

IoT Product Design and Coding Bootcamp

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- 5 Particle Argon

IoT Fun



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Brian Rashap, Ph.D.

- Proud husband of Krista and father of Shelby (21) and Ethan (18)
- Electrical Engineer with 25 years industrial experience
- High School track coach
- Hobbies: running, cycling, reading, spending time with family



Introductions

INTRODUCTIONS

Class Rules

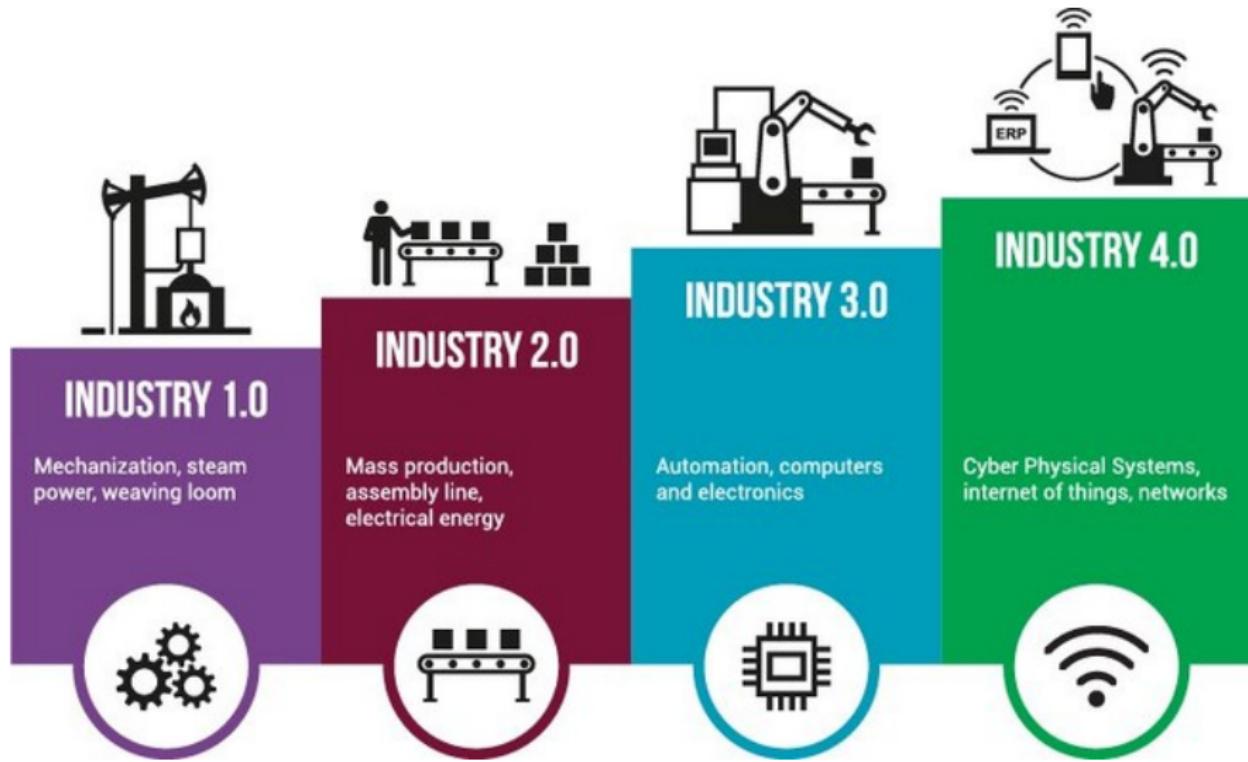
- Respect Each Other, Help Each Other
- Ask Questions
- Be On Time (let's us know via Slack if you won't be here)
- Keep Your Workspace and the Classroom Neat and Tidy
- If you are struggling, let myself, Susan, or Esteban know. We are here to HELP!

Grading

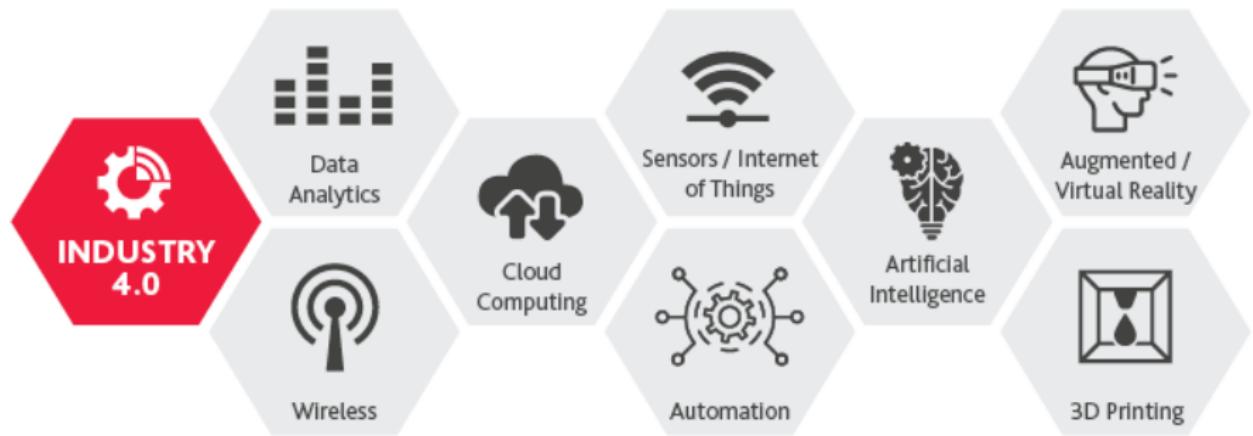
- ① Weekly IoT assignments: 40
- ② Lab Notebook: 10
- ③ Weekly quizzes: 10
- ④ Individual Midterm Project: Smart Room Controller: 20
- ⑤ Team Capstone Project: 20

More information later today on how assignments are turned in

Evolution of Industry



Components of Industry 4.0



IoT and Data Science



AI: Data-based learning

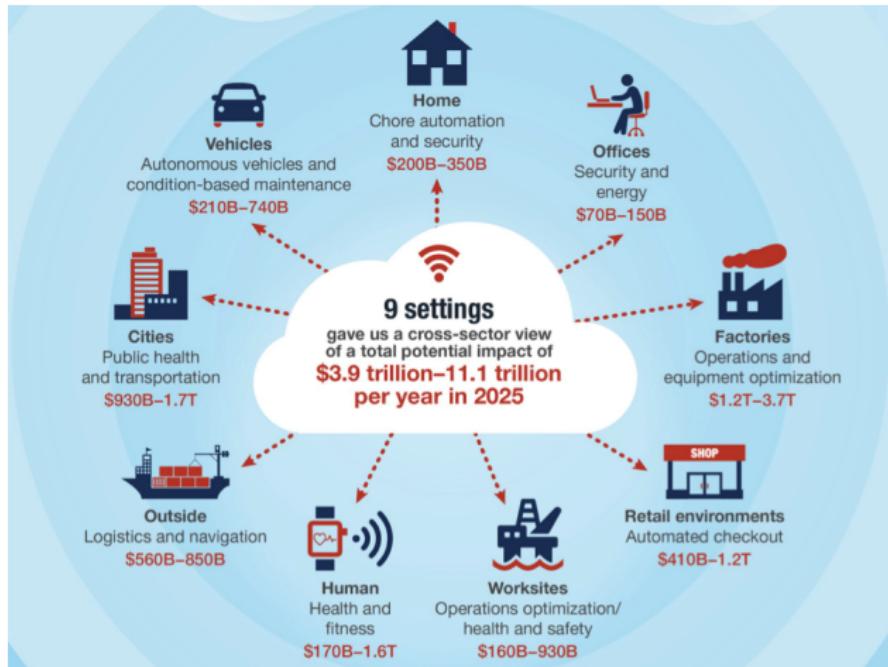


Big Data: Capture, storage, analysis of data



IOT: Data Collection through IoT

IoT 2025



Smart Facilities



Healthcare 2025



Smart World

Libelium Smart World



And Out of This World



IoT Growth



Let's Begin Our Journey



Computer Languages

Mother Tongues

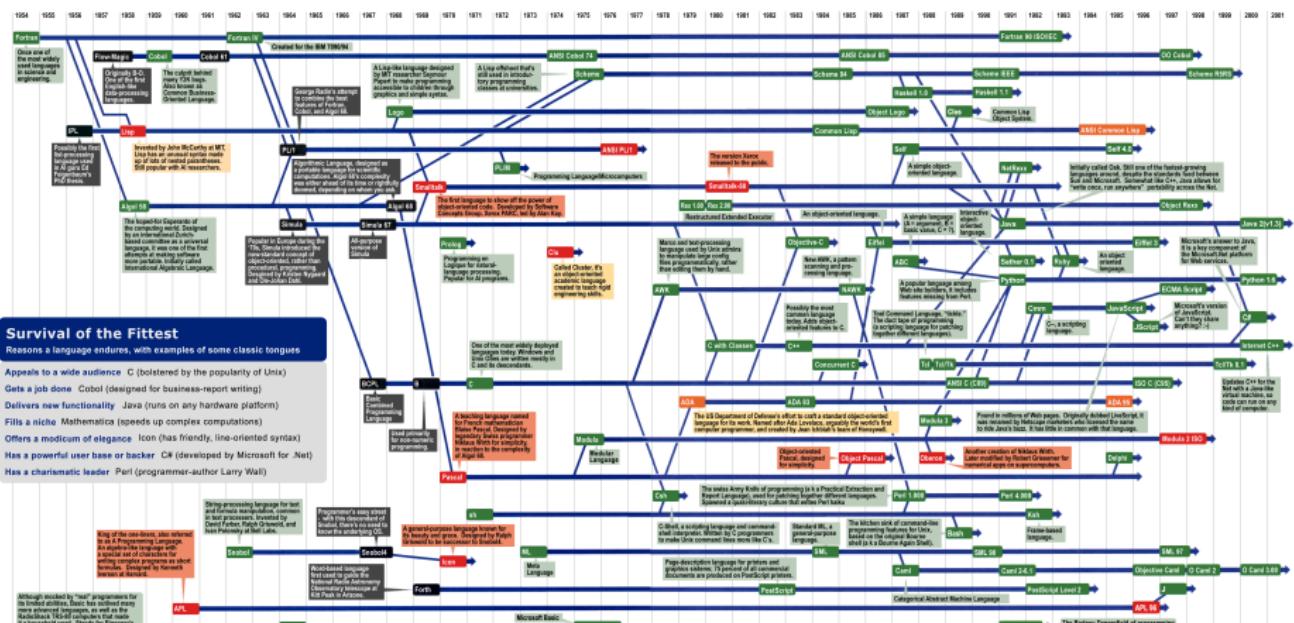
Tracing the roots of computer languages through the ages

Just like half of the world's spoken tongues, most of the 2,300-plus computer programming languages are either endangered or extinct. As powerhouses C/C++, Visual Basic, Java, C#, Cobol, Java and other modern source codes dominate our systems, hundred of other languages are running in the background.

An ad hoc collection of ancient and electronic lexicographers, if you will—aim to save, or at least document the lineage of classic software. They're combing the globe's 9 million developers in search of codes still fluent in these nearly forgotten linguafagues. Among the most endangered are Ada, APL, B (the predecessor of C), Lisp, Oberon, Smalltalk, and Simula.

Code-raker Grady Booch, Rational Software's chief scientist, is working with the Computer History Museum in Silicon Valley to record and, in some cases, maintain languages by writing new compilers so our ever-changing hardware can grok the code. Why bother? "They tell us about the history of software, provide the missing link between the technical, social, and economic material that shapes history," he says. "Booch explains, "We've got the raw material for software archaeologists, historians, and developers to learn what worked; what was brilliant, and what was an utter failure." Here's a peek at the strongest branches of programming's family tree. For a nearly exhaustive rundown, check out the Language List at [HTTP://WWW.INFORMATIK.UNI-FREIBURG.DE/JAVA/MSVC/LANG_LIST.HTML](http://www.informatik.uni-freiburg.de/Java/msvc/lang_list.html). - Michael Menduno

Key
Year Introduced
Active: thousand of users
Protected: taught at universities; compilers available
Extinct: usage dropping off
Extinct: no known active users or up-to-date compilers
Lineage continues

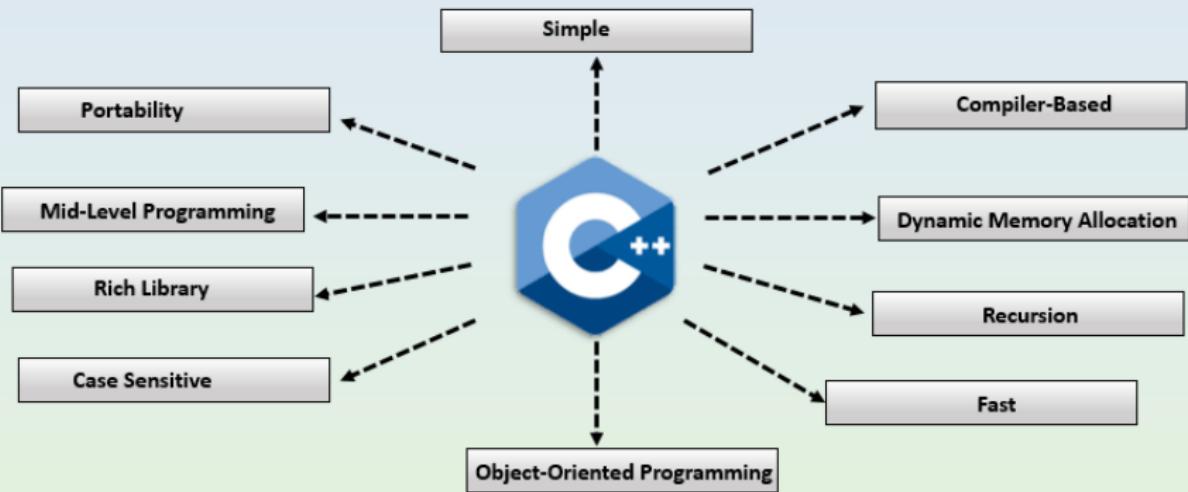


Computer Languages

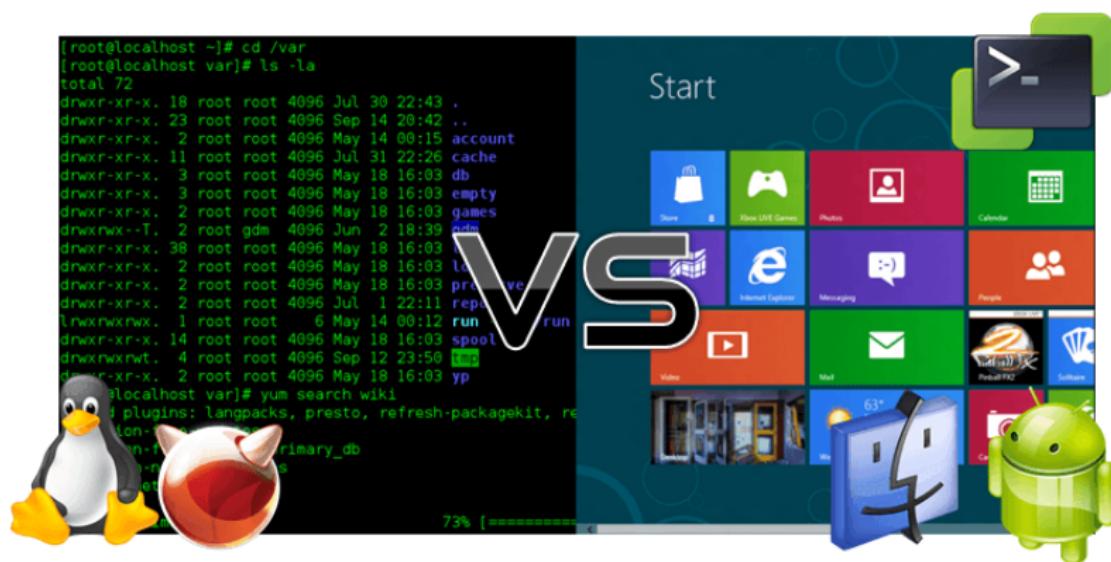


Why C++

Features of C++



CLI vs GUI



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 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's working is almost similar to cp command but it deletes copy of file or directory from 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

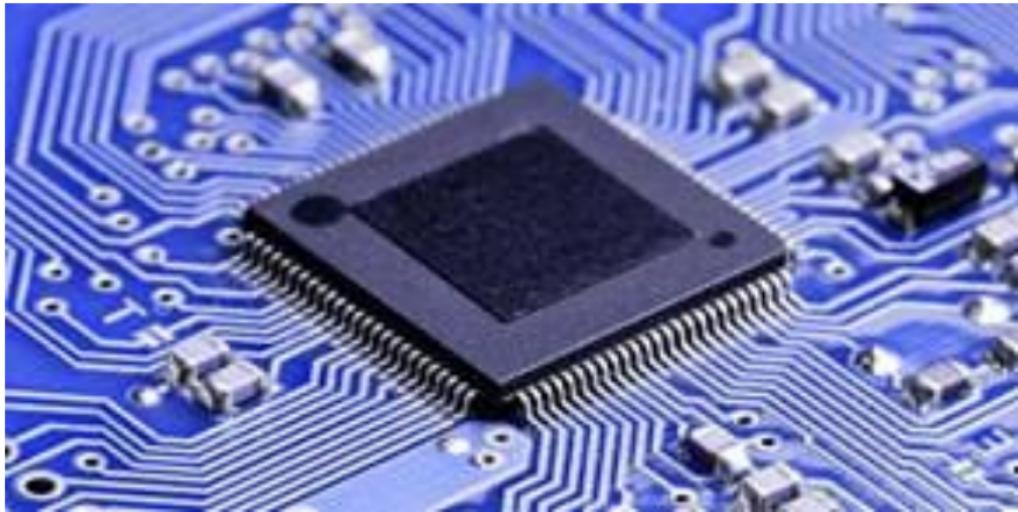
- cat: It is generally used to concatenate the files. It gives the output on the standard output.
- more: It is a filter for paging through text one screenful at a time.

The below commands are not available in PowerShell:

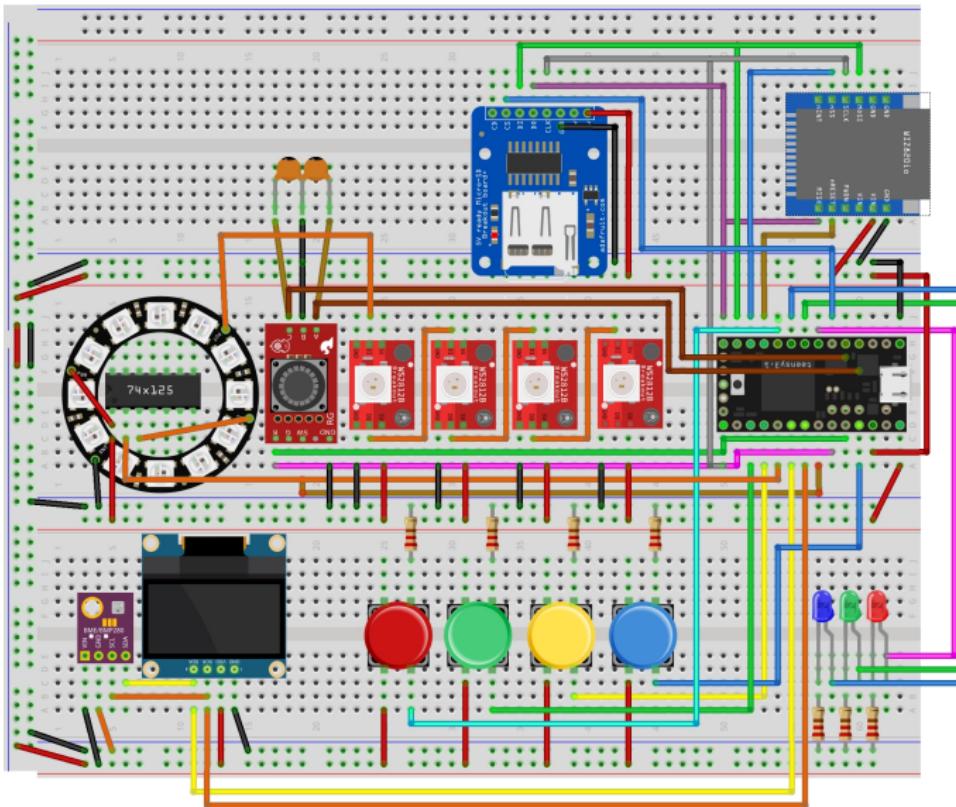
- less: It is used to viewing the files instead of opening the file. Similar to more command but it allows backward as well as forward movement.
- head: Used to print the first N lines of a file. It accepts N as input and the default value of N is 10.
- tail: Used to print the last N-1 lines of a file.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

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

Our First Microcontroller



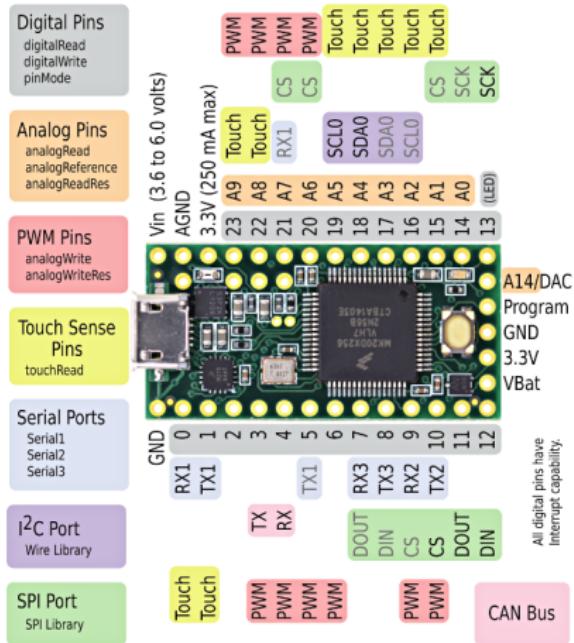
Smart Room Controller



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 IDE¹. The Arduino IDE is programmed essentially using C++ code, but make the compiling and loading onto the microcontroller simpler.

We begin by installing the Arduino IDE:

<https://www.arduino.cc/en/main/software>

Then, we install the Teensyduino add-on:

https://www.pjrc.com/teensy/td_download.html

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

Other Software

① Fritzing

- IoT Bootcamp Teams Site

② Drawio

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

③ Fusion 360

- Instructional Videos - Teams Site

④ Formlab's Preform

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

⑤ Ultimaker's Cura

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

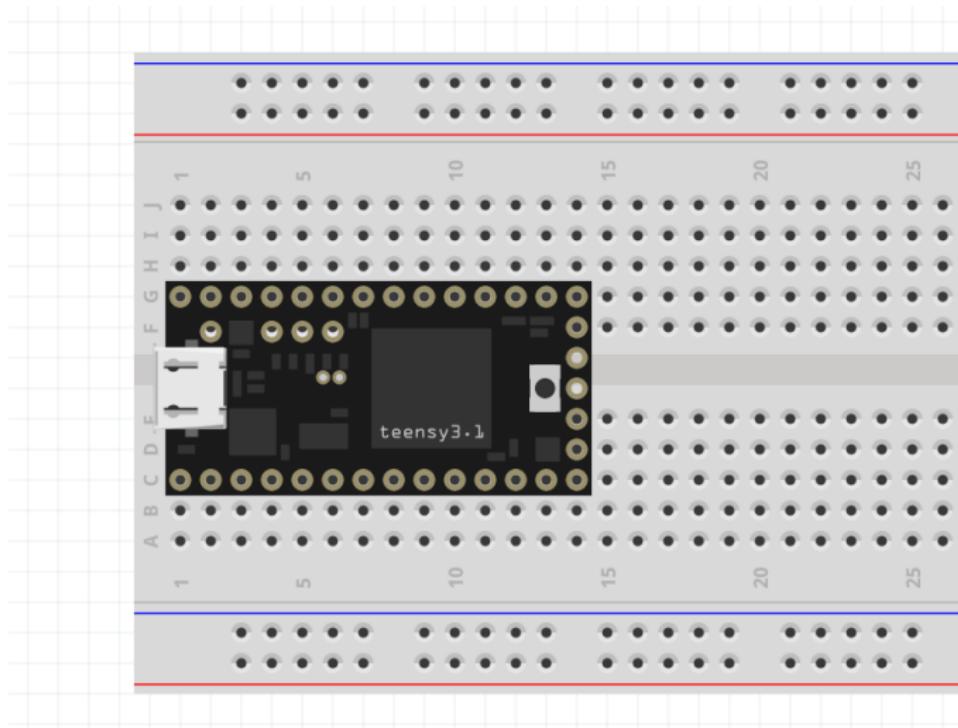
⑥ Git

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

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"
```

Teensy on Breadboard



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
```

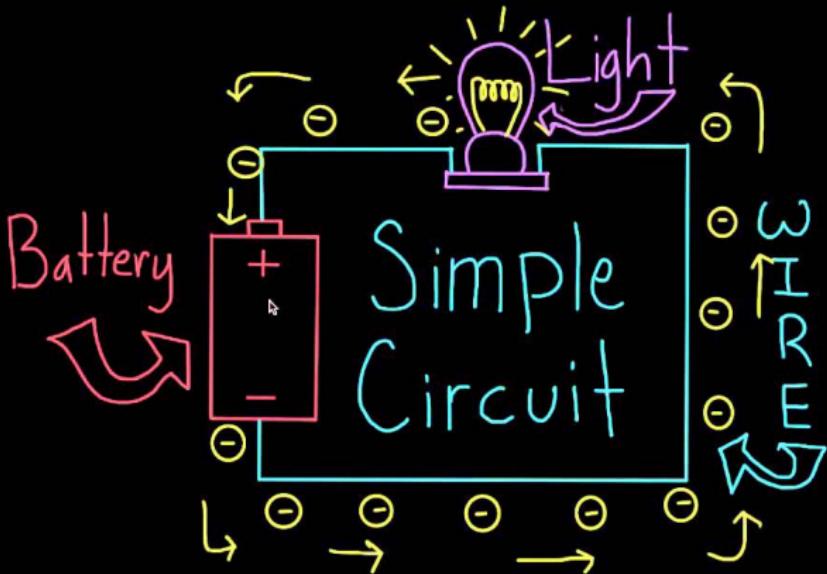
Assignment L01_01_HelloWorld



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

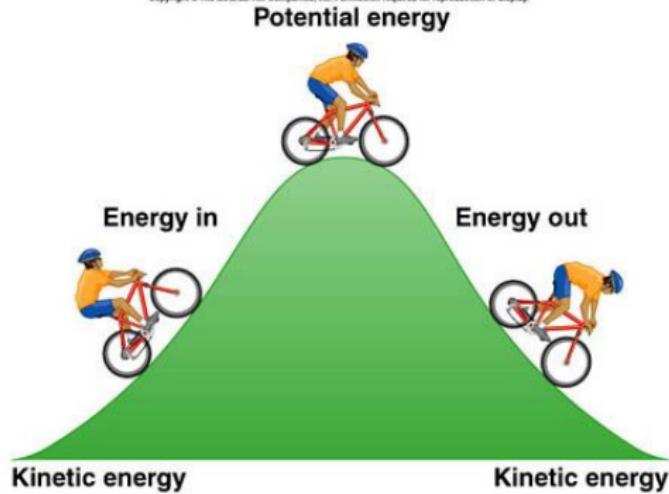
- `pinMode(pin,mode)`
- `digitalWrite(pin,state)`
- `delay(delay_time)`

Introduction to Electrical Circuits



Energy

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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

$$V = I \cdot R$$



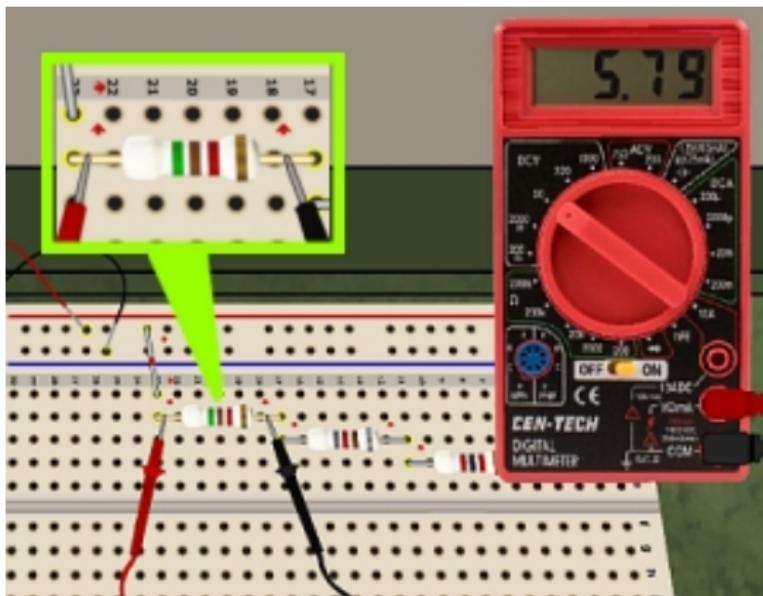
Resistor Color Bands

4-Band-Code

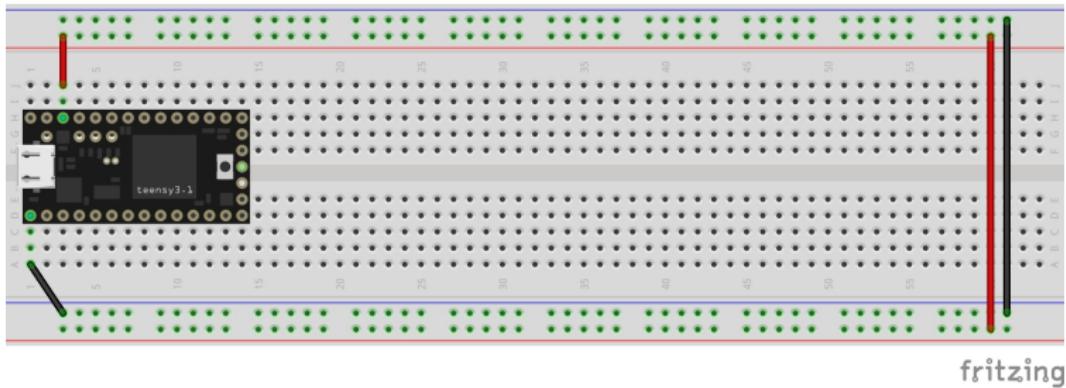
COLOR	1 ST BAND	2 ND BAND	3 RD BAND	MULTIPLIER	TOLERANCE
Black	0	0	0	1Ω	
Brown	1	1	1	10Ω	± 1% (F)
Red	2	2	2	100Ω	± 2% (G)
Orange	3	3	3	1KΩ	
Yellow	4	4	4	10KΩ	
Green	5	5	5	100KΩ	± 0.5% (D)
Blue	6	6	6	1MΩ	± 0.25% (C)
Violet	7	7	7	10MΩ	± 0.10% (B)
Grey	8	8	8	100MΩ	± 0.05%
White	9	9	9	1GΩ	
Gold				0.1Ω	±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

5-Band-Code

Measuring Voltage, Current, and Resistance



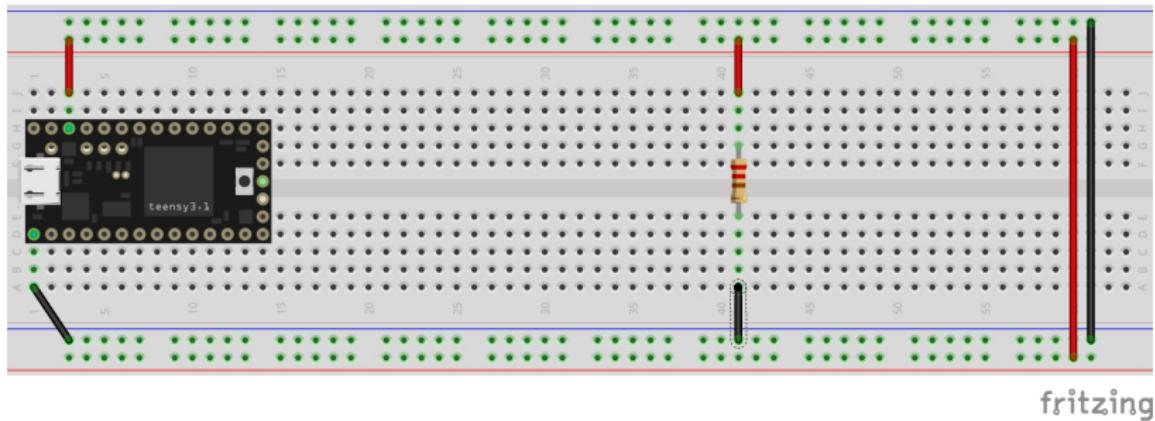
Power from the Teensy 3.2



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

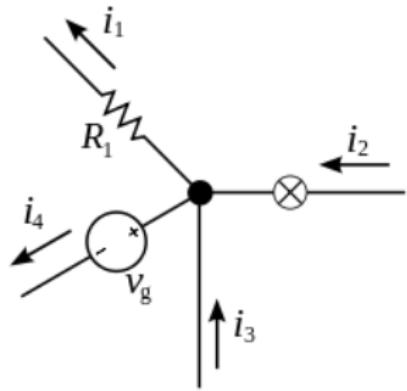


fritzing

Kirchhoff's First Law

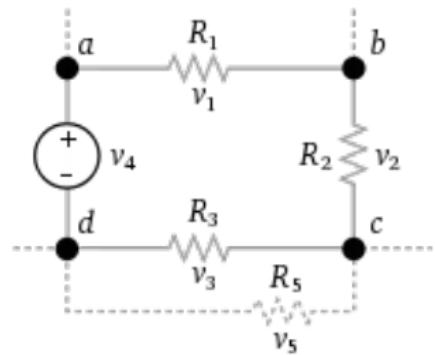
Gustav Robert Kirchhoff (12 March 1824 – 17 October 1887) was a German physicist who contributed to the fundamental understanding of electrical circuits. His first law:

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



Kirchhoff's Second Law

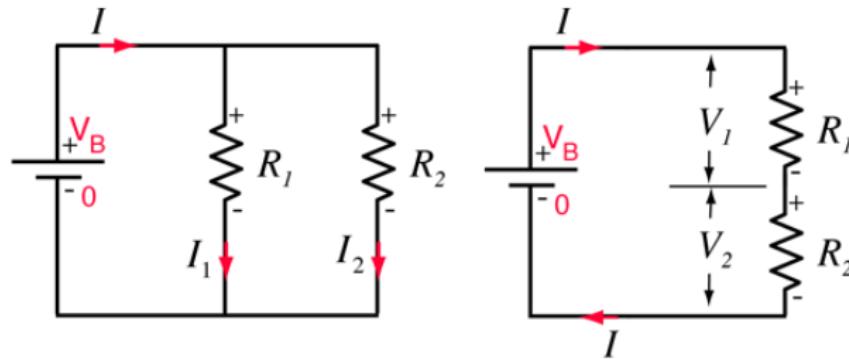
The directed sum of the potential differences (voltages) around any closed loop is zero.



Resistors in Series and Parallel



Resistors in Series and Parallel



Parallel resistors

$$\frac{1}{R_{\text{equivalent}}} = \frac{1}{R_1} + \frac{1}{R_2}$$

Series resistors

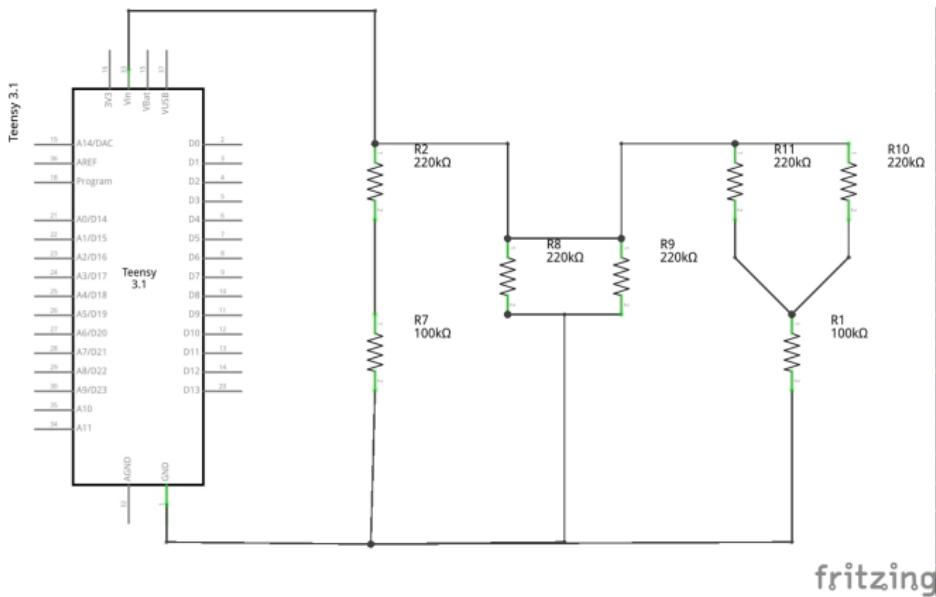
$$R_{\text{equivalent}} = R_1 + R_2$$

Resistor Lesson



- In your lab notebook, draw the circuit diagrams
 - ① Series: $220k\Omega$ and $100k\Omega$
 - ② Parallel: $220k\Omega$ and $220k\Omega$
 - ③ Combined: Two $220k\Omega$ in series with $100k\Omega$
- Calculate the combined resistance and the voltage at each point
- Create Fritzing diagram
- Build (one at a time*) on your breadboard and test with 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.

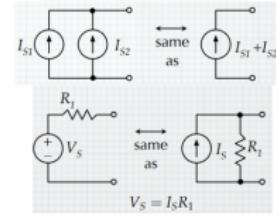
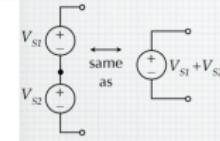
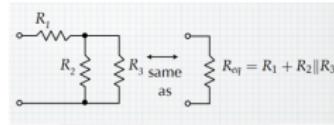
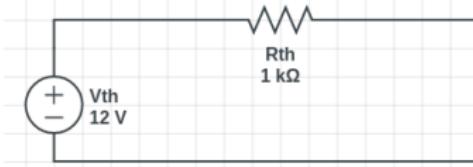
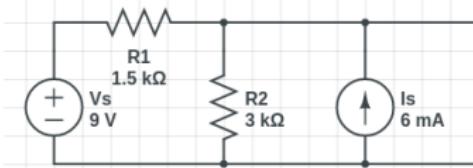
Thevenin Equivalent Circuits

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} .

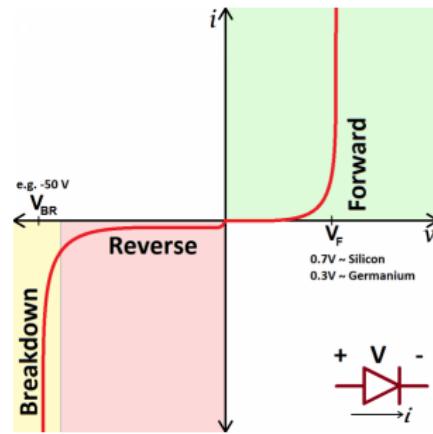
Useful relationships

Equivalent Circuit



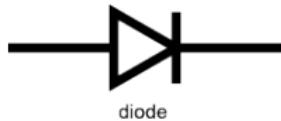
Diodes

The key function of an 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.



diode



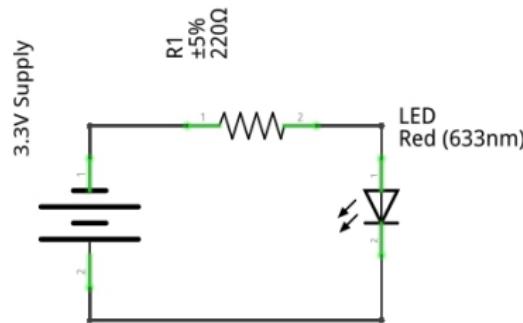
light emitting diode

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.

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

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 29Ω.



fritzing

Assignment L02_01_helloLED



- Using Pin 5 as an output and the appropriate current limiting resistor, blink the LED once per second.
- Change the resistor to $1\text{k}\Omega$ and then $10\text{k}\Omega$, what happens to the brightness?

REMEMBER: Lab notebook, Fritzing, breadboard, then code

Constants and Variables

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

- Constant is a declaration that does not change throughout the code.
For example a the pin that an LED is attached to.
- 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 $\pm 675,376,778$
- float**: a Floating point number with 7-digits precision

Constant 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

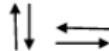


Use `analogWrite` to change the brightness of the LED, using values:

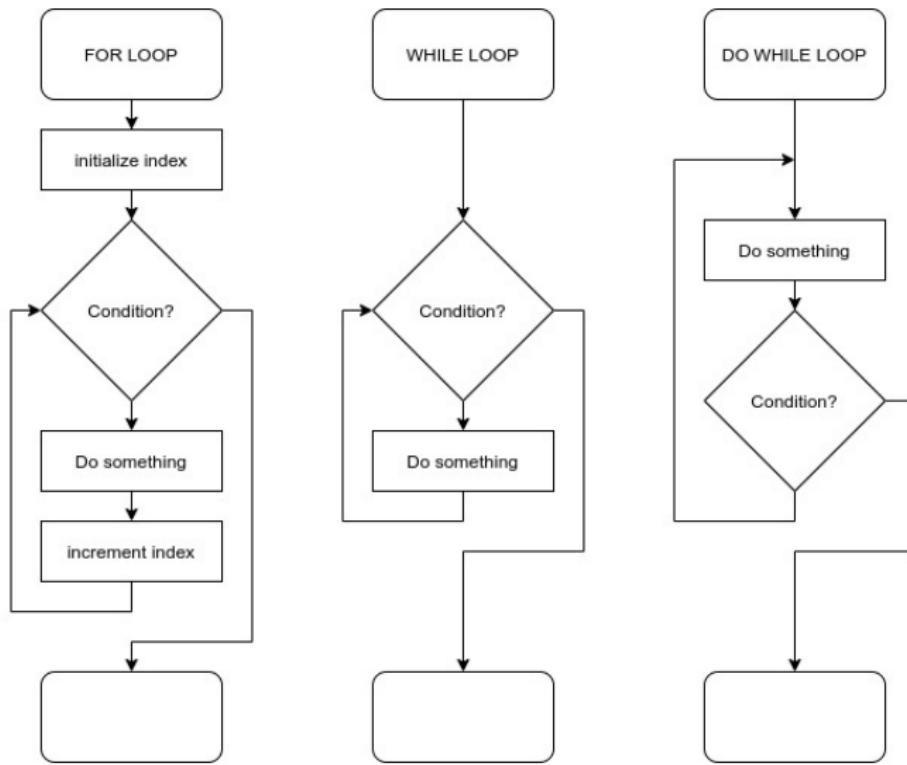
- 255
- 63
- 171
- 16

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
```

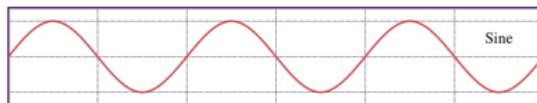
For vs While Loops

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.

Number Systems



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	
int08_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 7.5×10^{18} grains of sand on Earth. A long long integer and the floating point numbers are larger than this.

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:

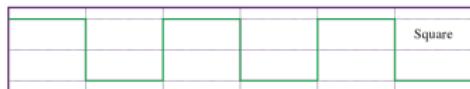
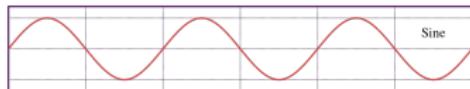
- `#include <file.h>` for system header files.
- `#include "file.h"` for user created header files in the directory that contains the current code.

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

Basic Structure of Arduino Sketch Revisited

```
1 #include <file.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(13, 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 }
```

Assignment L02_05_helloLEDsin

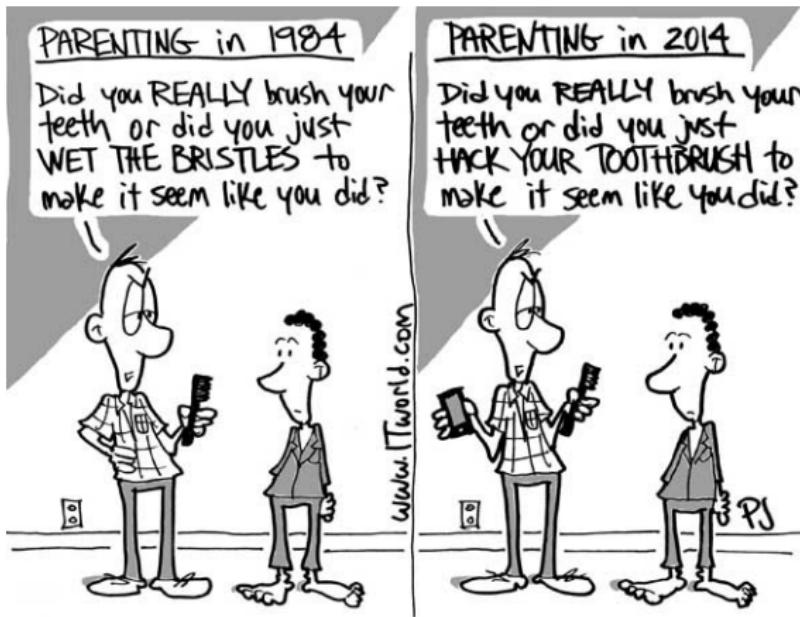


Use a `sin()` function to vary brightness of your LED

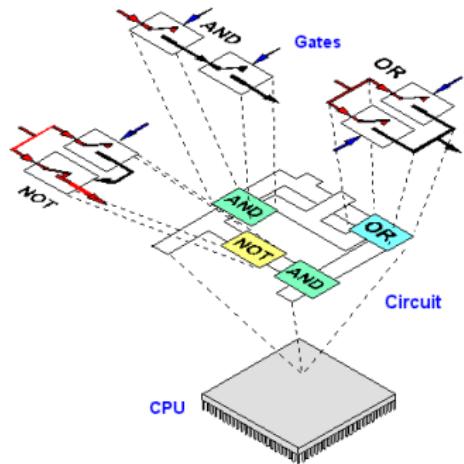
- Use `math.h`
- Function `sin` take a double as an input and returns a double.
- Set the period to 5 seconds. One cycle of $\sin(2\pi n)$ for each integer value of n .

The function `millis()` returns milliseconds since Teensy has been powered on. $n = (\text{millis}() / 5000) / \text{period in seconds}$.

IoT Fun



Data Types: Boolean



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 In Action

```
1 x = !x;           // invert x
2
3 if (!x) {         // if x is false
4     // statements
5 }
6
7 // if both pins read HIGH
8 if ((digitalRead(pin1) == HIGH) && (digitalRead(
9     pin2) == HIGH) {
10    //statements
11 }
12
13 // if either value is greater than zero
14 if (x > 0 || y > 0) {
15     // statements
16 }
```

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 }
```

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

specifier	Output	Example
d or i	Signed decimal integer	392
u	Unsigned decimal integer	7235
o	Unsigned octal	610
x	Unsigned hexadecimal integer	7fa
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.90FEP-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.	%

```
Serial.printf("Let's print an integer %i and a float %0.4f \n", int, float);
```

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, by using:
 - Serial.print();
 - Serial.println();
 - Serial.printf();

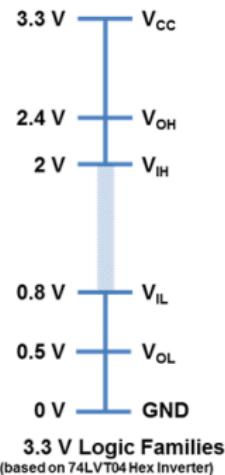
One Pin - Many Functions



Software Programmable: Input or Output and Digital or Analog.

Digital Input/Output

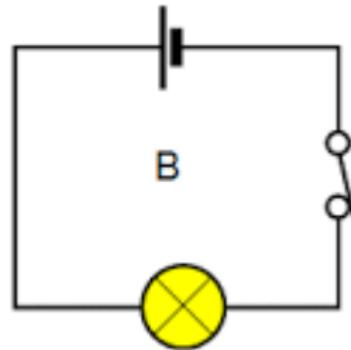
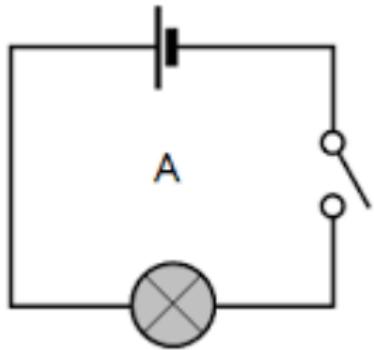
Digital electronics rely on binary logic to store, process, and transmit data or information. Binary Logic refers to one of two states – ON or OFF. This is commonly translated as a binary 1 or binary 0. A binary 1 is also referred to as a HIGH signal and a binary 0 is referred to as a LOW signal.



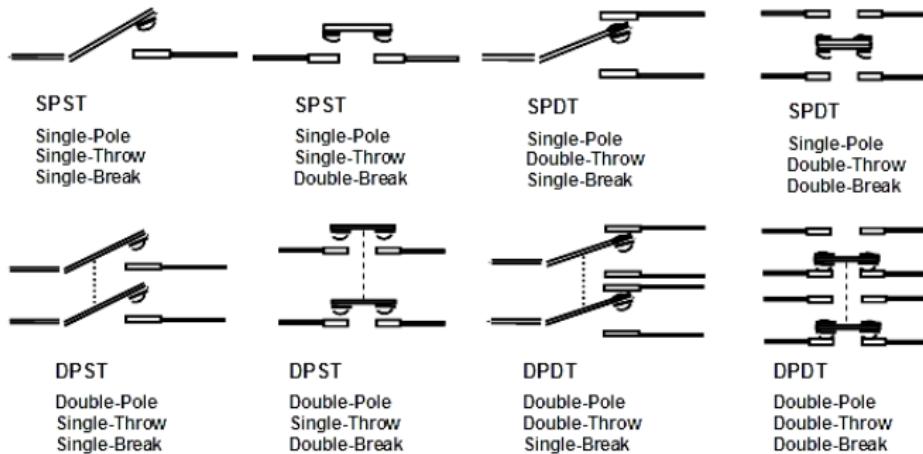
- `digitalWrite(pin,value);`
- `inputValue = digitalRead(pin);`

where, value equals HIGH or LOW.

Switches



Types of Switches



Our First Button and Pull Down Resistors



Wait - why is there a resistor connected to ground?

Assignment: Buttons



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

① L03_01_button

- Connect button (Pin 23)
- Print button state to the screen.
- Now, remove the pull-down resistor and restart your code.

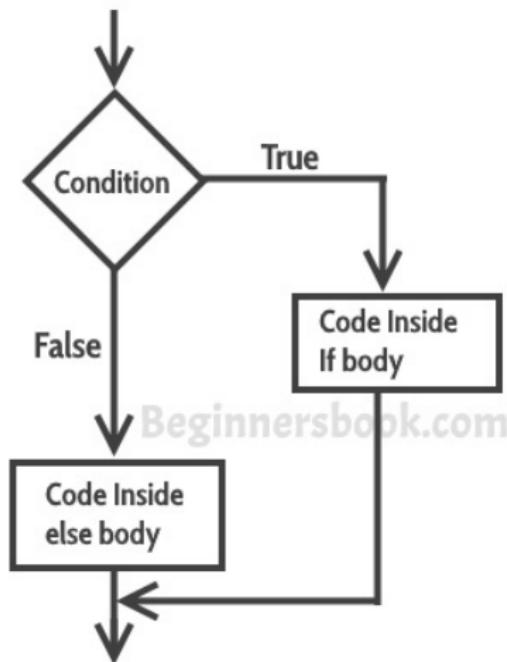
② L03_02_button_pullup

- Replace the pull-down resistor with a pull-up resistor.
- Not pressed: 3.3V
- Pressed: GND
- How does the logic change?

③ L03_03_button_input_pullup

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

IF-ELSE Statements

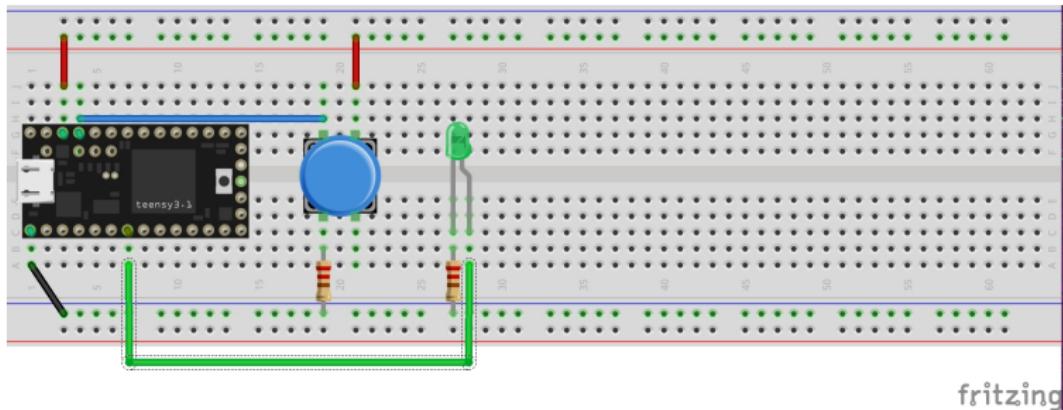


Beginnersbook.com

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 (button == HIGH) {
11     Serial.printf("Button is not pressed \n");
12 }
13 else {
14     Serial.printf("Button is pressed \n");
15 }
```

Button and LED



Assignment: Buttons and LEDs



① L03_04_buttonLED

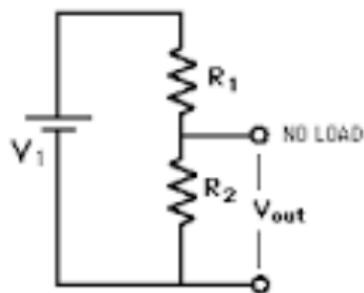
- Add an LED to Pin 5 and use the button to turn the LED on and off.
- Also, print button state to the screen

② L03_05_twobuttonLED

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

Voltage Divider

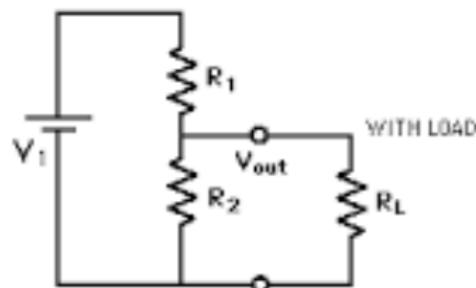
OPEN CIRCUIT BEHAVIOR



$$V_{out} = V_1 \frac{IR_2}{I(R_1 + R_2)} = \frac{V_1 R_2}{(R_1 + R_2)}$$

for open circuit

BEHAVIOR UNDER LOAD



$$V_{out} = \frac{V_1(R_2||R_L)}{(R_1 + R_2||R_L)}$$

for loaded circuit

Voltage Dividing

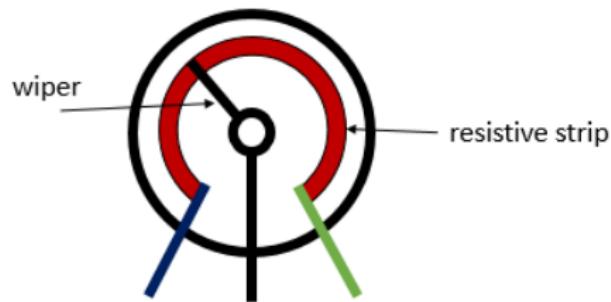


fritzing

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

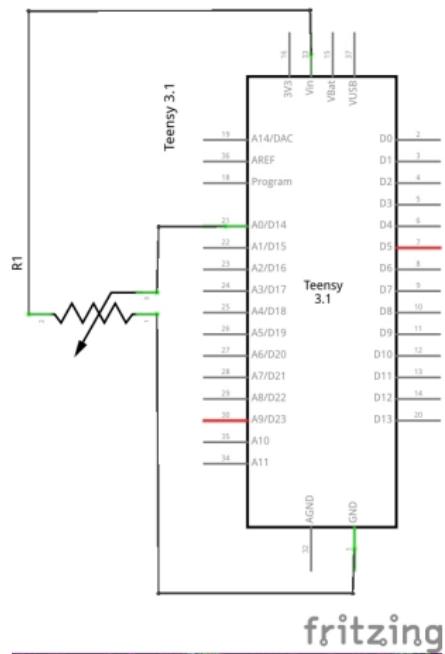
- Use various combinations of $22k\Omega$, $47k\Omega$, $100k\Omega$, $220k\Omega$ resistors.
- Calculate the Series resistance and the voltage between the two resistors in your Lab Notebook.
- Measure with your multimeter and compare.

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_06_AnalogInput



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

Anatomy of a Function

Anatomy of a C function

Datatype of data returned,
any C datatype.

"void" if nothing is returned.

Parameters passed to
function, any C datatype.

```
int myMultiplyFunction(int x, int y){  
    int result;  
    result = x * y;  
    return result;  
}
```

Function name

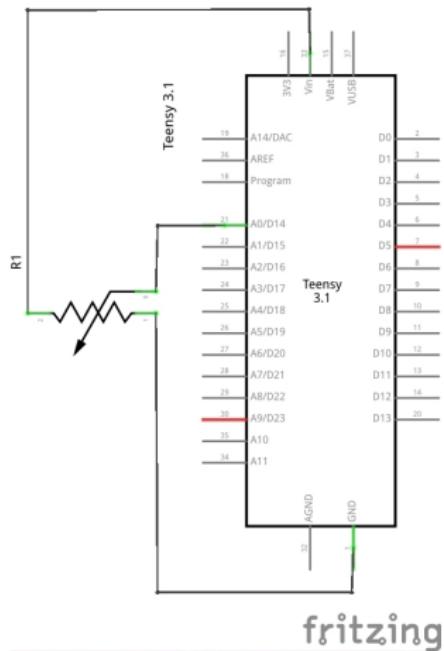
Return statement,
datatype matches
declaration.

Curly braces required.

Basic Structure of Arduino Sketch Revisited

```
1 // include header files, declare variables
2 // declare global variables
3 void setup() {           // runs once
4   //initialize variables, begin processes
5 }
6
7 void loop() {           // loops indefinitely
8   doubleNum = twotimes(Num)
9 }
10
11 int twotimes(int Num) {
12   int answer;    // answer is a local variable
13   answer = 2 * Num;
14   return answer;
15 }
```

Assignment L03_06_AnalogInput



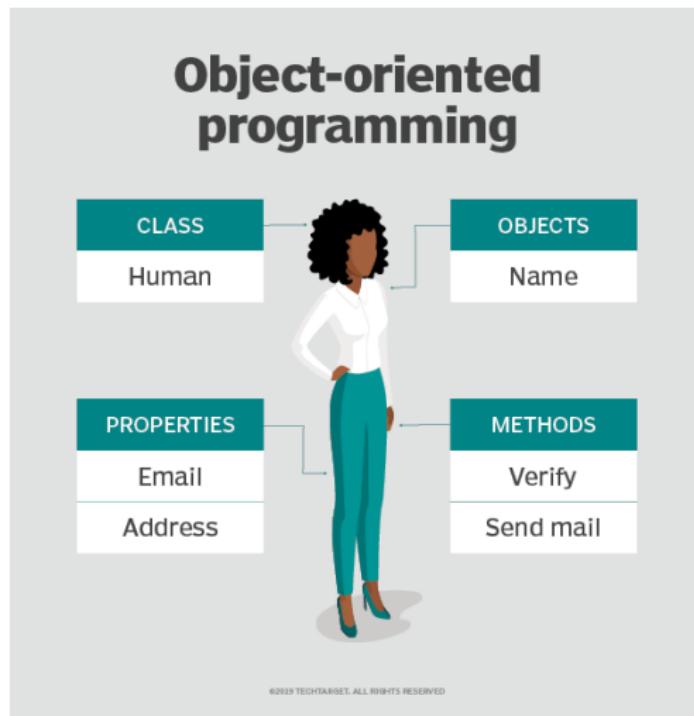
- ➊ Utilize `analogRead()` to measure analog input across potentiometer (voltage divider) using Pin 14.
- ➋ Determine the range of the `analogRead` across the entire range of the potentiometer.
- ➌ Write a function, `in2volts()`, that converts the analog input value to voltage.

IoT Humor

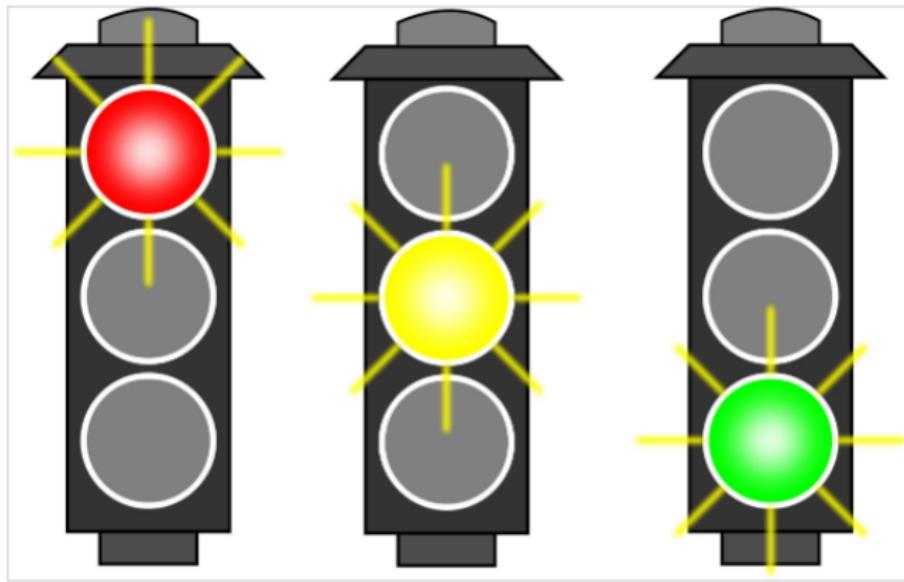


"I remember when you could only lose a chess game to a supercomputer."

Objects

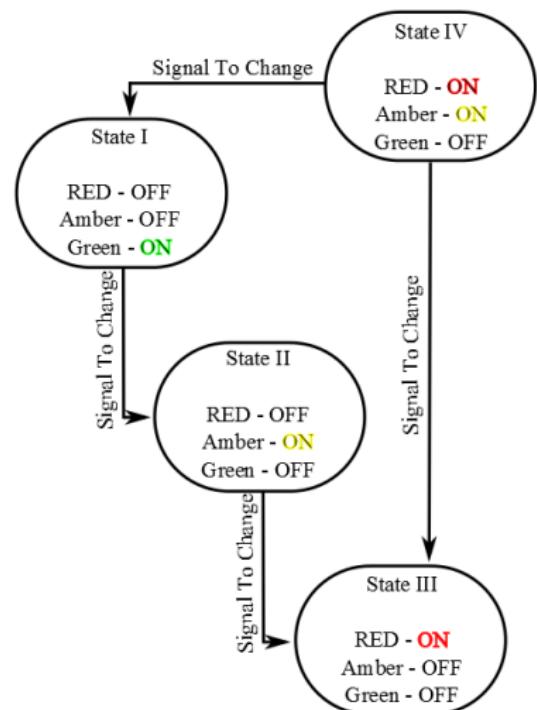
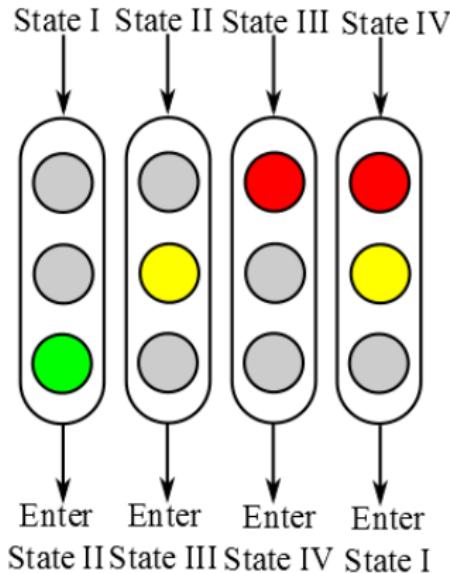


Traffic Light



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

State Machine - Traffic Lights, British Style



SWITCH...CASE syntax - multiple IFs

```
1 // SWITCH...CASE syntax
2 switch (var) {
3     case label1:
4         // statements
5         break;
6     case label2:
7         // statements
8         break;
9     default:
10        // statements
11        break;
12 }
```

Where:

- var: variable whose value is compared to the case values
- label1, label2 are the case values (int or char)

Enumeration (enum)

The C-language has a declaration type, enum, which allows for multiple states.

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

```
1 // ENUM example:  
2 // A variable State with four states  
3 enum State {  
4     GREEN,  
5     YELLOW,  
6     RED,  
7     RED_YELLOW  
8 };
```

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 <bme280.h> // library files
3 #include <Adafruit_SSD1306.h>
4 Adafruit_BME280 bme; // name object in class
5 Adafruit_SSD1306 display(WIDTH, HEIGHT, &Wire);
6 bool onoffState;      // declare global variables
7
8 void setup() {
9     display.begin(SSD1306_SWITCHCAPVCC, 0x3C);
10    bme.begin(0x76);           // begin processes
11    onoffState = false;        // set variables
12 }
13
14 void loop() {
15 }
```

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
4         button
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 flash.

② L04_02_oneButtonLED

- Toggle LED on/off with buttonState.

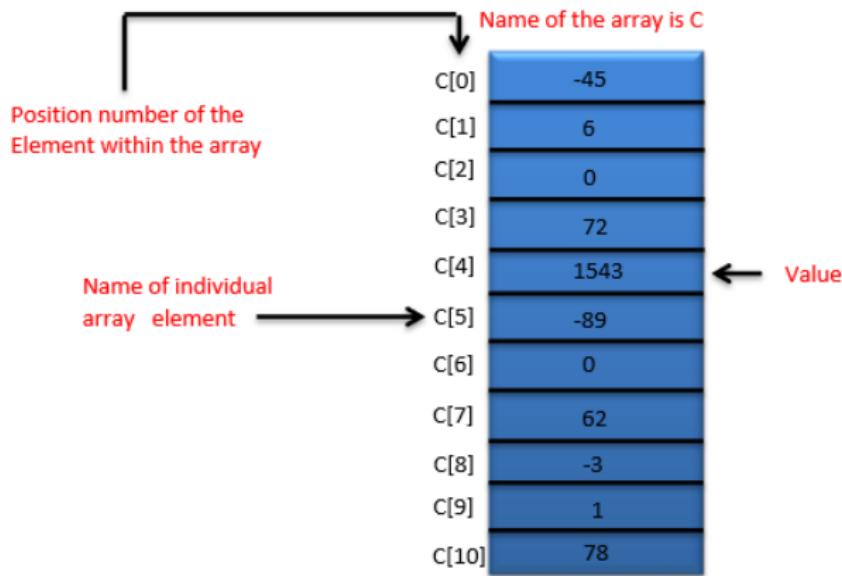
③ L04_03_oneButtonLEDblink

- When ON, toggle from solid to blinking with flash.

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



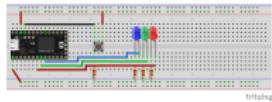
- Syntax: datatype var[] = {element 1, element 2, element 3};
- Example: int ledArray[] = {greenPin, yellowPin, redPin};

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
- Click() - toggle current LED on/off
- doubleClick() - using an array, select the next LED
- longPressStart() - light up the three LEDs in sequence
- longPressStop() - light up the three LEDs in reverse order

Assignment: Serial Read

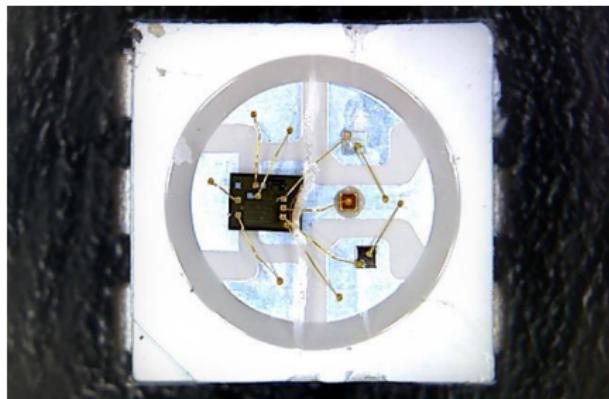


- SerialReadExample.ino

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.
- Long Press for reset

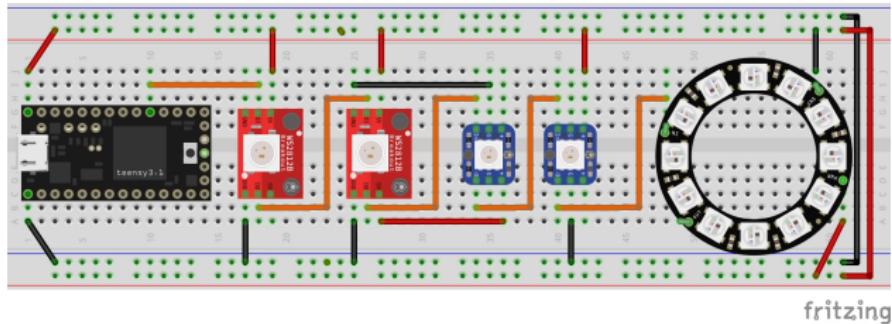
NeoPixels



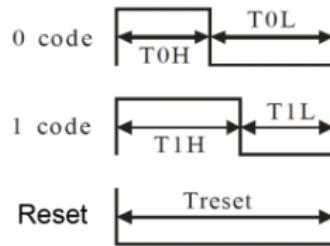
NeoPixels are:

- 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.

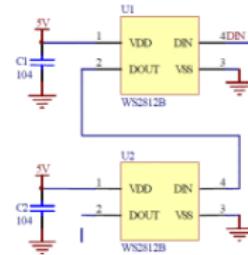
NeoPixel Programming



WS2812 Protocol



LED-Chain



NeoPixel Declaration

```
1 #include <Adafruit_NeoPixel.h>
2
3 Adafruit_NeoPixel strip(LED_COUNT, LED_PIN,
4     NEO_GRB + NEO_KHZ800);
5 /* Argument 1 = Number of pixels
6  * Argument 2 = GPIO pin number
7  * Argument 3 = Pixel type flags, add together:
8  * NEO_KHZ800 800 KHz bitstream (WS2812)
9  * NEO_KHZ400 400 KHz (WS2811)
10 * NEO_GRB      Pixels are wired for GRB bitstream
11   (most NeoPixel products)
12 * NEO_RGB      Pixels are wired for RGB bitstream
13   (v1
14 * NEO_RGBW     Pixels are wired for RGBW
15   bitstream
16 */
17
```

Using NeoPixel Methods

```
1 void setup() {  
2     pixel.begin();  
3     pixel.show(); //initialize all off  
4 }  
5  
6 void loop() {  
7     pixel.setPixelColor(n, red, green, blue);  
8     pixel.setPixelColor(n, color); \\hex code  
9     pixel.fill(color, first, count);  
10    pixel.setBrightness(bri) \\ 0 - 255  
11    pixel.show(); \\nothing changes until show()  
12    pixel.clear();  
13    pixel.show();  
14 }
```

Assignment: NeoPixels



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

① L05_01_neoPixel

- Light up the 4 pixels and the ring using a FOR-loop.

② L05_02_colorHeader

- Implement a header file that contains the pixel colors.

③ L05_03_pixelStrip, using FOR-loop, implement functions that:

- 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 6 segments of different colors using the fill() method

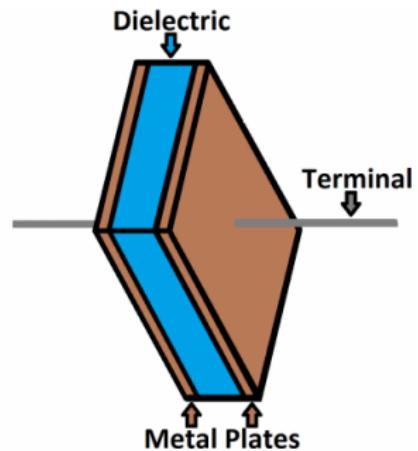
IoT Humor



Capacitors

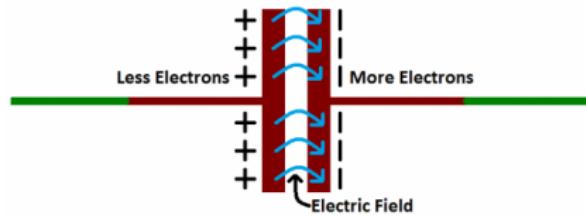
A capacitor is created out of two metal plates and an insulating material called a dielectric. The metal plates are placed very close to each other, in parallel, but the dielectric sits between them to make sure they don't touch.

- 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

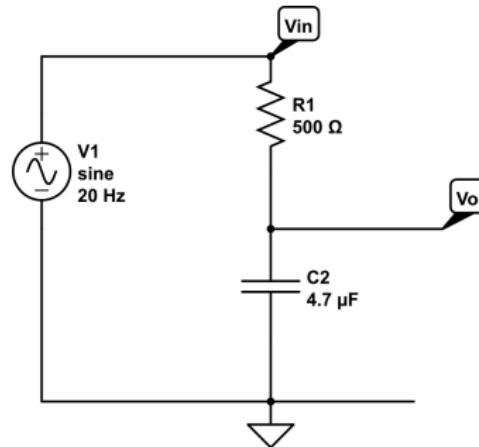
When current flows into a capacitor, the charges get "stuck" on the plates because it can not get past the insulating dielectric. Electrons build up on one of the plates, and it becomes overall negatively charged. The large amount of negative charges pushes away like charges on the other plate, making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



The stationary charges on these plates create an electric field, which influence 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.

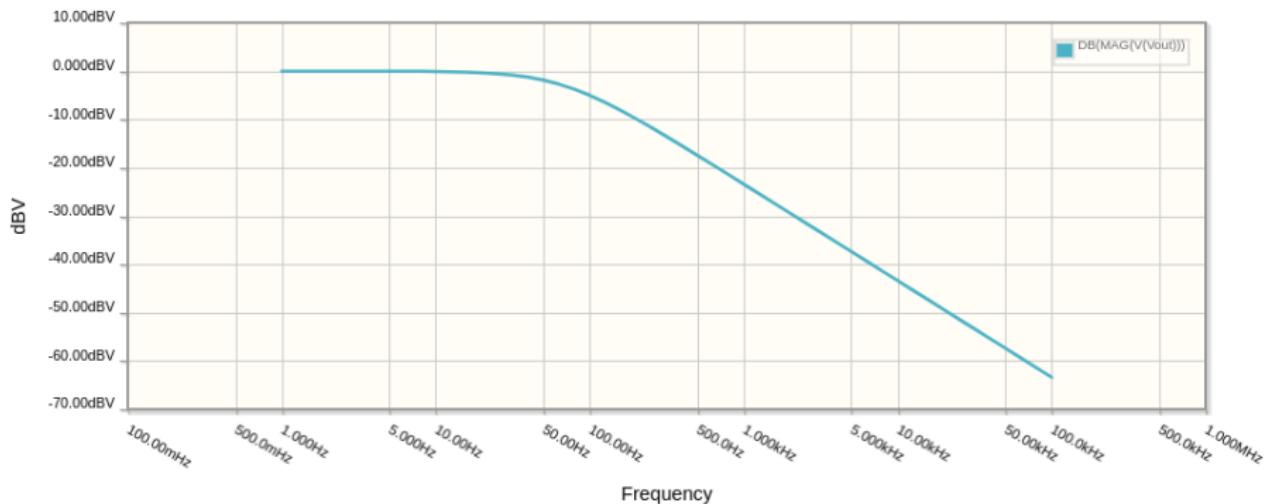
Low Pass Filter - cutoff frequency f_c

- 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

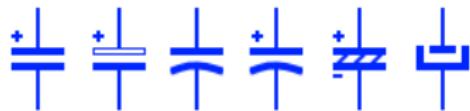


$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(500)(4.7 \times 10^{-6})} = 67.5678 \text{ Hz}$$

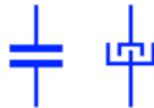
Capacitors - does it matter how they are placed

- 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.

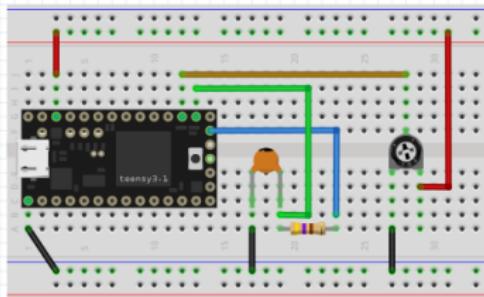
Polarized Electrolytic Capacitor



Generic Capacitor



Assignment: Low Pass Filters



① L06_00_lowPass

- Create code that generates a sine wave of frequency ν : $\sin(2\pi\nu t)$
- Connect the output to an input
- Using the Serial Plotter, plot both the output and the input.
- Create a low pass filter with $f_c \approx 67\text{Hz}$
- Pass the output through the low pass filter before inputting back to the Teensy.
- In code, vary the frequency and observe the difference between the two signals.
- Use the potentiometer to now vary the frequency.

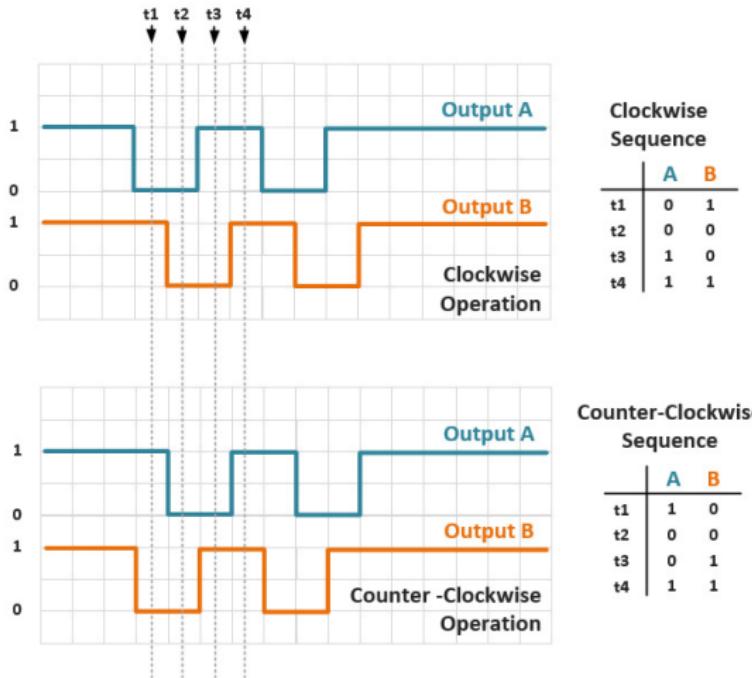
Using Serial Plotter:

- `Serial.begin(9600);`
- `Serial.printf("%i , %i, %0.3f \n", d1,d2,d3);`
- Close Serial Monitor

Encoders



Encoders



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 }
```

Assignment: Encoders



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

① L06_01_encoder

- Write encoder position to the screen

② L06_02_encoderScaled

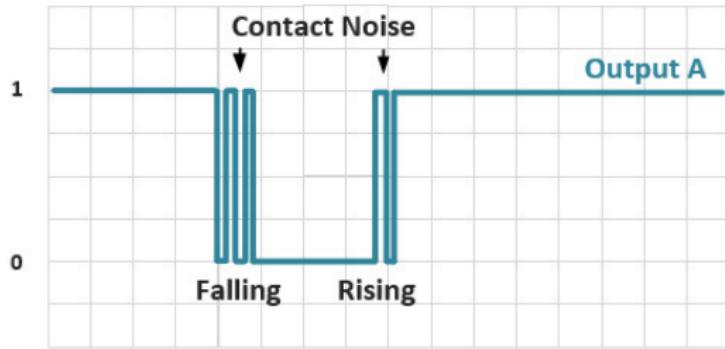
- The encoder has 96 positions
- Manually map the encoder to 12 pos ($0-7 = 0, 8-15 = 2$, etc.). Show your work to an instructor before moving on to the map() function.
- Next, use the map() function.

③ L06_03_encoder_NeoPixel

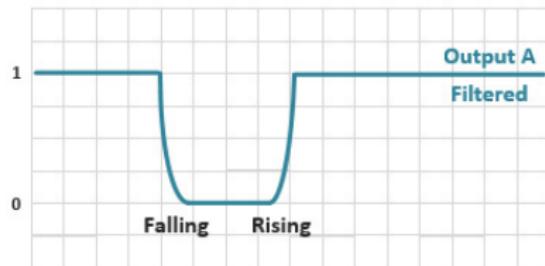
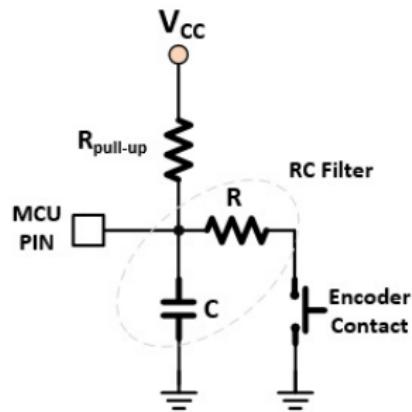
- Use the encoder to light up the pixel ring

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

Encoder Jitter



Encoder - Low Pass Filter



Assignment: Encoders



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

① L06_04_encoder_switch

- Connect your microcontroller to the encoder switch and LEDs
- Use the switch to turn on/off the NeoPixels.
- Also, the encoder LED should be red for off and green for on.

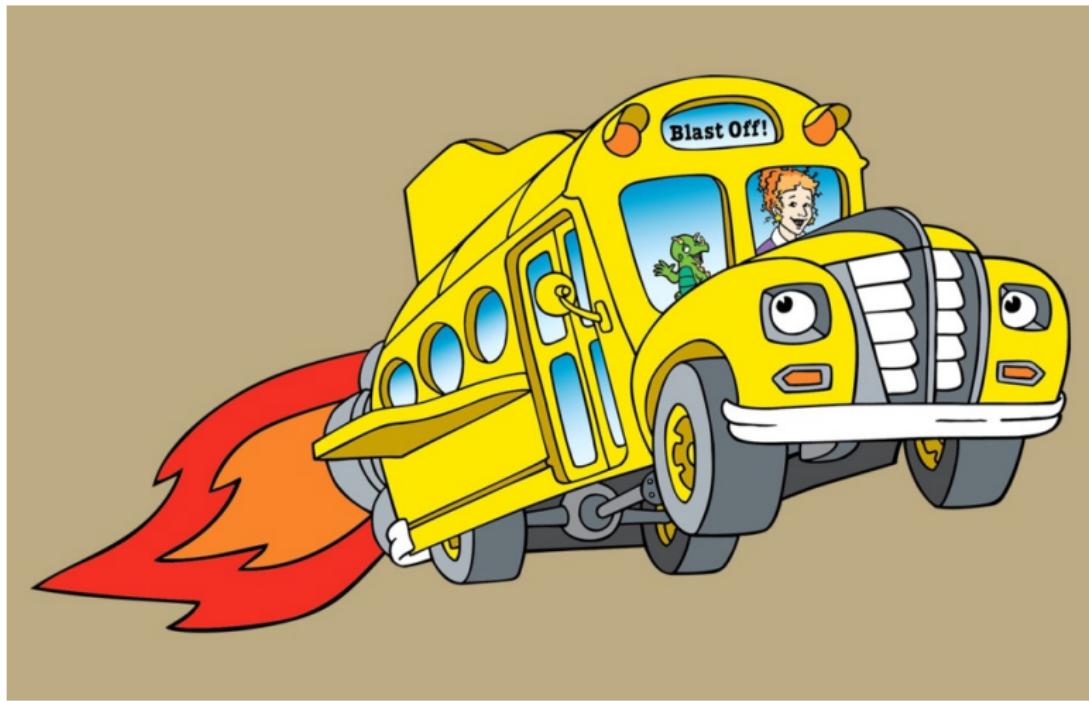
② L06_05_rainbow1 - extra credit

- 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_06_rainbow2 - extra credit

- With OneButton: Use have it continuously cycle (i.e, while pressed colors changes every one second).

Buses and Interfaces

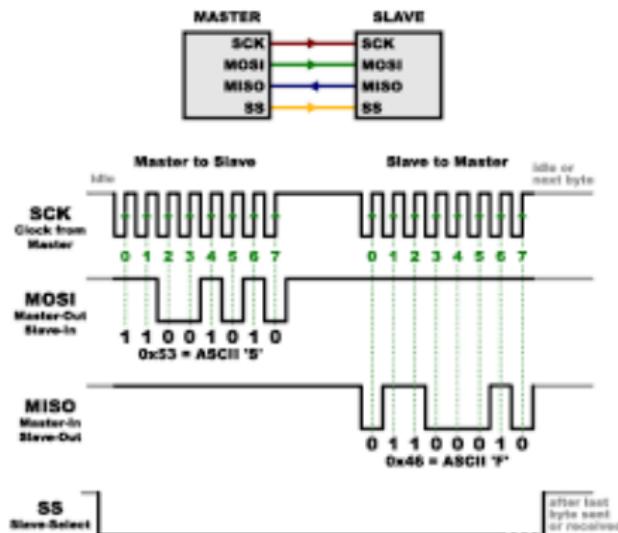


UART



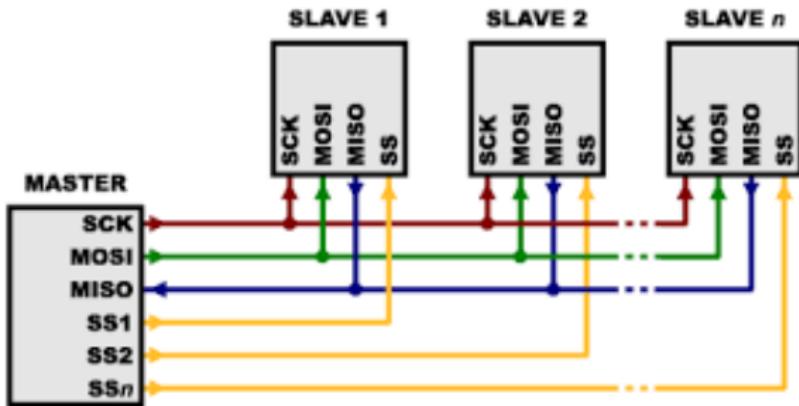
Universal Asynchronous Receiver/Transmitter

Serial Peripheral Interface



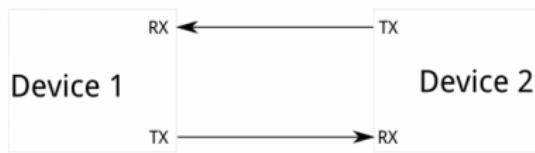
- Master Out, Slave In (MOSI) connects to Data In
- Master In, Slave Out (MISO) connects to Data Out

Serial Peripheral Interface

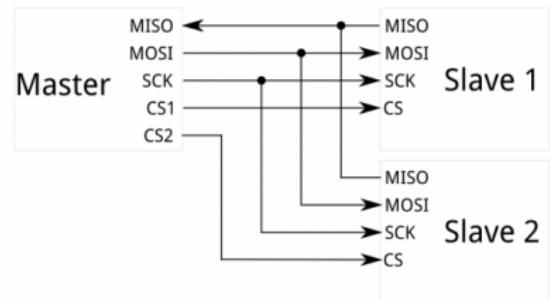


Serial +/−

UART



SPI



Assignment: Write to μ SD Card



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

① L07_01_dataLogger

- String datatype
- SPI and SD libraries
- File object
- SD.begin()
- dataFile.print()
- Simulate 3 data streams and write to SD card

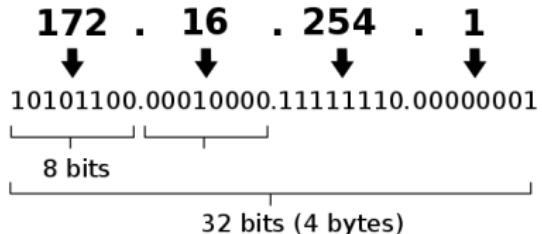
The Internet



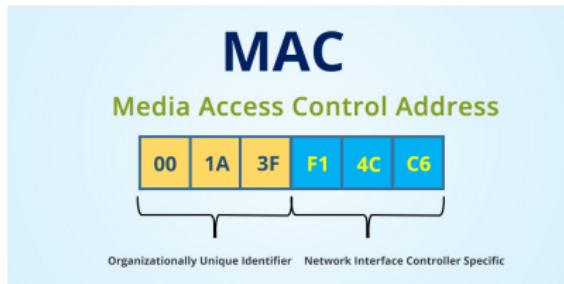
IP Addresses

- 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 quadrilliard
- In Powershell, try:
`ipconfig/all`
- In Terminal (MAC), try:
`ipconfig getifaddr en0`

IPv4 address in dotted-decimal notation



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



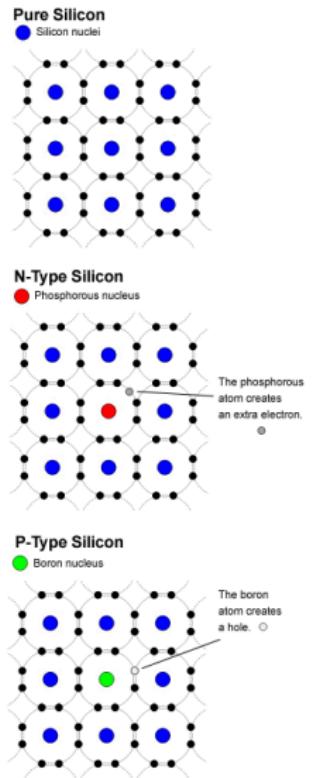
- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

Create your own mac.h
header file

- ➊ L08_00_EthernetTest
 - Modify to use your mac.h file
- ➋ L08_01_Wemo
 - Using the wemo.h library and WemoH_Example as a template, create code that turns on and off multiple Wemo Smart Outlets in the classroom.
- ➌ L08_02_Wemo_Timer
 - Add to your code a timer that turns off a Wemo after 10 secs
- ➍ L08_03_Wemo_Object
 - Modify the wemo.h library to be a Class and Methods.
 - Modify your wemo code the create and use a wemo object.

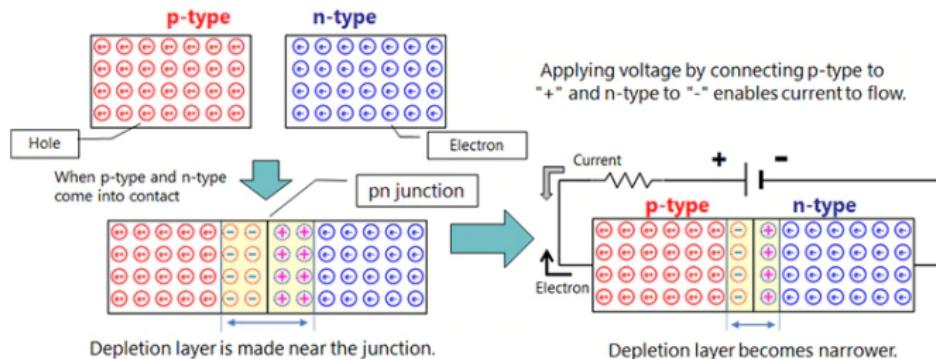
Semiconductor

- 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.



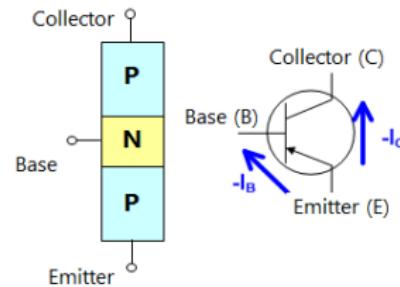
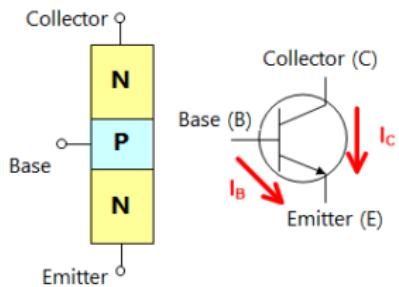
pn junction diode

- 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.



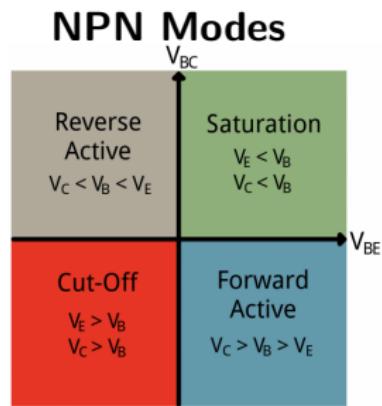
Bipolar Junction Transistor

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.



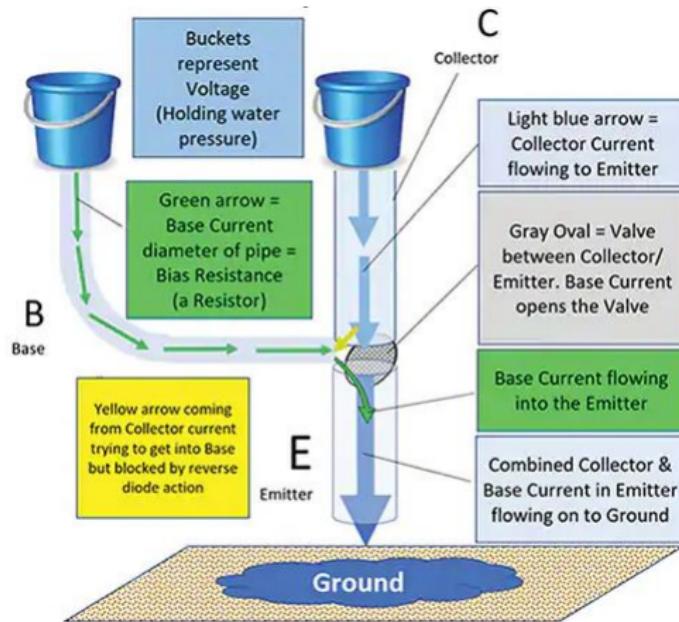
Bipolar Junction Transistor - Modes of Operation

- **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).



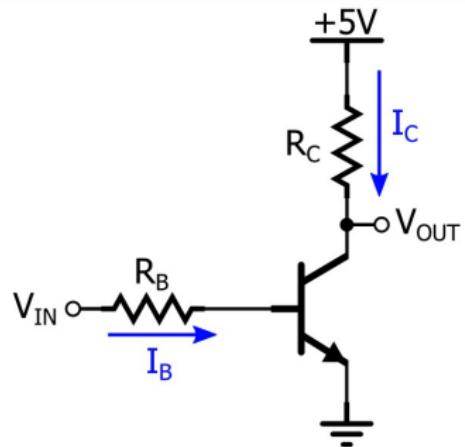
Voltage relations	NPN Mode	PNP Mode
$V_E < V_B < V_C$	Active	Reverse
$V_E < V_B > V_C$	Saturation	Cutoff
$V_E > V_B < V_C$	Cutoff	Saturation
$V_E > V_B > V_C$	Reverse	Active

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.

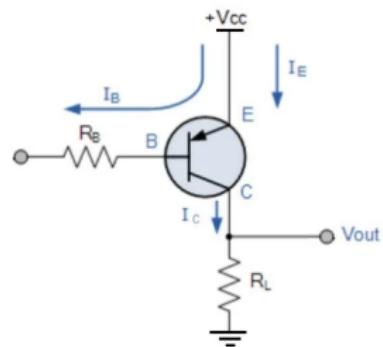


NOTE: V_{OUT} is an amplified but inverted signal of V_{IN} . This simple circuit will step-up an 0 - 3.3V output from the microcontroller to 0 - 5.0V (inverted). The low impedance of the output will also provide sufficient current to drive a higher current device (e.g., a relay).

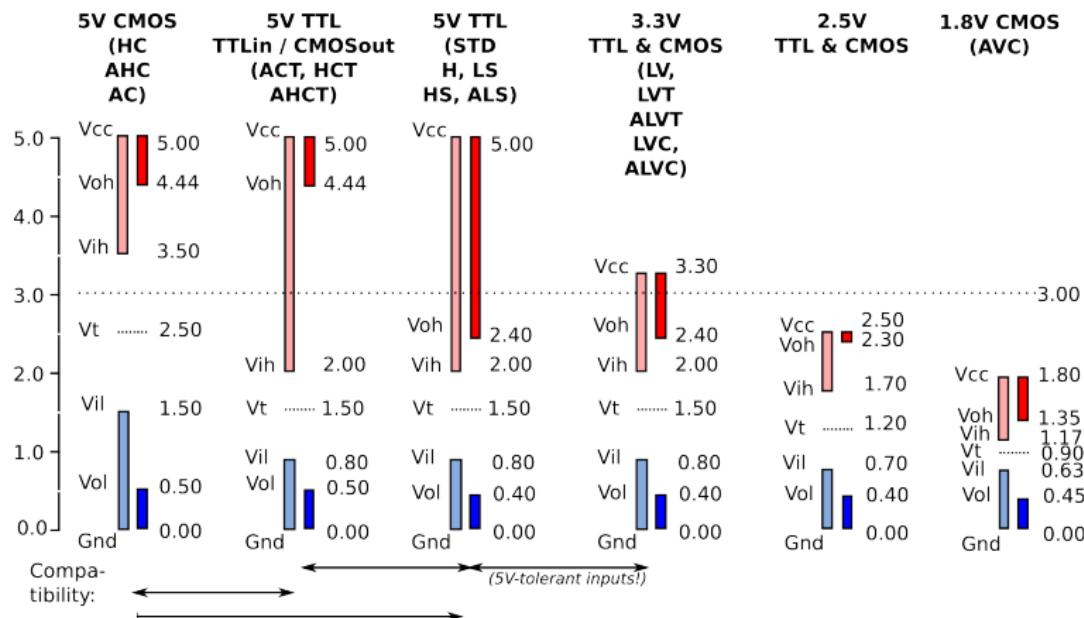
PNP Transistor

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

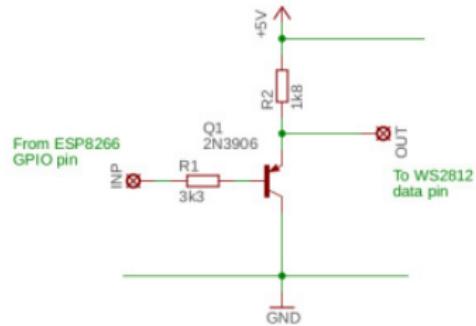


Data source: EETimes, A brief recap of popular logic standards (Mark Pearson, Maxim).

Or, what is wrong with the NeoPixels.

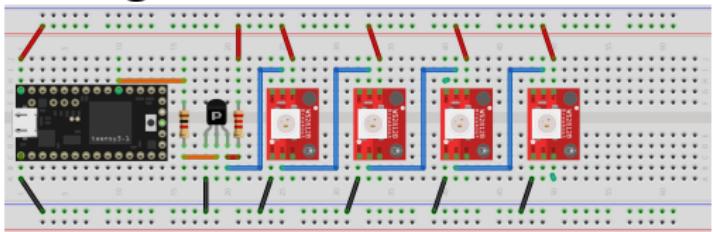
Emitter Follower

- NeoPixels are designed around 5V CMOS transistors
 - $V_{IH} > 3.5V$
 - 3.3V Microcontroller
 - $V_{OH} = 3.3V$
- An Emitter Followers (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.



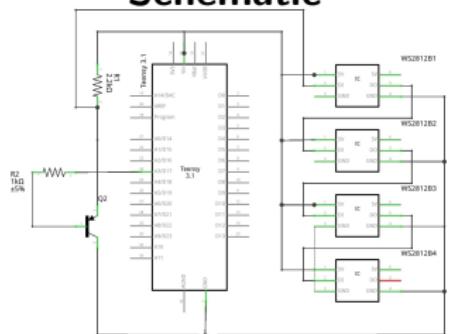
Emitter Follower Layout

Fritzing



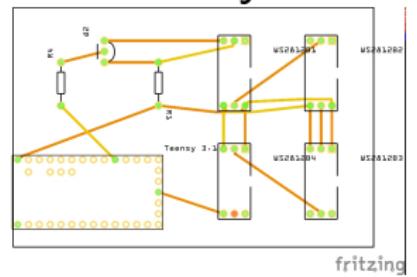
fritzing

Schematic



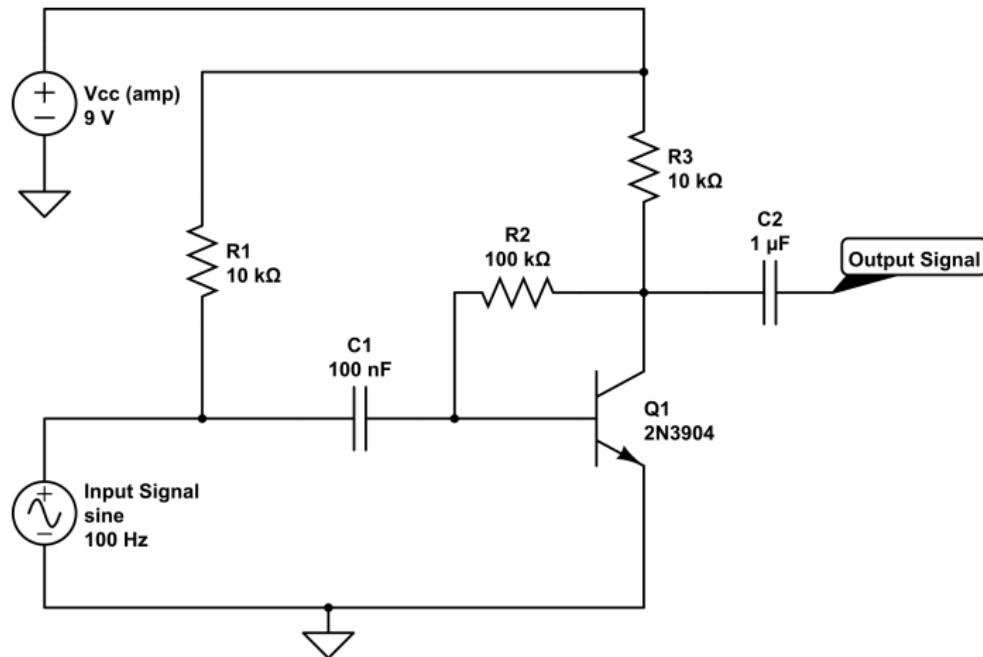
fritzing

PCB Layout



fritzing

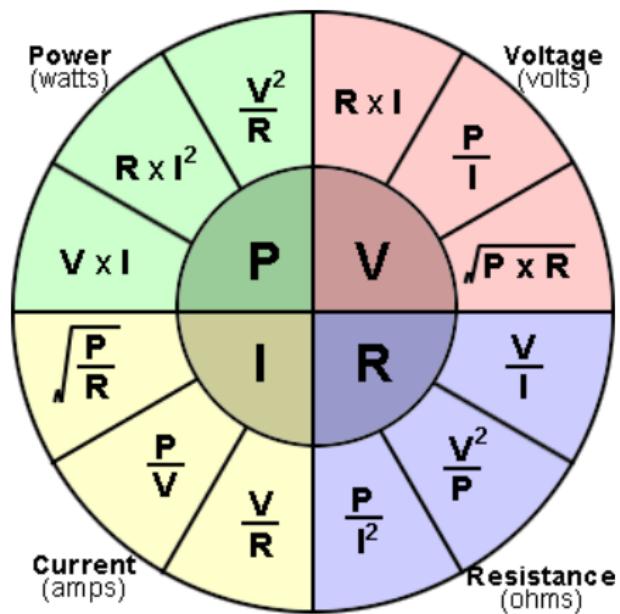
NPN Pre-Amplifier Circuit



Two Stage Pre-Amplifier



Ohm's Law - Revisited



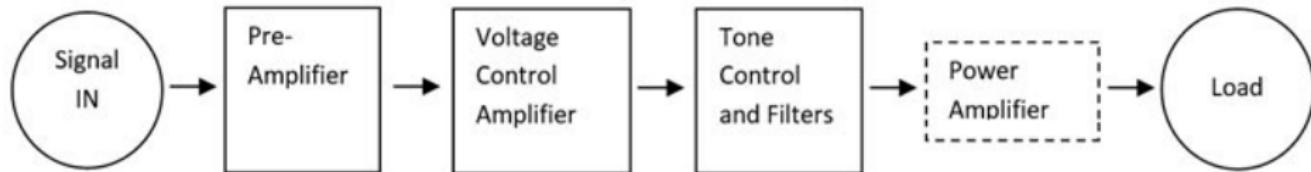
PreAmp vs PowerAmp

PreAmp:

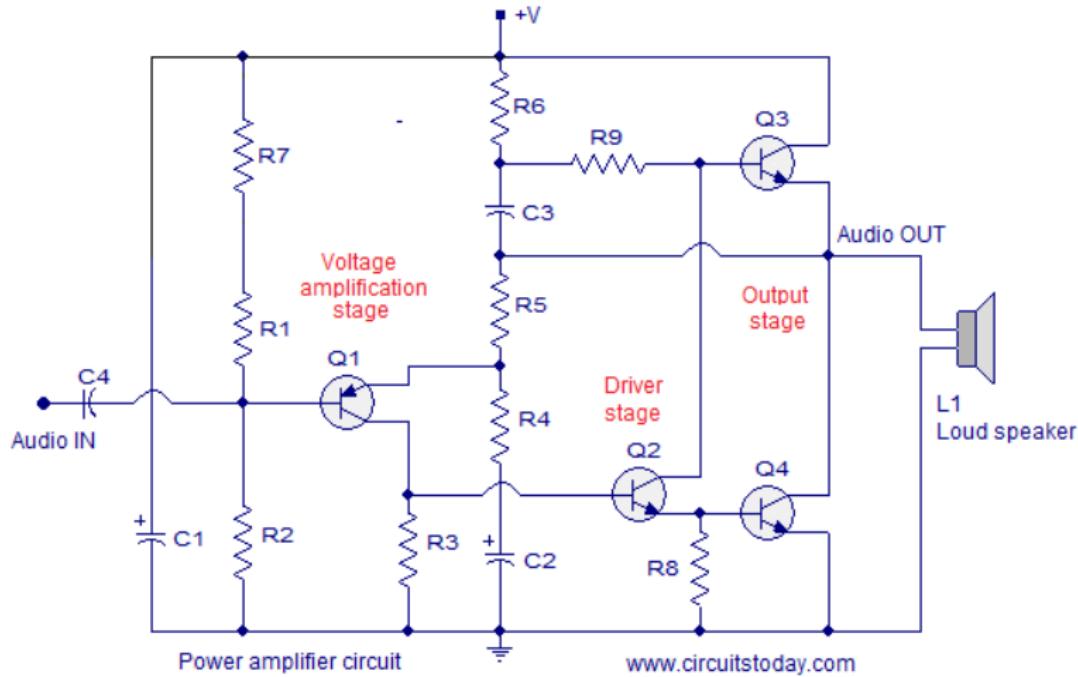
- A preamp boosts the signal up to 'line level'.
- Guitar PreAmp
 - A pure guitar signal typically sounds weak and anaemic, as is seen if a guitar is directly plugged PA system.
 - A preamp is able to raise a guitar's signal up to an audible volume.
 - It can also be used to affect the audio characteristics.

PowerAmp:

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

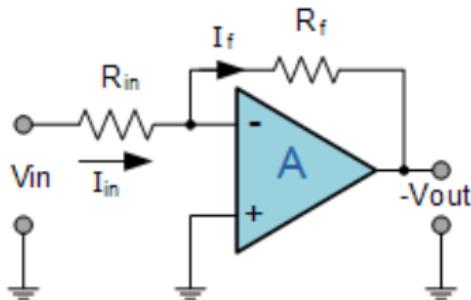


Power Amplifier



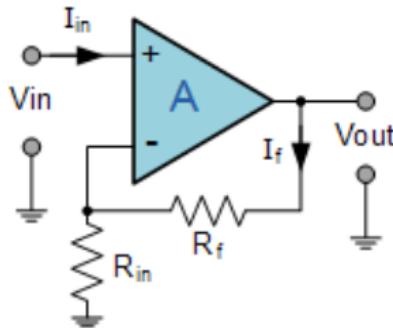
Op Amp Lesson - Under Construction

Inverting Op-amp



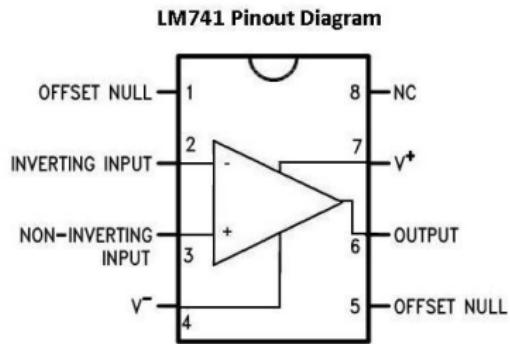
$$A = \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$$

Non-inverting Op-amp



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

Assignment: Amplifiers



① L09_01_NeoPixel

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

② L09_02_NPNAMP (no Teensy)

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

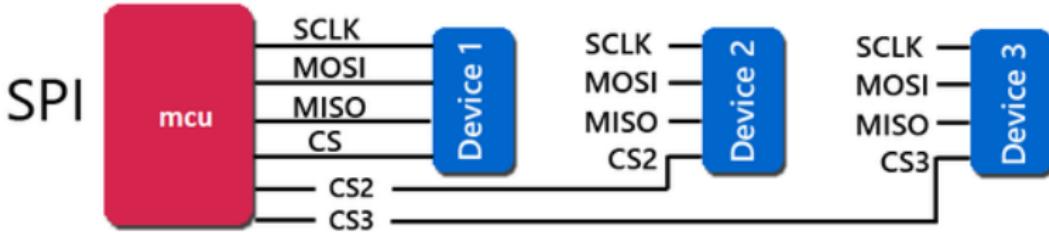
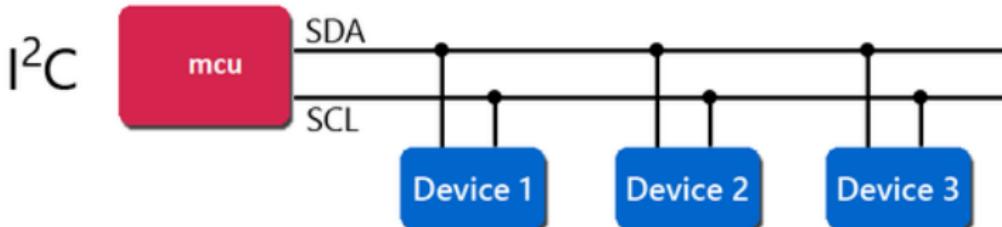
③ L09_03_OpAmp

- Create an OpAmp circuit to amplify your mic
- Use a NeoPixel string (either your ring or a strip) to display the audio level.

IoT Humor



Inter-integrated Circuit (I^2C)



I²C vs SPI

I2C v/s SPI

I2C	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 I2C
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

- Create a Fritzing diagram for adding the BME280 and the OLED to your Teensy.
- 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
- Wire up your schematic and determine the I2C addresses of each device.

Assignment: I²C

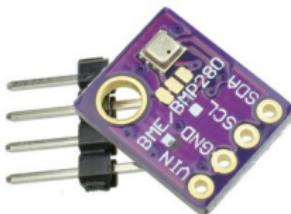


- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

① L10_01_OLEDWrite

- Install Adafruit_SSD1306 library
- Review and run SSD_1306_128x32_i2c example
- Create variables for your birthday. Using the syntax from testdrawstyles() print using printf():
 - Hello World
 - Your Name
 - Your Birthday
 - Your Favorite Color
- Experiment with rotating the screen using the rotationSet(int) method.

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: I²C



- 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

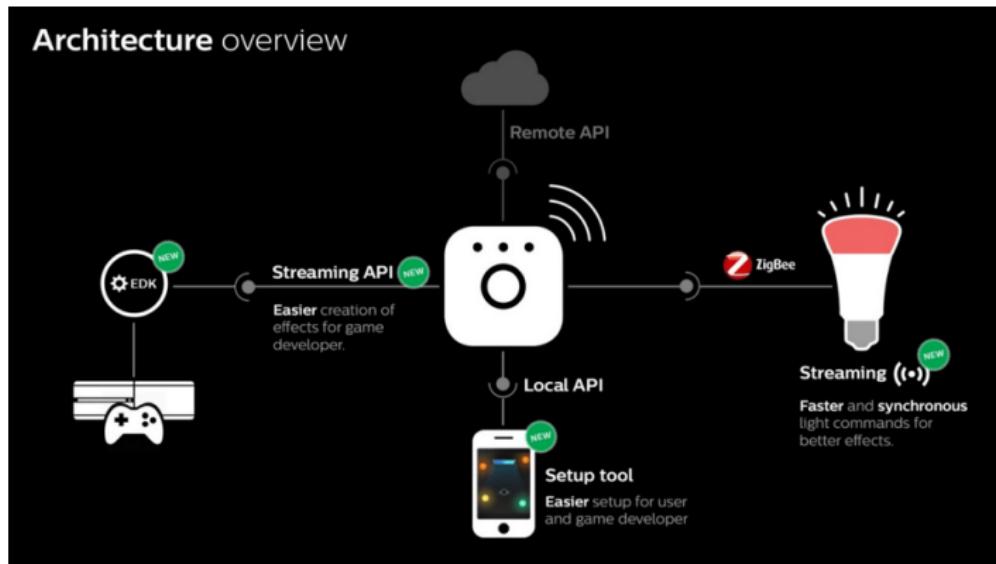
② L10_03_BME280_OLED

- Print data to the OLED display

③ L10_04_BME280_SDMicro

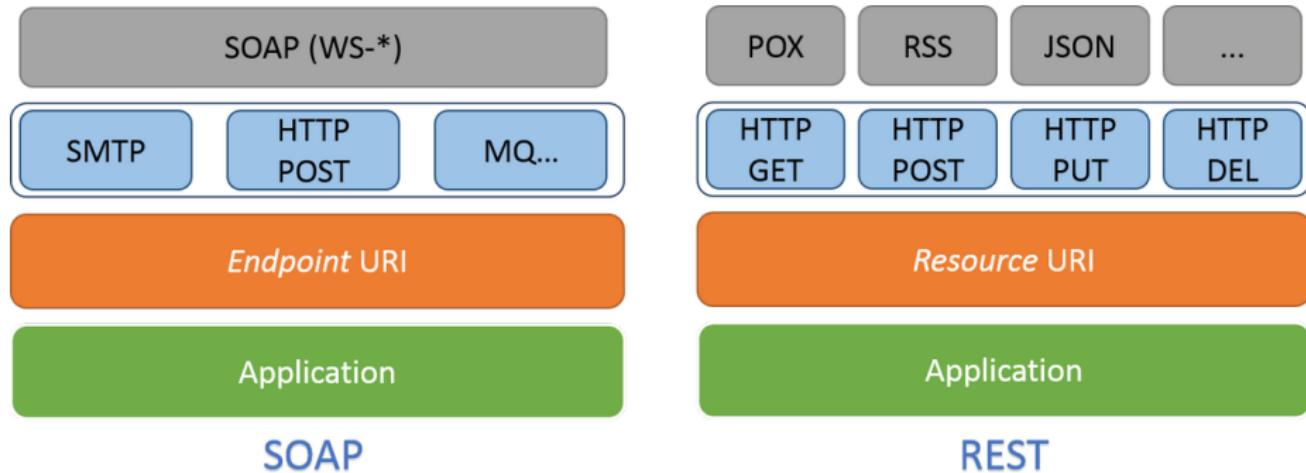
- Add in saving data to the µSD card
- Use your NeoPixels to give a visual indication of room conditions

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 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)

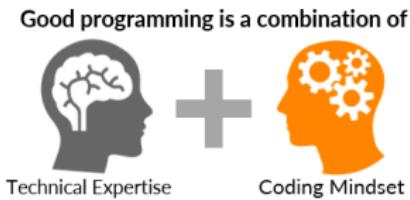
Our Second Microcontroller



Expectations for the rest of the course



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?
 - ➒ variableNames
 - ➒ nameFunction
 - ➒ CONSTANTS
 - ➒ Classes and Enum

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)

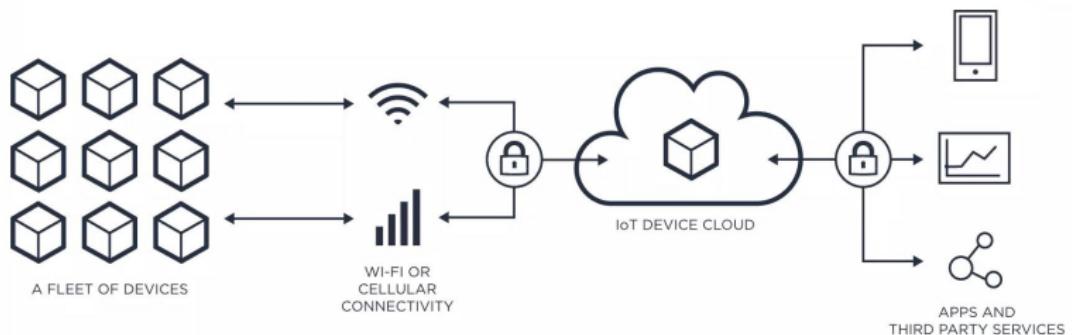
Why Particle



- 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

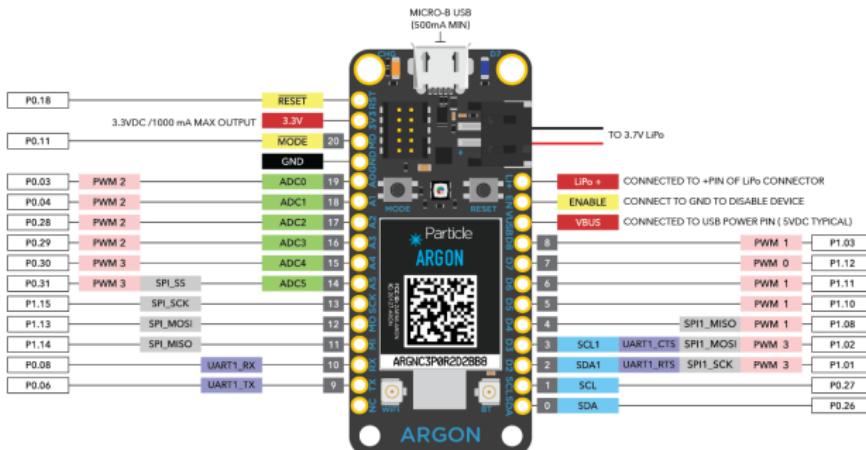


3

CELLULAR, BLE
& WI-FI CONNECTIVITY



Particle Argon Pin Layout



PWM 0 GROUP 0 PWM PINS

PWM 1 GROUP 1 PWM PINS

PWM 2 GROUP 2 PWM PINS

PWM 3 GROUP 3 PWM PINS

ADC ANALOG TO DIGITAL INPUT PINS

SDA/SCL I2C COMMUNICATION PINS (WIRE)

SPI SPI COMMUNICATION PINS (SPI)

PX.XX nRF52840 PIN NAMES

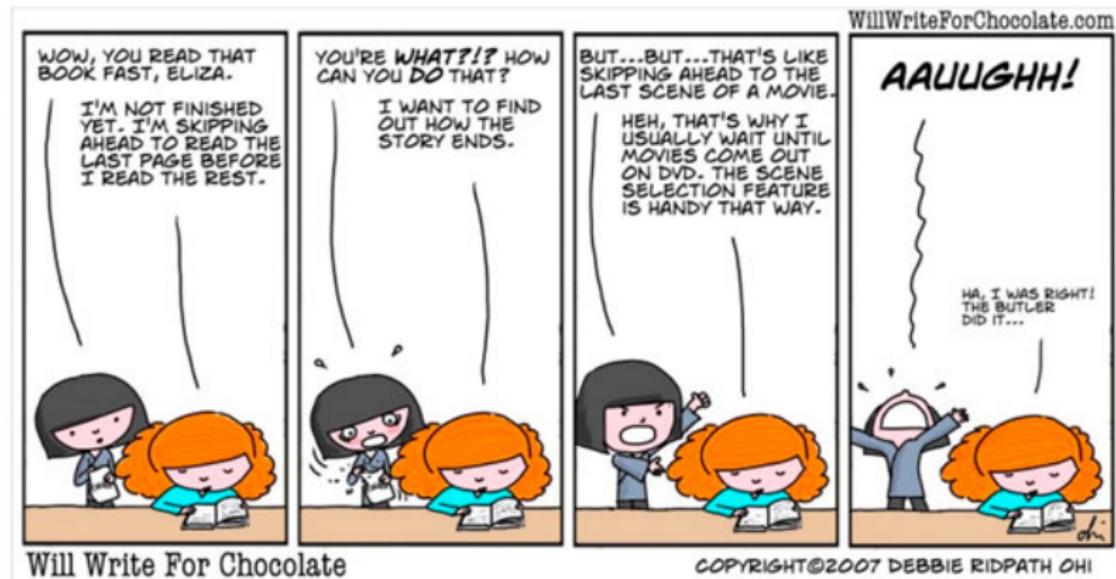
UART1 SERIAL COMMUNICATION PINS (SERIAL1)

SDA1/SCL1 I2C COMMUNICATION PINS (WIRE1)

SPI1 SPI COMMUNICATION PINS (SPI1)

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/.](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/.](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.

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.
```

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

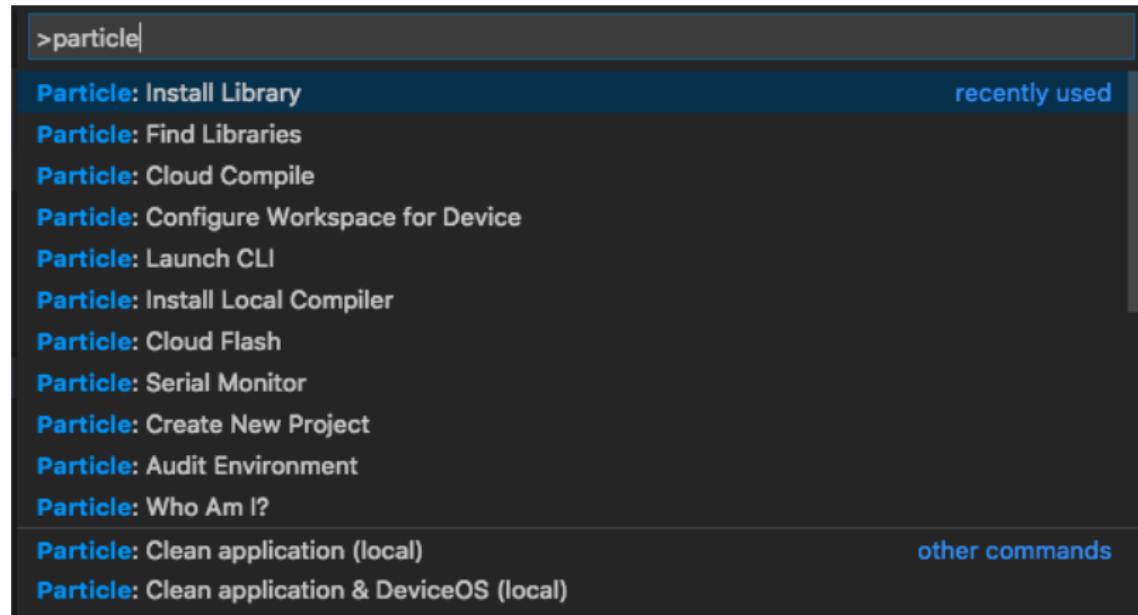
Directory Structure - VERY IMPORTANT

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

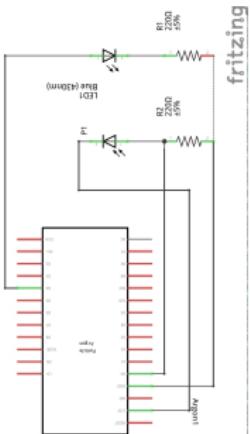
- EXPLORER** view: Shows the project structure.
 - OPEN EDITORS**: 1 UNSAVED
 - PM25_Test.ino** (active)
 - PM25_TEST**
 - .vscode**: *launch.json*, *settings.json*
 - lib\Seeed_HM330X**: *examples\basic_demo*, *basic_demo.ino*
 - src**: *HM330XErrorCode.h*, *I2COperations.cpp*, *I2COperations.h*, *Seeed_HM330X.cpp*, *Seeed_HM330X.h*
 - PM25_Test.cpp**
 - PM25_Test.ino**
 - target\1.5.0\argon**
 - project.properties**
 - README.md**
- CODE** view: The content of the **PM25_Test.ino** file.

```
src > PM25_Test.ino > ...
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 ****SetUp HM330X*****
11 HM330X sensor;
12 uint8_t buf[30];
13 int PM25;
14
15 const char* str[] = {"sensor num: ", "PM1.0 concentration(CF=1,Standard particulate matter",
16 "PM2.5 concentration(CF=1,Standard particulate matter,unit:ug/m3): ",
17 "PM10 concentration(CF=1,Standard particulate matter,unit:ug/m3): ",
18 "PM1.0 concentration(Atmospheric environment,unit:ug/m3): ",
19 "PM2.5 concentration(Atmospheric environment,unit:ug/m3): ",
20 "PM10 concentration(Atmospheric environment,unit:ug/m3): ",
21 };
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;
31 }
```

Command Palette - Ctrl-Shift-P



Assignment: L12_HelloParticle



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

① L12_01_HelloParticle

- Blink the onboard LED (Pin D7)

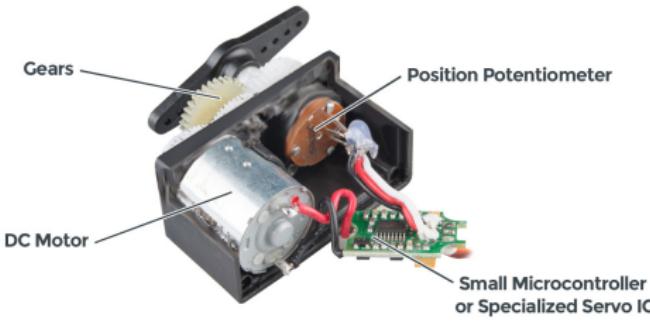
② L12_02_HelloNightLight

- 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

Servo Motors



A servo is any motor-driven system with a feedback element built in.

A servo motor basically has three core components:

- a DC motor,
- a controller circuit,
- a potentiometer or similar feedback mechanism.

Assignment: Servo.h library

There are a number of libraries that are automatically added into your Particle DeviceOS code, Servo.h is one of them.

① Header

- Servo myServo; - create object myServo of class Servo

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: L13_Servo



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

① L13_01_Servo

- Have your Servo cycle from 0 to 180 degrees

② L13_02_ServoSine

- Have the Servo move in a sine wave pattern
- Add a button (using pinMode: INPUT_PULLDOWN) that starts and stops the motion.

SparkFun_Qwiic_Twist RGB Encoder

```
1 #include <SparkFun_Qwiic_Twist_Arduino_Library.h>
2 TWIST twist; //Create instance of this object
3
4 void setup() {
5     Serial.begin(9600);
6     Serial.println("Qwiic Twist Example");
7
8     if(twist.begin() == false)
9     {
10         Serial.print("Twist does not appear to be
11 connected.");
12         Serial.println("Please check wiring. Freezing
13 ...");
14         while(true);
15     }
16 }
```

SparkFun_Qwiic_Twist Commands

- `bool twist.begin()` - initializes the sensor with basic settings and returns false if sensor is not detected
- `int twist.getCount()` - returns the number of indents the user has twisted the knob
- `int twist.getDiff()` - returns the difference between the last two `getCount()` calls
- `bool twist.isMoved()` - returns true if knob has been twisted
- `int twist.timeSinceLastMovement()` - returns the number of milliseconds since the last encoder movement
- `bool twist.clicked()` - returns true if a click event has occurred
- `int twist.timeSinceLastPress()` - returns the number of milliseconds since the last button event (press and release)
- `bool twist.isPressed()` - returns true if button is currently being pressed
- `void twist.setCount(pos)` - set the encoder count to a specific pos
- `void twist.setColor(R,G,B)` - sets the color of the encoder.

Assignment: L13_Servo



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

① L13_03_Qwiic

- Clone and place in <project folder>/<project name>/lib the appropriate library.
- Print encoder position, only if Moved
- Using ENUM, create 3 button pressed states lighting up different colors for each
- Display time since last moved and last pressed

② L13_04_QwiicServo

- Create two states: OFF and ON. Red for OFF, Green for ON.
- When OFF, encoder does nothing.
- When ON, encoder moves Servo. Half rotation moves encoder from 0 to 180
- When button is pressed and held, turning encoder changes ON color.

Too Much Time On My Hands

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

```
1 void sync_my_time() {  
2     String DateTime, TimeOnly;  
3     char currentDateTime[25], currentTime[9];  
4  
5     Time.zone(-7); // Set Time Zone to MDT(UTC-7)  
6     unsigned long cur=millis();  
7  
8     // Request time synch from Particle Cloud  
9     Particle.syncTime();  
10    waitUntil(Particle.syncTimeDone);  
11 }
```

Using Particle Time

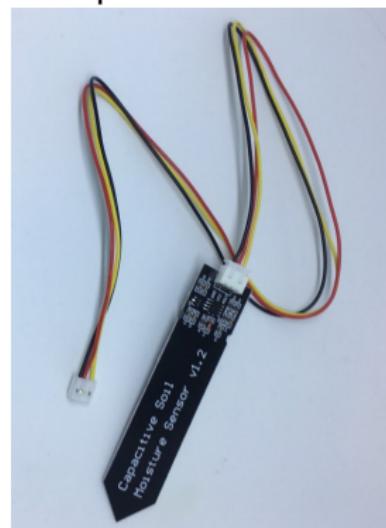
```
1 // Get Current Time
2 DateTime = Time.timeStr();
3 TimeOnly = DateTime.substring(11,19);
4 Serial.println(DateTime);
5 Serial.println(TimeOnly);
6
7 // Using Time with Formatted Print Statements
8 DateTime.toCharArray(currentDateTime,25);
9 TimeOnly.toCharArray(currentTime,9);
10 Serial.printf("Date and time is %s\n",
11     currentDateTime);
11 Serial.printf("Time is %s\n",currentTime);
```

Soil Moisture Sensors

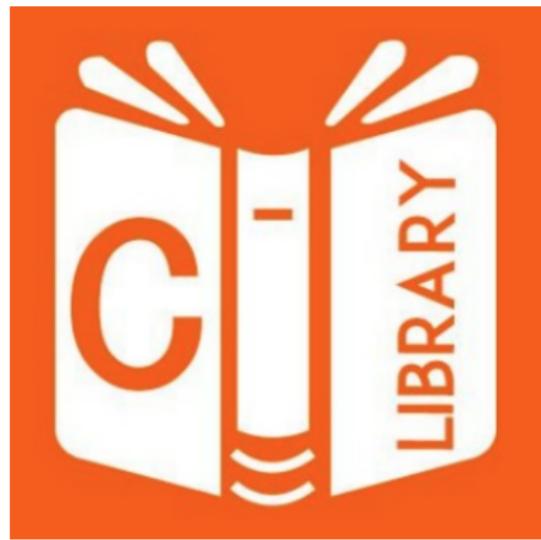
Resistive Sensor



Capacitive Sensor



Installing Libraries



Assignment: L14_SoilMoisture



① L14_01_OLED

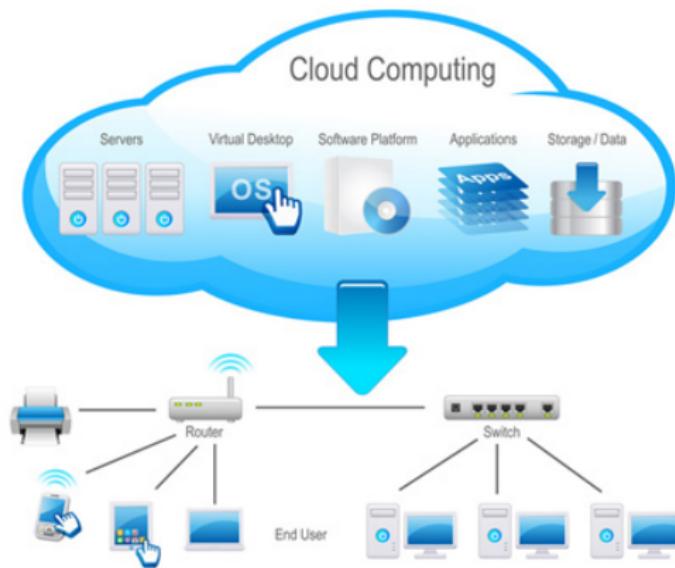
- Install the Adafruit_SSD1306 library
- NOTE: you have full 128x64 pixel access
- Create sample code displaying your name and time to the OLED

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

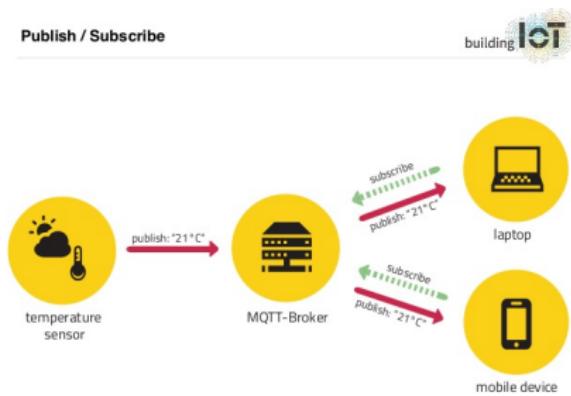
- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

The Cloud

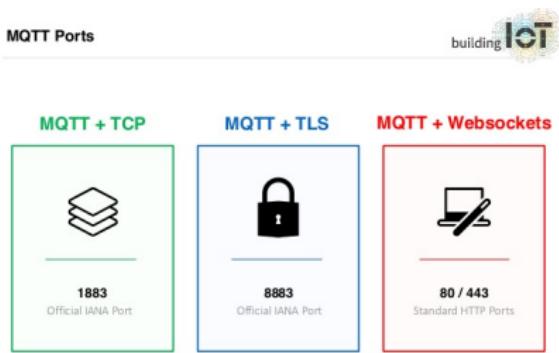


MQTT: MQ Telemetry Transport

Publish / Subscribe



MQTT Ports



Adafruit.io



Let's create 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](#)

Power Up

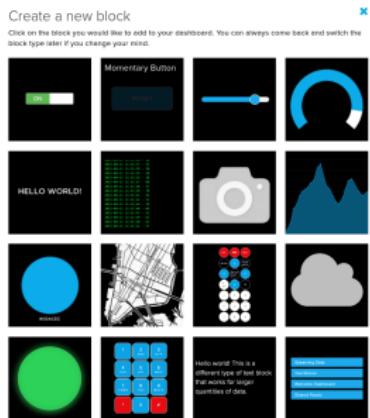
\$10 or \$99
per month per year

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

[Learn more about IO+>](#)

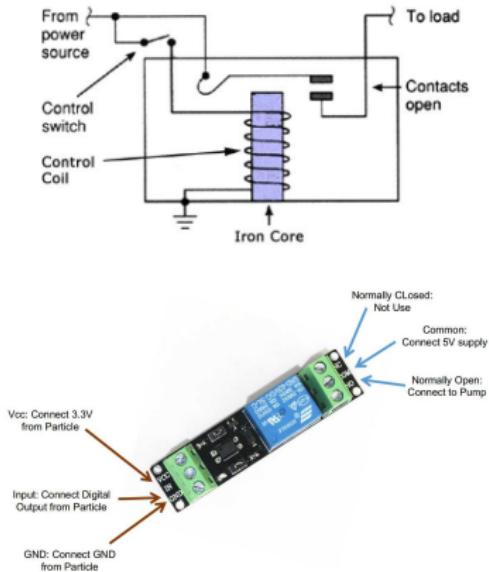
[Sign Up Now](#)

Assignment: L14_03_SubscribePublish



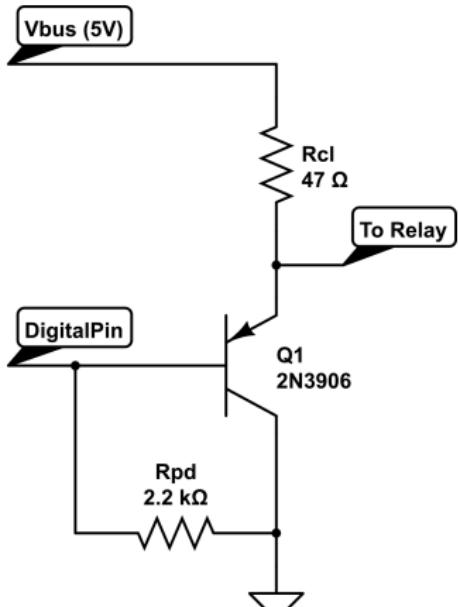
- ① Modify the starter code for your Adafruit.io
- ② Subscribe
 - Add a button to your Adafruit.io dashboard and connect it to a feed called buttonOnOff
 - Subscribe to the buttonOnOff and turn on the on board LED when pressed.
- ③ Publish
 - Publishing a random number to a feed once per minute (do not 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 than 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.

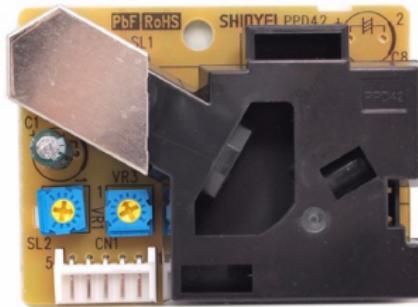
Assignment: L14_04_PlantWater



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 with 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 plan.

Seeed Sensors



Seeed Grove - Dust Sensor



Seeed Grove - Air Quality
Sensor v1.3

Assignment: More L14

① L14_05_PulseIn

- Look up the `pulseIn()` command in the Arduino reference
- Connect PWM pin to Analog input. Use `pulseIn` to measure length of PWM-pulse while varying voltage output with encoder.

② L14_04_PlantWater (revisited): 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.

③ Include Hackster.io story

Negative Numbers

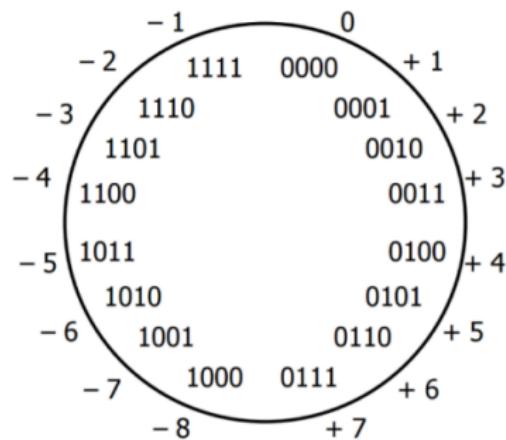
Question: How are negative numbers represented in binary?

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.

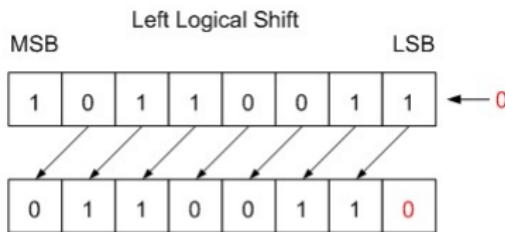
Bitwise Operations

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

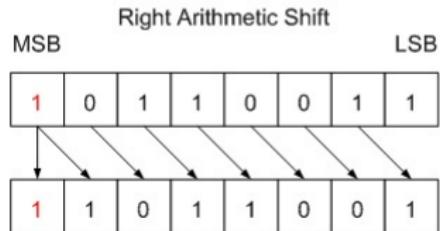
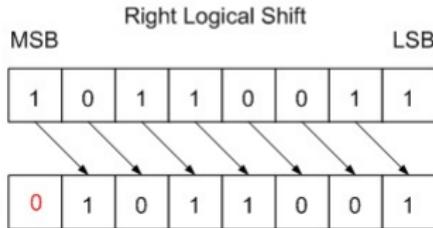
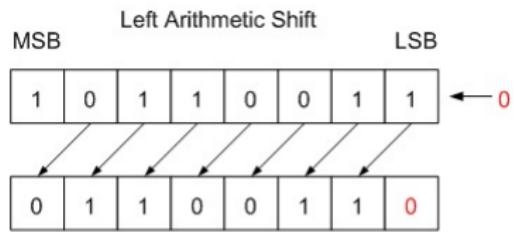
Operator	Description	Example
&	Binary AND Operator copies a bit to the result if it exists in both operands.	$(A \& B) = 12$, i.e., 0000 1100
	Binary OR Operator copies a bit if it exists in either operand.	$(A B) = 61$, i.e., 0011 1101
^	Binary XOR Operator copies the bit if it is set in one operand 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

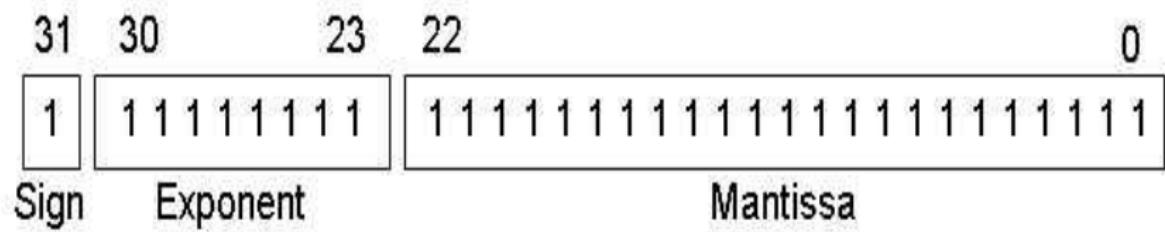
Logical Bit Shift



Arithmetic Bit Shift



BONUS: But what about Floating Point



Example:

$$-36382.366 = -3.6382366 \times 10^5 = 1000001011101111000010001011110$$

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.

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

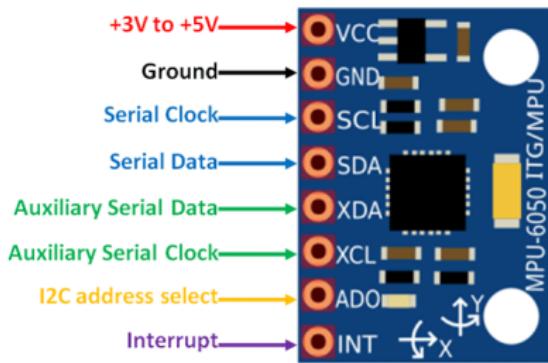
② L15_02_RetrieveShow

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

③ L15_03_Interrupt Create an interrupt Stop Button

- Wire a button, a GREEN and a RED LED to your Argon
- Using delays, blink your GREEN LED (once per second)
- Using an Interrupt, when the button is pressed, the GREEN turns off and the RED lights up.

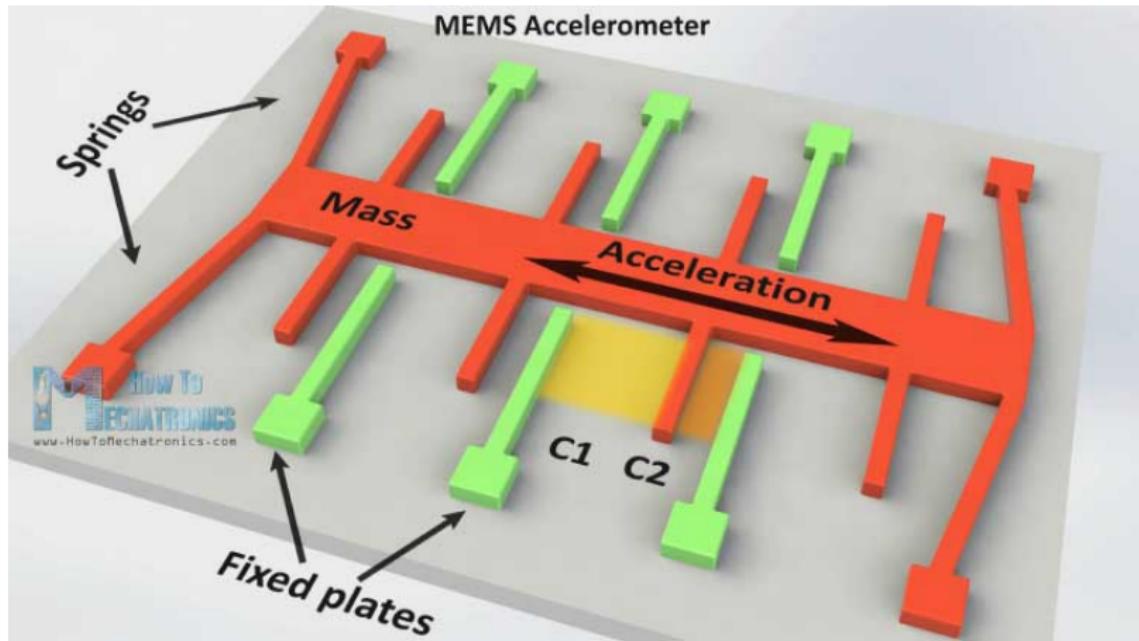
MPU6050 Accelerometer



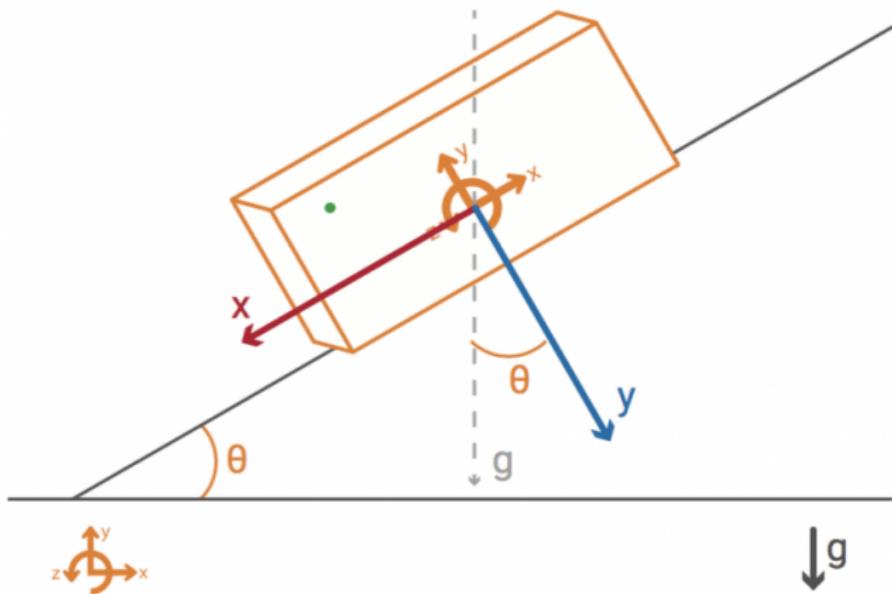
- Data Output - 16 Bit
- Gyros range: ± 250 ± 500 ± 1000 ± 2000 °/s
- Accel range: ± 2 ± 4 ± 8 ± 16 g

- 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



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

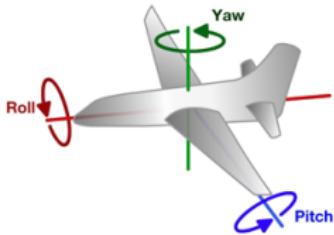
Initializing MPU6050

```
1 // Begin I2C communications
2 Wire.begin();
3
4 // begin transmission to GY-521
5 Wire.beginTransmission(MPU_ADDR);
6
7 // Select and write to PWR_MGMT1 register
8 Wire.write(0x6B);
9 Wire.write(0); // set to 0 (wakes up MPU-6050)
10
11 // end transmission
12 Wire.endTransmission(true);
```

Initializing MPU6050

```
1 // Using Wire.requestFrom()  
2 // Wire.requestFrom(address, quantity, stop)  
3  
4 Wire.beginTransmission(MPU_ADDR);  
5 Wire.write(0x3B); // starting with register 0x3B  
6 Wire.endTransmission(false); keep active.  
7  
8 // Request and then read 2 bytes  
9 Wire.requestFrom(MPU_ADDR, 2, true);  
10 accel_x_h = Wire.read(); x accel MSB  
11 accel_x_l = Wire.read(); x accel LSB
```

Assignment: L16_Motion



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

① L16_01_MP6050

- Connect the GY-521 and OLED
- Read the memory addresses for X, Y, and Z acceleration
- Convert the returned bytes to acceleration measured in G.

② L16_02_AutoRotate

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

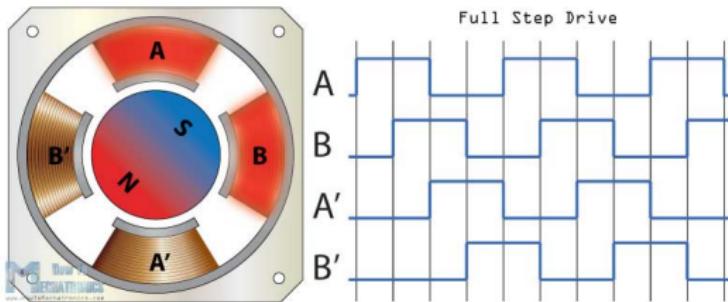
③ L16_03_Airplane

- 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

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)

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 11-bit)
- Move the stepper the amount of steps corresponding to the mapped gyro change.

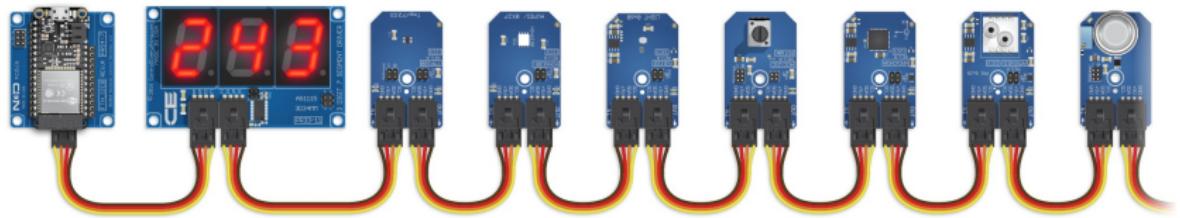
Piezoelectric Elements



- 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.

ThingSpeak and IFTTT

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

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>

Capstone Project Timeline

- ① Select Capstone teams (Aug 12)
- ② Teambuilding exercise with Sue/Esteban (Aug 12)
- ③ Review of Rev 0 ideas with instructors (Aug 20)
- ④ Start work on CapStone (Aug 26)
- ⑤ Videos due to Digital Media (Sept 4)
- ⑥ Employer Roundtable (Sept 11)



Servo Motors

PWM=Orange (⊤⊤)
Vcc = Red (+)
Ground=Brown (-)

