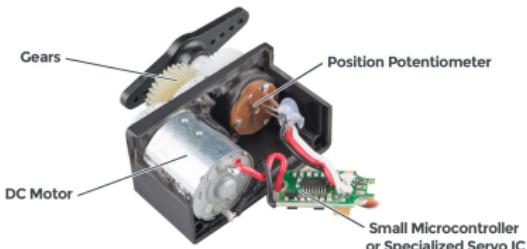
- Modify the wemo.h library to be a Class and Methods.
- Modify your wemo code to create and use a wemo object.

# L09\_Servo



# Servo Motors

- A servo is any motor-driven system with a feedback element built in.
- A servo motor basically has three core components:
  - ① a DC motor,
  - ② a potentiometer that measures its position,
  - ③ a feedback controller circuit
- The servo is controlled by a PWM signal from a digital pin. The width of the pulse determines the position that the servo moves to.





# Servo library

For the Teensy 3.2, we will be using the PWMServo.h library

## ① Header

- PWMServo myServo; - create object myServo of class PWMServo

## ② void setup()

- myServo.attach(pin) - attach the Servo object to a pin

## ③ void loop()

- myServo.write(angle) - move servo to angle (in degrees)
- myServo.read() - returns the current angle of the servo



# Assignment: L09\_Servo



- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

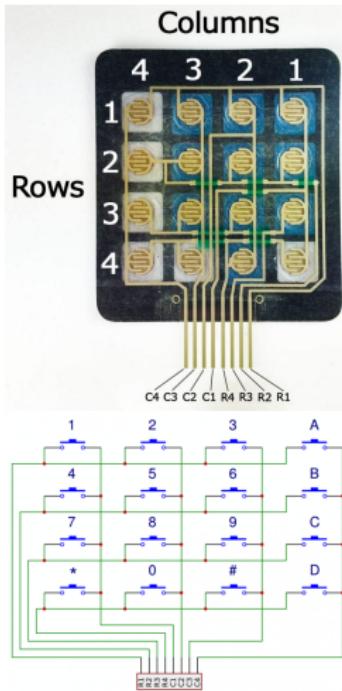
## ① L09\_01\_Servo

- Connect the servo and a button to the Teensy
- Have the servo oscillate between 0 and 180 degrees using a sine wave pattern.
- Use the button to start and stop the motion.

On the Teensy, we can use PI for  $\pi$ , note however, in C++ (math.h) the math constants are M\_<name>. For example, M\_PI =  $\pi$ . Use M\_PI for this exercise.



# KeyPad



- The Keypad is a two dimensional array of buttons.
- Pushing a button connects one row pin with one column pin.
- We will use the Keypad.h library to access the Keypad.

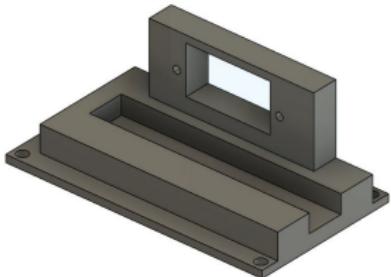


# Keypad.h

```
1 #include <Keypad.h>
2
3 const byte ROWS = 4;
4 const byte COLS = 4;
5 char customKey;
6
7 char hexaKeys[ROWS][COLS] = {
8     {'1', '2', '3', 'A'},
9     {'4', '5', '6', 'B'},
10    {'7', '8', '9', 'C'},
11    {'*', '0', '#', 'D'}
12};
13
14 byte rowPins[ROWS] = {9, 8, 7, 6};
15 byte colPins[COLS] = {5, 4, 3, 2};
16
17 Keypad customKeypad = Keypad(makeKeymap(hexaKeys), rowPins, colPins, ROWS, COLS);
18
19 void setup(){
20     Serial.begin(9600);
21 }
22
23 void loop(){
24     customKey = customKeypad.getKey();
25
26     if (customKey){
27         Serial.println(customKey);
28     }
29 }
```



# Assignment: L09\_02\_Lock

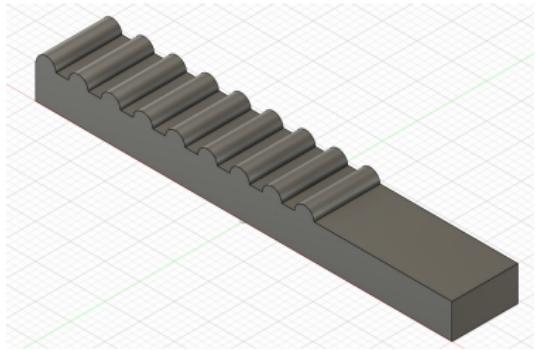
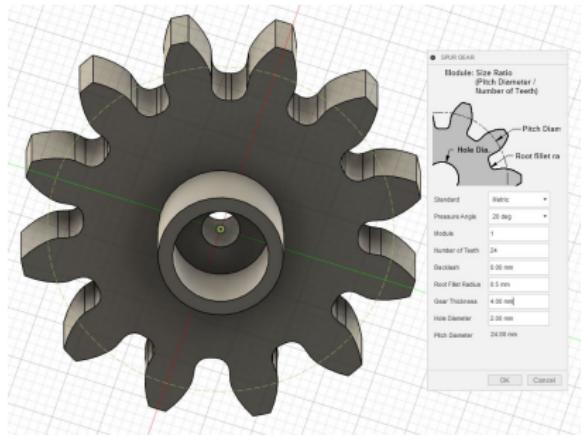


- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

- ➊ Design and print a lockholder based on the class example.
  - Optional: design and print your own gear and lock slider
- ➋ Using the keypad, create an digital lock
  - Implement 4-digit code to lock and unlock
  - Use the servo to lock and unlock based on a correctly entered code
  - Green LED and lock disengaged when unlocked
  - Red LED and lock engaged when locked.



# Optional Designs



L10\_I<sup>2</sup>C

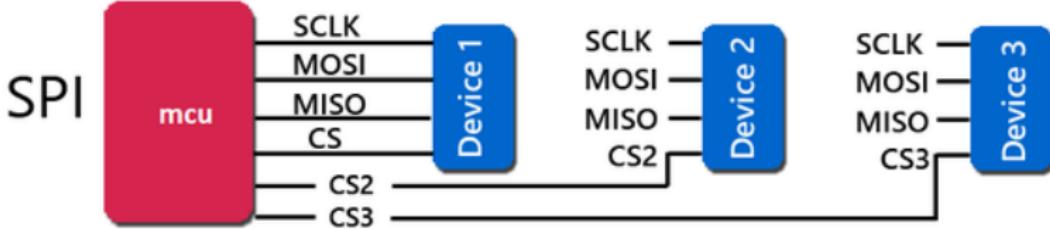
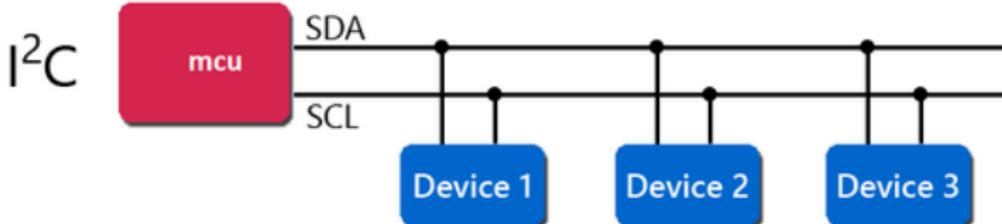


# IoT Humor





# Inter-integrated Circuit (I<sup>2</sup>C)





# I<sup>2</sup>C vs SPI

## I<sup>2</sup>C v/s SPI

I <sup>2</sup> C	SPI
Speed limit varies from 100kbps, 400kbps, 1mbps, 3.4mbps depending on i2c version.	More than 1mbps, 10mbps till 100mbps can be achieved.
Half duplex synchronous protocol	Full Duplex synchronous protocol
Support Multi master configuration	Multi master configuration is not possible
Acknowledgement at each transfer	No Acknowledgement
Require Two Pins only SDA, SCL	Require separate MISO, MOSI, CLK & CS signal for each slave.
Addition of new device on the bus is easy	Addition of new device on the bus is not much easy a I <sup>2</sup> C
More Overhead (due to acknowledgement, start, stop)	Less Overhead
Noise sensitivity is high	Less noise sensitivity



# L10\_00\_I2CScanner

Let's create an I2C scanner

- ① Follow along to create the I2C code.
  - Use library wire.h
  - Wire.begin();
  - Wire.beginTransmission(i);
  - Wire.endTransmission();
    - 0: Transmission Successful
    - 1: Data too long to fit in transmit buffer
    - 2: Received NACK (Negative Acknowledgment) on transmit of address
    - 3: Received NACK on transmit of data
    - 4: Other error
- ② Create a Fritzing diagram for adding the BME280 and the OLED to your Teensy.
- ③ Wire up your schematic and determine the I2C addresses of each device.



# Char Datatype

The char data type is a single byte in size and can be used to represent text characters (ASCII).

ASCII control characters		ASCII printable characters		Extended ASCII characters	
00	NULL (NUL or zero)	32	space	64	Ø
01	SOH (Start of Header)	33	!	65	A
02	STX (Start of Text)	34	"	66	B
03	ETX (End of Text)	35	#	67	C
04	EOT (End of Trans.)	36	\$	68	D
05	ENQ (Enquiry)	37	%	69	E
06	ACK (Acknowledgement)	38	&	70	F
07	BEL (Bell)	39	'	71	G
08	BS (Backspace)	40	(	72	H
09	HT (Horizontal Tab)	41	)	73	I
10	LF (Line feed)	42	*	74	J
11	VT (Vertical Tab)	43	+	75	K
12	FF (Form feed)	44	-	76	L
13	CR (Carriage return)	45	.	77	M
14	SO (Shift Out)	46	,	78	N
15	SI (Shift In)	47	/	79	O
16	DLE (Data link escape)	48	0	80	P
17	DC1 (Device control 1)	49	1	81	Q
18	DC2 (Device control 2)	50	2	82	R
19	DC3 (Device control 3)	51	3	83	S
20	DC4 (Device control 4)	52	4	84	T
21	NAK (Negative acknowledgement)	53	5	85	U
22	SYN (Synchronous idle)	54	6	86	V
23	ETB (End of transmission block)	55	7	87	W
24	CAN (Cancel)	56	8	88	X
25	EM (End of medium)	57	9	89	Y
26	SVD (Start of verbal data)	58	0	90	Z
27	ESC (Escape)	59	:	91	Ø
28	FS (File separator)	60	<	92	Ø
29	GS (Group separator)	61	=	93	Ø
30	RS (Record separator)	62	>	94	Ø
31	US (Unit separator)	63	?	95	-
127	DEL (Delete)				

ASCII 248



alt + 248  
(Degree symbol)

most consulted

- 1 érye, n with tilde (alt + 164)
- 2 black square (alt + 254)
- 2 superscript two, square (alt + 255)
- o degree symbol (alt + 248)
- 1 apostrophe, single quote (alt + 39)
- µ letter Mu, miro, miornos (alt + 232)
- © copyright symbol (alt + 164)
- ® registered trademark (alt + 169)
- 3 superscript three, cube (alt + 252)
- á a with acute accent (alt + 160)

```

1 const char degree = 0xF8; // Decimal 248 = 0xFB
2 float temp = 98.6;
3 void setup() {
4   Serial.begin(9600);
5   //NOTE: extended ASCII characters don't always print correctly to Serial Monitor
6   Serial.printf("My temperature is %0.1f %c", temp, degree);
7 }

```



# Assignment: I<sup>2</sup>C



- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

## ① L10\_01\_OLEDWrite

- Install Adafruit\_SSD1306 library
- Review and run SSD\_1306\_128x64\_i2c example
  - Change the I2C address in the example to match your OLED
- Create variables for your birthday. Using the syntax from testdrawstyles() print using printf():
  - Hello World
  - Your Name using spanish honorific (señor, señora, señorita).
  - Your Birthday (04/03/1968)
- Experiment with rotating the screen using the setRotation(rot) method.
  - rot is an int from 0 to 3



# Assignment: BME280



- ① Header - define BME280 object
  - I2C: Adafruit\_BME280 bme();
  - SPI: Adafruit\_BME280 bme(BME\_CS);
- ② Setup - start BME280
  - status = bme.begin(hex address);
  - if(status==false) → initialization failed
- ③ Loop - read from sensor
  - tempC = bme.readTemperature();
  - pressPA = bme.readPressure()/100.0;
  - humidRH = bme.readHumidity();



# Assignment: I<sup>2</sup>C



- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

## ① L10\_02\_BME280

- Read BME280 data
- Convert to tempF and inHg
- Print to Serial.Monitor and the OLED display

## ② L10\_03\_BME280\_SDMicro

- Add in saving data to the  $\mu$ SD card once per minute using millis() as the timestamp
- Use your NeoPixels to give a visual indication of room conditions

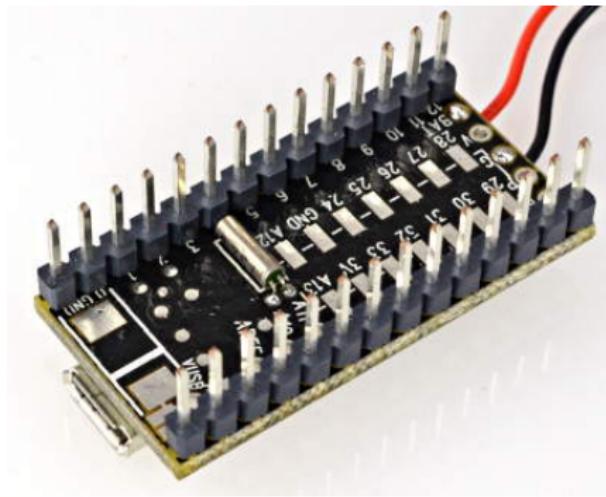
## ③ L10\_04\_RTC (Optional)

- Add the 12.5 pF crystal to the Teensy
- Display the time on the OLED
- Add a true timestamp to the saved data



## Real Time Clock

To use the Teensy 3.2 RTC, you need to add a 32.768 kHz, 12.5 pF crystal to the bottom side of the board.

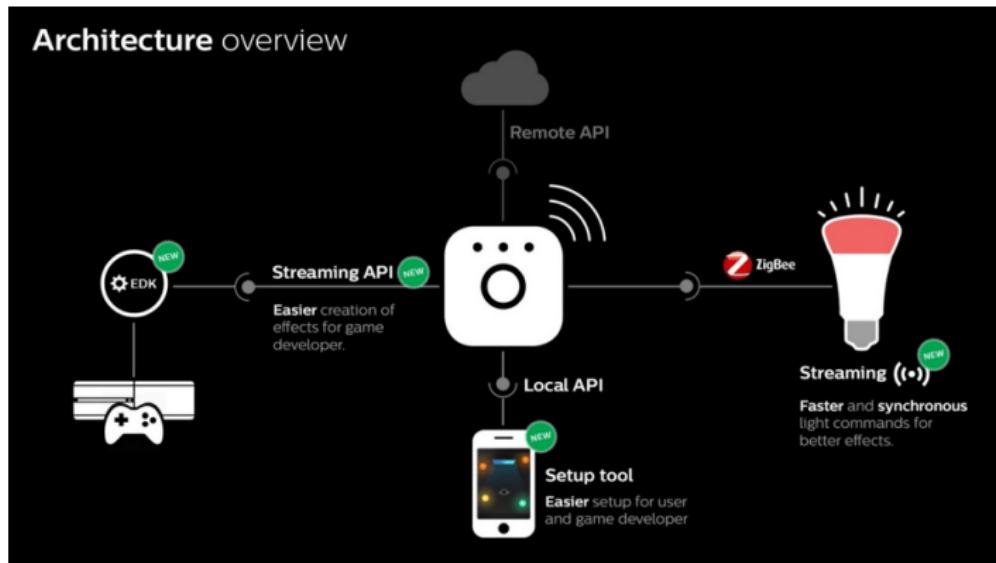


Example can be found at FILE → Examples → Time → TimeTeensy3.

# L11\_Hue



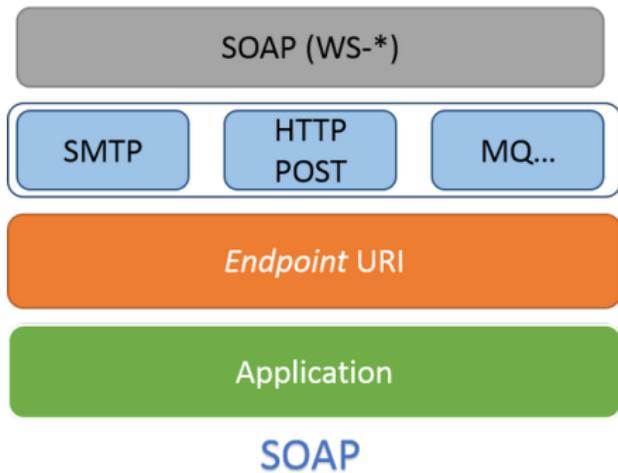
# Phillips Hue API



Application Programming Interface: a set of functions and procedures allowing the creation of applications that access the features or data of an operating system, application, or other service.



# SOAP vs REST





# Assignment: L11\_01\_Hue



- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

① Using the hue.h library and HueH\_Example as a template, create code that

- button that turns on and off the Hue light at your pod
- uses the encoder to change the brightness of the Hue bulb
- has a method of cycling the Hue light through the colors of the rainbow.

# Midterm 1 - Smart Room Controller



# Getting with GIT



Go To GitHub Lecture



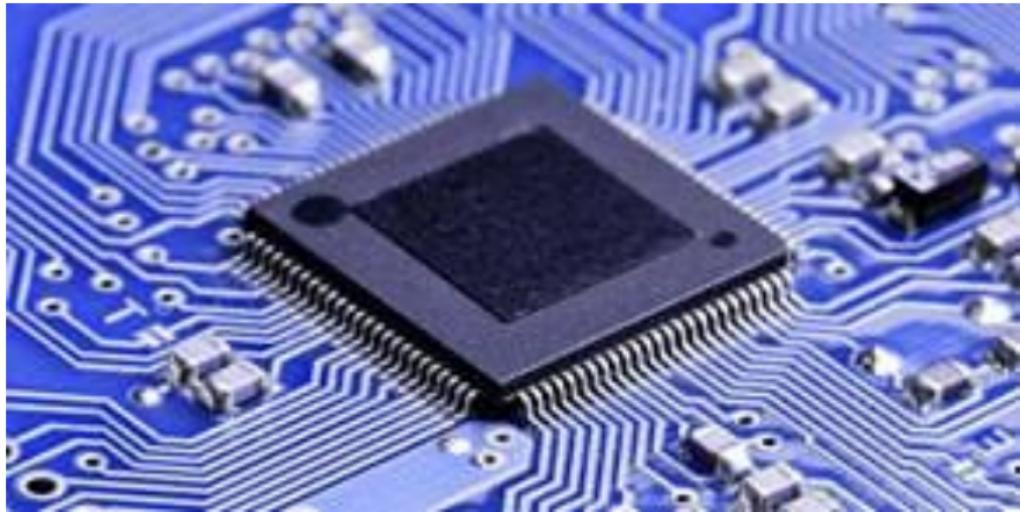
# Midterm Project - Smart Room Controller

- ① Determine functionality of your Smart Room Controller
  - Use the components that we have learned over the last 3 weeks.
  - Get minimum requirements from the Instructor.
  - Sketch out the basic layout of your room controller in your lab notebook.
  - Draw flowcharts of the main functions you plan to implement.
  - Get feedback from at least 3 peers on your planned functionality.
- ② Layout your circuitry in Fritzing along with a legible schematic.
- ③ Wire up your circuitry as if you're going to demo your controller for a perspective customer.
- ④ Code, debug, test.
- ⑤ Documentation and Demonstration:
  - Ensure all files are uploaded to GitHub with an appropriate README.md
  - Upload your project to hackster.io
  - Prepare a presentation/demonstration for the class on your controller
  - Participate in class demonstrations (Friday morning - Week 4)

# Particle Argon



# Our Second Microcontroller





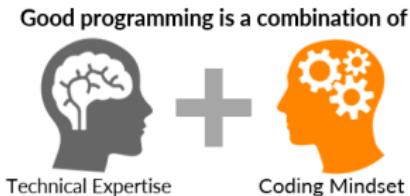
# Expectations for the rest of the course

I will not write any more bad code  
I will not write any more bad code





# Expectations for the rest of the course



A programmer's three high-level goals  
are to write code that...

- ➊ Solves a specific problem
- ➋ Is easy to read
- ➌ Is maintainable and extendable

- ➊ Most important: Be Consistent
- ➋ Proper Indentation
- ➌ Brace placement: K&R or BSD
- ➍ Do not check boolean for equality.
- ➎ A variable's name (noun) should describe its contents.
- ➏ A function's name (verb) should describe the set of actions it performs.
- ➐ Reduce duplication / Modularize
- ➑ So, what about capitalization?
  - ➊ variableNames
  - ➋ nameFunction
  - ➌ CONSTANTS
  - ➍ Classes and Enum



# Previous Capstones



## Previous Capstone Playlist

<https://www.youtube.com/watch?v=s4TslpITeVw&list=PL0t2Pk5ETDgxfVptdyr6xbL6MW1-5CJey>



# Particle Argon

## Main processor:

Nordic Semiconductor nRF52840 SoC

- ARM Cortex-M4F 32-bit processor @ 64MHz
- 1MB flash, 256KB RAM
- Bluetooth LE (BLE) central and peripheral support
- 20 mixed signal GPIO (6 x Analog, 8 x PWM), UART, I2C, SPI
- Supports DSP instructions, HW accelerated Floating Point Unit (FPU) calculations
- ARM TrustZone CryptoCell-310 Cryptographic and security module
- Up to +8 dBm TX power (down to -20 dBm in 4 dB steps)
- NFC-A radio

## Argon Wi-Fi network coprocessor:

Espressif ESP32-D0WD 2.4 GHz Wi-Fi coprocessor

- On-board 4MB flash for the ESP32
- 802.11 b/g/n support
- 802.11 n (2.4 GHz), up to 150 Mbps



## Argon general specifications:

- On-board additional 4MB SPI flash
- Micro USB 2.0 full speed (12 Mbps)
- Integrated Li-Po charging and battery connector
- JTAG (SWD) Connector
- RGB status LED
- Reset and Mode buttons
- On-board 2.4GHz PCB antenna for Bluetooth (does not support Wi-Fi)
- Two U.FL connectors for external antennas (one for Bluetooth, another for Wi-Fi)
- Meets the [Feather specification](#) in dimensions and pinout
- FCC, CE and IC certified
- RoHS compliant (lead-free)



# Why Particle

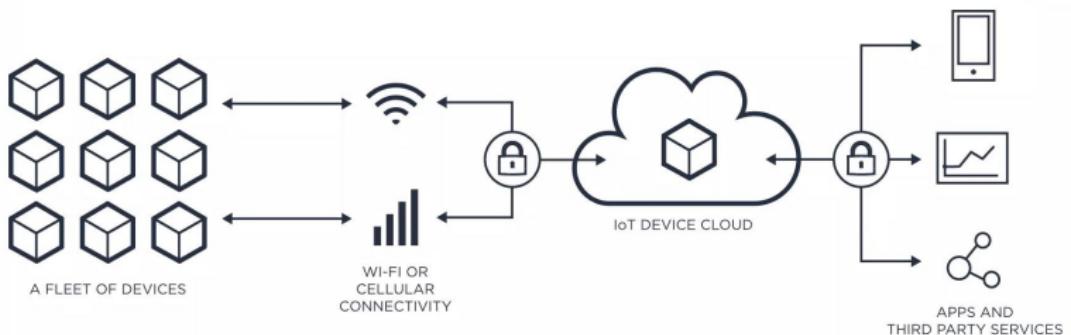


- Global reach with over 200,000 IoT professionals
- Edge-to-Cloud infrastructure
- Prototyping to Production with same code
- WI-FI, Bluetooth, and Cellular
- Secure Device OS
- Built in cloud communication
- Real-Time OS that works across all products



# Particle: Edge to Cloud

## EDGE-TO-CLOUD IOT PLATFORM



IOT DEVICE HARDWARE AND FIRMWARE

WI-FI AND CELLULAR MVNO

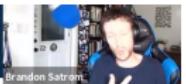
IOT DEVICE CLOUD

WEB/MOBILE APP SDKS AND  
INTEGRATIONS WITH THIRD-PARTY  
SERVICES



# Particle: Prototyping to Production

## HARDWARE AND CONNECTIVITY



1

HARDWARE FOR  
PROTOTYPING  
& PRODUCTION



2

USE-CASE-SPECIFIC  
MODULES AND PRODUCTS



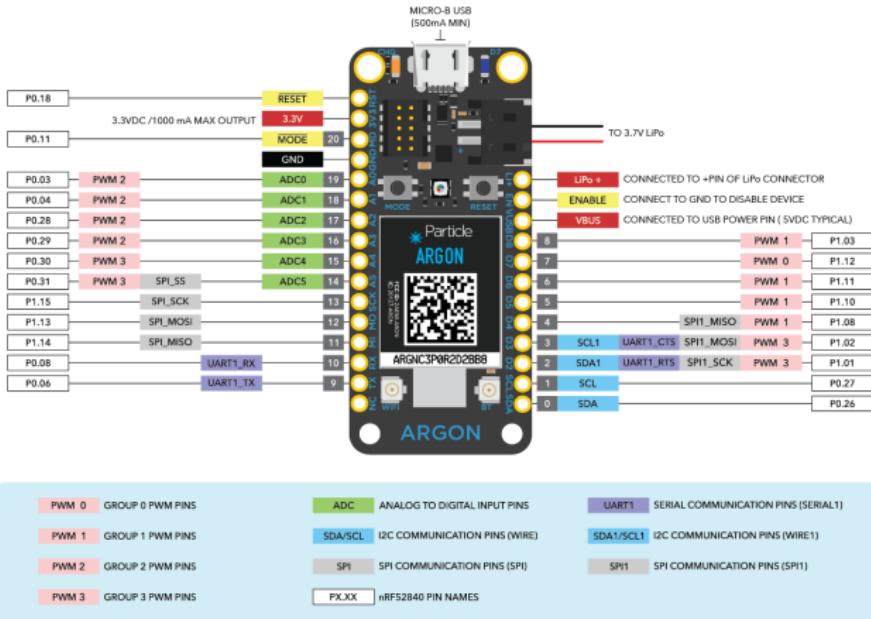
3

CELLULAR, BLE  
& WI-FI CONNECTIVITY





# Particle Argon Pin Layout



v1.0



# Please Do Not Skip Ahead During Setup





# Particle Software - ParticleCLI and Visual Studio Code

- ① Create Particle login: <https://login.particle.io/signup>
- ② Install Particle Command Line Interface. Download from <https://docs.particle.io/tutorials/developer-tools/cli/>.
  - On Windows, you need to run this by right-clicking on it and selecting "Run As Administrator."
  - Test that the Particle CLI installed correctly by going to PowerShell or Terminal and type particle
- ③ Download Particle Workbench / Visual Studio Code <https://docs.particle.io/quickstart/workbench/>.
  - Select all default values during install.
  - **Do NOT install Azure IoT.**
  - After it is installed, when you launch it, it may ask you to Install Dependencies. If so, select yes.



# Particle Setup

- ① Attach the Wi-Fi antenna to your Argon. Use the correct connector, there are 3 U.FL connectors: WiFi, BT, and NFC.
- ② Plug the Argon into a USB port. It should begin blinking blue.
- ③ Open PowerShell or Terminal.
- ④ Login into your Particle Account

```
1 particle login
```

- ⑤ Ensure you have the latest Particle CLI

```
1 particle update-cli
```

- ⑥ Put the Argon in DFU mode (blinking yellow) by holding down MODE. Tap RESET and continue to hold down MODE. The status LED will blink magenta (red and blue at the same time), then yellow. Release when it is blinking yellow.



# Updating your Argon to latest Device OS

- ① Update the device by running the following two commands. If the device goes out of blinking yellow after the first command, put it back into DFU mode. See Note <sup>2</sup>.

```
1 particle update  
2 particle flash --usb tinker
```

- ② When the command reports Flash success!, reset the Argon. It should go back into listening mode (blinking dark blue).
- ③ Verify that the update worked by running the following command:

```
1 particle serial identify  
2  
3 Your device id is e00fce681fffffffffc08949b  
4 Your system firmware version is 1.5.2
```

---

<sup>2</sup>particle flash –usb tinker can be used for device troubleshooting



# Setting Up WiFi

- Set your Argon into Listening Mode by holding the MODE button for three seconds, until the RGB LED begins blinking blue.
- Execute the command: `particle serial wifi`

```
brian:~$ particle serial wifi
? Should I scan for nearby Wi-Fi networks? No
? SSID DDCIOT
? Security Type WPA2
? Cipher Type AES+TKIP
? Wi-Fi Password ddcIOT2020
Done! Your device should now restart.
```

After setting, your Argon should go through the normal sequence of blinking green, blinking cyan (light blue), fast blinking cyan, and breathing cyan.



# Claim Your Device

- ① Claim the device to your account. This can only be done if it's breathing cyan. Replace e00fce681ffffffffc08949b with the device ID you got earlier from particle serial identify. Then, rename it to the name of your choice.

```
1 particle device add e00fce681fffffffffc08949b  
2 particle device rename e00fce681fffffffffc08949b  
      myArgon
```

- ② Ensure that your setup flag is marked as done

```
1 particle usb setup -done
```

- ③ You have successfully set up your Argon!



# Useful Particle CLI Commands

- ① Enter DFU mode from the CLI

```
1 particle usb dfu
```

- ② If Argon won't enter DFU mode or is otherwise acting strangely, restore the base firmware

```
1 particle flash --usb tinker
```

- ③ Get a list of your Particle devices and their connection status

```
1 particle list
```

- ④ Search for available libraries

```
1 particle library search <search term>
```

- ⑤ Link for the Particle Setup procedures: [Particle Setup via CLI](#)



# Argon LED Modes

Mode	LED Status
Connected	Breathing Cyan
OTA Firmware Update	Blinking Magenta (red and blue together)
Looking for Internet	Blinking Green
Connecting to Cloud	Rapid Blinking Cyan
Listening Mode	Blinking Blue
Network Reset	Rapid Blinking Blue
WiFi Off	Breathing White
Safe Mode	Breathing Magenta (red and blue together)
DFU (Device Firmware Upgrade)	Blinking Yellow
Restore Factory Firmware	Rapid Blinking Yellow
Factory Reset	Rapid Blinking White
Decryption Error	Blinking Cyan followed by 1 Orange Blink
No Internet	Blinking Cyan followed by 2 Orange Blink
No Particle Cloud	Blinking Cyan followed by 3 Orange Blink
Authentication Error	Blinking Cyan followed by 1 Magenta Blink
Handshake Error	Blinking Cyan followed by 1 Red Blink
Decryption Error	Blinking Cyan followed by 1 Orange Blink
SOS - Firmware Crash	Blinking Red - 3 short, 3 long, 3 short, error code



# Directory Structure - VERY IMPORTANT

The screenshot shows the VS Code interface with the following details:

- EXPLORER** view: Shows the project structure.
  - OPEN EDITORS**: 1 UNSAVED
  - PM25\_Testino** (selected)
  - PM25\_TEST**
  - .vscode**: *launch.json*, *settings.json*
  - lib\Seeed\_HM330X**: *examples\basic\_demo*, *basic\_demo.ino*
  - src**: *HM330XErrorCode.h*, *I2COperations.cpp*, *I2COperations.h*, *Seeed\_HM330X.cpp*, *Seeed\_HM330X.h*
  - PM25\_Testino**
  - target\1.5.0\argon**
  - project.properties**
  - README.md**
- CODE** view: Displays the *PM25\_Testino* file content.

```
src > PM25_Testino > ...
1 /*
2  * Project PM25
3  * Description: 2.5um Particle Measurement with H3301 Sensor
4  * Author: Brian Rashap
5  * Date: 17-APR-2020
6 */
7 #include <Particle.h>
8 #include <Seeed_HM330X.h>
9 #include <Wire.h>
10
11 //*****SetUp HM330X*****
12 HM330X sensor;
13 uint8_t buf[30];
14 int PM25;
15
16 const char* str[] = {"sensor num: ", "PM1.0 concentration(CF=1,Standard particulate matter",
17 "PM2.5 concentration(CF=1,Standard particulate matter,unit:ug/m3): ",
18 "PM10 concentration(CF=1,Standard particulate matter,unit:ug/m3): ",
19 "PM1.0 concentration(Atmospheric environment,unit:ug/m3): ",
20 "PM2.5 concentration(Atmospheric environment,unit:ug/m3): ",
21 "PM10 concentration(Atmospheric environment,unit:ug/m3): ",
22 };
23
24 HM330XErrorCode print_result(const char* str, uint16_t value) {
25     if (NULL == str) {
26         return ERROR_PARAM;
27     }
28     Serial.print(str);
29     Serial.println(value);
30     return NO_ERROR;
}
```



# Command Palette - Ctrl-Shift-P

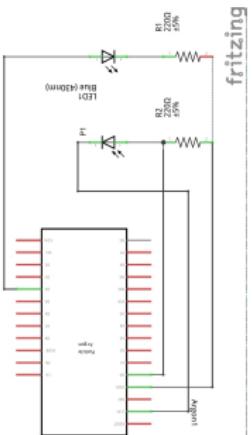
>particle|

- Particle: Install Library** recently used
- Particle: Find Libraries**
- Particle: Cloud Compile**
- Particle: Configure Workspace for Device**
- Particle: Launch CLI**
- Particle: Install Local Compiler**
- Particle: Cloud Flash**
- Particle: Serial Monitor**
- Particle: Create New Project**
- Particle: Audit Environment**
- Particle: Who Am I?**
- **Particle: Clean application (local)** other commands
- Particle: Clean application & DeviceOS (local)**

## L12\_HelloParticle



# Assignment: L12\_HelloParticle



- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

## ① L12\_01\_HelloParticle

- Blink the onboard LED (Pin D7)

## ② L12\_02\_HelloNightLight

- The anode of the photodiode is connected to Pin A0. Note, unlike an LED, the cathode (short pin) of the photodiode is connected to 3.3V.
- The LED anode to Pin D4.
- Using analogRead/digitalWrite, turn on the LED when photodiode is dark.
- Using digitalWrite, turn on LED slowly as room darkens

## ③ L12\_03\_HelloRes

- Create code to determine the resolution (in bits) of read / write.
- Use Serial Monitor via Command Palette



# Particle Publish

One of the advantages of the Argon is seamless publishing to the Cloud.

EVENTS			
			Search for events
NAME	DATA	DEVICE	PUBLISHED AT
particle/device/updat...	false	Lalonde	10/3/20 at 1:21:01 pm
spark/device/diagnost...	{"device": {"network": "..."}, "last_r...	Lalonde	10/3/20 at 1:21:00 pm
spark/device/app-hash	B665BE9CD4ABE921E3...	Lalonde	10/3/20 at 1:21:00 pm
Humidity	42.000000	Lalonde	10/3/20 at 1:20:58 pm
Pressure	29.780001	Lalonde	10/3/20 at 1:20:58 pm
Temperature	69.129997	Lalonde	10/3/20 at 1:20:58 pm
particle/device/updat...	false	Lalonde	10/3/20 at 1:20:58 pm
particle/device/updat...	true	Lalonde	10/3/20 at 1:20:58 pm
spark/device/last_reset	dflu_mode	Lalonde	10/3/20 at 1:20:58 pm
spark/status	online	Lalonde	10/3/20 at 1:20:58 pm

```

1 float temp, prs, hum; // BME280 variables
2 String Temp, Prs, Hum; // Strings to hold BME280 values
3
4 void loop() {
5   Temp = String(temp);
6   Prs = String(prs);
7   Hum = String(hum);
8
9   Particle.publish("Temperature", Temp, PRIVATE);
10  Particle.publish("Pressure", Prs, PRIVATE);
11  Particle.publish("Humidity", Hum, PRIVATE);
12 }
```



# JSON

JSON (JavaScript Object Notation) is a lightweight data-interchange format. It is easy for humans to read and write. It is easy for machines to parse and generate. It is based on a subset of the JavaScript Programming Language Standard ECMA-262 3rd Edition - December 1999. JSON is a text format that is completely language independent but uses conventions that are familiar to programmers of the C-family of languages, including C, C++, C#, Java, JavaScript, Perl, Python, and many others. These properties make JSON an ideal data-interchange language.

JSON is built on two structures:

- A collection of name/value pairs. In various languages, this is realized as an object, record, struct, dictionary, hash table, keyed list, or associative array.
- An ordered list of values. In most languages, this is realized as an array, vector, list, or sequence.



# JSON Parser Generator

Creating objects in JSON are straightforward but can be tedious. There is a JSON Parser available to simplify the process.

```
1 #include <JsonParserGeneratorRK.h>
2
3 void createEventPayLoad(float tempValue, float presValue, float humValue) {
4     JsonWriterStatic<256> jw;
5     {
6         JsonWriterAutoObject obj(&jw);
7
8         jw.insertKeyValue("Temperature", tempValue);
9         jw.insertKeyValue("Pressure", presValue);
10        jw.insertKeyValue("Humidity", humValue);
11    }
12    Particle.publish("env-vals", jw.getBuffer(), PRIVATE);
13 }
```



# Assignment: L12\_HelloParticle

EVENTS   VITALS   HEALTH CHECK

NAME	DATA	DEVICE	PUBLISHED AT
particle/device/updat...	false	Lalonde	10/3/20 at 1:09:40 pm
spark/device/diagnos...	{"device": "network", "s...	Lalonde	10/3/20 at 1:09:40 pm
spark/device/app-hash	651A9E3A5D0A02A4115...	Lalonde	10/3/20 at 1:09:39 pm
env-vals	{"PhotoDiode": 487, "LED": 47}	Lalonde	10/3/20 at 1:09:38 pm
LED Output	47	Lalonde	10/3/20 at 1:09:38 pm
PhotoDiode	487	Lalonde	10/3/20 at 1:09:38 pm

**env-vals**

Published by e00fce68e7addcdcfabbb57d on 10/3/20 at 1:09:38 pm

**PRETTY**   **RAW**    

```
-
  "PhotoDiode": 487
  "LED": 47
}
```

## ① L12\_04\_HelloPublish

- Using Particle.publish() send the photodiode and LED values to the Particle Cloud.
- Use the Command Palette to Install Library JsonParserGeneratorRK.
- Use this library to send the same data using the JSON Generator.



# SYSTEM\_MODE

System modes help control how the device manages the connection with the cloud. By default, the device connects to the Cloud and processes messages automatically. However there are many cases where a user will want to take control over that connection. There are three available system modes:

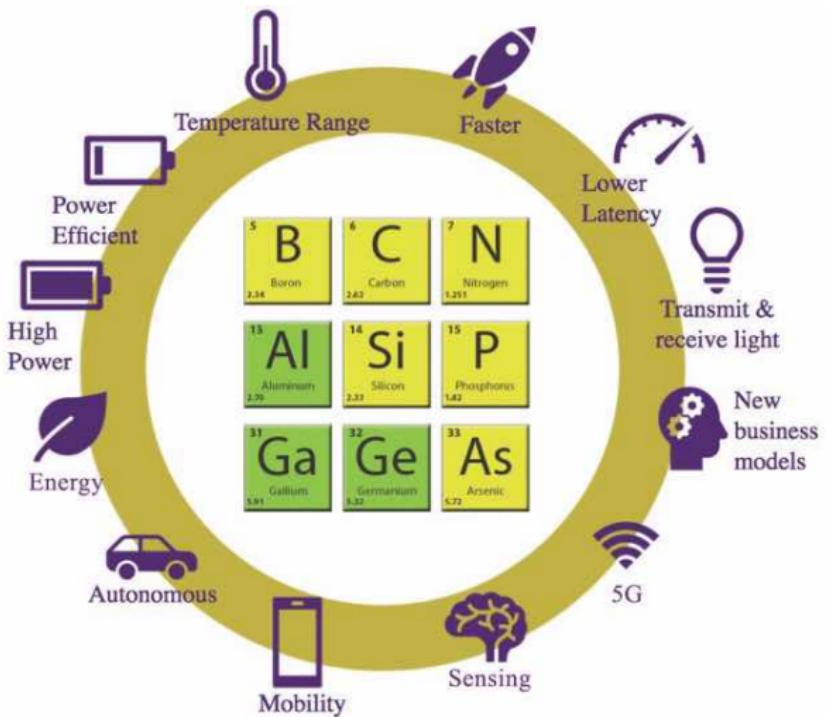
- AUTOMATIC,
- SEMI\_AUTOMATIC,
- MANUAL.

```
1 //The below is placed in the header before Void Setup()
2
3
4 // SYSTEM_MODE(AUTOMATIC);           // Default if no SYSTEM_MODE included
5 // SYSTEM_MODE(SEMI_AUTOMATIC);     // Uncomment if using without Wifi
6 // SYSTEM_MODE(MANUAL);            // Fully Manual
```

# L13\_Semiconductors



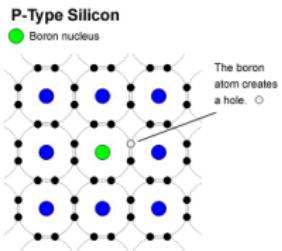
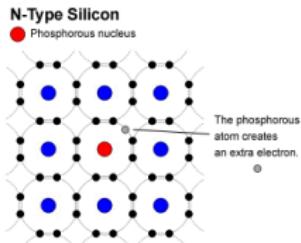
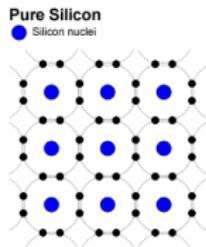
# Semiconductors





# Semiconductor

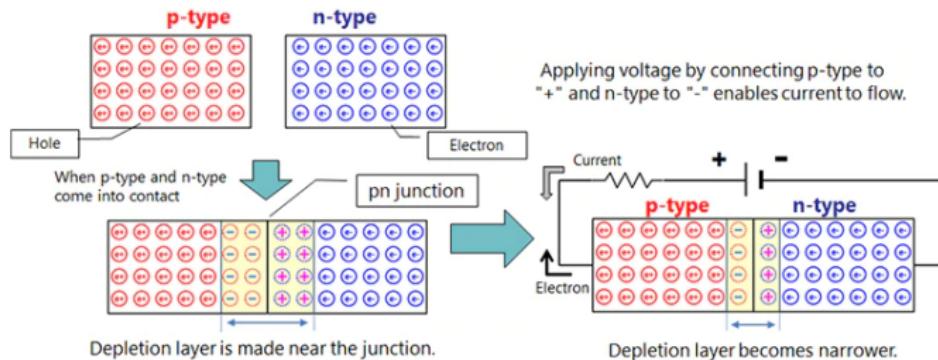
- A silicon atom has four electrons in its outer shell and bonds tightly with four surrounding silicon atoms creating a crystal matrix with eight electrons in the outer shells. The tight bonds make pure silicon non-conducting.
- Phosphorus has five electrons, and when combined, the fifth electron becomes a "free" electron that moves easily within the crystal when a voltage is applied.
- Boron has only three electrons in its outer shell and can bond with only three of surrounding silicon atoms. Thus one silicon atom has a vacant location in its outer shell, called a "hole," that readily accepts an electron.





# pn junction diode

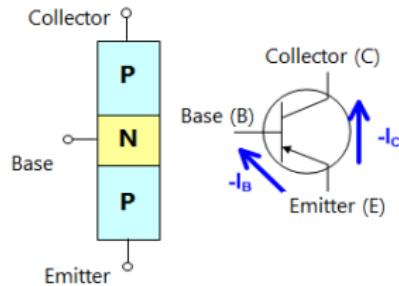
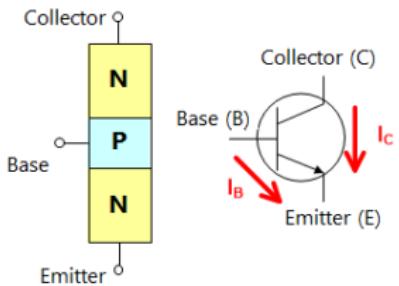
- When p-type and n-type semiconductors are bonded, holes and free electrons are attracted, combine, and disappear near the boundary. Since there are no carriers in this area, it is called a depletion layer and it is an insulator.
- A positive voltage applied to the p-type region causes electrons to flow sequentially from the n-type. The electrons will first disappear by combining with holes, but excess electrons move to the positive pole and current will flow.





# Bipolar Junction Transistor

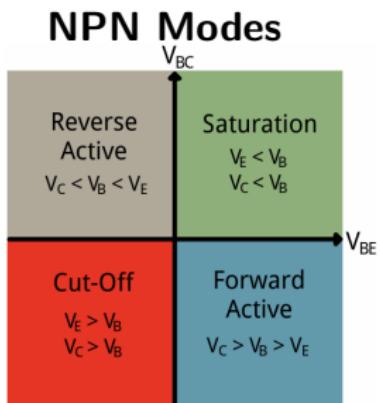
The transistor has three regions, namely base, emitter and collector. The emitter is a heavily doped terminal and emits electrons into the base. Base terminal is lightly doped and passes the emitter-injected electrons on to the collector. The collector terminal is intermediately doped and collects electrons from base. This collector is large as compared with other two regions so it dissipates more heat.





# Bipolar Junction Transistor - Modes of Operation

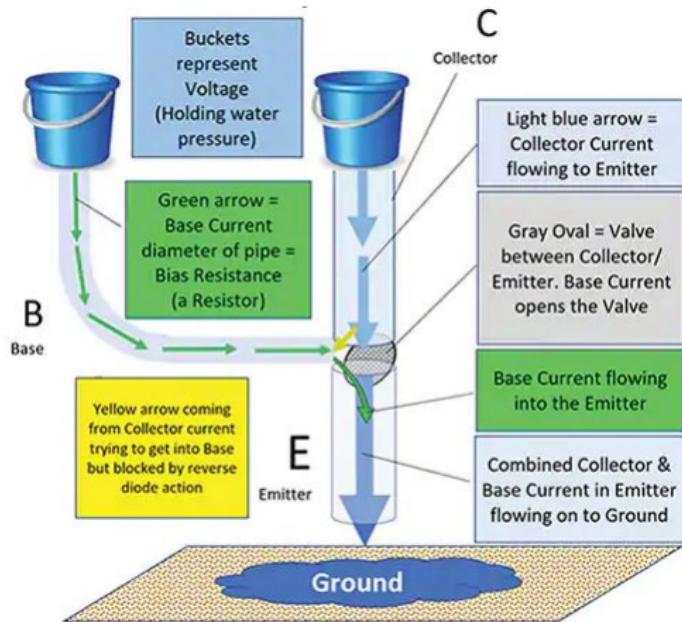
- **Saturation:** Current freely flows from collector to emitter. (ON Switch)
- **Cut-off:** No current flows from collector to emitter. (OFF Switch)
- **Active:** The current from collector to emitter is proportional to the current flowing into the base. (Amplifier)
- **Reverse-Active:** Like active mode, the current is proportional to the base current, but it flows reverse from emitter to collector (not the purpose transistors were designed for).



Voltage relations	NPN Mode	PNP Mode
V <sub>e</sub> < V <sub>b</sub> < V <sub>c</sub>	Active	Reverse
V <sub>e</sub> < V <sub>b</sub> > V <sub>c</sub>	Saturation	Cutoff
V <sub>e</sub> > V <sub>b</sub> < V <sub>c</sub>	Cutoff	Saturation
V <sub>e</sub> > V <sub>b</sub> > V <sub>c</sub>	Reverse	Active



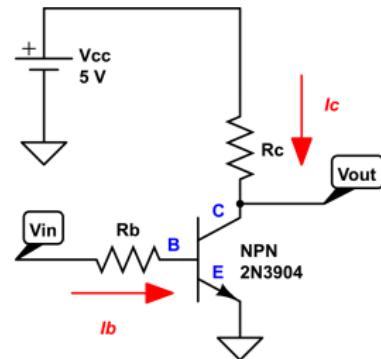
# Water Analogy





# Active Mode NPN Transistor Circuit

If you apply a voltage  $V_{IN}$  that is high enough to forward-bias the base-to-emitter junction, current ( $I_B$ ) will flow from the input terminal, through  $R_B$ , through the BE junction, to ground. Current ( $I_C$ ) will also flow through  $R_C$  and the collector-to-emitter portion of the transistor.



**NOTE:**  $V_{OUT}$  is an amplified but inverted signal of  $V_{IN}$ .

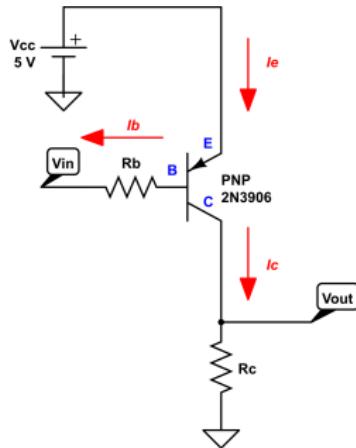
This simple circuit will step-up a 0 - 3.3V output from the microcontroller to 0 - 5.0V (inverted). The low impedance of the output will also provide sufficient current to drive a higher current device (e.g., a relay).



# PNP Transistor

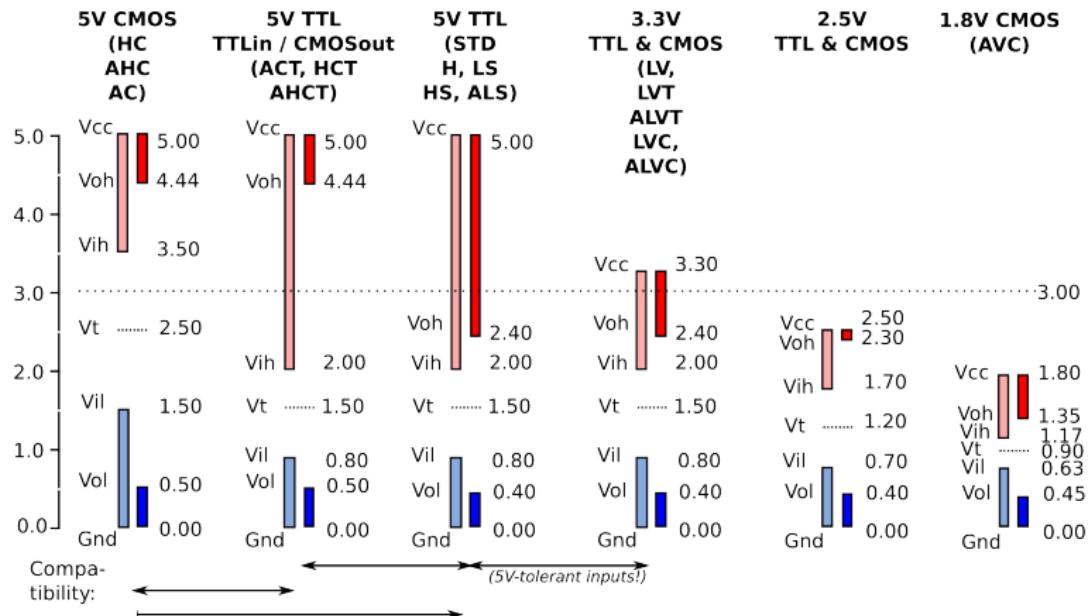
NPN Transistors are more common than PNP for a number of reasons:

- The voltage and current behavior of an NPN transistor is significantly more intuitive.
- When a switch or driver circuit is required, NPNs provide a more straightforward interface to digital output signals (such as a control signal generated by a microcontroller).
- NPNs are higher performance (faster switching speeds) due to higher mobility of electrons vs holes.





# Logic Voltage Level Standards



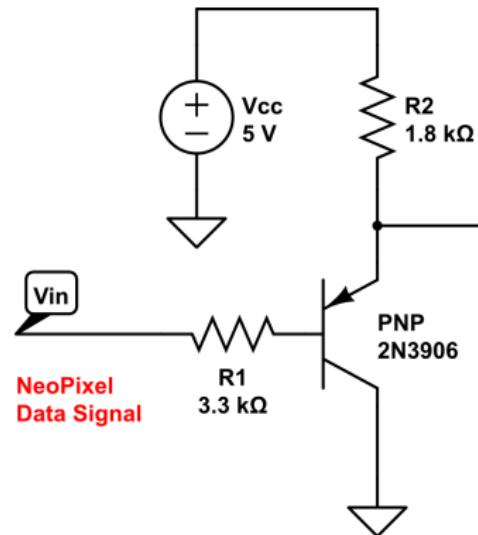
Data source: EETimes, A brief recap of popular logic standards (Mark Pearson, Maxim).

Or, what is wrong with the NeoPixels.



# Emitter Follower

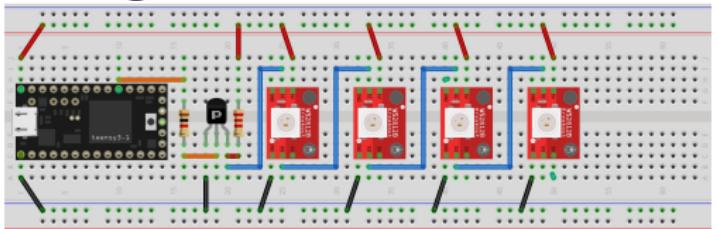
- NeoPixels are designed around 5V CMOS transistors
  - $V_{IH} > 3.5V$
  - 3.3V Microcontroller
  - $V_{OH} = 3.3V$
- An Emitter Follower (i.e., a PNP transistor wired backwards) is a current amplifier, but will also produce a  $V_{OUT} = 3.9V$ .
- Alternatively, the first NeoPixel could be sacrificed by reducing its  $V_{cc}$  to 4.3V with a diode.





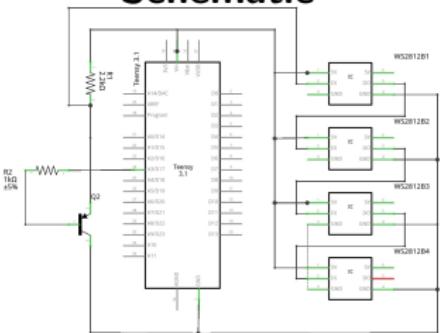
# Emitter Follower Layout

## Fritzing



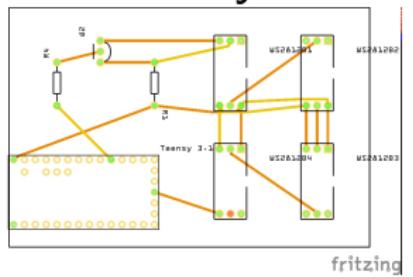
fritzing

## Schematic



fritzing

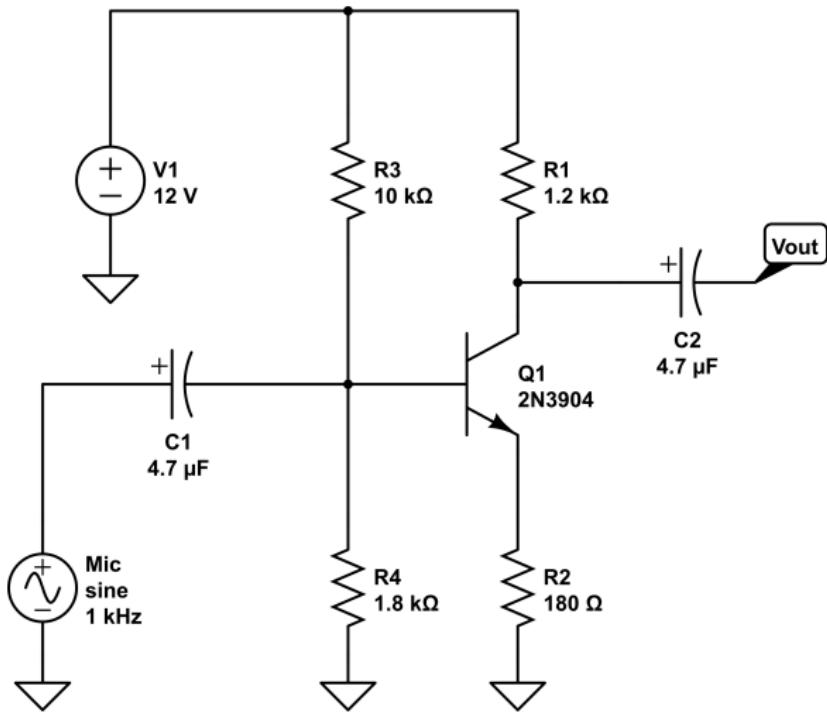
## PCB Layout



fritzing

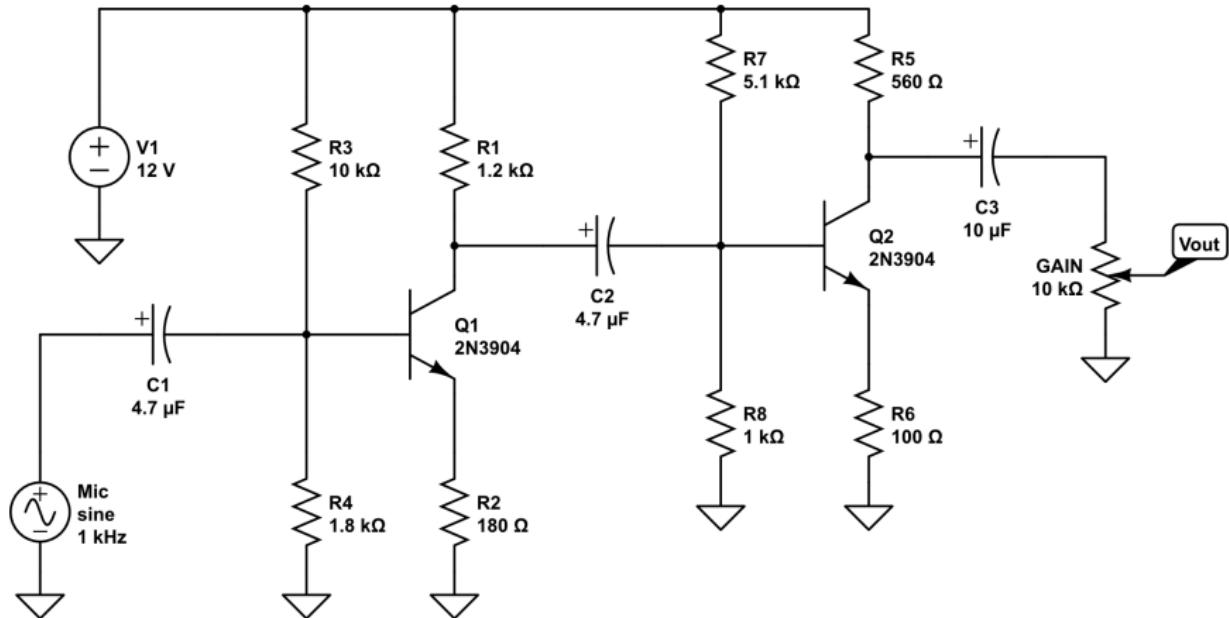


# NPN Pre-Amplifier Circuit



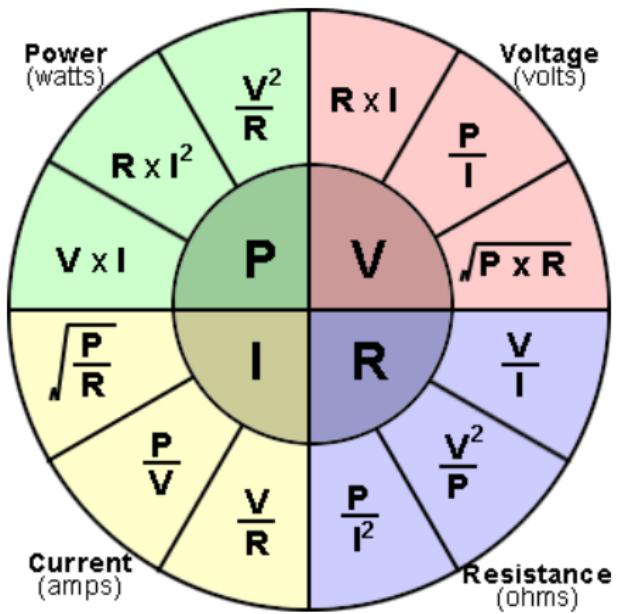


# Two Stage Pre-Amplifier





# Ohm's Law - Revisited





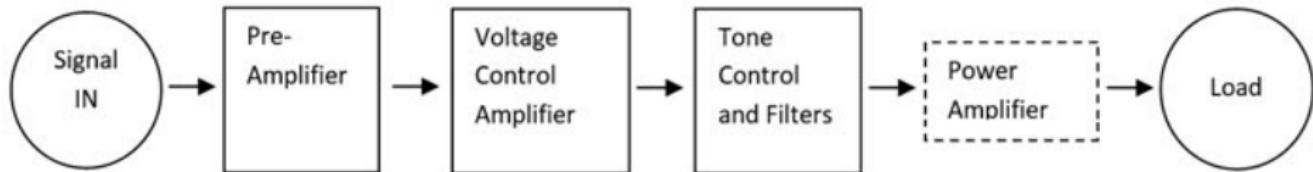
# PreAmp vs PowerAmp

PreAmp:

- A preamp boosts the signal up to 'line level'.
- Guitar PreAmp
  - A pure guitar signal typically sounds weak and anaemic, as is seen if a guitar is directly plugged PA system.
  - A preamp is able to raise a guitar's signal up to an audible volume.
  - It can also be used to affect the audio characteristics.

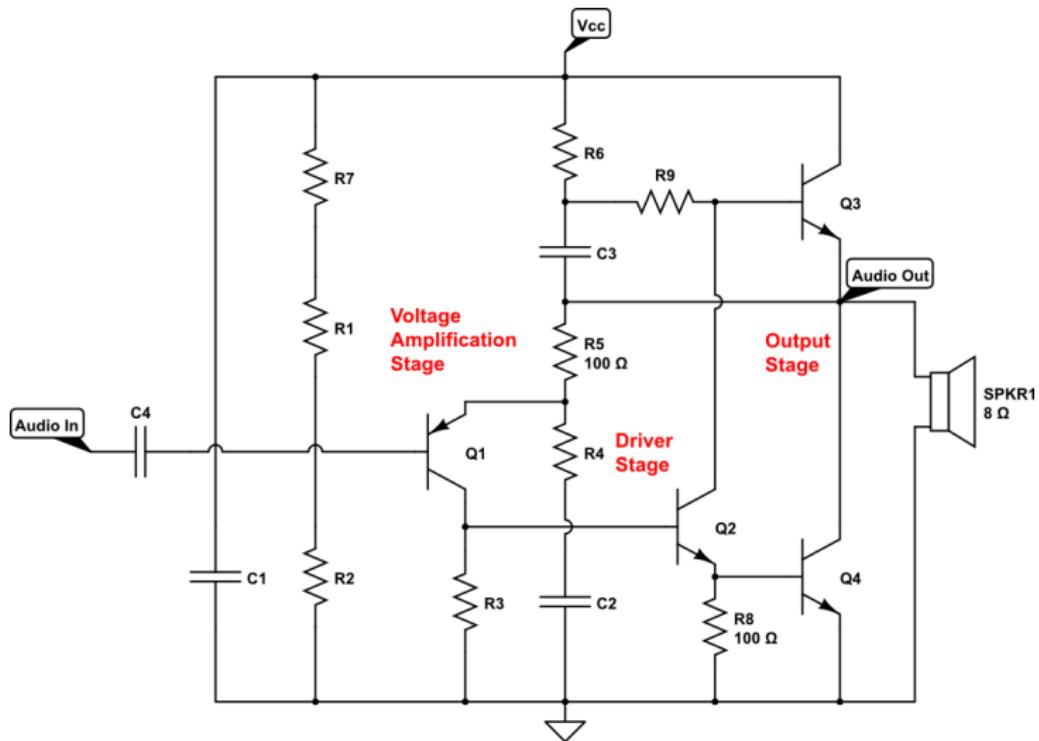
PowerAmp:

- A power amp boosts that line level signal even more – so that it can be projected through speakers.





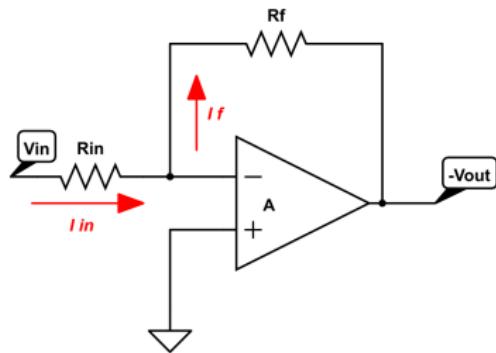
# Power Amplifier



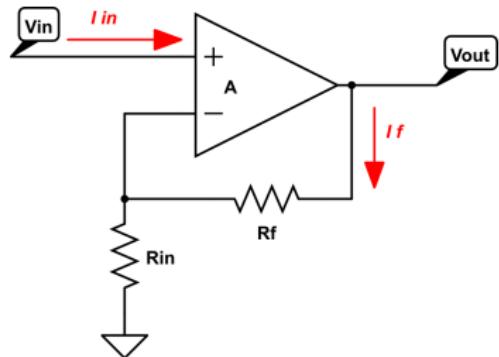


# Op Amp Lesson

Inverting Op Amp



Non-inverting Op Amp

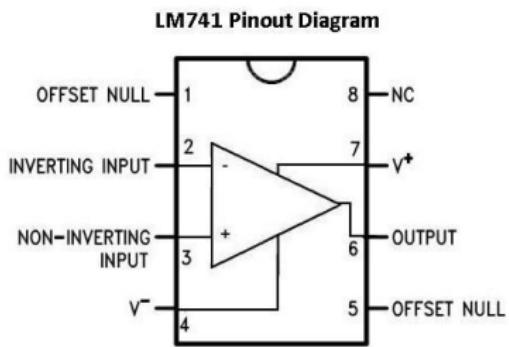


$$A = \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$$

$$A = \frac{V_{out}}{V_{in}} = 1 + \frac{R_f}{R_{in}}$$



# Assignment: Amplifiers



## ① L13\_01\_NeoPixel

- Add a Emitter-Follower into your NeoPixel circuit to boost the pixel commands to 5V.

## ② L13\_02\_NPNAmp (no Teensy)

- Make NPN Preamp
- Test your NPN Preamp with the signal generator and oscilloscope.

## ③ L13\_03\_OpAmp

- Create a preamp using your LM741 OpAmp

# L14\_PlantWatering



# More DataTypes - Strings, strings, and char[]

```
1 // A string is an array of characters
2 char firstName[6];
3 char *name = {"B", "R", "I", "A", "N"}; //The "*" indicates a pointer
4 char *myName = "BRIAN"; //We will learn pointers later
5
6 // A String is a Class that holds a character array
7 String instructor = "BRIAN RASHAP";
8
9
10 // Because String is a Class it has methods
11 instructorName.substring(0,4);
12 instructorName.toCharArray(firstName,5);
13
14 // Using Serial.print and strings
15 // The %s in formatted print inserts an array of char
16 Serial.println(instructorName);
17 Serial.printf("My name is %s \n",firstname);
```

To learn more about the String Class: <https://www.arduino.cc/reference/en/language/variables/data-types/stringobject/>



# Too Much Time On My Hands

When the Particle Argon connects to the Particle Cloud, it synchronizes its clock to the current time.

```
1 // Declare Global Variables in Header
2 String DateTime, TimeOnly;
3 char currentDateDateTime[25], currentTime[9];
4
5 void setup() {
6     Time.zone(-7);           // MST = -7, MDT = -6
7     Particle.syncTime();    // Sync time with Particle Cloud
8 }
9
10 void loop() {
11     DateTime = Time.timeStr();           //Current Date and Time from Particle Time class
12     TimeOnly = DateTime.substring(11,19); //Extract the Time from the DateTime String
13
14     // Convert String to char arrays - this is needed for formatted print
15     DateTime.toCharArray(currentDateTime,25);
16     TimeOnly.toCharArray(currentTime,9);
17
18     //Print using formatted print
19     Serial.printf("Date and time is %s\n",currentDateTime);
20     Serial.printf("Time is %s\n",currentTime);
21
22     delay(10000); //only loop every 10 seconds
23 }
```

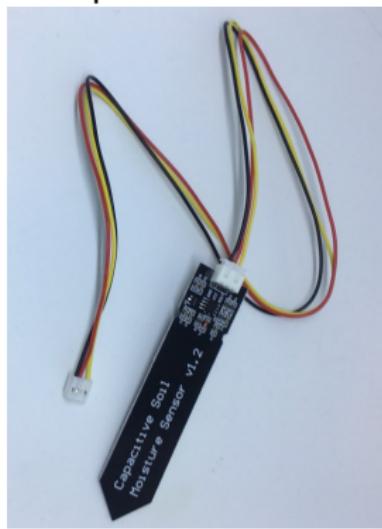


# Soil Moisture Sensors

Resistive Sensor

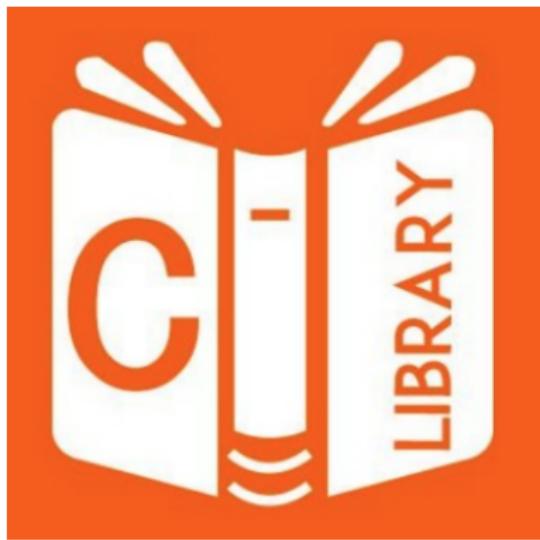


Capacitive Sensor





# Installing Libraries



Using the Command Palette within VSCode:

- `ctrl-shift-p` → Particle: Find Libraries
- `ctrl-shift-p` → Particle: Install Library



# Assignment: L14\_SoilMoisture



## ① L14\_01\_OLED

- Install the Adafruit\_SSD1306 library
- Use I2C\_Scan to get the OLED I2C address
- Create sample code displaying your name and time to the OLED

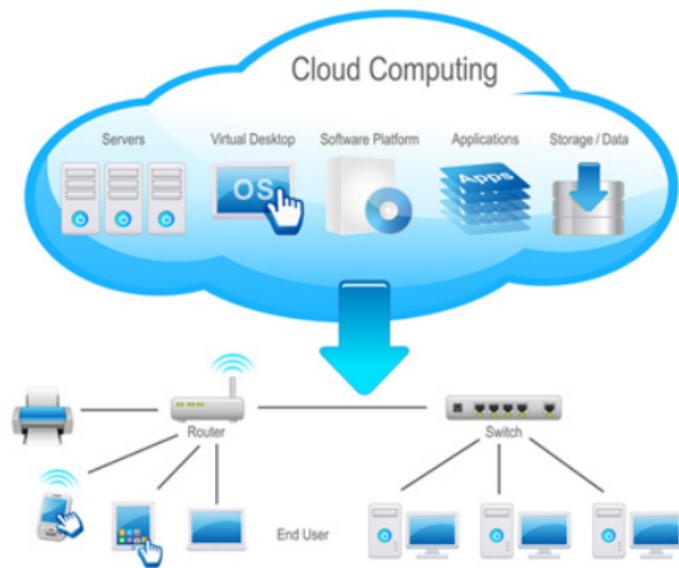
## ② L14\_02\_Moisture

- Using the Capacitive Soil Moisture probe. In your notebook note the moisture readings when:
  - Empty Cup
  - Submerged in water to the notch
  - Dry Soil
  - Soil after watered
- Display the moisture to the OLED with a Time-stamp

- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code



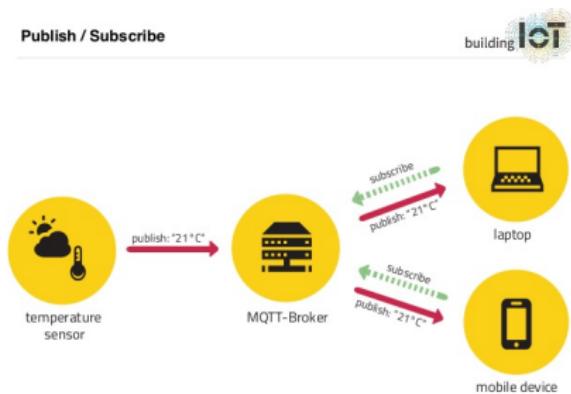
# The Cloud



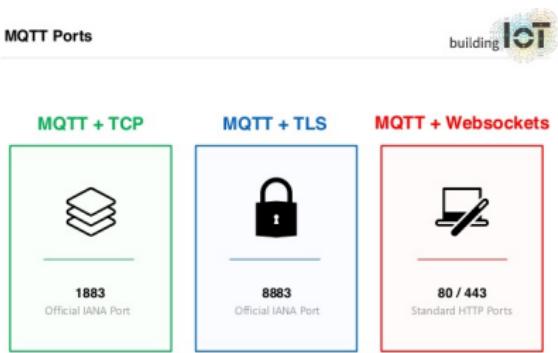


# MQTT: MQ Telemetry Transport

Publish / Subscribe

building **ICT**

MQTT Ports

building **ICT**



# Adafruit.io



## Let's create an Adafruit.io account

**Get Started**

**FREE**  
forever

30 data points per minute  
30 days of data storage  
Triggers every 15 minutes  
5 feed limit

[Sign Up Now](#)

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**\$10 or \$99**  
per month      per year

60 data points per minute  
60 days of data storage  
Triggers every 5 seconds  
Unlimited feeds

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# MQTT Elements explained

- TheClient - object that defines the TCP (Transmission Control Protocol) connection over WiFi.
- mqtt - object that defines the MQTT connection using the WiFi object, the MQTT server/port, and user name/password.
- FeedName - a "variable" located on Adafruit.io that can be subscribed or published to. There can be many of these.
- mqttObj - object that will be used in the C++ code that will be used to publish or subscribe to an Adafruit.io feed. There needs to be one object for each feed.
- value - Variable in the C++ code that stores information to be published or to receive information from a feed that is subscribed to.

NOTE: FeedName, mqttObj, and value should be given descriptive "names" similar to the naming convention for all variables and objects in the C++ code.



# MQTT Elements in VSCode

```
1 #include <Adafruit_MQTT.h>
2
3 #include "Adafruit_MQTT/Adafruit_MQTT.h"
4 #include "Adafruit_MQTT/Adafruit_MQTT_SPARK.h"
5 #include "Adafruit_MQTT/Adafruit_MQTT.h"
6
7 /***** Global State (you don't need to change this!) *****/
8 TCPClient TheClient;
9
10 /***** Adafruit.io Setup *****/
11 #define AIO_SERVER      "io.adafruit.com"
12 #define AIO_SERVERPORT  1883           // use 8883 for SSL
13 #define AIO_USERNAME    "<username>"
14 #define AIO_KEY         "<key>"
15
16 // Setup the MQTT client class with the WiFi client, MQTT server and login details.
17 Adafruit_MQTT_SPARK mqtt(&TheClient,AIO_SERVER,AIO_SERVERPORT,AIO_USERNAME,AIO_KEY);
18
19 /***** Feeds *****/
20 // Setup Feeds to publish or subscribe
21 // Notice MQTT paths for AIO follow the form: <username>/feeds/<feedname>
22 Adafruit_MQTT_Subscribe mqttObj1 = Adafruit_MQTT_Subscribe(&mqtt, AIO_USERNAME "/feeds/
   FeedNameA");
23 Adafruit_MQTT_Publish mqttObj2 = Adafruit_MQTT_Publish(&mqtt, AIO_USERNAME "/feeds/
   FeedNameB");
24
25 /*****Declare Variables*****/
26 float value1;    //variable that will hold data received from adafruit.io feed
27 float value2;    //variable that will hold data to be published to adafruit.io feed
```

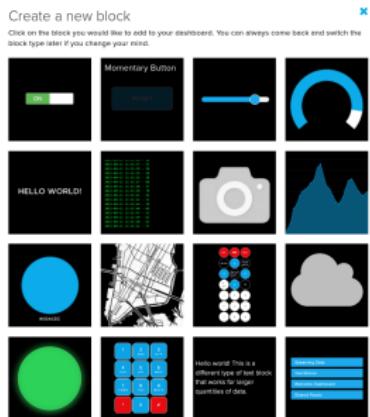


# MQTT Publish and Subscribe

```
1 // Publishing to a MQTT feed
2 if(mqtt.Update()) {    //if mqtt object (Adafruit.io) is available to receive data
3     Serial.printf("Publishing %0.2f to Adafruit.io feed FeedNameB \n",value2);
4     mqttObj2.publish(value2);
5 }
6
7
8 // Two new functions that will be useful
9 // atof() - ASCII to Float: converts an ASCII string to a floating point number
10 // atoi() - ASCII to Integer: converts an ASCII string to an integer
11
12
13 // Receive data from a subscription to an MQTT feed
14 Adafruit_MQTT_Subscribe *subscription;
15 while ((subscription = mqtt.readSubscription(10000))) { //wait 10 sec for new feed data
16     if (subscription == &mqttObj1) {          // assign new data to appropriate variable
17         value1 = atof((char *)mqttObj1.lastread); //value1 equals data from MQTT subscription
18         Serial.printf("Received %0.2f from Adafruit.io feed FeedNameA \n",value1);
19     }
20 }
```



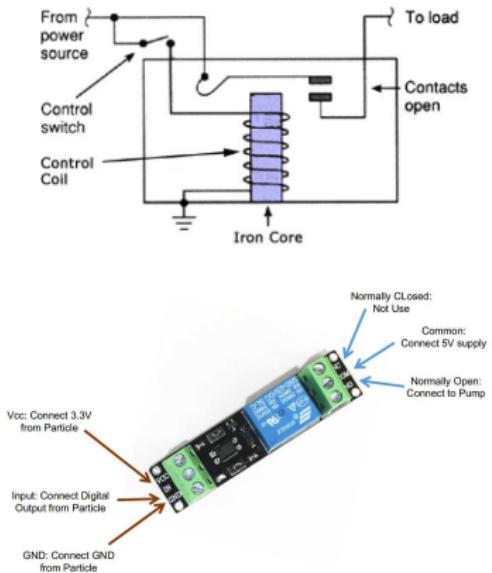
# Assignment: L14\_03\_SubscribePublish



- ① Modify the starter code for your Adafruit.io dashboard and connect it to a feed called buttonOnOff
- ② Subscribe
  - Add a button to your Adafruit.io dashboard and connect it to a feed called buttonOnOff
  - Subscribe to the buttonOnOff and turn on the on board LED when pressed.
- ③ Publish
  - Publishing a random number to a feed once per minute (do not use a delay).
  - Create a line chart on your dashboard to display the random number.
- ④ Experiment with other blocks
  - Replace the button with a slider.
  - Control the brightness of an LED
  - Display data with other dashboard blocks.



# Relays

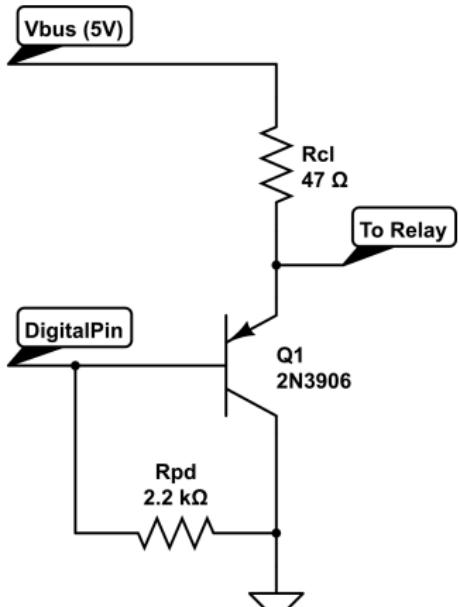


- When a device (e.g. a pump) requires higher voltage ( $> 5V$ ) or higher current, then a relay can be used as a switch for the device
- The relay is activated by a digital pin from the microcontroller.
- However, as the relay requires 100mA from the digital pin, we will use a transistor switch to draw power directly from the USB connection.

# Midterm 1 - Plant Watering System



# Assignment: L14\_04\_PlantWater

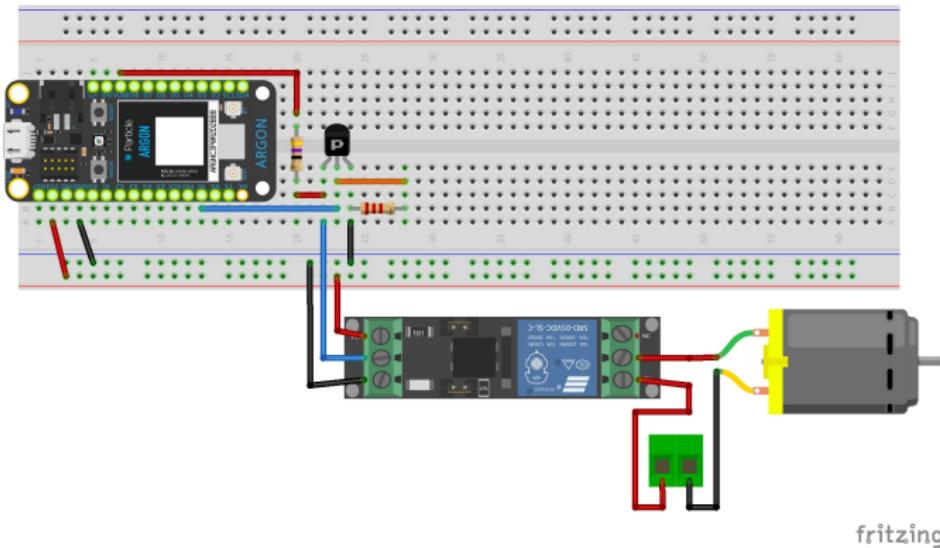


PNP Emitter Follower

- ① Integrate an 2N3906 Emitter Follower and Relay, as well as a BME280 and Display.
- ② Publish soil moisture and room environmental data to a new dashboard
- ③ Automatically water your plant when the soil is too dry
  - Only turn on the pump for a very short period of time ( $\frac{1}{2}$  sec).
- ④ Integrate a button into your dashboard that manually waters the plant.

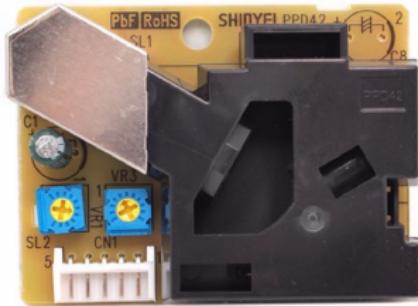


# Relay and Pump Fritizing Diagram





# Seeed Sensors



Seeed Grove - Dust Sensor



Seeed Grove - Air Quality  
Sensor v1.3



## Assignment: More L14

- ① L14\_04\_PlantWater (revisted): Integrate into your Plant Water project both Seeed sensors.
  - Look up the Seeed sensors online to see how they work.
  - Do not blindly copy the examples, only use the code you need.
  - By looking at the .cpp code, determine how to get a quantitative value for air quality, in addition to the qualitative level.
- ② Include Hackster.io story



# Using Zapier



Zapier is an online automation tool that connects your favorite apps, such as Outlook, Slack, Mailchimp, and more. You can connect two or more apps to automate repetitive tasks.



# Optional Assignment: L14\_04\_PlantWater



```
Adafruit_MQTT_Subscribe *subscription;
while ((subscription = mqtt.readSubscription(10000))) {
    if (subscription == &gotmail) {
        Serial.printf("You Got Mail \n");
        digitalWrite(D7, HIGH);
        flagServo.write(90);
        delay(10000);
        digitalWrite(D7, LOW);
        flagServo.write(5);
    }
}
```

- ① Use the Zapier instructions in Class\_Slides to light up your D7 LED when new mail arrives in your cnm.edu outlook account.
- ② Add to your L14\_04\_PlantWater project to send you an SMS text whenever your soil is too dry. In Zapier:
  - Create Feed Trigger from Adafruit.io
  - Add a "Only Continue If..."
  - Add a Send to SMS action

# L15\_BEI - Binary, EEPROM, and Interrupts



# Counting Sheep





# Negative Numbers

Question: How are negative numbers represented in binary?

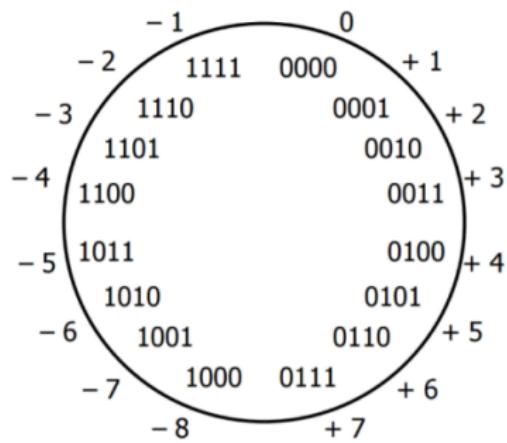
Type	Storage size	Value range
char	1 byte	-128 to 127 or 0 to 255
unsigned char	1 byte	0 to 255
signed char	1 byte	-128 to 127
int	2 or 4 bytes	-32,768 to 32,767 or -2,147,483,648 to 2,147,483,647
unsigned int	2 or 4 bytes	0 to 65,535 or 0 to 4,294,967,295
short	2 bytes	-32,768 to 32,767
unsigned short	2 bytes	0 to 65,535
long	4 bytes	-2,147,483,648 to 2,147,483,647
unsigned long	4 bytes	0 to 4,294,967,295

Answer: Left-most bit is 1 to signify negative. But wait...



## 2's Compliment

2's compliment is used as it makes the math consistent.



Integer		2's Complement
Signed	Unsigned	
5	5	0000 0101
4	4	0000 0100
3	3	0000 0011
2	2	0000 0010
1	1	0000 0001
0	0	0000 0000
-1	255	1111 1111
-2	254	1111 1110
-3	253	1111 1101
-4	252	1111 1100
-5	251	1111 1011

The negative plus the positive equals zero.



# Bitwise Operations

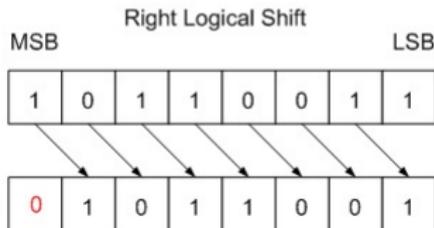
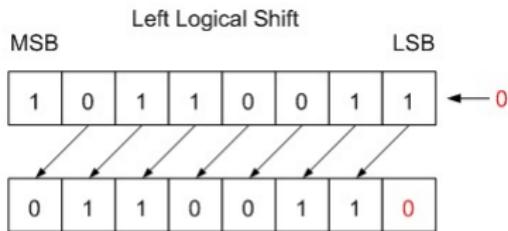
The following table lists the Bitwise operators supported by C. Assume variable 'A' holds 60 and variable 'B' holds 13, then –

Operator	Description	Example
&	Binary AND Operator copies a bit to the result if it exists in both operands.	$(A \& B) = 12$ , i.e., 0000 1100
	Binary OR Operator copies a bit if it exists in either operand.	$(A   B) = 61$ , i.e., 0011 1101
^	Binary XOR Operator copies the bit if it is set in one operand but not both.	$(A ^ B) = 49$ , i.e., 0011 0001
~	Binary One's Complement Operator is unary and has the effect of 'flipping' bits.	$(\sim A) = \sim(60)$ , i.e., 1100 0011
<<	Binary Left Shift Operator. The left operand's value is moved left by the number of bits specified by the right operand.	$A << 2 = 240$ i.e., 1111 0000
>>	Binary Right Shift Operator. The left operand's value is moved right by the number of bits specified by the right operand.	$A >> 2 = 15$ i.e., 0000 1111

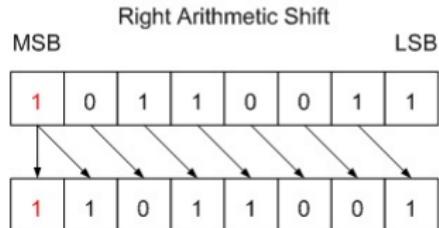
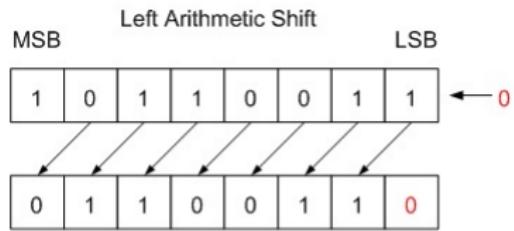


# Bit Shifting

## Logical Bit Shift

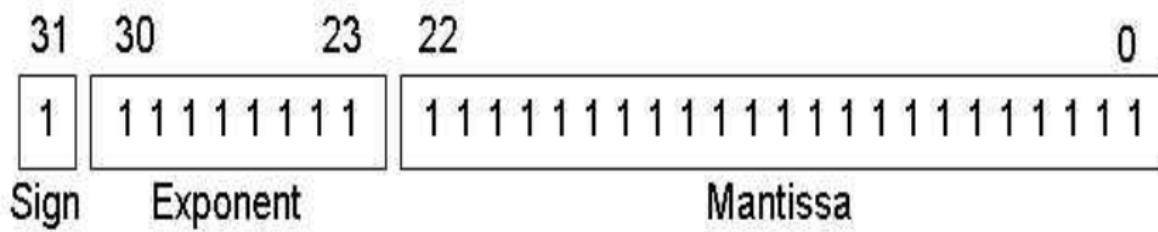


## Arithmetic Bit Shift





## BONUS: But what about Floating Point



Example:

$$-36382.366 = -3.6382366 \times 10^4 = 1000001011101111000010001011110$$



# Electrically Erasable Programmable Read Only Memory

EEPROM emulation allows small amounts of data to be stored and persisted even across reset, power down, and user and system firmware flash operations. Since the data is spread across a large number of flash sectors, flash erase-write cycle limits should not be an issue in general.

```
1 len = EEPROM.length(); //available EEPROM bytes
2 // Argons have 4096 bytes of emulated EEPROM.
3 // Addresses 0x0000 through 0xFFFF
4
5 addr = 0x00AE;      //addr between 0 and len-1
6
7 val = 0x45;
8 EEPROM.write(addr, val);
9
10 value = EEPROM.read(addr);
```



# Interrupts

Interrupts are a way to write code that is run when an external event occurs. As a general rule, interrupt code should be very fast, and non-blocking. This means performing transfers, such as I2C, Serial, TCP should not be done as part of the interrupt handler. Rather, the interrupt handler can set a variable which instructs the main loop that the event has occurred.

```
1 attachInterrupt(pin, function, mode);
```

Mode: defines when the interrupt should be triggered. Three constants are predefined as valid values:

- CHANGE to trigger the interrupt whenever the pin changes value,
- RISING to trigger when the pin goes from low to high,
- FALLING for when the pin goes from high to low.



## RandomSeed()

- The "pseudo" in pseudo-random refers it not truly being random.
- randomSeed() initializes the pseudo-random number generator, causing it to start at an arbitrary point in its random sequence. This sequence, while very long, and while appearing random, is always the same.
- If it is important for a sequence of values generated by random() to differ, on subsequent executions, use randomSeed() to initialize the random number generator with a fairly random input, such as analogRead() on an unconnected pin.

```
1 // Leave an Analog Input (A0) floating
2 pinMode(A0, INPUT);
3 randomSeed(analogRead(A0));
4
5 // print a random number hex color value
6 randNumber = random(0x0000,0xFFFFFFF);
7 Serial.println(randNumber);
```



# L15.BEI Assignments

## ① L15\_01\_ConvertStore

- Convert random hex color into R, G, and B components using Bit Shifting and Bitwise AND.
  - First sketch out how this might be done in your lab notebook. Show to instructor.
  - Then, and only then, write the code.
- Store the components of the color as bytes in the Argon's EEPROM

## ② L15\_02\_RetrieveShow

- Retrieve the color from EEPROM memory
- Convert to Hex code
- Display color in NeoPixel.

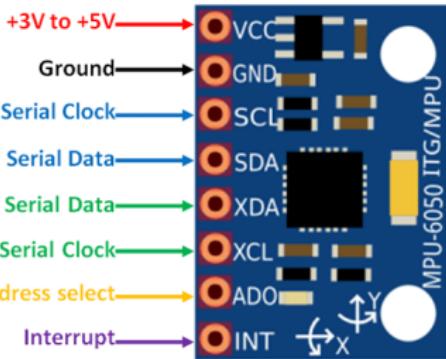
## ③ L15\_03\_Interrupt Create an interrupt Stop Button

- Add a button to your Argon
- Using delays, blink your NeoPixel GREEN (once per second)
- Using an Interrupt, when the button is pressed, the NeoPixel turns to rapidly flashing RED.

# L16\_Motion



# MPU6050 Accelerometer

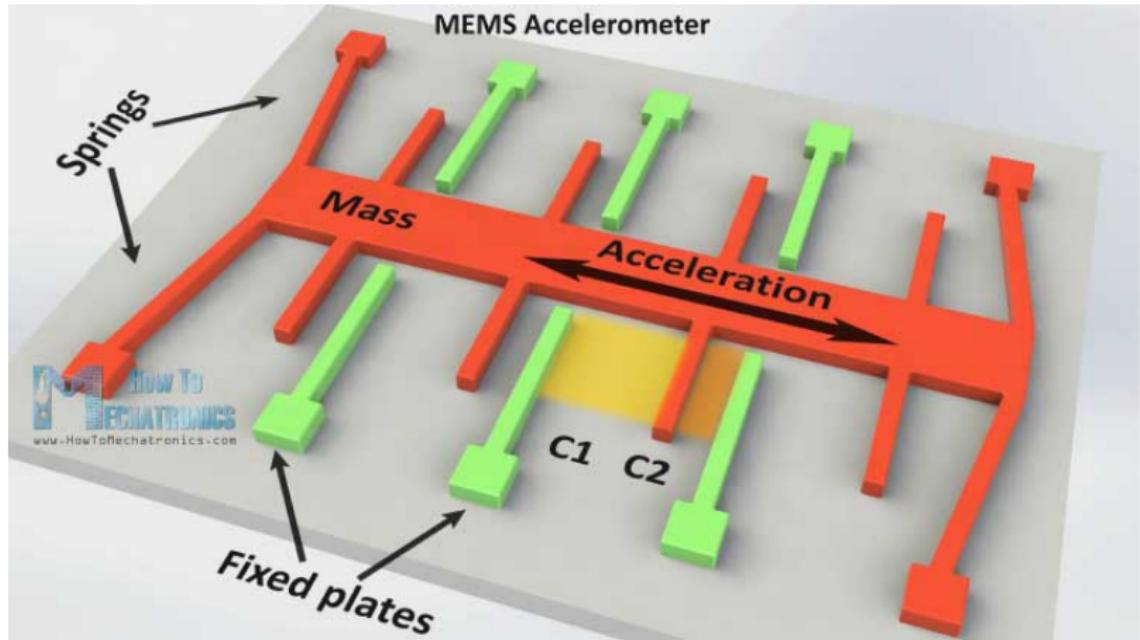


- Data Output - 16 Bit
- Gyros range:  $\pm 250 \ 500 \ 1000 \ 2000 \text{ } ^\circ/\text{s}$
- Accel range:  $\pm 2 \pm 4 \pm 8 \pm 16\text{g}$

- The interrupt pin lets the MPU be notified about available data. To reduce power consumption the processor can go into sleep mode, the interrupt can be used as a wake up.
- XDA and XCL refer to the I2C bus that the MPU-6050 controls, so it can read from slave devices such as magnetometers etc.

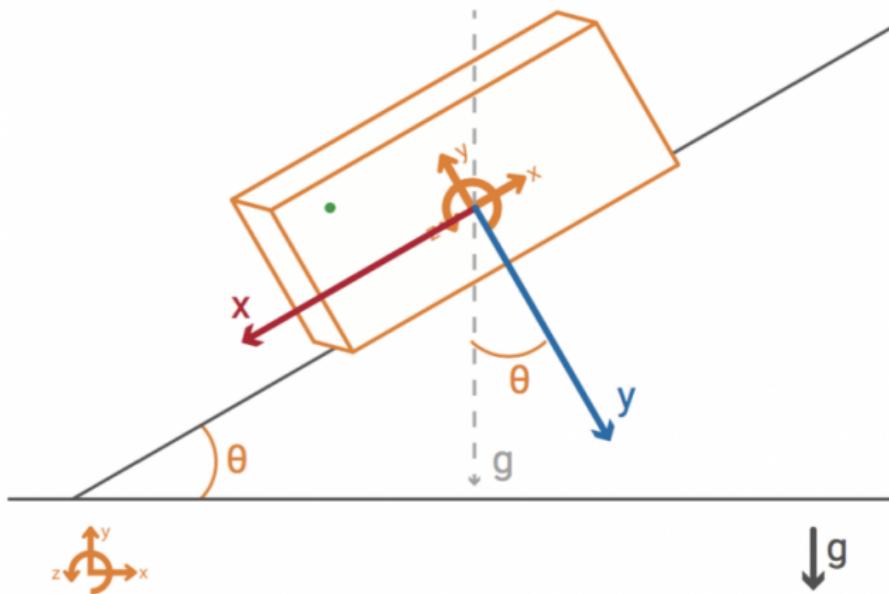


# Accelerometers





# Gravity and Orientation



$$a_y = g * \cos(\theta)$$



# REMINDER - Data Types: Numbers

Data Type	8-bit AVR systems (Arduino Uno)				32-bit ARM systems (Teensy 3.2)		
	bytes	range (signed)	range (unsigned)	bytes	range (signed)	range (unsigned)	
char	1	-128 to 127	0 to 255	1	-128 to 127	0 to 255	
short	2	+/- 32,767	0 to 65,353	2	+/- 32,767	0 to 65,353	
int	2	+/- 32,767	0 to 65,353	4	+/- 2,147,483,648	0 - 4,294,967,295	
long	4	+/- 2,147,483,648	0 - 4,294,967,295	4	+/- 2,147,483,648	0 - 4,294,967,295	
long long	8	+/- 9,223,372,036,854,770,000	0 to 18,446,744,073,709,551,615	8	+/- 9,223,372,036,854,770,000	0 to 18,446,744,073,709,551,615	
float	4	3.4E +/- 38 (7 digits)	n/a	4	3.4E +/- 38 (7 digits)	n/a	
double	4	3.4E +/- 38 (7 digits)	n/a	8	1.7E +/- 308 (15 digits)	n/a	
long double	8	1.7E +/- 308 (15 digits)	n/a	8	1.7E +/- 308 (15 digits)	n/a	
Unambiguous							
uint8_t	1	n/a	0 to 255	1	n/a	0 to 255	
int8_t	1	-128 to 127	n/a	1	-128 to 127	n/a	
uint16_t	2	n/a	0 to 65,353	2	n/a	0 to 65,353	
int16_t	2	+/- 32,767	n/a	2	+/- 32,767	n/a	
uint32_t	4	n/a	0 - 4,294,967,295	4	n/a	0 - 4,294,967,295	
int32_t	4	+/- 2,147,483,648	n/a	4	+/- 2,147,483,648	n/a	

There are  $7.5 \times 10^{18}$  grains of sand on Earth. A long long integer and the floating point numbers are larger than this.



# Initializing MPU6050

```
1 // Initialize the MPU in the void setup()
2 void setup() {
3     // Begin I2C communications
4     Wire.begin();
5
6     // Begin transmission to MPU-6050
7     Wire.beginTransmission(MPU_ADDR);
8
9     // Select and write to PWR_MGMT1 register
10    Wire.write(0x6B);
11    Wire.write(0); // set to 0 (wakes up MPU-6050)
12
13    // End transmission and close connection
14    Wire.endTransmission(true);
15 }
```



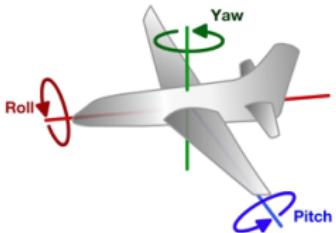
# Reading Acceleration Data from the MPU-6050

```
1 // Declare variables
2 byte accel_x_h, accel_x_l;      //variables to store the individual bytes
3 int16_t accel_x;                //variable to store the x-acceleration
4
5 // Set the "pointer" to the 0x3B memory location of the MPU and wait for data
6 Wire.beginTransmission(MPU_ADDR);
7 Wire.write(0x3B); // starting with register 0x3B
8 Wire.endTransmission(false); // keep active.
9
10 // Request and then read 2 bytes
11 // Syntax:
12 //    Wire.requestFrom(I2C_addr, quantity, stop);
13 //    Wire.read(); //repeat this for each byte to be read
14
15 Wire.requestFrom(MPU_ADDR, 2, true);
16 accel_x_h = Wire.read(); // x accel MSB
17 accel_x_l = Wire.read(); // x accel LSB
18
19 accel_x = accel_x_h << 8 | accel_x_l;      // what happens if declared int instead?
20 Serial.printf("X-axis acceleration is %i \n",accel_x);
```

Note, the data is stored in Big Endian Byte Order. The most significant byte (the "big end") of the data is placed at the byte with the lowest address. The rest of the data is placed in the next byte.



# Assignment: L16\_Motion



- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

## ① L16\_01\_MP6050

- Read the memory addresses for X, Y, and Z acceleration
- Convert the returned acceleration value to standard gravity units (e.g., when flat on the table,  $a_z = -1G$ ).

## ② L16\_02\_AutoRotate

- Create a Clock on an OLED Display
- Use GY-521 to auto-rotate the OLED

## ③ L16\_03\_Airplane

- Calculate pitch  $\theta = -\arcsin(a_x)$
- Calculate roll  $\phi = \arctan2(a_y / -a_z)$

## ④ L16\_04\_Shock

- Store  $a_{tot}$  in an array every 10ms for 5s
- Find and print the max value
- Repeat



# Pitch and Roll Improved

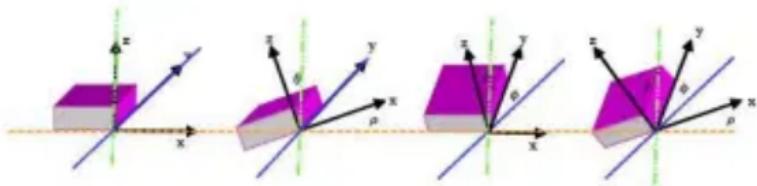


Figure 8. Three Axis for Measuring Tilt

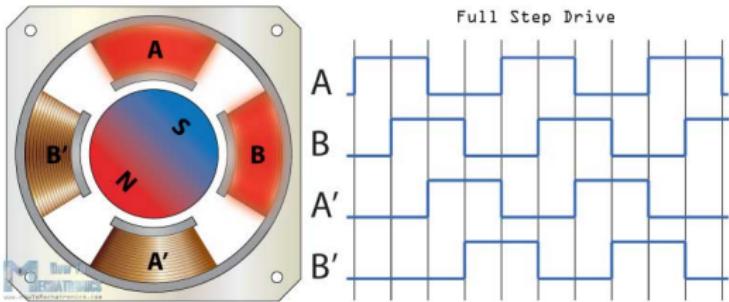
$$\rho = \arctan\left(\frac{A_X}{\sqrt{A_Y^2 + A_Z^2}}\right)$$

$$\phi = \arctan\left(\frac{A_Y}{\sqrt{A_X^2 + A_Z^2}}\right)$$

$$\theta = \arctan\left(\frac{\sqrt{A_X^2 + A_Y^2}}{A_Z}\right)$$



# Stepper Motors



## 28BYJ Stepper Motor

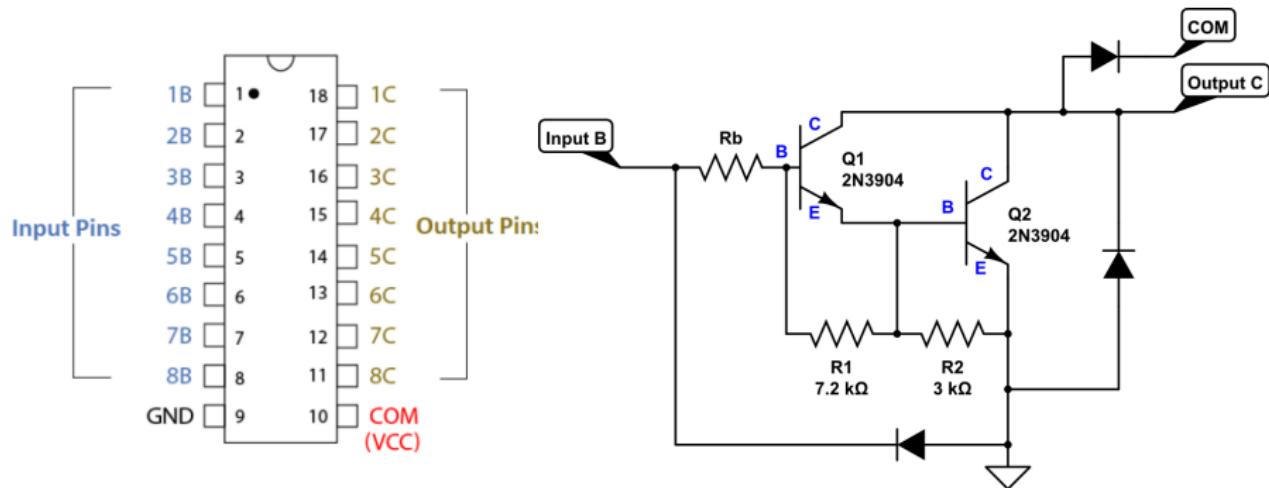
- 2048 steps per revolution
  - 32 steps per rotor revolution
  - Gear ratio 1:64
- Capable of 10-15 RPM (at 5V)
- ULN2003 Darlington Array driver

## Stepper.h

- Stepper myStepper (spr,IN1,IN3,IN2,IN4)
- myStepper.setSpeed(speed)
- myStepper.step(steps)



# ULN2003 Darlington Array



A Darlington Array is a set of current amplifying circuits that take outputs from the microcontroller and boost the current used to drive the motor.



# Assignment: L16\_Motion



- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

## ① L16\_05\_StepperGyro

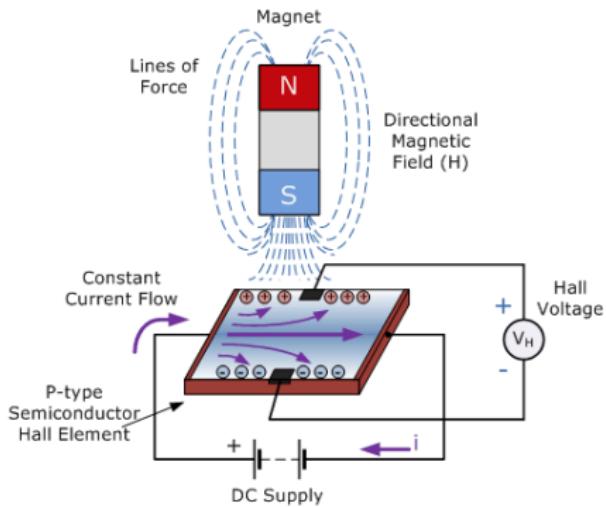
- Wire the Stepper Motor noting the order: IN1, IN3, IN2, IN4
- Move the motor 2 rotations clockwise, pause, 1 rotation counter-clockwise, repeat.

## ② L16\_06\_Gyro

- Connect the GY-521 to your system
- Obtain the z-axis rotation from the appropriate register on the GY-521.
- Map the change in gyro position (signed 16-bit) to one revolution of the Stepper (signed 12-bit)
- Move the stepper the amount of steps corresponding to the mapped gyro change.



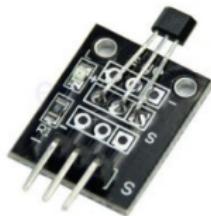
# Hall Effect Sensor



Discovered by Edwin Hall in 1879, the Hall Effect is the production of a voltage difference (the Hall voltage) across an electrical conductor, transverse to an electric current in the conductor and to an applied magnetic field perpendicular to the current.



# Assignment: L16\_Motion



## ① L16\_07\_Alarm

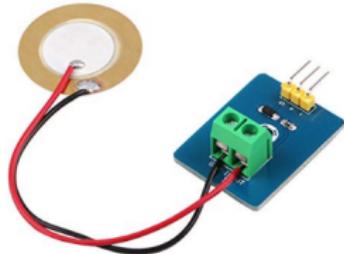
- Connect Hall Effect Sensor, button, and Neopixel
- Use the button to enable / disable alarm
- When armed:
  - Green when magnet detected
  - Blinking Red when magnet not detected

## ② L16\_08\_RPM

- Notebook:  
schematic
- Fritzing diagram
- Wire your circuit
- Write the code
- Place magnet on shaft of Lathe
- Using Hall Sensor, measure time per rotation
- Convert to rotations per minute
- Display on Adafruit.io databoard
- EXTRA: Create a jig to hold the sensor
- EXTRA: Measure RPM on other equipment at FUSE.



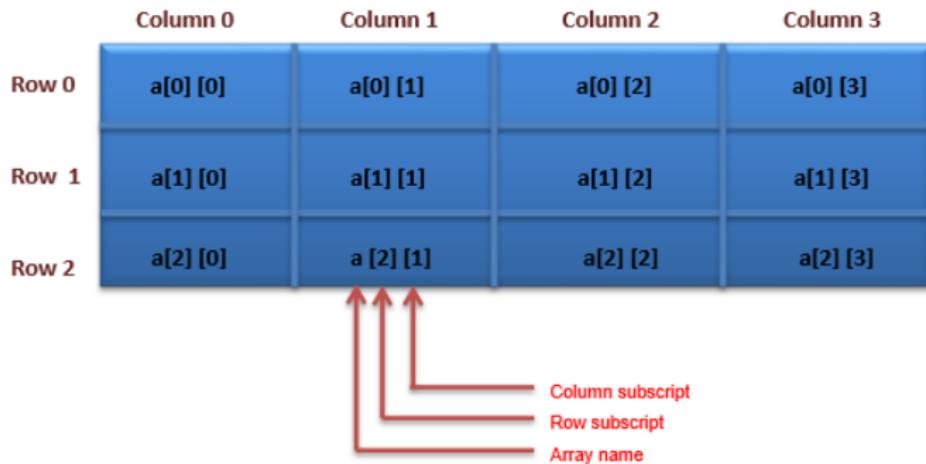
# Piezoelectric Elements



- The piezoelectric effect is the appearance of electrical potential (voltage) across the side of a crystal when subject to mechanical stress.
- Conversely, a crystal becomes mechanically stressed (deformed in shape) when a voltage is applied across opposite faces.
- By utilizing an `analogRead()`, the vibration (change in mechanical stress) can be monitored over time.



## 2-dimensional arrays



- Declare Array: `int a[3][4] = {{0,1,2,3},{4,5,6,7},{8,9,10,11}};`
- Set a Cell: `a[1][2] = 7;`
- Access a Cell: `x = a[0][0];`



# FAT File System - SDCard Argon Project

Feature	FAT32	NTFS
Maximum Partition Size	2TB	2TB
Maximum File Size	4GB	16TB
Maximum File Name	8.3 Characters	255 Characters
File/Folder Encryption	No	Yes
Fault Tolerance	No	Auto Repair
Security	Network Only	Local and Network
Compression	No	Yes
Compatibility	Win 95/98/2000/XP and the derivations	Win NT/2000/XP/Vista/7 and the later versions

The FAT (File Allocation Table) file system, originally designed in 1977 for Floppy Disks, is simple and robust. It offers good performance in very light-weight implementations, but doesn't deliver the performance, reliability and scalability as modern file systems (such as NTFS or exFAT).

Note: FAT file name follows a 8.3 format (e.g., ABCDEFGH.txt). We will be appending two digits, so our base name can be up to 6 characters (e.g. FILE\_BASE\_NAME = "mydata" → mydata42.csv).



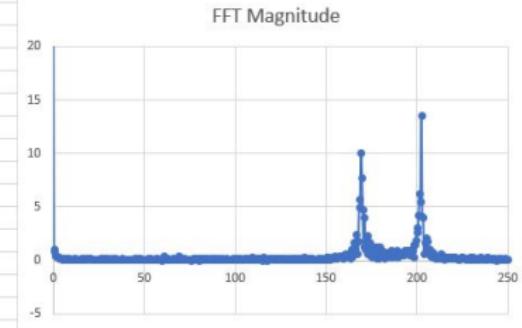
# Galaxy S9+ Vibration Analysis

## Using the FTT Tutorial in Class\_Slides

Time Stamp	Piezo Data	Frequency	FFT Magnitude	Complex FFT
0	0	0	34.01318359	69659
495.795197	0	0.48828	0.834211076	-1688.50727764188+260.371627432835i
495.795776	0	0.97656	0.990540712	1160.28073176531+1664.05458422262i
495.796356	0	1.46484	0.335296983	470.271617580932+500.38517069302i
495.796936	22	1.95312	0.350903895	718.458646378537+16.6339444111701i
495.797516	42	2.4414	0.296405963	-347.540356147162+497.70293053373i
495.798096	45	2.92968	0.188787007	66.5063987685909+380.872856200835i
495.798645	38	3.41796	0.23257935	21.7131959975456+475.827353423851i
495.799255	0	3.90624	0.181340831	-361.737320108222-84.105221575463i
495.799805	0	4.39452	0.219111001	-151.891749008158+422.250971182262i
495.800415	0	4.8828	0.185155013	-343.539789040933+160.533895023591i
495.800964	0	5.37108	0.027207649	3.29352891642554-55.6238447102985i
495.801544	0	5.85936	0.0940408245	168.013999708849+94.1818379444134i
495.802155	0	6.34764	0.107193183	-12.442997448963-219.178721949085i
495.802704	18	6.83592	0.201162273	210.468430396862+354.162160126848i
495.803314	45	7.3242	0.123920667	163.758018048072+193.887687505018i
495.803864	45	7.81248	0.071023469	60.4052139160327-132.320356144062i
495.804474	36	8.30076	0.087211846	89.2879735866281+154.690466161755i

stop = 1/.0005 = 2000

step = 2000/4096 = 0.48828



This particular phone vibrates at a combination of 174 and 202 Hz.



# Assignment: L16\_Motion



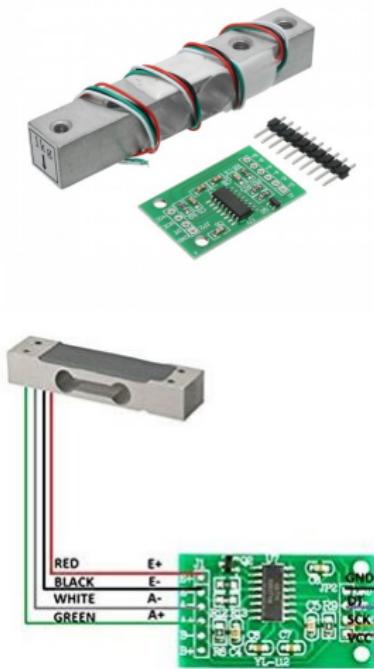
- Notebook:  
schematic
- Fritzing diagram
- Wire your circuit
- Write the code

## ① L16\_09\_Vibration

- Connect the Piezo, a Button, and a  $\mu$ SD module to your Argon
- Executing a loop 4096 times:
  - Every  $500\mu$ sec, collect piezoelectric data (without using a delay)
  - Save the pizeo data and a timestamp (converting `micros()` to seconds) to a 2-dimensional array
- When the loop is complete, write the timestamp and data to a file.
- Collect vibration data from Lathe, cellphone vibration, other machines at FUSE
- Use Excel and the FFT Tutorial (Class\_Slides) to resample graph data in frequency domain (this process will be reviewed as a class).



# Load Cells

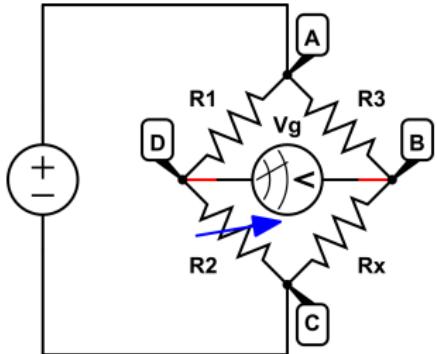


- ① A load cell is a force transducer. It converts a force such as tension, compression, pressure, or torque into an electrical signal that can be measured and standardized. As the force applied to the load cell increases, the electrical signal changes proportionally. The most common types of load cells used are hydraulic, pneumatic, and strain gauge.
- ② HX711 module is a precision 24-bit analog-to-digital converter (ADC) designed for weigh scales and industrial control applications to interface directly with a bridge sensor.



# Wheatstone Bridge

- ① The Wheatstone bridge was invented by Samuel Hunter Christie in 1833 and improved and popularized by Sir Charles Wheatstone in 1843.
- ② A Wheatstone bridge is an electrical circuit used to measure an unknown electrical resistance by balancing two legs of a bridge circuit, one leg of which includes the unknown component.
- ③ The primary benefit of the circuit is its ability to provide extremely accurate measurements (in contrast with something like a simple voltage divider)



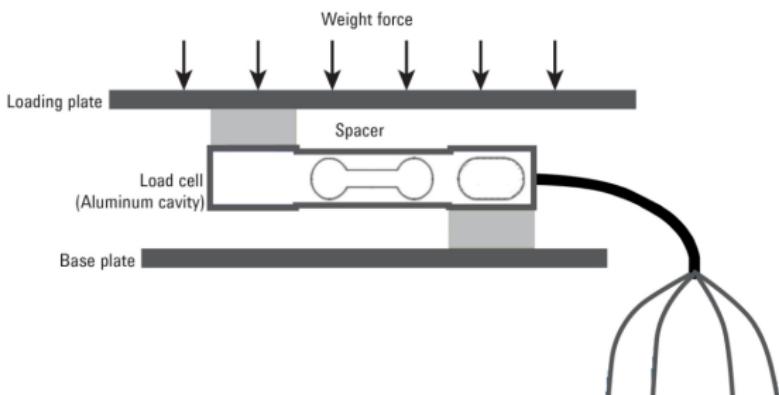


# HX711A Library

```
1 // From the Command Palette install the HX711A library, that will give you HX711.h
2 #include "HX711.h"
3 HX711 myScale(DT,CLK);      // any two digital pins
4
5 const int cal_factor=1000; //changing value changes get_units units (lb, g, ton, etc.)
6 const int samples=10; //number of data points averaged when using get_units or get_value
7
8 float weight, rawData, calibration;
9 int offset;
10
11 void setup() {
12   myScale.set_scale();           // initialize loadcell
13   delay(5000);                 // let the loadcell settle
14   myScale.tare();               // set the tare weight (or zero)
15   myScale.set_scale(cal_factor); //adjust when calibrating scale to desired units
16 }
17
18 void loop() {
19   // Using data from loadcell
20   weight = myScale.get_units(samples); // return weight in units set by set_scale();
21   delay(5000)                         // add a short wait between readings
22
23   // Other useful HX711 methods
24   rawData = myScale.get_value(samples); // returns raw loadcell reading minus offset
25   offset = myScale.get_offset();        // returns the offset set by tare();
26   calibration = myScale.get_scale();    // returns the cal_factor used by set_scale();
27 }
```



# Assignment: L16\_Motion (Learn to Calibrate)



## ① L16\_10\_Scale

- Notebook: schematic
  - Fritzing diagram
  - Wire your circuit
  - Write the code
- Set initial cal\_factor to 1000 and measure calibration\_weight
  - Revise cal\_factor to get proper measurement in grams
  - Post data to Adafruit.io (once / min)
  - Optional: Send text via IFTTT



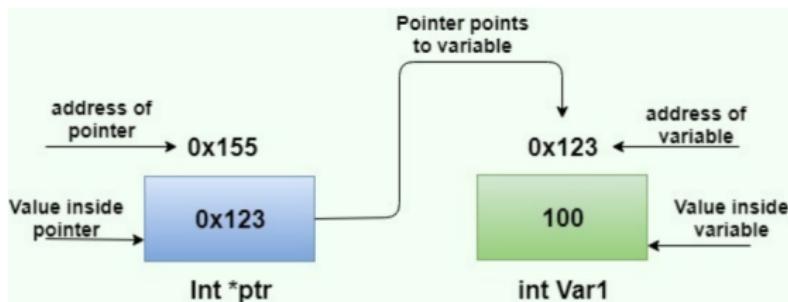
# IFTTT



If This Then That, also known as IFTTT, is a freeware web-based service that creates chains of simple conditional statements, called applets. An applet is triggered by changes that occur within other web services such as Gmail, Facebook, Telegram, Instagram, or Pinterest.



# Pointers



- ① A pointer is a variable whose value is the address of another variable.
- ② When you declare a pointer, the \* symbol denotes that this variable is a pointer variable. For example:
  - Pointer to an Integer: `int *ptr;`
- ③ Reference operator (&) gives the address of a variable.
- ④ To get the value stored in the memory address, we use the dereference operator (\*).



# Pointers

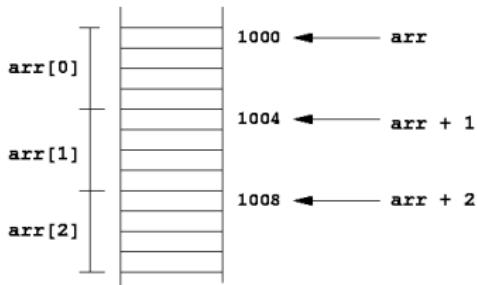
```
1 int data = 13;
2 int data2;
3 int *ptr;
4
5 void setup() {
6   Serial.begin(9600);
7   delay(1000);
8   ptr = &data;           //point ptr to the memory location of data
9   data2 = *ptr;         //set data2 to value of data (13)
10
11 // Print the Value and Address of the Variables
12 Serial.printf("Variable      Value      Address \n");
13 Serial.printf("  data        %i        0x%X  \n",data, &data);
14 Serial.printf("  ptr         0x%X        0x%X  \n",ptr, &ptr);
15 Serial.printf("  data2       %i        0x%X  \n",data2,&data2);
16 }
```

Serial monitor opened successfully:

Variable	Value	Address
data	13	0x2003E380
ptr	0x2003E380	0x2003E3F4
data2	13	0x2003E3F0



# Pointers and Arrays



```
1 int arr[] = {100, 200, 300};  
2  
3 void loop() {  
4     // Compiler converts below to *(arr + 2).  
5     Serial.printf("%i \n", arr[2]);  
6  
7     // So below also works.  
8     Serial.printf("%i \n", *(arr + 2));  
9 }
```

When an array (`arr[]`) is declared, the variable is a pointer to the first element of a continuous block of memory. In this case 3 elements, 4-bytes each in size, so a total of 12-bytes.



# Finding Average of an Array

```
1 // This function finds the average of an array
2 // The array is passed to it as a pointer
3
4 float getAve(int *array,int size) {
5     int j;
6     float total=0;
7     for(j=0;j<size;j++) {
8         total += array[j];
9     }
10    return total/size;
11 }
```



# Finding Average of Arrays in Action

```

1 int xArray[4], yArray[256];
2 int *pointerX, *pointerY;
3 float average;
4 int i, sizeX, sizeY;
5
6 void setup() {
7   pointerX=&xArray[0];
8   sizeX=sizeof(xArray)/4;
9   pointerY=&yArray[0];
10  sizeY=sizeof(yArray)/4;
11  for(i=0;i<sizeX;i++) {
12    xArray[i] = random(0,255);
13  }
14  for(i=0;i<sizeY;i++) {
15    yArray[i] = random(256,512);
16  }
17  average = getAve(pointerX, sizeX);
18  average = getAve(pointerY, sizeY);
19 }
```

```

Array X Average = 162.50
Array Y Average = 388.35
xArray[0] value: 173, *pointerX: 173, pointerX: 0x2003E3DC
xArray[1] value: 179, *(pointerX+1): 179, pointerX+1: 0x2003E3E0
xArray[2] value: 110, *(pointerX+2): 110, pointerX+2: 0x2003E3E4
xArray[3] value: 188, *(pointerX+3): 188, pointerX+3: 0x2003E3E8
```



# Array of Functions via Pointers

```
1 //Array of pointers to each of the functions
2 int (* funky[4])(int x, int y) = {add,sub,mult,divi};
3
4 int a,b,answer,i;
5
6 void setup() {
7     Serial.begin(9600);
8 }
9
10 void loop() {
11     a = random(0,100);
12     b = random(0,100);
13     for(i=0;i<4;i++) {
14         answer = funky[i](a,b);
15         Serial.printf("For function %i: a = %i and b = %i equals %i \n",i,a,b,answer);
16         delay(250);
17     }
18     Serial.printf("\n\n\n");
19     delay(3000);
20 }
21
22 // The Functions
23 int add(int x,int y) {return x+y;}
24
25 int sub(int x,int y) {return x-y;}
26
27 int mult(int x,int y) {return x*y;}
28
29 int divi(int x,int y) {return x/y;}
```



# Returning Multiple Values from a Function

Arguments can be passed to a function by reference; thus, allowing multiple parameters to be returned by a function.

```
1 void setup() {
2     x = 4;
3     y = 2;
4 }
5
6 void loop() {
7     swap(&x, &y);
8     Serial.printf("%i%i\n", x, y);
9     delay(1000);
10}
11
12 void swap(int *x, int *y) {
13     int temp;
14
15     temp = *x;
16     *x = *y;
17     *y = temp;
18 }
```



# Struct datatype and Member Operators

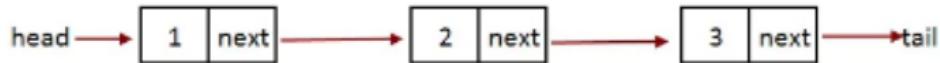
```
1 struct geo {
2     float lat;
3     float lon;
4     int alt;
5 };
6 geo myLoc;
7 geo *ptLoc;
8
9 void setup() {
10     Serial.begin(9600);
11     delay(500);
12
13     ptLoc = &myLoc;
14     myLoc.lat = 35.120606;
15     myLoc.lon = -106.65818;
16     myLoc.alt = 1517;
17
18     Serial.printf("Location: lat %f, lon %f, alt %i \n",myLoc.lat,myLoc.lon,myLoc.alt);
19     Serial.printf("Location: lat %f, lon %f, alt %i \n",ptLoc->lat,ptLoc->lon,ptLoc->alt);
20 }
```

The . (dot) operator and the -> (arrow) operator are used to reference individual members of structures.

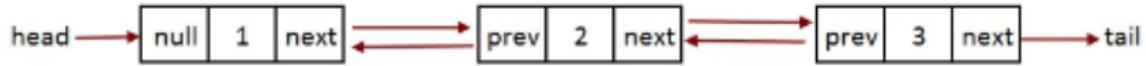
- The dot operator is applied to the actual object.
- The arrow operator is used with a pointer to an object.



# Linked Lists and Doubly Linked Lists



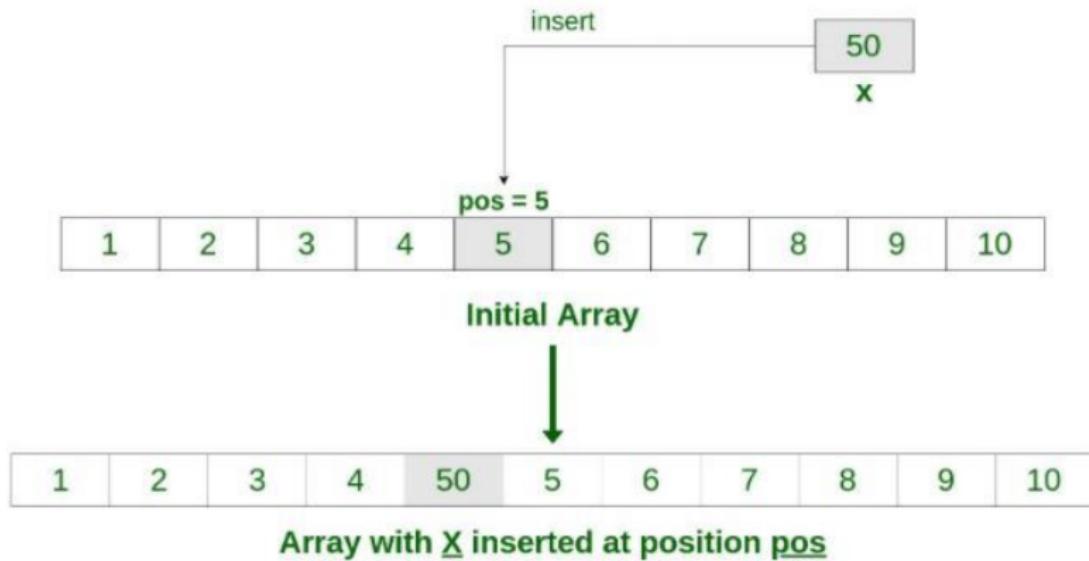
Singly Linked List



Doubly Linked List

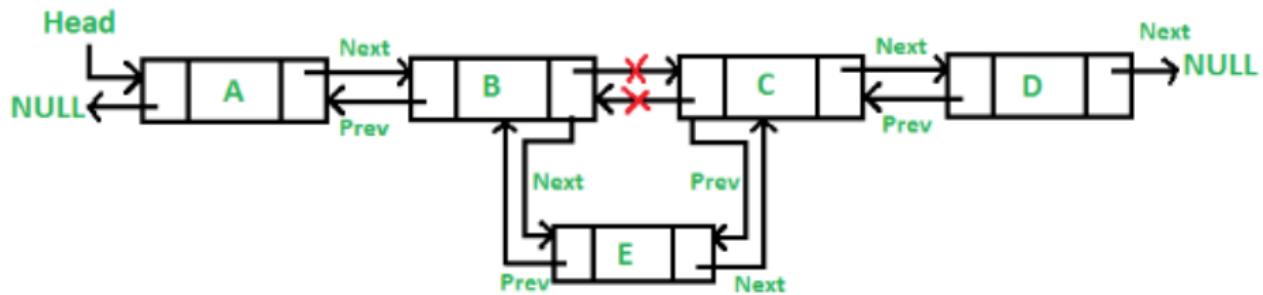


# Inserting a "cell" into an Array



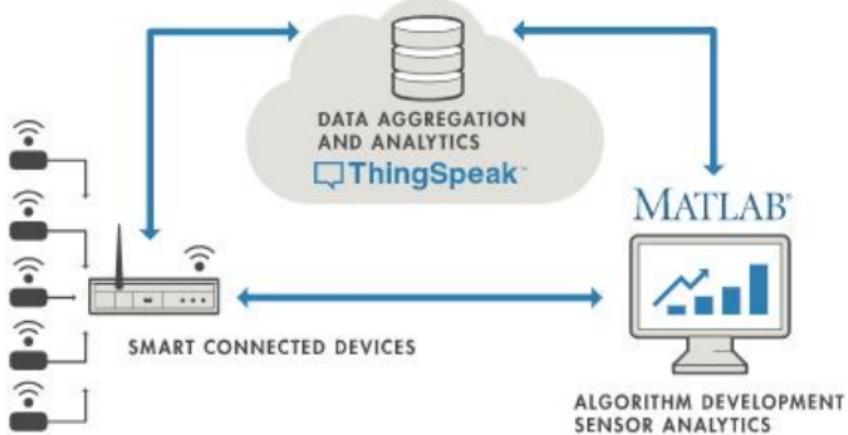


# Inserting a "cell" into a Linked List





# ThingSpeak Dashboard and Matlab Analysis



ThingSpeak™ is an IoT analytics platform service from MathWorks®, the makers of MATLAB® and Simulink®. ThingSpeak allows you to aggregate, visualize, and analyze live data streams in the cloud.



# ThingSpeak.h

```
1 #include "ThingSpeak.h"
2 TCPClient client;
3
4 // Change the below to your channel number and APIKeys
5 unsigned int myChannelNumber = 31461;
6 const char * myWriteAPIKey = "LD79E0AAWRVYF04Y";
7 const char * myReadAPIKey = "NKX4Z5JG04M5I18A";
8
9 void setup() {
10     ThingSpeak.begin(client);
11 }
12
13 void loop() {
14
15     float voltage = ThingSpeak.readFloatField(myChannelNumber, 1, myReadAPIKey);
16
17     pinVoltage = analogRead(A1) * (3.3 / 4095.0);
18     ThingSpeak.setField(1,pinVoltage);
19
20     ThingSpeak.writeFields(myChannelNumber, myWriteAPIKey);
21
22 }
```

Information on ThingSpeak channels can be found at: <https://community.thingspeak.com/tutorials/thingspeak-channels/>



# Capstone Projects

## Intent:

- Based on a direct observation or a need expressed by one of our guest speakers.
- Original work demonstrating the skills obtained in this class.
- Demonstrate the ability to work as part of a team.
- A pitch to potential employers or investors.

## Guidelines:

- Break class into 3 or 4 teams.
- Practical application of smart home, manufacturing, city environment or immersive entertainment.
- Needs to include a Cloud Dashboard component.
- Project will include a video presentation as well as a Hackster.io post.

Previous capstone projects can be found at: <https://www.youtube.com/playlist?list=PL0t2Pk5ETDgxfVptdyr6xbL6MW1-5CJey>



# The Big Question: What about main()

```
1 #include <Arduino.h>
2
3 extern "C" int main(void)
4 {
5 #ifdef USING_MAKEFILE
6
7 // To use Teensy 3.0 without Arduino, simply put your code here.
8 // For example:
9
10 pinMode(13, OUTPUT);
11 while (1) {
12     digitalWriteFast(13, HIGH);
13     delay(500);
14     digitalWriteFast(13, LOW);
15     delay(500);
16 }
17
18
19#else
20 // Arduino's main() function just calls setup() and loop()....
21 setup();
22 while (1) {
23     loop();
24     yield();
25 }
26#endif
27 }
```



# Hello World - What a microcontroller sees

## HelloWorld.ino

```
1 void setup() {
2   Serial.begin(9600);
3   Serial.printf("Hello World! \n");
4 }
5
6 void loop() {}
```

## Hex Code and Assembly Language

```
1 HelloWorld.bin:      file format binary
2 Disassembly of section .data:
3 00000000 <.data>:
4     101c: bd10      pop {r4, pc}
5     101e: 4402      add r2, r0
6     1020: 4603      mov r3, r0
7     1022: 4293      cmp r3, r2
8     1024: d002      beq.n 0x102c
9     1026: f803 1b01  strb.w r1, [r3], #1
10    102a: e7fa      b.n 0x1022
11    102c: 4770      bx lr
12    102e: 0000      movs r0, r0
13    1030: b538      push {r3, r4, r5, lr}
```

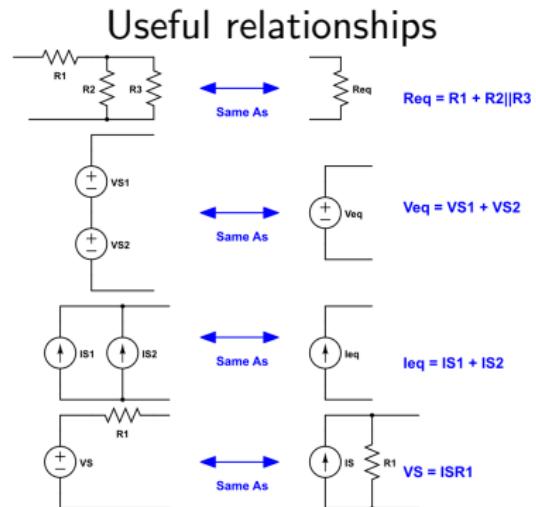
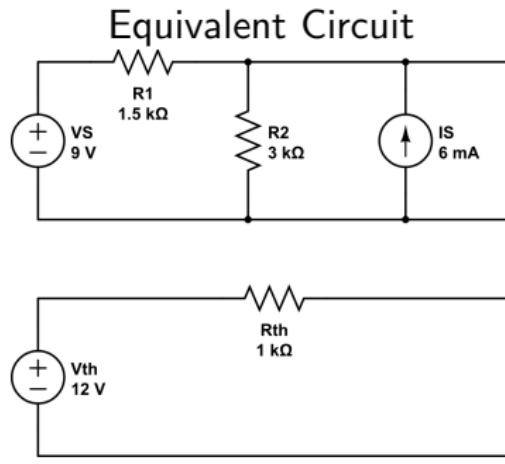




# Thevenin Equivalent Circuits

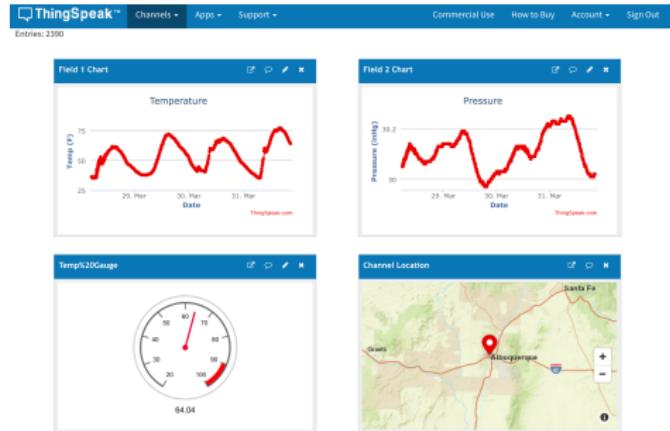
Léon Charles Thévenin ( 30 March 1857 – 21 September 1926) was a French telegraph engineer who extended Ohm's law to complex circuits.

Any combination of batteries and resistances with two terminals can be replaced by a single voltage source  $V_{th}$  and a single series resistor  $R_{th}$ .





# ThingSpeak Via Webhooks



We will be learning how to use Particle Webhooks to publish between cloud services. For this, you will need:

- 1 Particle Argon
- 2 BME280



# JSON

JSON (JavaScript Object Notation) is a lightweight data-interchange format. It is easy for humans to read and write. It is easy for machines to parse and generate. It is based on a subset of the JavaScript Programming Language Standard ECMA-262 3rd Edition - December 1999. JSON is a text format that is completely language independent but uses conventions that are familiar to programmers of the C-family of languages, including C, C++, C#, Java, JavaScript, Perl, Python, and many others. These properties make JSON an ideal data-interchange language.

JSON is built on two structures:

- A collection of name/value pairs. In various languages, this is realized as an object, record, struct, dictionary, hash table, keyed list, or associative array.
- An ordered list of values. In most languages, this is realized as an array, vector, list, or sequence.



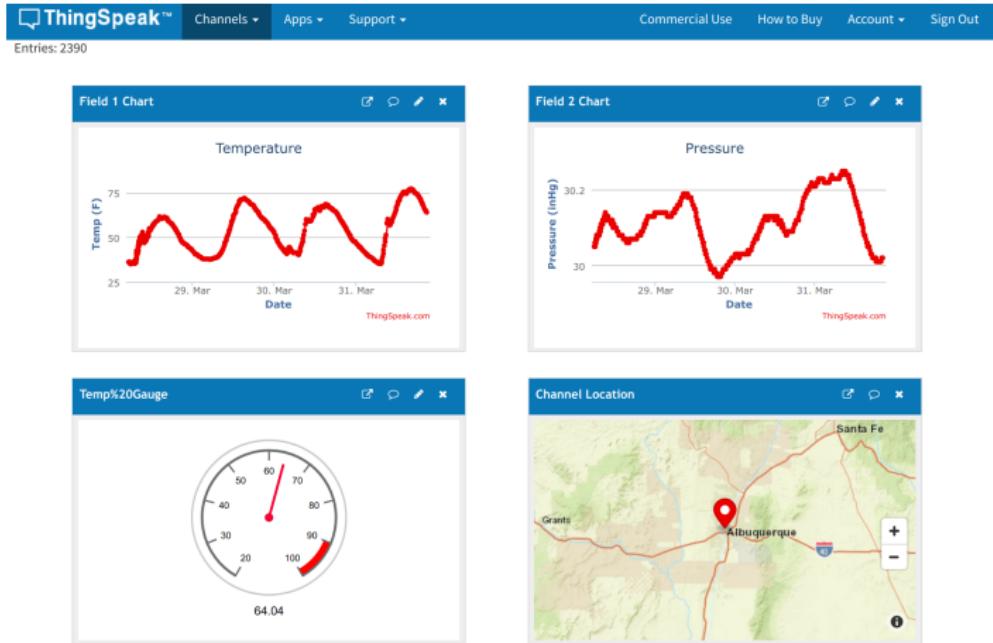
# JSON Parser Generator

Creating objects in JSON are straightforward but can be tedious. There is a JSON Parser available to simplify the process.

```
1 #include <JsonParserGeneratorRK.h>
2
3 void createEventPayLoad(int moistValue, float tempValue, float presValue, float humValue,
4                         int waterED) {
5     JsonWriterStatic<256> jw;
6     JsonWriterAutoObject obj(&jw);
7
8     jw.insertKeyValue("Moisture", moistValue);
9     jw.insertKeyValue("Temperature", tempValue);
10    jw.insertKeyValue("Pressure", presValue);
11    jw.insertKeyValue("Humidity", humValue);
12    jw.insertKeyValue("Plant Watered", waterED);
13 }
14 Particle.publish("env-vals", jw.getBuffer(), PRIVATE);
15 }
```



# ThingSpeak Dashboard





# Step 1 - Create ThingSpeak Channel

**ThingSpeak™** Channels Apps Support Commercial Use How to Buy Account Sign Out

## My Channels

Name	Created	Updated
FUSEMakerspace	2020-01-09	2020-03-27 16:04
Home IoT Plant Watering	2020-04-16	2020-04-16 19:56
Dew Point Measurement	2020-04-16	2020-04-19 13:38
Home Weather Station	2020-04-17	2020-04-17 18:52

New Channel Search by tag

**Help**

Collect data in a ThingSpeak channel from a device, from another channel, or from the web.

Click **New Channel** to create a new ThingSpeak channel.

Click on the column headers of the table to sort by the entries in that column or click on a tag to show channels with that tag.

Learn to [create channels](#), explore and transform data.

Learn more about [ThingSpeak Channels](#).

**Examples**

- [Arduino](#)
- [Arduino MKR1000](#)
- [ESP8266](#)
- [Raspberry Pi](#)
- [Netduino Plus](#)

**Upgrade**

Need to send more data faster?

Need to use ThingSpeak for a commercial project?

**Upgrade**



# Step 2 - Get API Key

ThingSpeak™

Channels • Apps • Support • Commercial Use How to Buy Account • Sign Out

## Dew Point Measurement

Channel ID: 1039626  
Author: mwa0000017234878  
Access: Private

Private View Public View Channel Settings Sharing API Keys Data Import / Export

### Write API Key

Key: BK1I6D1UTGPQ5B5H

Generate New Write API Key

### Read API Keys

Key: SQG42005TWWWF26R

Note:

Save Note Delete API Key

Add New Read API Key

### Help

API keys enable you to write data to a channel or read data from a private channel. API keys are auto-generated when you create a new channel.

### API Keys Settings

- Write API Key: Use this key to write data to a channel. If you feel your key has been compromised, click Generate New Write API Key.
- Read API Keys: Use this key to allow other people to view your private channel feeds and charts. Click Generate New Read API Key to generate an additional read key for the channel.
- Note: Use this field to enter information about channel read keys. For example, add notes to keep track of users with access to your channel.

### API Requests

**Write a Channel Feed**  
GET `https://api.thingspeak.com/update?api_key=BK1I6D1UTGPQ5B5H`

**Read a Channel Feed**  
GET `https://api.thingspeak.com/channels/1039626(feeds.json?tag=`

**Read a Channel Field**  
GET `https://api.thingspeak.com/channels/1039626(fields/1.json?tag=`

**Read Channel Status Updates**  
GET `https://api.thingspeak.com/channels/1039626/status.json?tag=`

Learn More



## Step 3 - Create Webhook

From `console.particle.io`:

The screenshot shows the Particle Integrations page. On the left is a sidebar with various icons: a star, a hexagon, three circles, a cloud, a mobile phone, a gear, a plus sign, and a double arrow. The main area has a header with "Personal" and a dropdown, and navigation links for "Docs", "Contact Sales", "Support", and an email address "barashap@gmail.com". Below this is a section titled "Integrations" with four cards:

- Webhook**
  - bme-vals
  - Lalonde
  - thingspeak.com
- Webhook**
  - temp
  - any device
  - thingspeak.com
- Webhook**
  - FUSEMakerspa...
  - any device
  - thingspeak.com
- Webhook**
  - env-vals
  - Herbert
  - thingspeak.com

To the right of these cards is a dashed-line box containing a large plus sign and the text "NEW INTEGRATION".



# Step 4 - Add JSON Data

Personal ☰

Integrations : Edit Integration

WEBHOOK BUILDER CUSTOM TEMPLATE

Read the Particle webhook guide

Event Name: env-vals

URL: https://api.thingspeak.com/update

Request Type: POST

Request Format: Web Form

Device: Herbert

Advanced Settings

For information on dynamic data that can be sent in any of the fields below, please visit [our docs](#).

FORM FIELDS

Custom

api_key	> XXXXXXXXXXXXXXXXXXXX	x
field1	> {{(Moisture)}}	x
field2	> {{(Temperature)}}	x
field3	> {{(Pressure)}}	x
field4	> {{(Humidity)}}	x
field5	> {{(Plant Watered)}}	x



# Step 5 - Particle Cloud Events

Personal ⚙

Docs | Contact Sales | Support | barashap@gmail.com •

## Events

Search for events ADVANCED

NAME	DATA	DEVICE	PUBLISHED AT
spark/status	offline	Herbert	4/20/20 at 10:06:49 am
spark/status	offline	Lalonde	4/20/20 at 10:06:26 am
hook-response/env-vals/0	1236	particle-internal	4/20/20 at 10:06:16 am
hook-sent/env-vals		particle-internal	4/20/20 at 10:06:16 am
env-vals	{"Moisture":2392,"Temperature":66.650000,"Pressure":30.033356,"Humidity":22.477539,"Plant Watered":0}	Herbert	4/20/20 at 10:06:16 am
Plant Watered	0	Herbert	4/20/20 at 10:06:16 am
Temperature	66.650000	Herbert	4/20/20 at 10:06:16 am
Moisture	2392	Herbert	4/20/20 at 10:06:16 am
spark/status	offline	Herbert	4/20/20 at 10:01:48 am

### env-vals

Published by e00fce6873080a74a8599312 on 4/20/20 at 10:06:16 am

PRETTY RAW

```
{ "Moisture": 2392, "Temperature": 66.650002, "Pressure": 30.033356, "Humidity": 22.477539, "Plant Watered": 0 }
```



# Step 6 - Create Channel

## Home IoT Plant Watering

Channel ID: 1039355

Author: mwaw0000017234878

Access: Public

Plant Watering in Home IoT Classroom

Private View    Public View

Channel Settings

Sharing

API Keys

Data Import

### Channel Settings

Percentage complete 50%

Channel ID 1039355

Name Home IoT Plant Watering

Description Plant Watering in Home IoT Classroom

Field 1 Moisture

Field 2 Temperature

Field 3 Pressure

Field 4 Humidity

Field 5 Watered

Field 6

Field 7

Field 8

Metadata JSON

### Help

Channels  
eight field  
status dat  
visualize i

### Chanr

- Per cha cha
- Chr
- Del
- Fiel cha
- Mel
- Tag
- Lin Thi
- Shc

- Vid infc



## Step 7 - Create Dashboard

You can change the colors of your lines, by editing the graph. The hex codes are found at <https://htmlcolorcodes.com/color-picker/>

### Home IoT Plant Watering

Channel ID: 1039355

Author: mwa0000017234878

Access: Public

Plant Watering in Home IoT Classroom

Private View    Public View    Channel Settings    Sharing    API Keys    Data Import / Export

Add Visualizations

Add Widgets

Export recent data

MATLAB Analysis

MATLAB Visualization

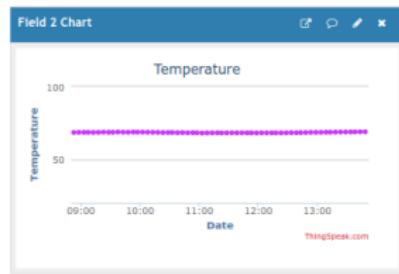
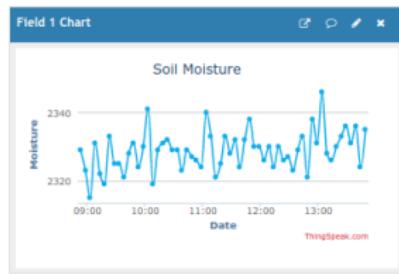
Channel 2 of 4 < >

### Channel Stats

Created: 3 days ago

Last entry: 2 minutes ago

Entries: 994



Field 4 Chart

Current Temperature



# NCD.io Control Everywhere





# NCDio TMG3993 Proximity/Color Sensor



- From Address 0x94
- Request 9 bytes
  - Byte 0 / 1 - LSB / MSB of Infrared Luminance
  - Byte 2 / 3 - LSB / MSB of Red Luminance
  - Byte 4 / 5 - LSB / MSB of Green Luminance
  - Byte 6 / 7 - LSB / MSB of Blue Luminance
  - Byte 9 - Proximity



# TMG3993 Initialization

```
1 Serial.println("Initializing TMG3993");
2 Wire.beginTransmission(Addr);
3 // Select Enable register
4 Wire.write(0x80);
5 // Power ON, ALS enable, Proximity enable, Wait enable
6 Wire.write(0x0F);
7 Wire.endTransmission();
8
9 Wire.beginTransmission(Addr);
10 // Select ADC integration time register
11 Wire.write(0x81);
12 // ATIME : 712ms, Max count = 65535 cycles
13 Wire.write(0x00);
14 Wire.endTransmission();
15
16 Wire.beginTransmission(Addr);
17 // Select Wait time register
18 Wire.write(0x83);
19 // WTIME : 2.78ms
20 Wire.write(0xFF);
21 Wire.endTransmission();
22
23 Wire.beginTransmission(Addr);
24 // Select control register
25 Wire.write(0x8F);
26 // AGAIN is 1x
27 Wire.write(0x00);
28 Wire.endTransmission();
29 }
```



# NCDio ACD121C MQ9 CO Sensor



## 12-Bit Analog to Digital Conversion

- From Address 0x00
- Request 2 bytes (raw\_adc)
  - Byte 0 - MSB
  - Byte 1 - LSB
- CO (ppm) =  $\frac{1000}{4096} * raw\_adc + 10$



# NCDio ACD121C MQ131 Ozone Sensor

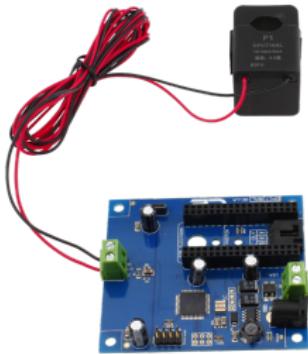


## 12-Bit Analog to Digital Conversion

- From Address 0x00
- Request 2 bytes (raw\_adc)
  - Byte 0 - MSB
  - Byte 1 - LSB
- $O_3 \text{ (ppm)} = \frac{1.99}{4095} * raw\_adc + 0.01$



# NCDio PECMAC Current Sensor



- 1 to 8 channels
- Full range between 10 and 100 amps
- Simple to use. Simply run an AC power wire through the opening of the current sensor. This controller will read the magnetic field inducted onto the current sensor and provide you with a real-world current measurement value that is 98 percent accurate (prior to calibration).

# GitHub



# Git and GitHub: Your Version Control Friends



# GitHub



# What is a version control system?

Version Control Systems (VCS) record changes made to files so that you can

- compare and track changes over time
- revert single files to a previous state
- revert an entire project to an earlier version

Git is a VCS, or Version Control System.

It is similar to Backup on Windows or Time Machine on the Mac.



# Why use a version control system?

Before Version Control Systems.

- Save multiple versions of the file and try to remember which is which.
- Run a text comparison tool to see what changed between versions.
- Work with system engineer to get your changes merged with production version.

With Git.

- Commit as you code.
- Versioning and timestamping automatically happen.
- Easy to see differences between versions using git diff or visually if using GitHub.
- Easy to merge changes to production or rollback versions.
- Links with ticketing system for better task management and customer support.



# Git vs. GitHub

Git is the version control system. This is on your local system.

→ git commit

GitHub is a GUI (Graphical User Interface) cloud-based product that allows you to save your work remotely and facilitates collaboration.

→ git push



# Commit vs. Push

## Commit

- File saved to **LOCAL** repository. File is given a timestamp and a unique commit number that is the file version.

## Push

- File is saved to **REMOTE** repository.

**Remember to Push your files** in order to save from data loss and to ensure your work is available for collaboration.



# When should you commit and push your work?

## When to commit? **OFTEN!**

- Any time you finish a task where you want to save or retain a version.

## When to push? **OFTEN!**

- Any time you have finished a task, milestone, or significant project.
- At the end of each work session
  - Before you take a break
  - Before a meeting
  - Before lunch
  - Before you go offline for the day



# Installing Git on Windows

There are two good ways to install Git on Windows.

- ① The official build is available at  
<https://git-scm.com/download/win>.
- ② You can also use the GitHub GUI tool at  
<https://windows.github.com>. During the installation of this tool you can choose to install command-line tools as well (i.e. Git's command-line interface).



# Installing Git on Mac

There are three ways to install Git on Mac.

- ① A Git installer is available at <https://git-scm.com/download/mac>.
- ② You can download the GitHub GUI tool at <https://mac.github.com>. During the installation of this tool, you can choose to install command-line tools as well (i.e. Git's command-line interface).
- ③ You can install the Xcode Command-Line Tools. On Mavericks (10.9) or above, you can do this simply by trying to run Git from the terminal the very first time. If you don't have it installed already, it will prompt you to install it.



# Installing Git on Linux

You can use the package management system that comes with your distribution.

On Debian based distributions like Ubuntu, use apt-get:

```
brian:~$ sudo apt-get install git-all
```



# Using Git: Command line or GUI?

Why should I use the command line when I could use a GUI instead?

- It's generally better supported than GUI-based tools.
- It's independent from your IDE.
- It helps you come to a better understanding of the principles of version control.
- It's much more commonly used in the industry and thus is more likely to get you a job.
- It's much more likely to be useful if you find yourself in a sticky merge/rebase situation that you can't seem to fix.
- It's faster to type the commands than to go through the GUI. These time savings add up.



# The command line

## Windows

- PowerShell - This is what we are using in class.
- GitBash - Linux commands and editors available.

## Mac or Linux

- Terminal - This is what our Mac users are using in class.

For basic commands, review IoT slides on *Command Line Interface*.



# The repository - aka the repo

- The git repository is the location where files are saved/staged.
- The git repository is also called a “repo”.
- You may create a new repository from scratch.
  - Your smart room controller, flower pot, and capstone projects
- You may clone a local repository from an existing remote repository.
  - Your class exercises, a 3rd party library
- The git repository keeps your version history in a hidden “.git” folder.
  - To view on Windows, in your project folder in File Explorer, click View, then check “Hidden Items”
  - To view in PowerShell, in your project folder, type dir -Force.
  - To view on Mac, in your project folder in Finder, press Shift + Control + dot



## Practice: Create a repo in GitHub

- ① Login to your GitHub account. If you do not have a GitHub account, then create one at <https://Github.com>
- ② On your GitHub home page, click “New” to create a new repository.
- ③ Type the following name for your new repo.
  - gitdemo-yourname
- ④ Indicate if the repo is public or private.
- ⑤ Select a readme, .gitignore, license option if applicable.
- ⑥ Click “Create Repository”
- ⑦ Your new repository is created.



## Practice: Clone the repo to your local machine

- ① Open your new repository in GitHub if it is not already open.
- ② Click the “Code” button.
- ③ Copy the https address for your github repo.
  - Note: there is also an SSH option if you choose to link your public SSH key to your github repository.  
<https://docs.github.com/en/github/authenticating-to-github/about-authentication-to-github>
- ④ cd into your IoT directory.
- ⑤ git clone the https GitHub repo to initialize the git repo on your local machine. This creates your project folder and the hidden .git folder.



## Practice: Committing and pushing changes

- ① Go back to your repo directory on your computer.
- ② Create and add a file.
  - You can use Notepad orTextEdit or create it on the command line.
- ③ Make some changes to the file.
- ④ Commit and push the file.
- ⑤ Make some more changes to the file.
- ⑥ git diff [filename] to see the changes that will be committed.
- ⑦ Commit and push the file.
- ⑧ Go to GitHub and view “commits”
- ⑨ See how GitHub displays your changes.



## Practice: View changes

- ① Go to your project directory
- ② git log - to view version history
- ③ Copy one of the commit numbers to your clipboard
- ④ git show [commit] - to view content changes for that commit



# The .gitignore file

There may be times you want to omit directories and/or files from git.

Examples:

- Files with sensitive information such as password/credential files.
- Directories with 3rd party libraries. These will likely already be installed on the deployment server so do not need to go to Github.

Such files and directories are listed in a .gitignore file that usually resides at the root of your project directory.



## Practice: Creating and using a .gitignore file

- ➊ Open your test repo.
- ➋ Add a file called credentials.h. Type something into the file and save it.
- ➌ Type git status. What do you see?
- ➍ Now add a file called .gitignore.
- ➎ In the .gitignore file, type credentials.h and save.
- ➏ Type git status. What do you see?
- ➐ Commit and push to GitHub.



# What to do if you accidentally COMMIT a sensitive file

Suppose you accidentally **COMMIT** the sensitive file anyway?

<https://www.atlassian.com/git/tutorials/undoing-changes>

*Note: there are many different scenarios. So if you run into a situation where you need to revert a commit, check the above documentation and/or check procedures with your company to see how they want to resolve.*



# What to do if you accidentally PUSH a sensitive file

Suppose you accidentally **PUSH** the sensitive file anyway?

**FIRST CHANGE THE PASSWORD OR INFORMATION IMMEDIATELY.**

Then follow steps to remove the file from your git repository. *Note: deleting the file from your repo does not remove it completely.*

- If you are a solo-preneur or hobbyist, then you can decide how to resolve the issue.
- If you are working for a company, then check with your boss to see how to resolve.



# Typical GitHub workflow and branches

- Master or Main is the good code. This is generally the code that is also available on a production system.
- A production system is a live system that people are actually using.
- You don't want to push unfinished, untested code to your master or main branch.

Typical workflow:

Feature → development → staging/testing/release → master  
(main)/production

<https://www.atlassian.com/git/tutorials/comparing-workflows/gitflow-workflow>



# Practice: Branching and merging code

- ① Create a branch called “dev”
  - git branch dev → create the new branch
  - git checkout dev → switch to the new branch
  - git branch → confirm the branch you are now in.
- ② Make changes to your test file.
- ③ commit and push your changes.
- ④ git checkout main → to switch back to the main branch.
- ⑤ git branch → to see what branch you are in.
- ⑥ git merge dev → to merge your dev branch changes into main.
- ⑦ git push → to push the merged changes to main
- ⑧ Look at your commit history to see how the merge was handled.



# Using Git inside an IDE - Visual Studio Code

You can run Git commands from the Visual Studio Code terminal.  
Advanced IDEs (Interactive Development Environments) usually integrate with a VCS like Git.

- ① Open a project folder in VS Code.
- ② Open a terminal window in VS Code.
- ③ Choose your preferred Git command tool.
  - Windows Command
  - Windows Powershell
  - Git Bash → like Linux
- ④ Now type your Git and file/directory commands in the terminal.

*This is easier than Powershell because you are already in your project folder so VS Code can show your Git status in the IDE.*



## Review: Git commands

**git clone** → to copy a complete repo to your local machine.

**git log** → shows commit history for a repo.

**git show** <commit number> → shows details for a specified commit.

**git diff** <file name> → shows differences between file versions.

**git status** → shows what is staged for commit so you know what will be committed *BEFORE* you commit it.

**git branch** → to create a new branch or see what branch you are currently in.

**git checkout** <file name> → to rollback files to the current Git version.

**git checkout** <branch name> or **git switch** <branch name> → to change branches.

**git pull** → to get the latest code from a repo.

**git add** → to stage files to be committed.

**git commit** → to apply timestamp and version to files in a local repo.

**git push** → to upload commits to a remote repo.



# Collaboration in GitHub

- Collaboration allows multiple people (GitHub accounts) to work on the same project.
- For your capstones, you will need to add classmates as collaborators to your repo.
- Applying rules to the GitHub workflow helps avoid merge conflicts and problem code.
  - Communicate with other team members about changes you are making.
  - Segregate assignments if possible to avoid changing the same code at the same time.
  - **Always do a git pull from a branch** before merging to avoid having your branch ahead of a higher level branch.
  - Use a separate branch for development to avoid breaking the master or main branch of your teammates' code.
  - Thoroughly test your code before committing and pushing to GitHub.
  - Have a teammate do a code review before merging to a higher level branch.



# Collaboration workflow

- ① Share a project repo with all team members in GitHub.
- ② Clone the shared repo to your local machine.
- ③ If you do not have a development or working branch, create one.
- ④ Switch to the new branch in the repo.
- ⑤ Do your development and testing.
- ⑥ Commit and push your branch to GitHub.
- ⑦ Notify the repo owner that your code is ready for review and merging to the next higher level branch.

*Note: design a workflow that works for your team. Avoid working on the master or main branch. Reserve the master or main branch for final production-level, presentation-worthy code.*



# Practice: Collaborating

- ➊ Add your teammate as a collaborator to your repo.
  - Settings > Manage Access > Invite Collaborator
- ➋ Approve the invitation to collaborate in your email.
- ➌ Confirm that you can now see your teammate's repo.
- ➍ Clone your teammate's repo into your IoT folder.
- ➎ Create a new branch for your development.
  - git branch yourname-dev
  - git checkout yourname-dev
- ➏ Make a change to a file on your dev branch.
- ➐ Commit and push your change.
- ➑ Have your teammate confirm that they can see your new branch and change in their repo.



# Pull Requests

A pull request is a safety feature in GitHub that enforces a code review before merging code from a downstream branch into an upstream branch.

A pull request is initiated in the GitHub GUI.

To enforce pull requests before merge

- ① Go to Settings > Branches > Add Rule.
- ② Choose "Require pull request reviews before merging."
- ③ Click "Create" to save the rule.

*Note: some collaborator features may only be available with a GitHub Pro account.*



# Practice: Approving and merging pull requests

- ① Push your changes to your branch in GitHub.
- ② Create a pull request for your branch in GitHub.
- ③ Have your teammate review and approve your pull request.
- ④ Have your teammate merge your pull request into an upstream branch in the repo.
- ⑤ View the result in GitHub.



## Handling merge conflicts

In spite of your best efforts, you will eventually encounter a merge conflict. This occurs when Git cannot figure out how to merge two files because the changes are too disparate.

- ➊ Open the conflicted file in a text editor or VS Code or whatever IDE you are using.
- ➋ Notice the merge conflict markers in the file.
  - ➌ <<<<< HEAD text in HEAD version ===== text in your version >>>>> your-branch
- ➍ Select the text you want to keep and
- ➎ Remove the text you want to delete.
- ➏ Delete the conflict markers.
- ➐ Save the adjusted file.
- ➑ Commit and push to GitHub.
- ➒ Go to GitHub and confirm that your branch now has the corrected file.



## Additional Git resources

- **Installing git:** <https://git-scm.com/book/en/v2/Getting-Started-Installing-Git>
- **git cheat sheet:** <https://github.github.com/training-kit/downloads/github-git-cheat-sheet.pdf>
- **GitHub documentation:** <https://docs.github.com/en/github>
- **Git workflow:** <https://www.atlassian.com/git/tutorials/comparing-workflows/gitflow-workflow>
- **What to do if it goes all wrong:** <https://dangitgit.com/>
- **Resolving merge conflicts:** <https://docs.github.com/en/github/collaborating-with-issues-and-pull-requests/resolving-a-merge-conflict-using-the-command-line>