LECTURE III

Introduction to Embedded Systems and Microcontrollers

SECTION I

Meet Your Groups!

Review Question

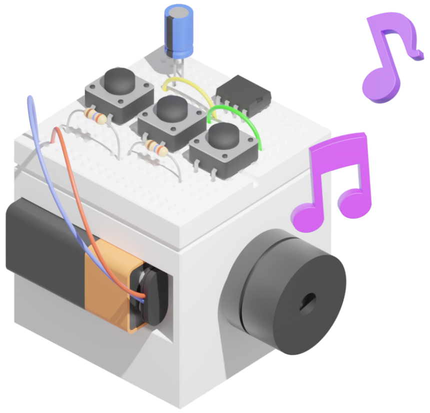
If you could make a computer that does a single task, what would it do?

SECTION I

Project II Review

Project 2 Review

- Official Due Date: Monday, November 10th by 11:59PM
- Ask questions and seek help (online or @Lab Hours), so you can finish it on time!
- Note: To get the $20 refund for Fall Quarter, you must complete all Projects by the end of Fall Quarter



Learning Concepts:

- Circuit Analysis (Nodes, Voltage Drop)
- Circuit Troubleshooting
- Multimeters
- 555 Timer
- Breadboarding
- Soldering

SECTION II

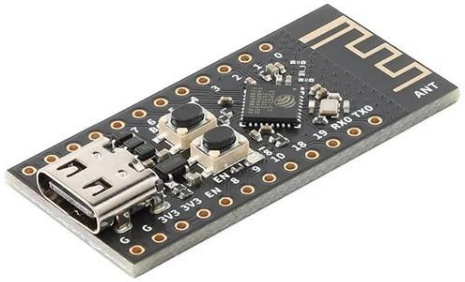
Project III

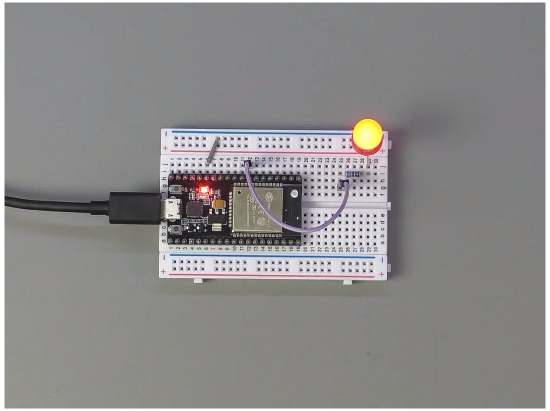
Project 3 Overview

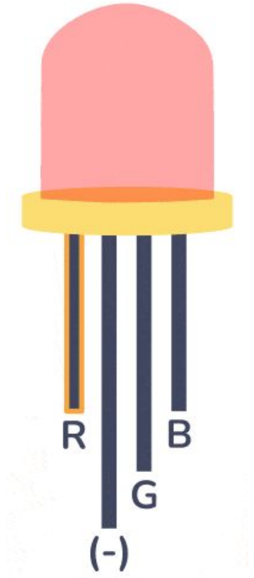
- Build and program a dimmable RGB LED using the **ESP32** and **potentiometers**.

You will learn:

- Embedded Systems
- Microcontrollers
- ESP32
- Arduino IDE
- Pulse Width Modulation (PWM)







SECTION III

What is an Embedded System?

Embedded Systems

- An **embedded system** is a combination of hardware and software designed for a *specific* purpose
  - Ex) alarm clock, camera, or MP3 player

  - Contrasts from a **general-purpose system**, like a smartphone or laptop
    - These devices can act as an alarm, camera, and a media player *combined*
    - They typically have much more functionality than an embedded system

Embedded Systems

- Large-scale mechanical and electrical systems often consist of **multiple, smaller embedded systems**
  - Each embedded system has a function that supports the larger system
  - Ex) **Airplanes** - in-flight entertainment system, temperature control, speed control, flight management, flight data recorder
- OPS Projects 3-7 and the Capstone project are all embedded systems

SECTION IV

Microcontrollers & ESP32

Microcontrollers

- A **microcontroller** (or **MCU**) is a **small computer** on a single integrated circuit
  - Complete with functionality to run and store programs
- An **architecture** defines the organization of hardware within the computer
  - **MCUs have different architectures**
    - ex. ESP32, ATmega, etc.

ESP32 Microcontroller Family

ESP32-C3Fx4 Board

- The ESP32-C3Fx4 board in your OPS kits was developed by WeAct Studios
- The ESP32 board is **hobbyist-friendly**
  - Wi-Fi and Bluetooth capabilities
  - ESP32 chip itself contains the processor, RAM, and flash storage
  - In OPS, we will refer to the **ESP32-C3Fx4 board as an ESP32** from now on for convenience

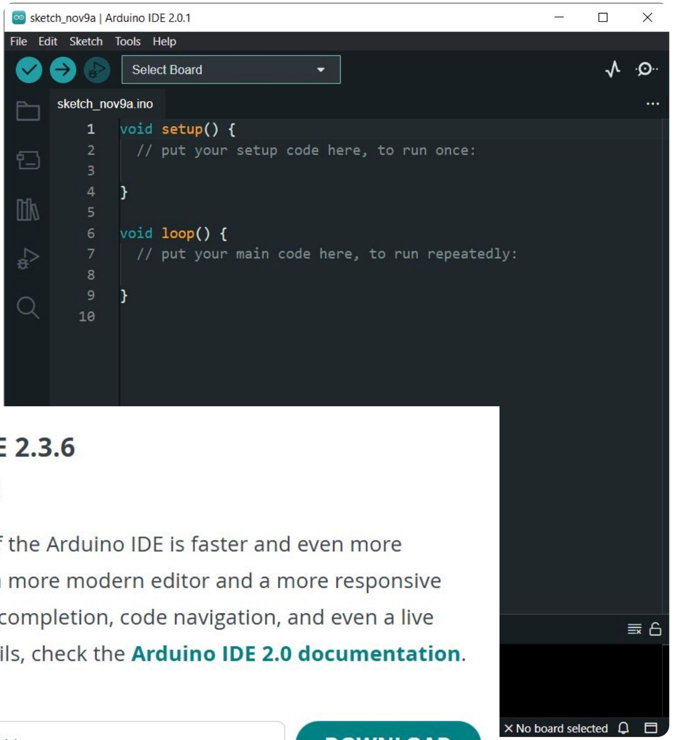
ESP32-C3Fx4

SECTION V

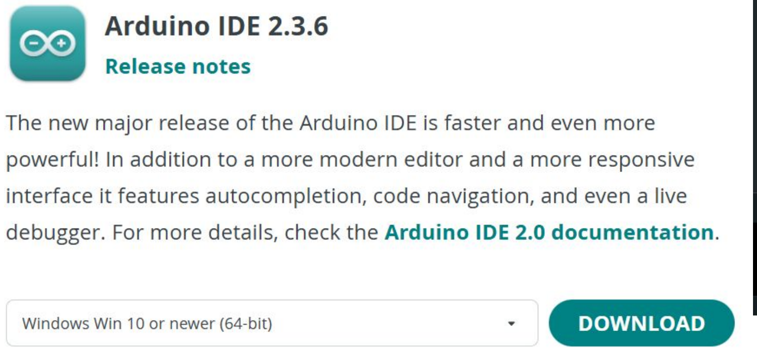
Arduino IDE

Arduino IDE

- We will write code, compile, and upload it to the ESP32 board from our personal computers using the **Arduino IDE** software kit
- Download the latest IDE installer here



```
void setup() {
  // put your setup code here, to run once:

}

void loop() {
  // put your main code here, to run repeatedly:

}

```



Arduino IDE 2.3.6

Release notes

The new major release of the Arduino IDE is faster and even more powerful! In addition to a more modern editor and a more responsive interface it features autocompletion, code navigation, and even a live debugger. For more details, check the **Arduino IDE 2.0 documentation**.

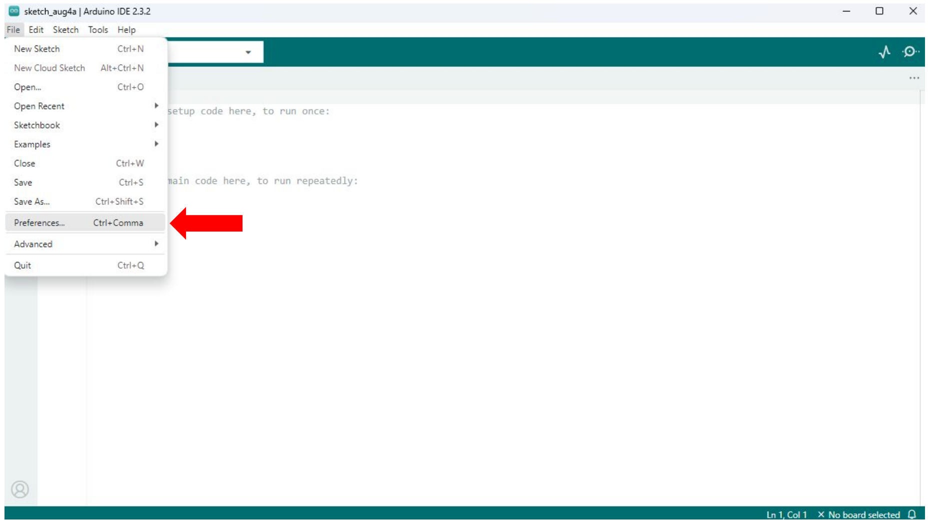
Windows Win 10 or newer (64-bit)

DOWNLOAD

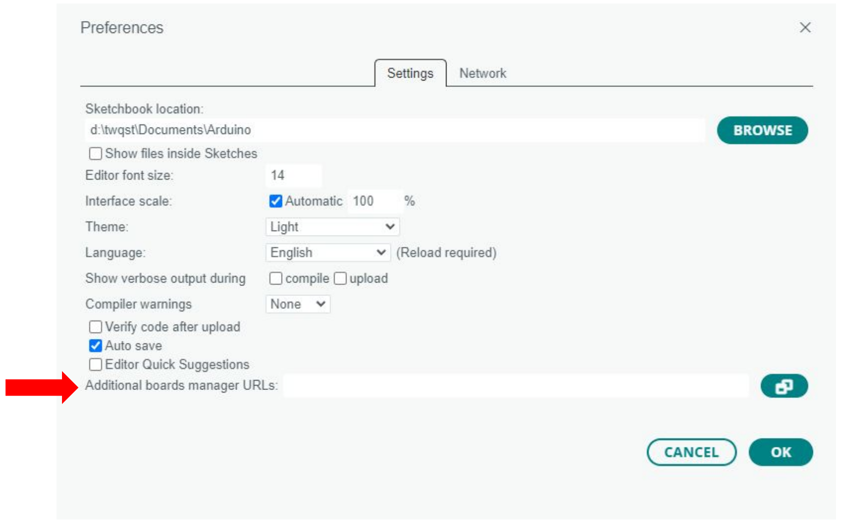
Arduino IDE Setup for ESP32 (cont.)

Step 2: Once it's installed, open Arduino IDE

- Go to File -> Preferences -> paste in this link under "Additional Boards Manager URLS", then click OK: https://dl.espressif.com/dl/package_esp32_index.json



sketch_aug4a | Arduino IDE 2.3.2
File Edit Sketch Tools Help
New Sketch Ctrl+N
New Cloud Sketch Alt+Ctrl+N
Open... Ctrl+O
Open Recent
Sketchbook
Examples
Close Ctrl+W
Save Ctrl+S
Save As... Ctrl+Shift+S
Preferences... Ctrl+Comma
Advanced
Quit Ctrl+Q
setup code here, to run once:
main code here, to run repeatedly:
Ln 1, Col 1
No board selected


Preferences

Settings | Network

Sketchbook location:
d:\twqst\Documents\Arduino BROWSE

☐ Show files inside Sketches

Editor font size: 14

Interface scale: ☑ Automatic 100 %

Theme: Light

Language: English (Reload required)

Show verbose output during ☐ compile ☐ upload

Compiler warnings None

☐ Verify code after upload

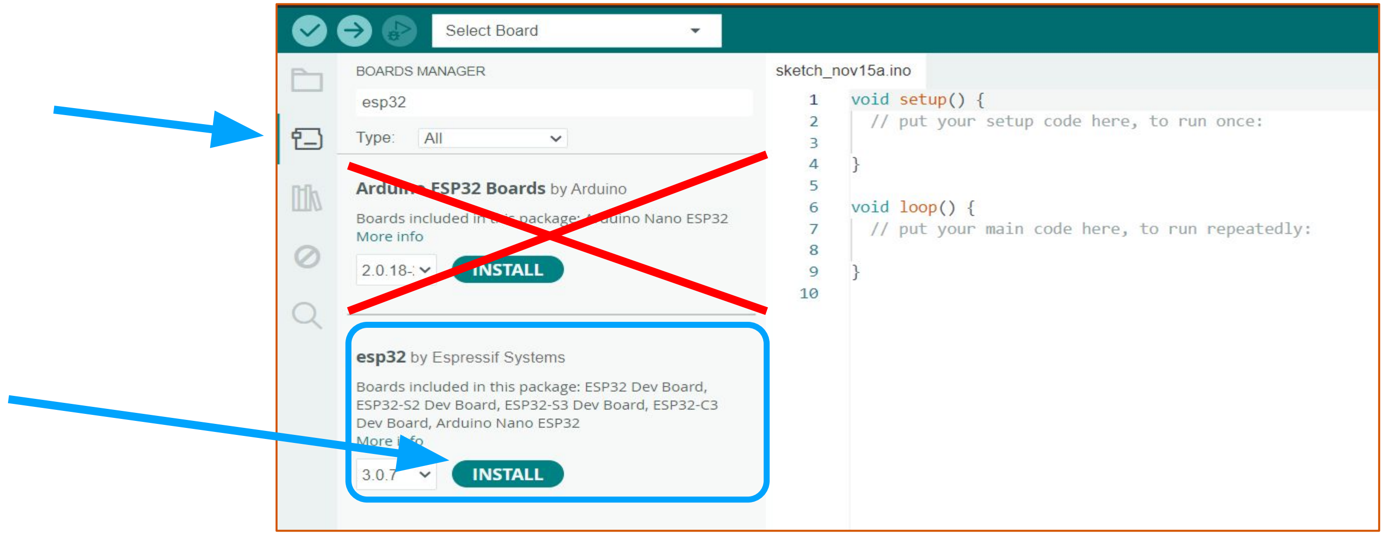
☑ Auto save

☐ Editor Quick Suggestions

Additional boards manager URLs:

CANCEL OK

Download ESP32 Board library



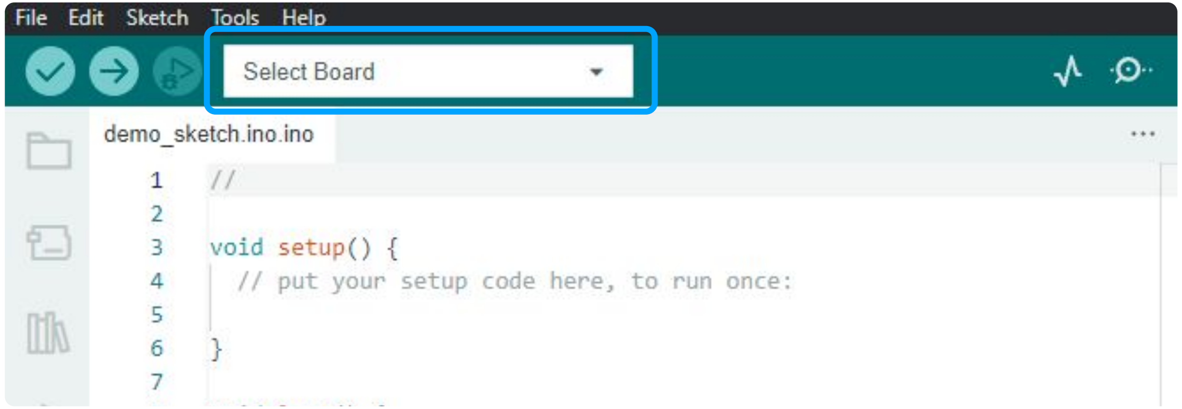
Arduino ESP32 Boards by Arduino
Boards included in this package: Arduino Nano ESP32
More info
2.0.18-

esp32 by Espressif Systems
Boards included in this package: ESP32 Dev Board, ESP32-S2 Dev Board, ESP32-S3 Dev Board, ESP32-C3 Dev Board, Arduino Nano ESP32
More info
3.0.7

```
void setup() {
  // put your setup code here, to run once:

}

void loop() {
  // put your main code here, to run repeatedly:

}
```

- Click on the board manager tab on the right hand side
- Type in “esp32” into the search bar
- Install the library made by “Espressif Systems”

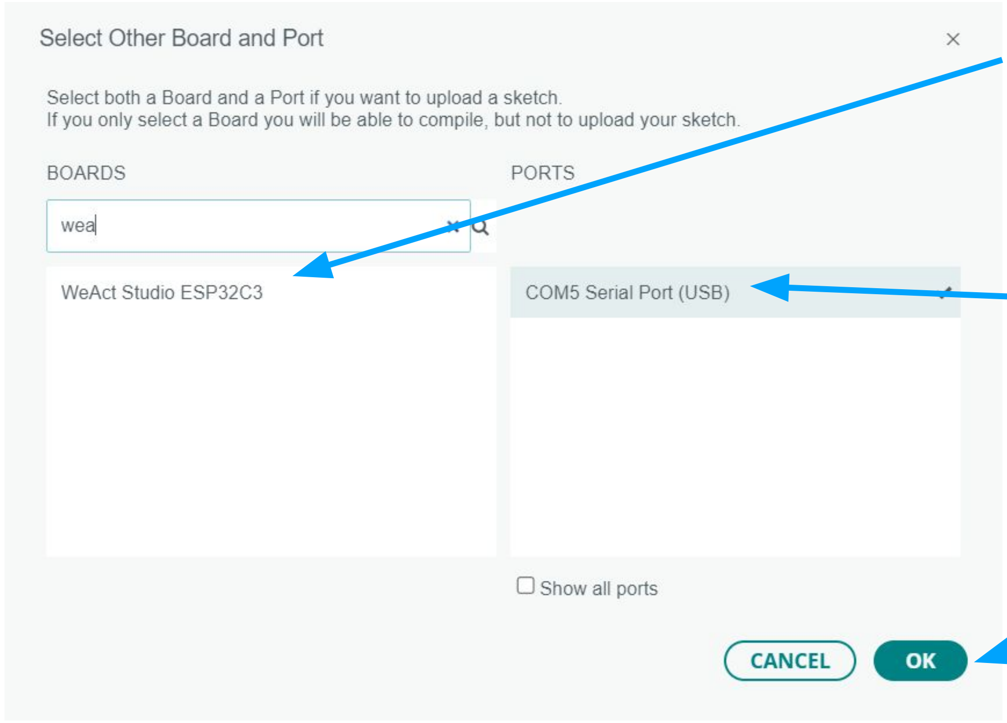
Setting the Target Board



```
//

void setup() {
  // put your setup code here, to run once:

}

```

- Before we can upload a sketch, we must **connect the ESP32 board via the USB-C to USB-A cable to the computer** and configure the IDE to the correct board and USB port
- Open the **Select Board** dropdown and select an available ESP32 board
    - If no option appears, **try replugging in the board…**

Setting the Target Board (Cont'd)



Select Other Board and Port

Select both a Board and a Port if you want to upload a sketch.
If you only select a Board you will be able to compile, but not to upload your sketch.

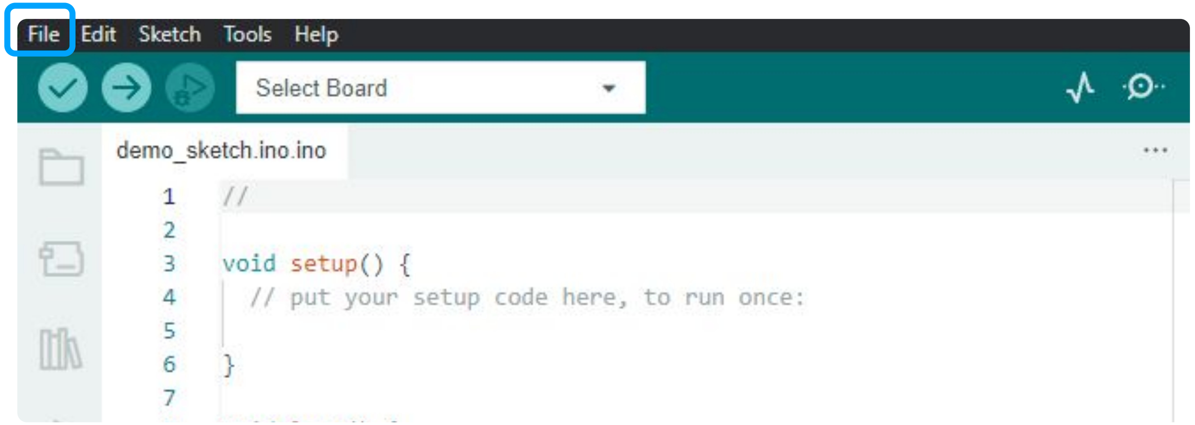
BOARDS: wea — WeAct Studio ESP32C3

PORTS: COM5 Serial Port (USB)

☐ Show all ports

- In the popup window, search **Boards** and select **WeAct Studio ESP32C3**
- From the available items under **Port**, select the USB port to which the board is currently connected
- Confirm the selections by clicking **OK**

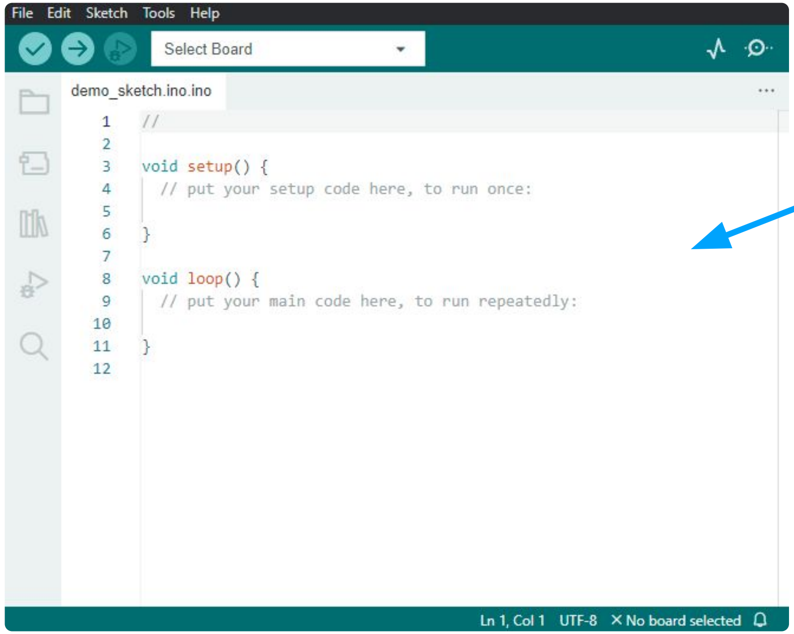
Creating a Sketch



```
//

void setup() {
  // put your setup code here, to run once:

}

```

- An Arduino source code file is called a **sketch** and has the **.ino** extension
- When the IDE opens, a new sketch will be created automatically or a previous sketch will open
    - To create a new sketch, select **File** → **New Sketch** from the menu

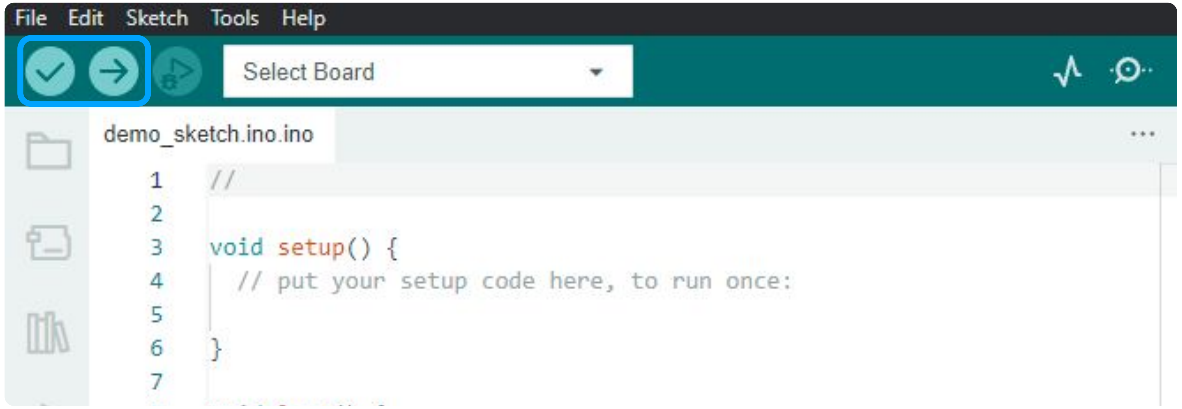
Editing a Sketch


File Edit Sketch Tools Help
Select Board
demo_sketch.ino.ino
Ln 1, Col 1 UTF-8 ✕ No board selected

```
//

void setup() {
  // put your setup code here, to run once:

}

void loop() {
  // put your main code here, to run repeatedly:

}

```

- Sketches can be modified from the **code editor**, which appears just below the menu
- New sketches opened in the editor come with **template code**

Verifying and Uploading a Sketch



```
//

void setup() {
  // put your setup code here, to run once:

}

```

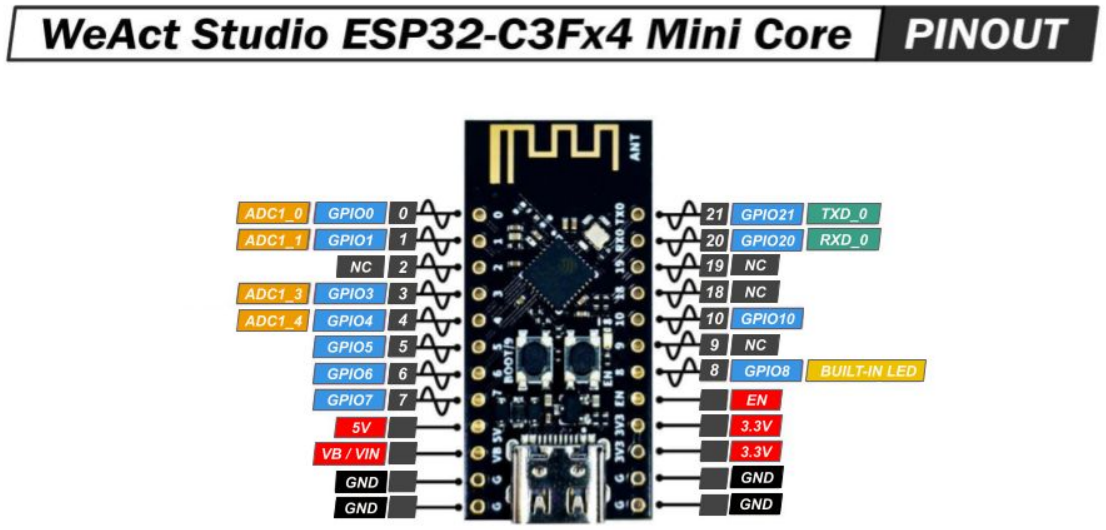
- Before uploading the sketch, select **Verify** (the **checkmark** icon) to compile the sketch
- Once the sketch compiles successfully, select **Upload** (the **right arrow** icon) to upload the compiled sketch to the Arduino board

SECTION VI

Basic ESP32 Pins

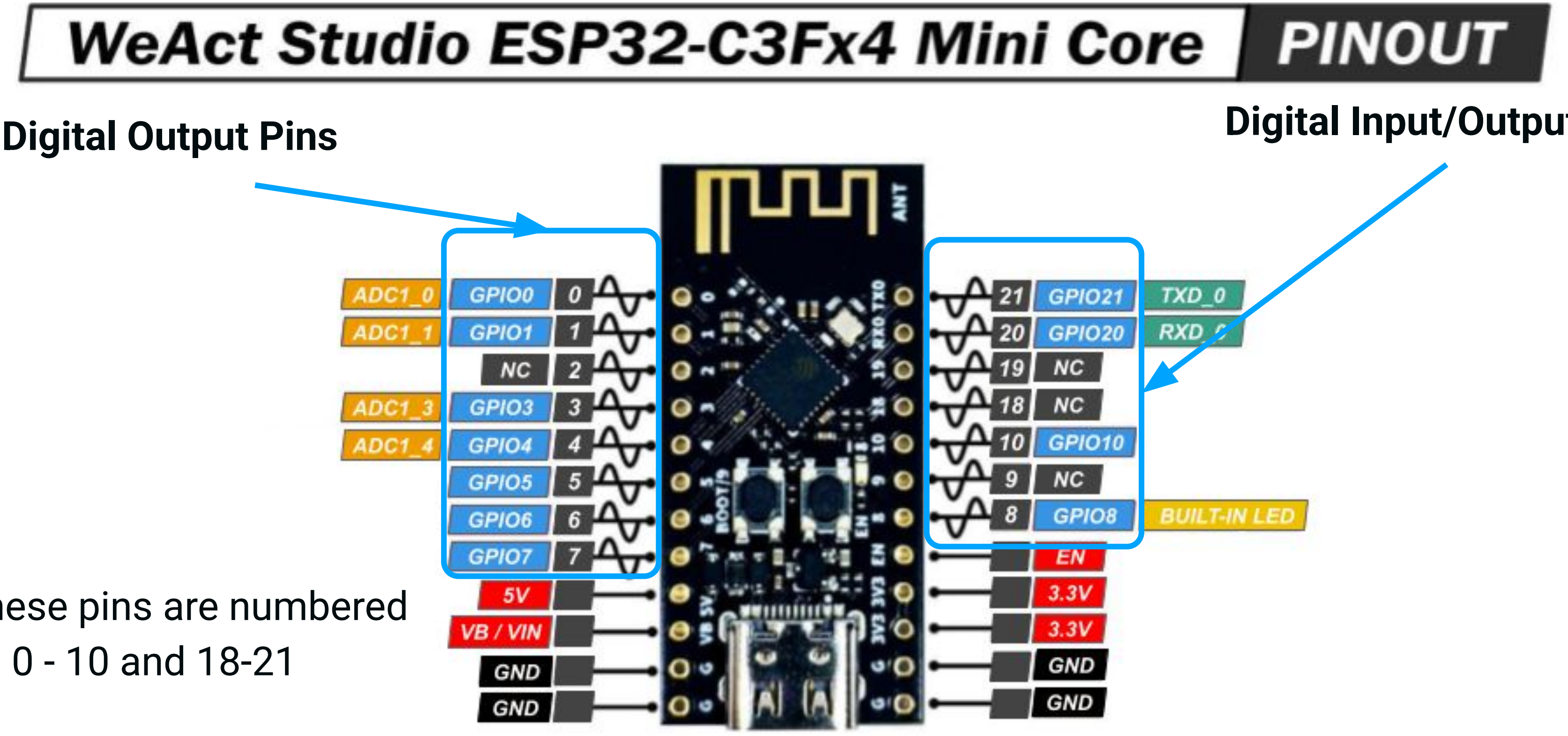
ESP32 Pinout Diagram

- A pinout diagram is included for the ESP32
- **General Purpose Input/Output** (**GPIO**) pins are pins that can be set as either INPUT or OUTPUT.



    - These are the **analog** and **digital pins** marked by the pinout diagram
    - We will design an Arduino sketch to control these pins

Digital Pins



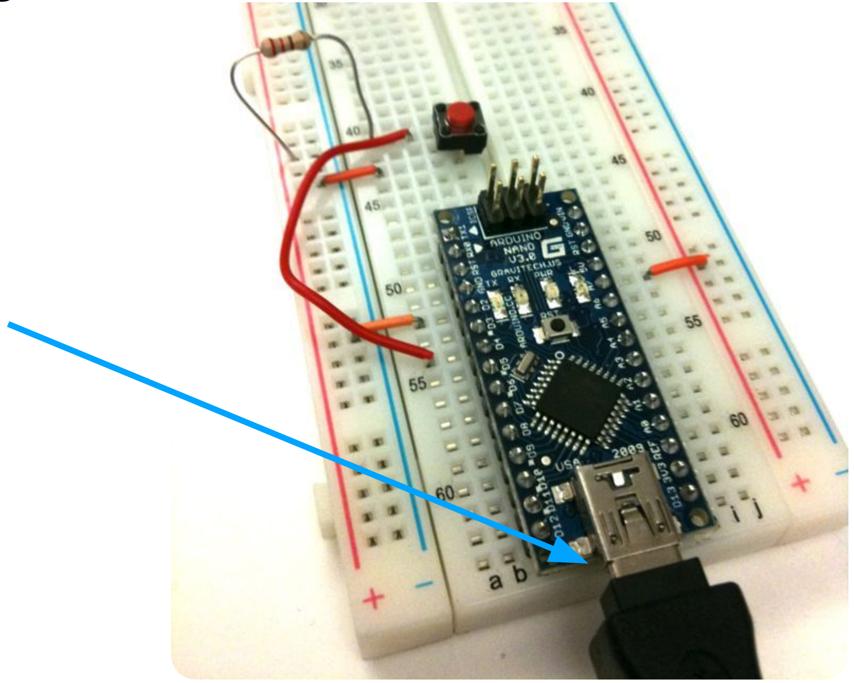
Digital Output Pins

Digital Input/Output Pins

These pins are numbered as 0 - 10 and 18-21

Prototyping with the ESP32

- The ESP32 can be **seated along the DIP channel** of a standard breadboard just like a DIP IC
- The **ESP32's USB port should be oriented away from the board**, so the connected cable doesn't obstruct the breadboard
- Circuits that interface with the ESP32 board must **share a common ground with the GND pin of the board**

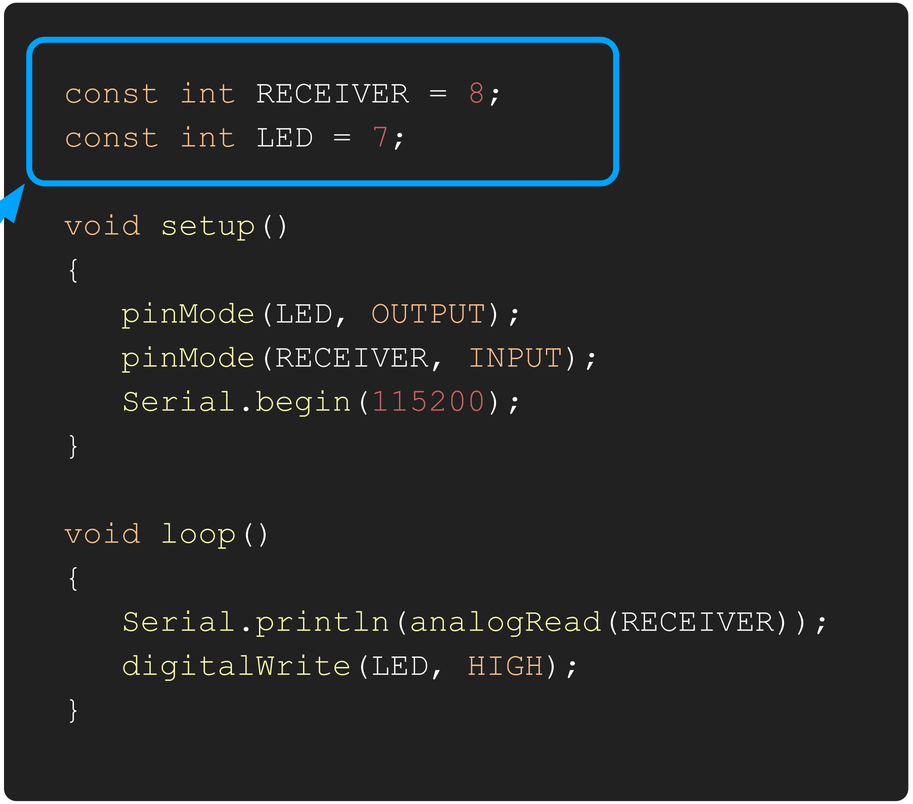


SECTION VII

Sketch Structure

Sketch Structure

- Sketches are written in the **Arduino language**, which is much like C++
- **Assign pins as global variables** at the beginning of the sketch:
  `const int pinName = pin#;`
  - Each GPIO pin is associated with an integer
- Don’t place the global variables inside functions (otherwise it won’t be a global variable!)



```
const int RECEIVER = 8;
const int LED = 7;

void setup()
{
   pinMode(LED, OUTPUT);
   pinMode(RECEIVER, INPUT);
   Serial.begin(115200);
}

void loop()
{
   Serial.println(analogRead(RECEIVER));
   digitalWrite(LED, HIGH);
}
```

Sketch Structure (Cont'd)

- Just like the C++ **`main`** function, Arduino IDE has built-in functions **`setup`** and **`loop`**, which must be defined by the programmer
- **`setup()`** runs once at the beginning of program execution
  - Used to initialize pin modes
- **`loop()`** runs repeatedly in an infinite loop

```
const int RECEIVER = 8;
const int LED = 7;

void setup()
{
   pinMode(LED, OUTPUT);
   pinMode(RECEIVER, INPUT);
   Serial.begin(115200);
}

void loop()
{
   Serial.println(analogRead(RECEIVER));
   digitalWrite(LED, HIGH);
}
```

Things to do in `setup`

- `pinMode(int pin, int mode)`
  - Call this function for each digital pin you want to use
  - Pass the global variable assigned to each pin to the `pin` parameter
  - Specify if your pin is **`INPUT`** or **`OUTPUT`** mode
    - We **read data from input pins** and **send data to output pins**

```
const int LED = 7;
const int RECEIVER = 8;

void setup()
{
   pinMode(LED, OUTPUT);
   pinMode(RECEIVER, INPUT);
   Serial.begin(115200);
}
```

Things to do in `setup` (Cont'd)

- `Serial.begin(115200)`
  - `Serial` is an object that facilitates communication between the ESP32 board and the computer via USB
  - Used to print statements to the computer
  - Pass **`115200`** bits per second as the argument for this member function
    - Known as the **baud rate**

```
const int LED = 7;
const int RECEIVER = 8;

void setup()
{
   pinMode(LED, OUTPUT);
   pinMode(RECEIVER, INPUT);
   Serial.begin(115200);
}
```

SECTION VIII

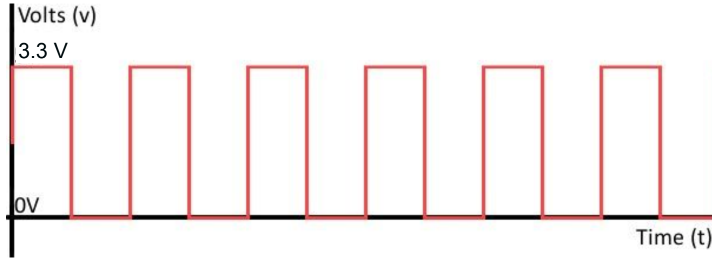
Arduino IDE Functions

Digital Pin Functions

- `digitalWrite(int pin, int value)`
  - **Sets the voltage** at the output pin to either a **`HIGH`** (3.3V) or **`LOW`** (0V) value
- `digitalRead(int pin)`
  - **Reads the voltage** at the input pin, returning **`HIGH`** (3.3V) or **`LOW`** (0V) as an integer (1 or 0)
- Analogy - light switch and light bulb:
  - You use the switch to set the bulb to either MAX brightness or MIN brightness

Digital Signals

- **Computers (and microcontrollers) transfer data** across wires/lines as **digital** (discrete) **voltage signals**
  - These signals are either a **HIGH** or **LOW** voltage
  - Contrasts from **analog signals** which can be values in a continuous range



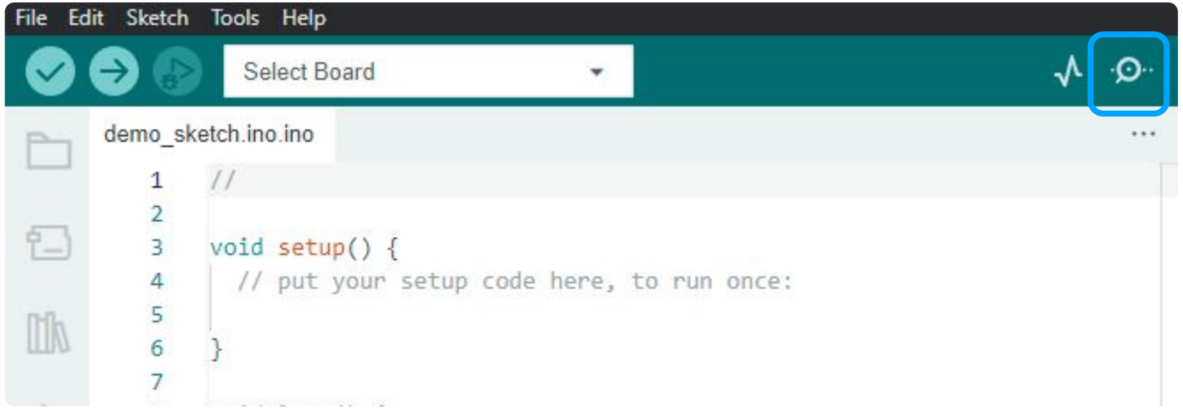
This is a **digital signal** where the waveform is either **3.3V** or **0V** (two *discrete* values)

- **Digital signals are translated** to the Binary number system (1s and 0s)

More Basic Functions

- `delay(int ms)`
  - **Pauses the program execution** by `ms` milliseconds
- `Serial.print("Message")`
  - Sends a string to the computer connected via USB and **displays the string on the Serial Monitor** in the IDE
- `Serial.println("Message")`
  - Sends a string to the computer connected via USB and **displays your string on the Serial Monitor** in the IDE, **followed by a newline**

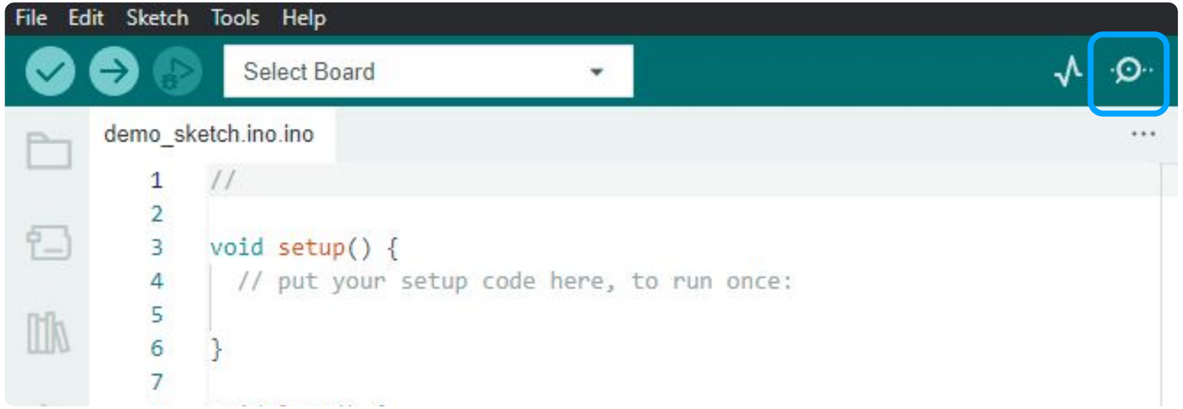
Using the Serial Monitor



```
//

void setup() {
  // put your setup code here, to run once:

}

```

- While the ESP32 board is connected to the personal computer via USB, select **Serial Monitor** (the **magnifying glass** icon) in the IDE
    - A pane will appear at the bottom of the IDE window which displays all data sent by the ESP32 board using `Serial.print`

Using the Serial Monitor (Cont’d)



```
//

void setup() {
  // put your setup code here, to run once:

}

```

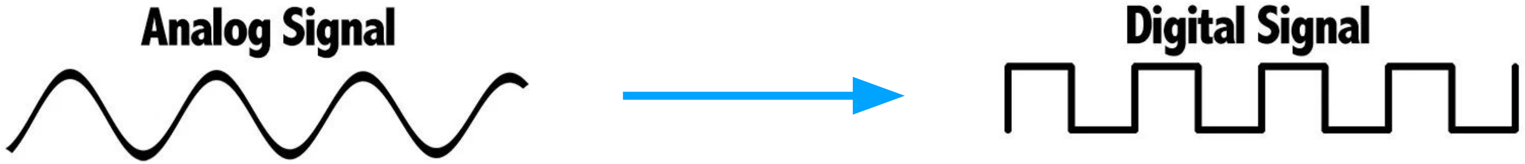
- In the absence of a debugger (the ESP32 is not capable of using one), `Serial.print` is an excellent tool to **help debug programs**
  - Print values to track across parts of your program
    - Unexpected values displayed to the Serial Monitor indicates an error

Analog Pin Functions

- `analogWrite(int pin, int value)`
  - **Sets the average voltage** on digital output pin to a value in the **range** `0-255` (0V to 3.3V)
  - This is a function for **~ PWM pins only**
- `analogRead(int pin)`
  - **Reads the voltage** at the input pin, maps it to a value in the **range** `0-1023` (0V to 3.3V) and returns that value
- Analogy - light dimmer:
  - You use the slide to set the bulb to anywhere *between* MAX brightness or MIN brightness

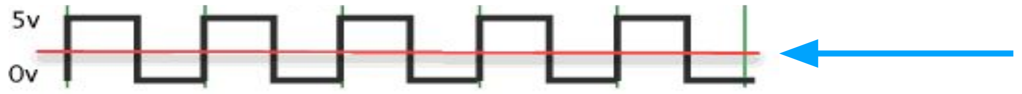
ADC and `analogRead`

- `analogRead` **utilizes the analog-to-digital converter** inside the microcontroller to **measure the real-world, analog signal** and **convert it to a digital signal**
  - The measurement resolution is 10 bits, which is why the function returns values from `0-1023`



PWM

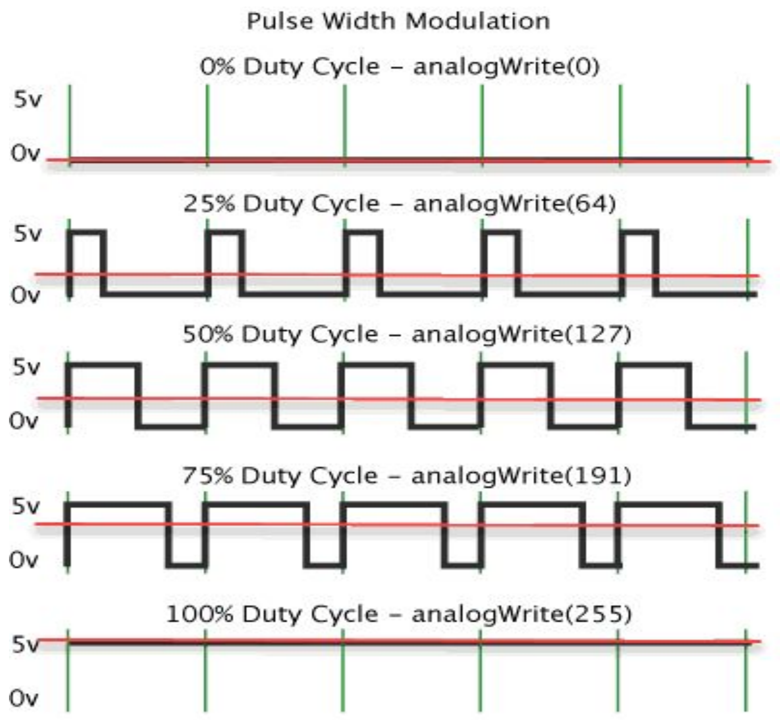
- The ESP32 board (the underlying AVR microcontroller) is a **digital source**, meaning it can only output a **`HIGH`** (5V) or **`LOW`** (0V) voltage
  - Then how does **`analogWrite`** output analog signals?
- Pulse Width Modulation (**PWM**) is an oscillating digital waveform that emulates an analog output
  - By oscillating a signal from **`HIGH`** to **`LOW`** quickly, the average voltage over time will be *between* **`HIGH`** and **`LOW`** - an analog value



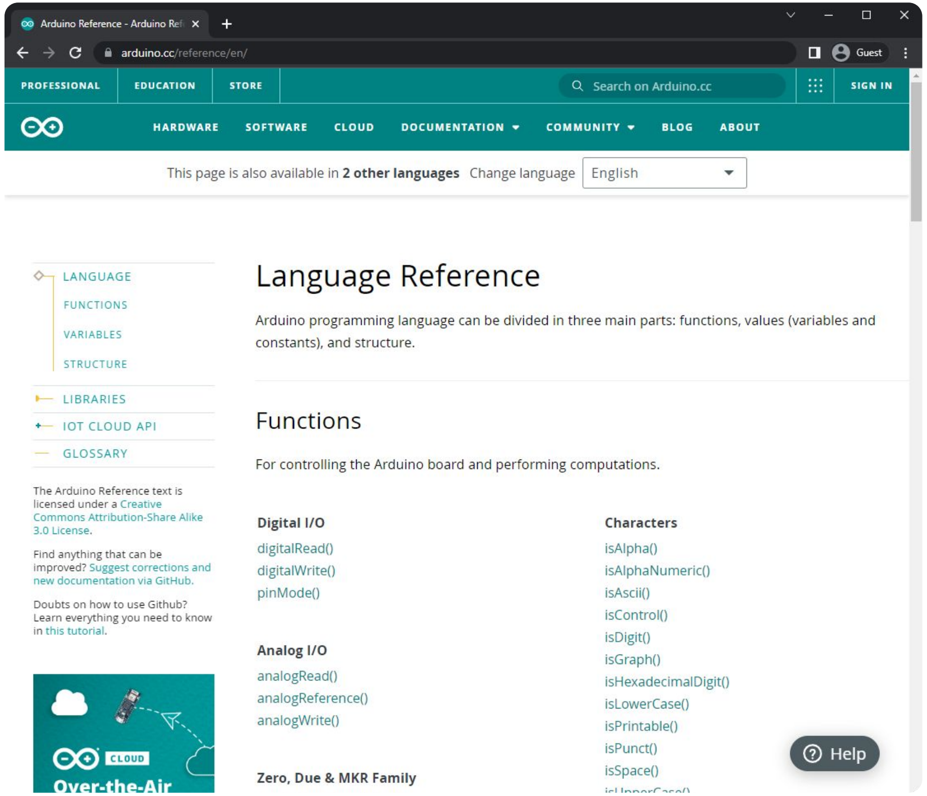
The average value, the *analog value*, of this waveform is **2.5V**

PWM Duty Cycle

- The **duty cycle** of the PWM wave is the percentage of time where the signal is `HIGH`
  - For example, a 50% duty cycle translates to an average value of 2.5V (50% of 5V)
  - Allows us to output a continuous range of voltages between `HIGH` and `LOW`
  - Duty cycle is **controlled by a timer** inside the AVR microcontroller


Pulse Width Modulation
0% Duty Cycle – analogWrite(0)
25% Duty Cycle – analogWrite(64)
50% Duty Cycle – analogWrite(127)
75% Duty Cycle – analogWrite(191)
100% Duty Cycle – analogWrite(255)
5v
0v

Arduino Reference Library



This page is also available in **2 other languages**

Language Reference

Arduino programming language can be divided in three main parts: functions, values (variables and constants), and structure.

Functions

For controlling the Arduino board and performing computations.

Digital I/O
digitalRead()
digitalWrite()
pinMode()

Analog I/O
analogRead()
analogReference()
analogWrite()

Zero, Due & MKR Family

Characters
isAlpha()
isAlphaNumeric()
isAscii()
isControl()
isDigit()
isGraph()
isHexadecimalDigit()
isLowerCase()
isPrintable()
isPunct()
isSpace()

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Find anything that can be improved? Suggest corrections and new documentation via GitHub.

Doubts on how to use Github? Learn everything you need to know in this tutorial.

- Learn more about Arduino functions and libraries here
- The **Arduino Reference Library** includes support for devices like LCDs, Sensors, and WiFi modules

SECTION IX

Digital LED Circuit Exercises

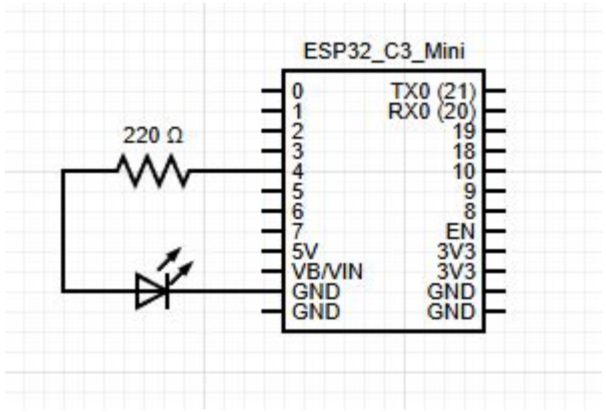
Important Tips for ESP32

- Code that you flash onto the ESP32 will stay on there indefinitely!
- Before uploading new code, reset the ESP32!
- To reset the ESP32, follow these instructions:
    1. Press the **BOOT** button and hold it down
    2. While holding the **BOOT** button, press the **EN** button and hold for a second or two
    3. Let go of the **EN** button, then wait a second or two
    4. Let go of the **BOOT** button
- After flashing new code onto the ESP32, press the **EN** button once to begin running the program on the ESP32!

Digital LED Circuit

I/A

Build the circuit below from the schematic. Then, complete the template code, flash it to the ESP32 board, and verify the circuit.

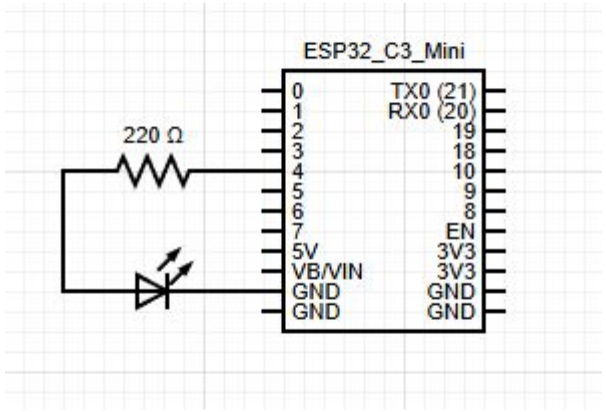


```
// Assign variable to pin number for LED

void setup() {
     // Configure LED pin's behavior to OUTPUT
     // Configure the Serial baud rate
}

void loop() {
     // Set LED pin to HIGH
}
```

Digital Blinking LED Circuit

I/A

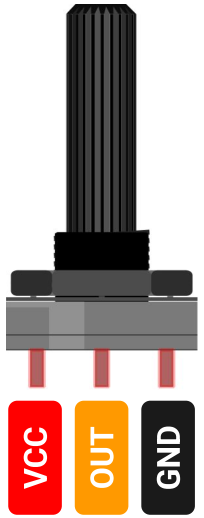
Build the circuit below from the schematic. Then, complete the template code, flash it to the ESP32, and verify the circuit.



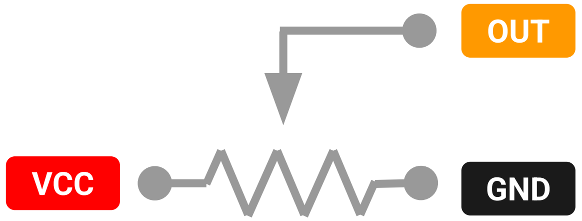
```
// Assign variable to pin number for LED

void setup() {
     // Configure LED pin's behavior to OUTPUT
     // Configure the Serial baud rate
}

void loop() {
     // Set LED pin to HIGH
     // Delay
     // Set LED pin to LOW
     // Delay
}
```

Potentiometers

- A **potentiometer** is a **three-terminal variable resistor**
- We will use the potentiometer as a **voltage divider** **-** a circuit which accepts a supply voltage and outputs a voltage which is a fraction of the supply voltage
- The voltage of the potentiometer's output pin ranges between the VCC and GND pin voltages

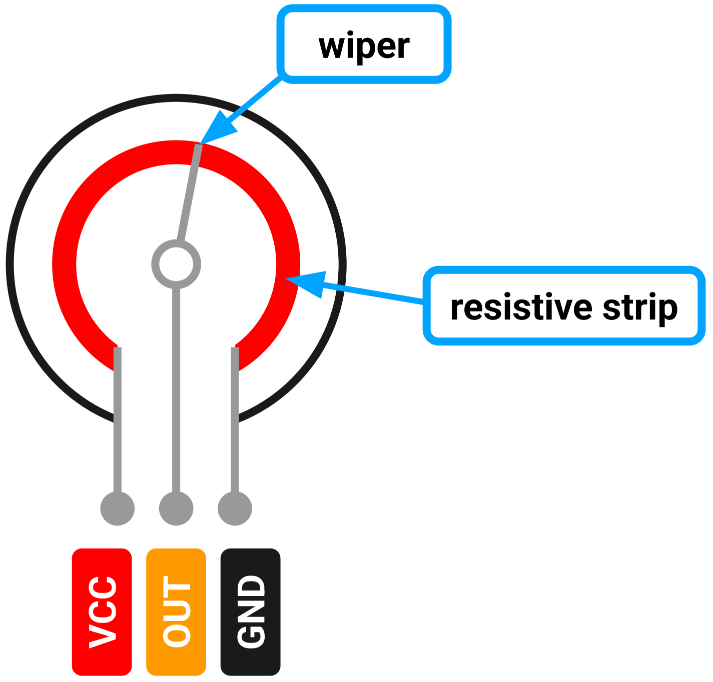


The positions of **VCC** and **GND** can be swapped



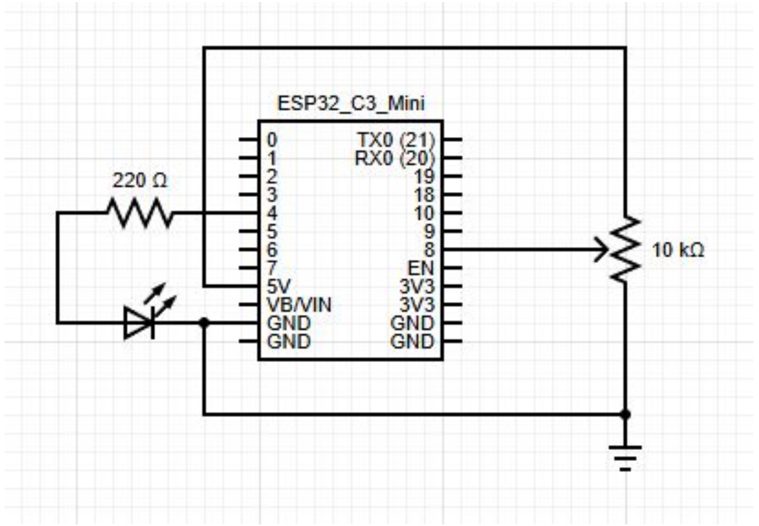
Potentiometers (Cont'd)

- Internally, a **resistive strip** connects its VCC and GND pins
    - A rotating **wiper** connects the output pin to the strip
- **The greater the distance** along the strip between the wiper and the VCC pin, **the greater the resistance** between the wiper and VCC
- The wiper **reduces the voltage** at the output pin the further it is **turned clockwise** (toward GND)



Digital Dimmable LED Circuit

Build the circuit below from the schematic. Then, complete the template code, flash it to the ESP32, and verify the circuit.



```
// Assign variable to pin number for LED
// Assign variable to pin number for Pot

void setup() {
  // Configure the LED pin's behavior to OUTPUT
  // Configure the Pot pin behavior to INPUT
  // Configure the Serial baud rate
}

void loop() {
      // Read pot pin value
      // Set LED pin to the pot pin value
}
```