

TinyML4D

An initiative to make Embedded Machine Learning
education available to everyone globally

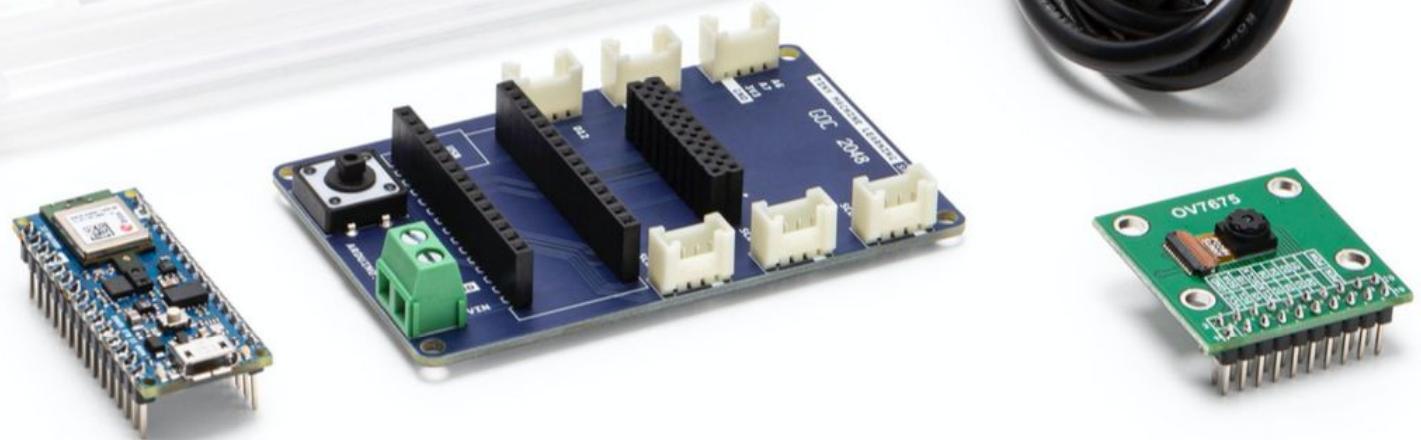


TinyML Kit Overview HW and SW installation & Test

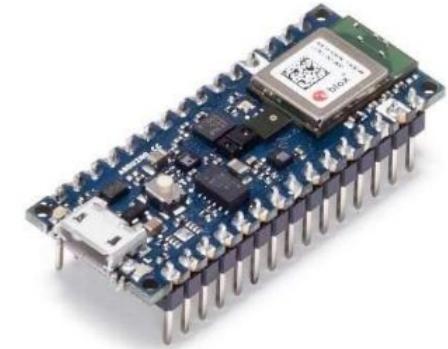
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rovai@unifei.edu.br
UNIFEI - Universidade Federal de Itajubá, Brazil*



TinyML Kit Overview



Nano 33 BLE Sense (+ USB cable)

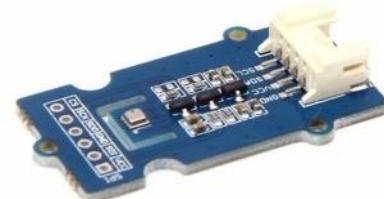


Purpose

AI-enabled developmental **microcontroller board** with USB-A to microB cable

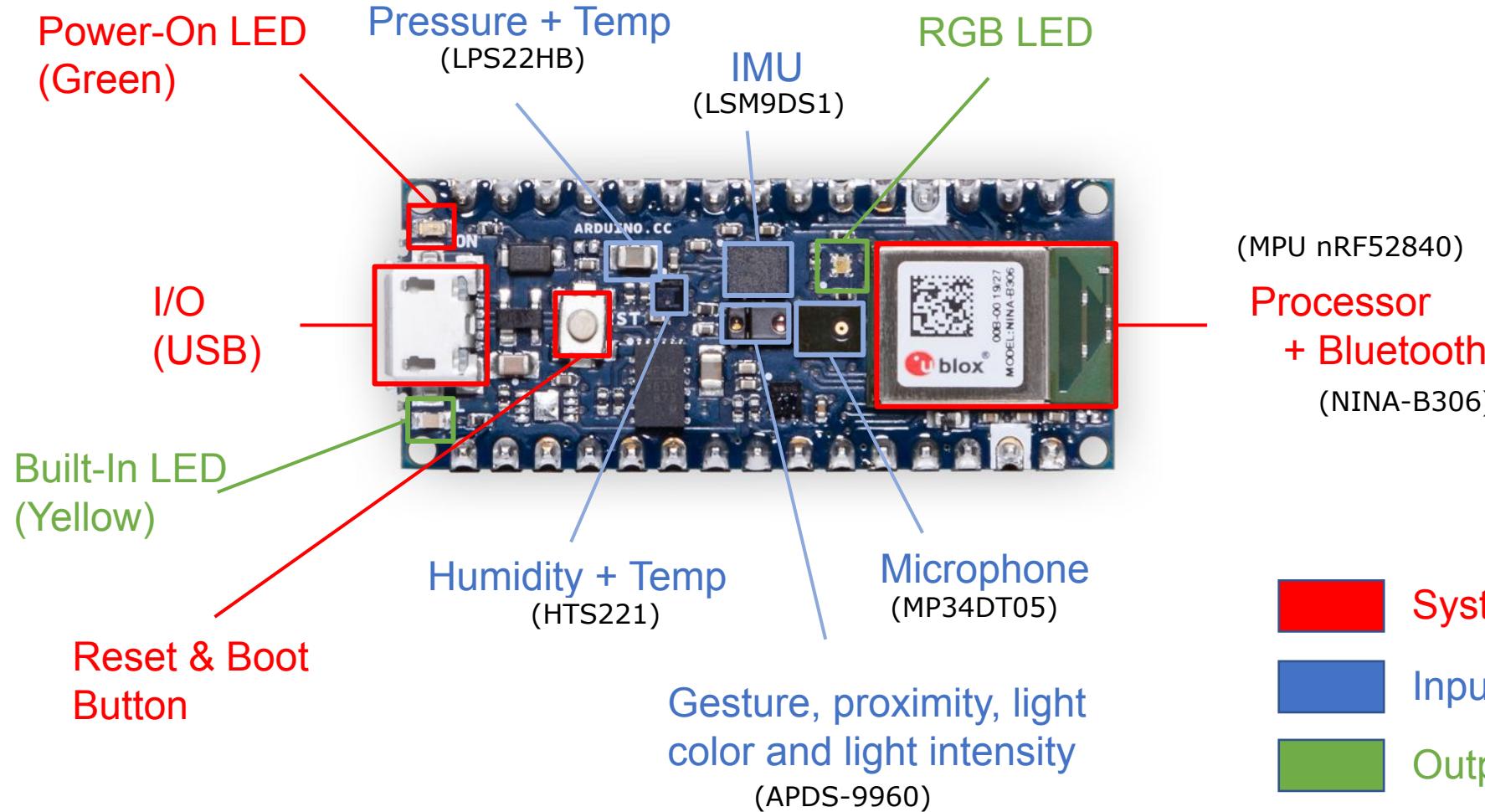
Specifications

- **MPU:** Nordic nRF52840 (ARM Cortex-M4 w/FPU): **3.3V**, 64MHz, 1MB flash, **256 kB RAM**
- **Sensors on board:** microphone, IMU (9 axis), color, light, proximity, barometric, temperature, **humidity***, gesture, and light intensity.
- BLE module covered by ArduinoBLE library
- RGB LEDs

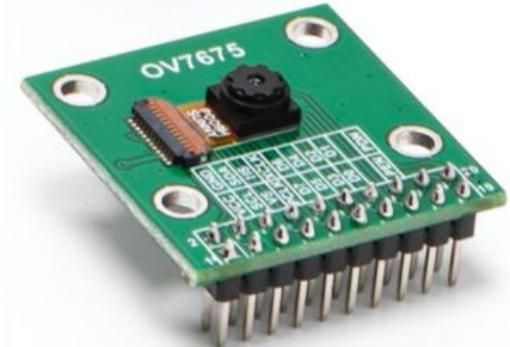


* Not included in some packages. For projects you can use the external Grove - Temp&Humi&Barometer Sensor (BME280)

Nano 33 BLE Sense (Development board)



OV 7675 Camera Module



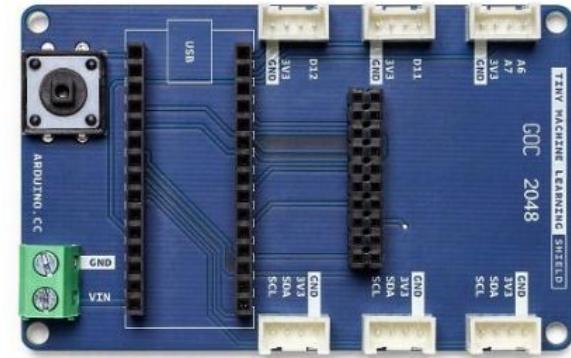
Purpose

Breakout PCB for *tiny* camera.

Specifications

- Low-cost, Low-voltage, **0.3 MP** CMOS VGA (can step down to **QVGA**, QQVGA) image sensor
- Serial Camera Control Bus (SCCB) + Camera Parallel Interface (CPI) / Digital Video Port (DVP) interface
- Breaks ribbon cable out to 2x10 pin array
- **1 or 5 fps** (Frames per Second)

Tiny Machine Learning Shield

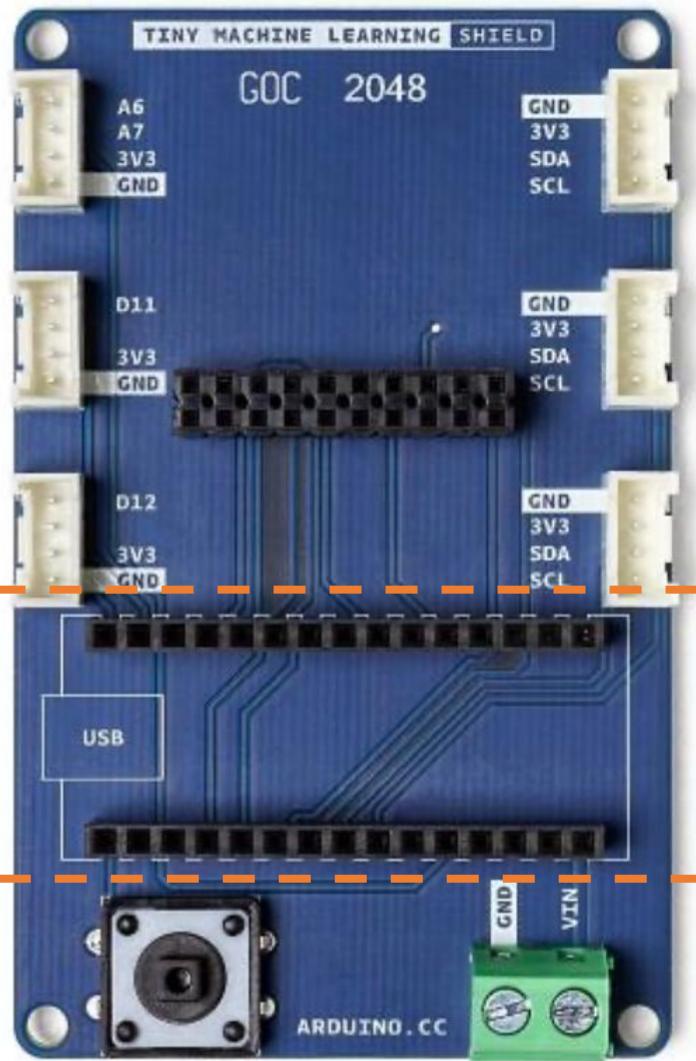


Purpose

A daughter PCB designed to **breakout the I/O** from the Nano 33 BLE sense to permit easy, reliable **communication with** other local, **off-board elements**

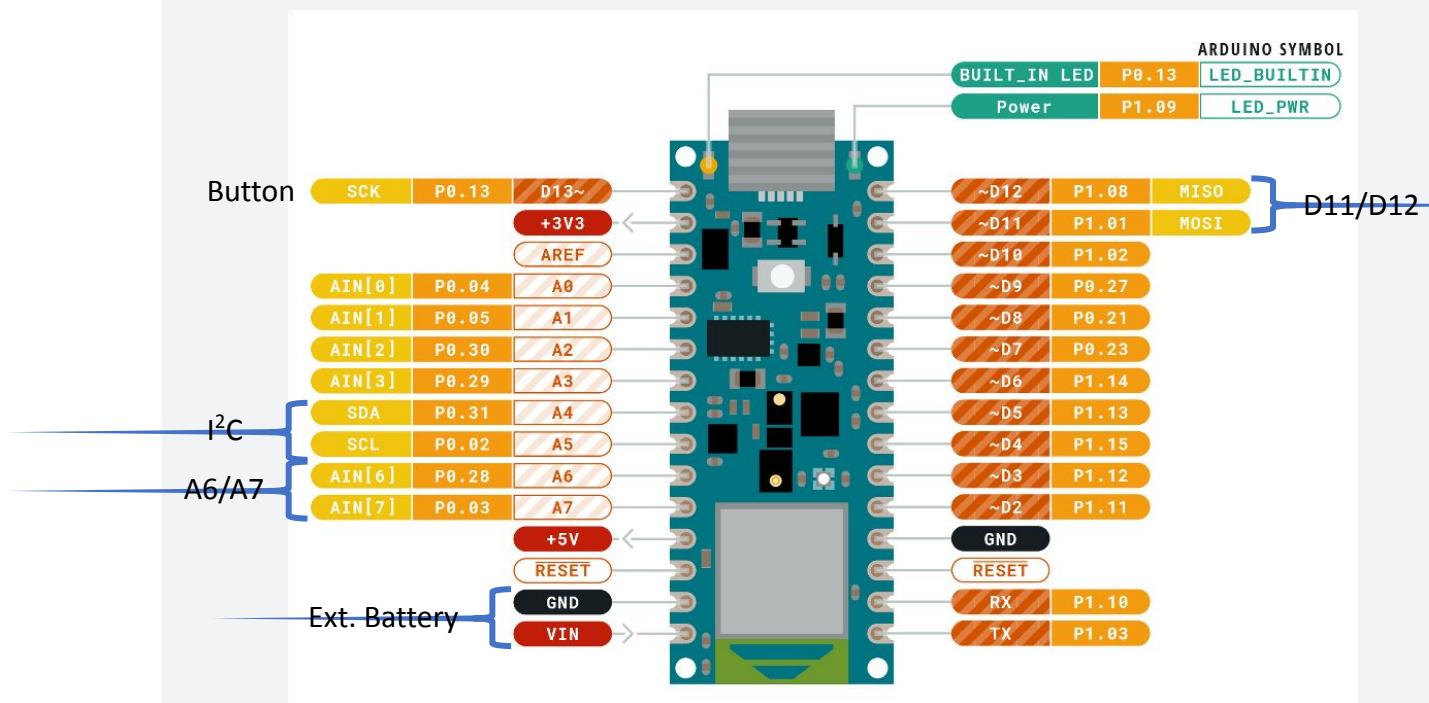
Specifications

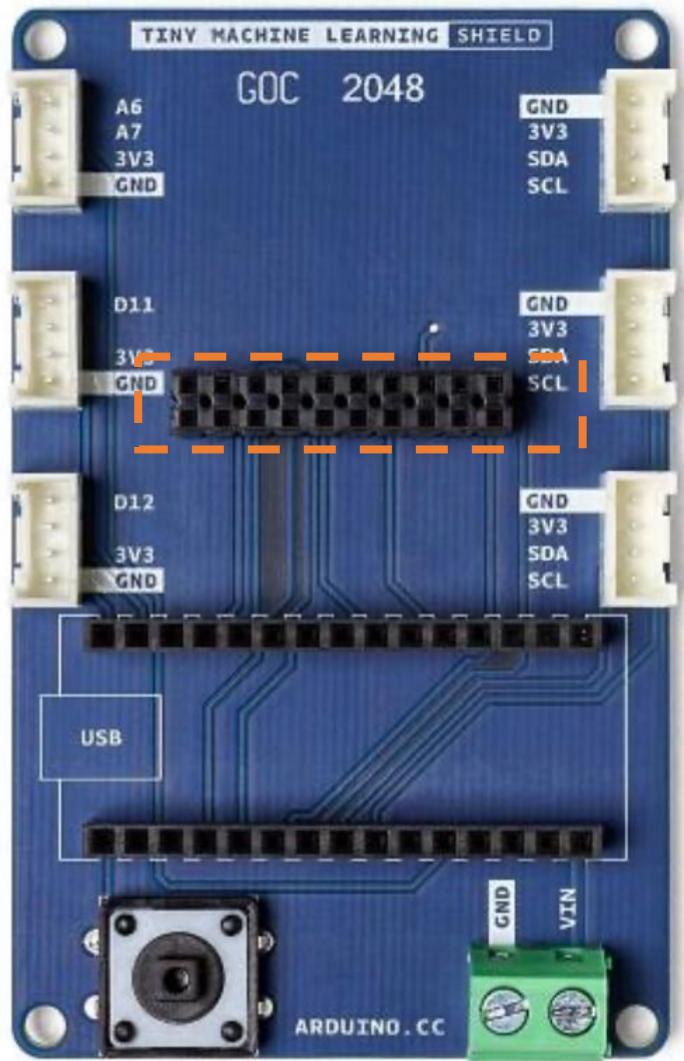
- Grove connectors (3.3V I2C and simple digital / analog - see pinouts)
- 2x10 pin array for OV7675 camera module
- Voltage input terminal block, accepts 4.5 to 21V (down regulated to 3.3V on Nano 33)



TinyML Shield

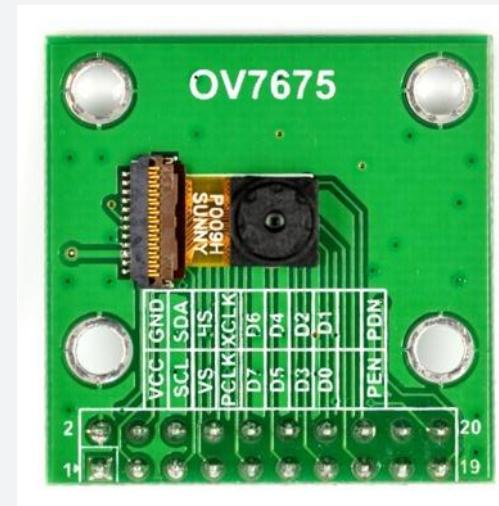
Two rows of 1x15 headers
that you can slot the Nano
33 BLE sense into



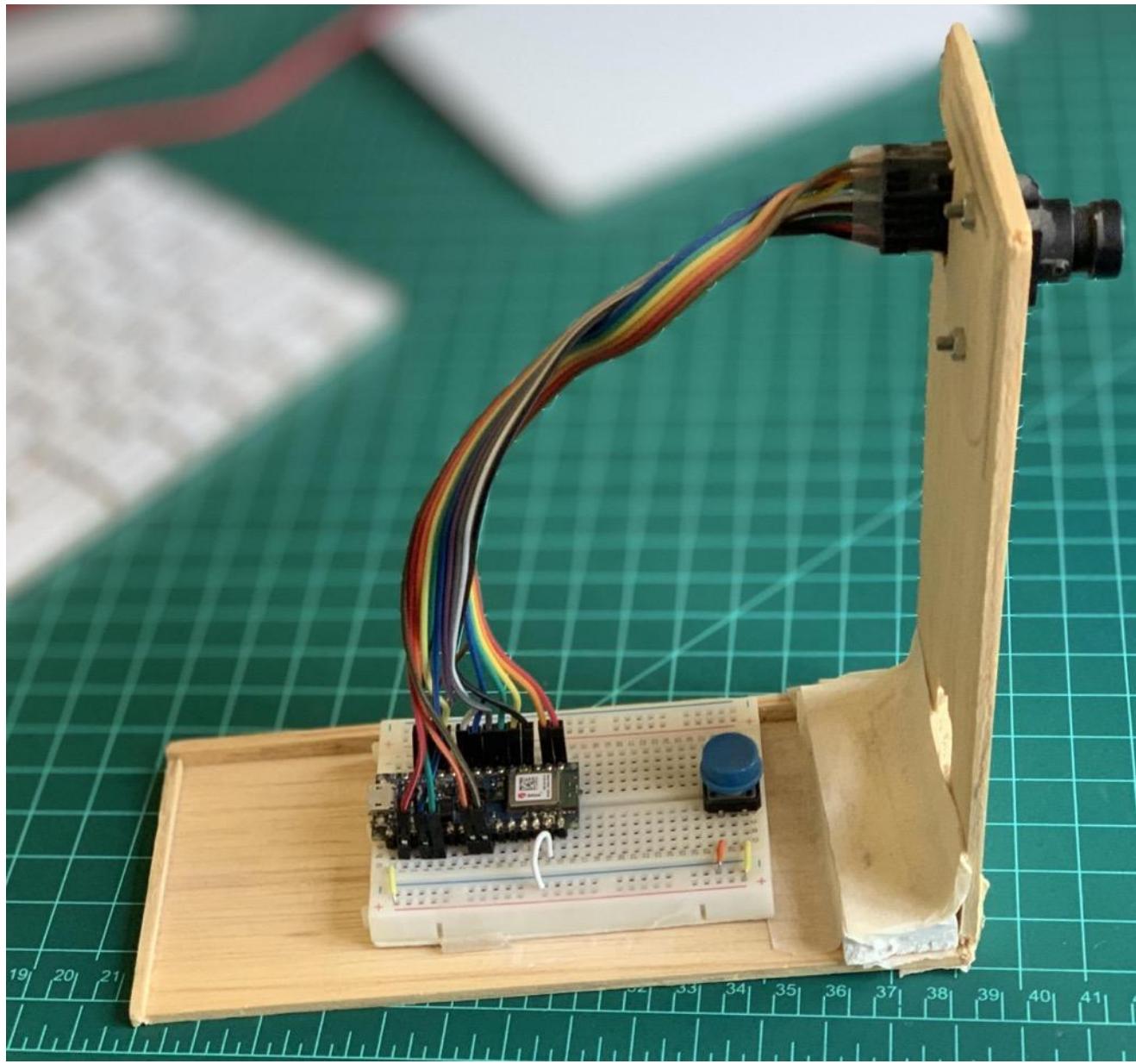


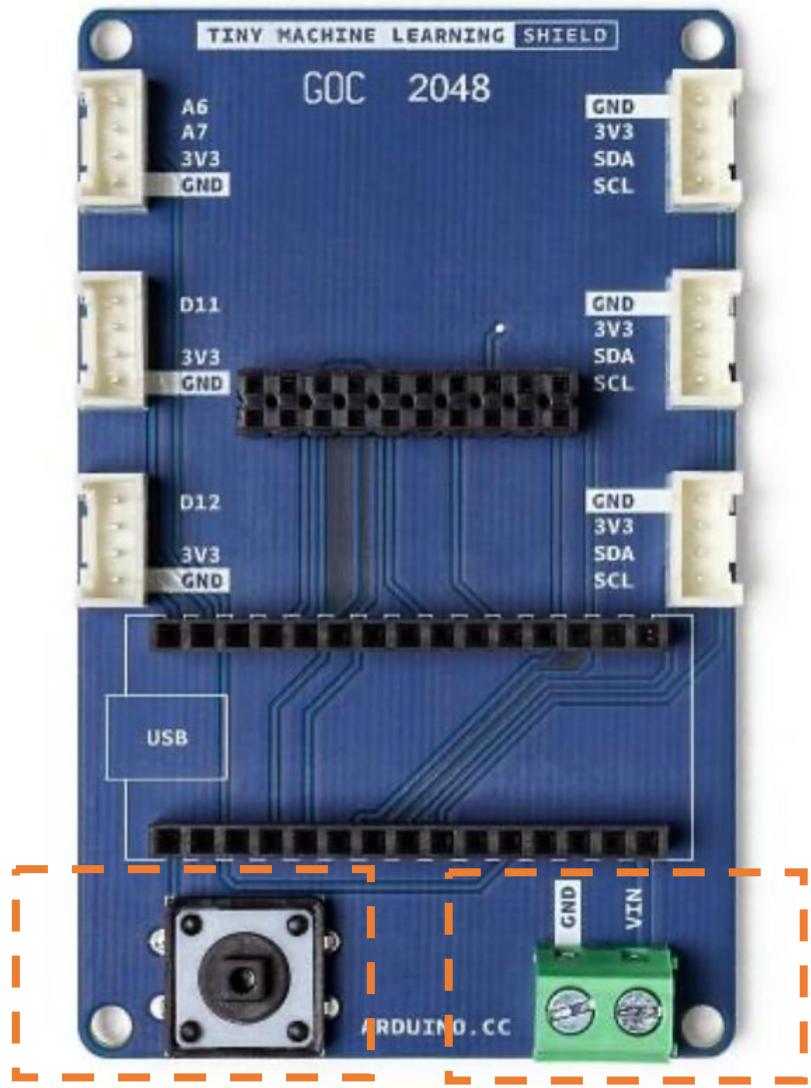
TinyML Shield

2x10 header that is intended to receive the corresponding pins of the OV7675 camera module



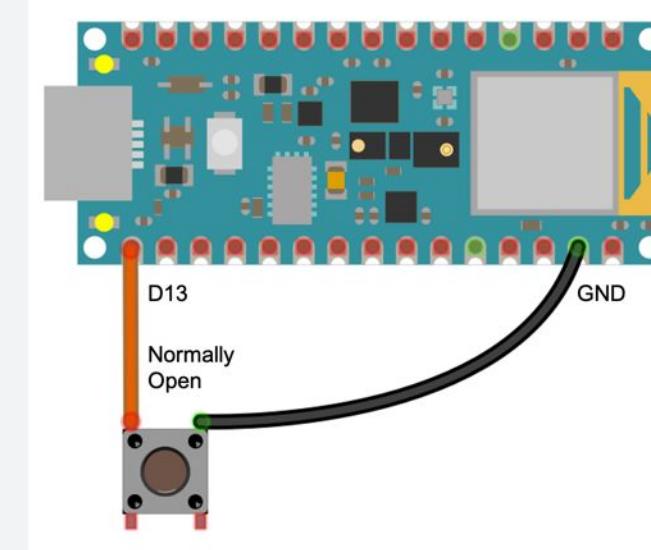
OV7670_VSYNC	8
OV7670_HREF	A1
OV7670_PLK	A0
OV7670_XCLK	9
OV7670_D0	10
OV7670_D1	1
OV7670_D2	0
OV7670_D3	2
OV7670_D4	3
OV7670_D5	5
OV7670_D6	6
OV7670_D7	4



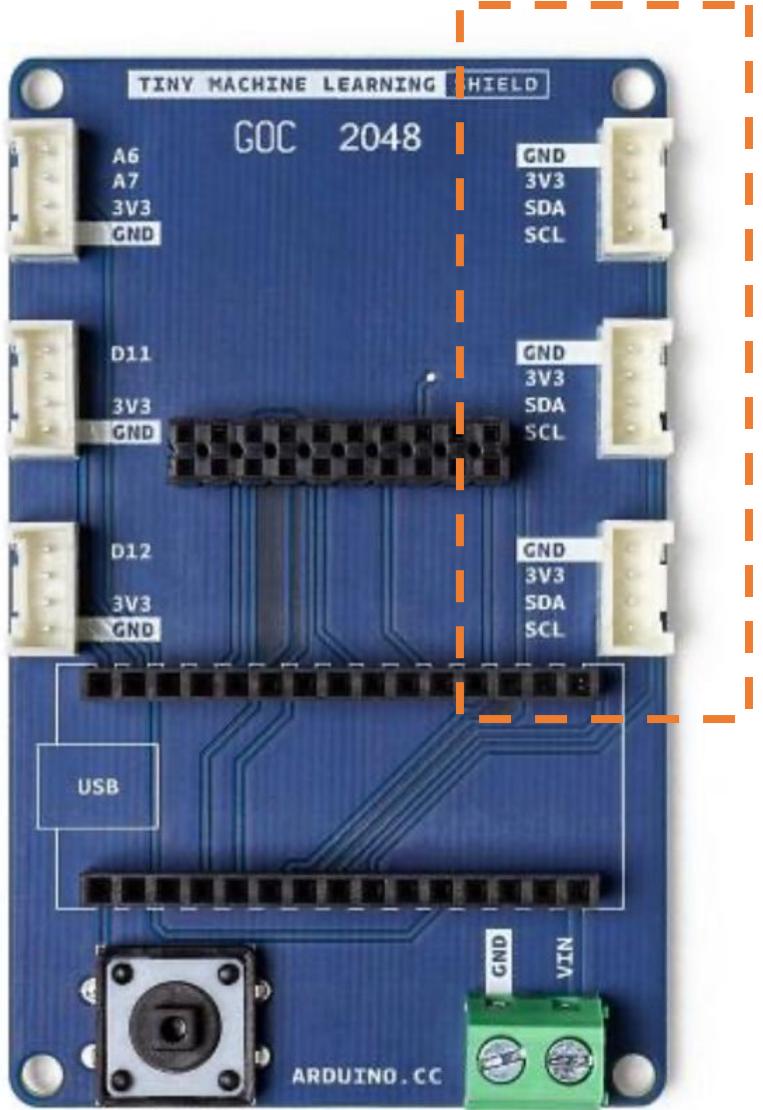


TinyML Shield

A easily programmable
button on the left

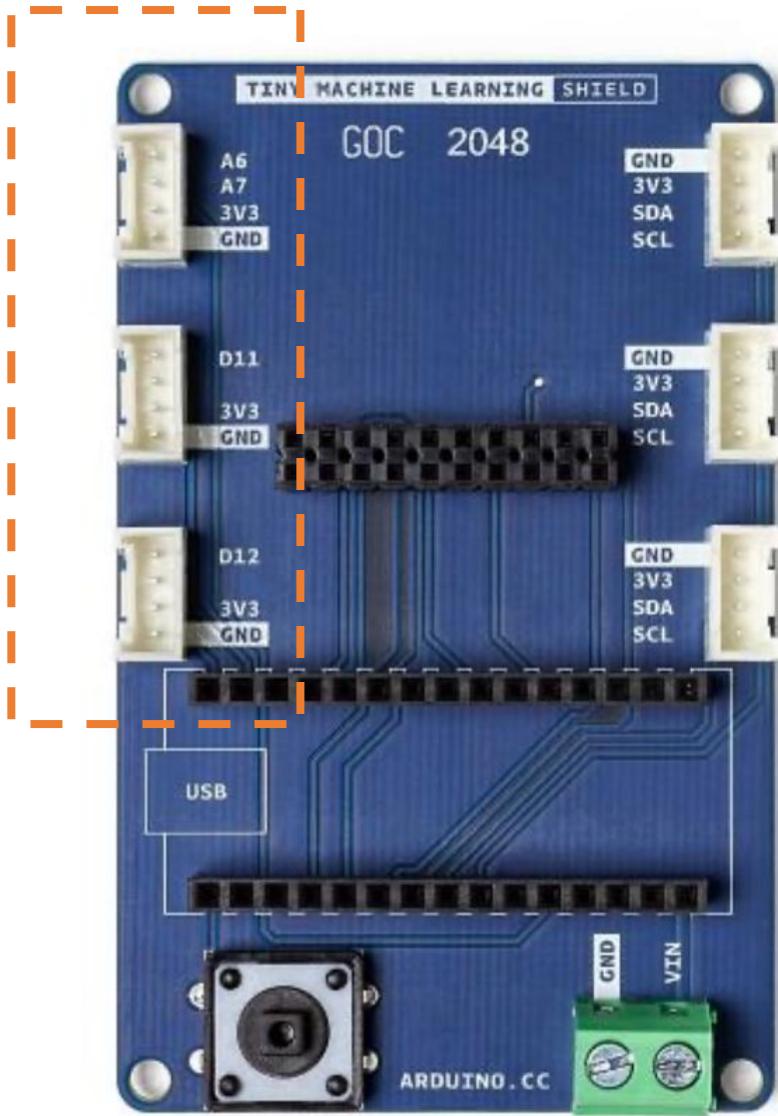


Screw-in terminal block for
external (battery) power (4.5V to 21V)



TinyML Shield

Standard Grove
connectors, to permit
serial communication (I2C
= power + data + clock)
with modules (both
sensors and actuators)



TinyML Shield

Grove connectors that
break out analog and
digital GPIO

Grove Connectors



Purpose

Facilitate **plug-and-play connections** to off-board modules to extend the possible scope of functionality to new **TinyML** applications

Specifications

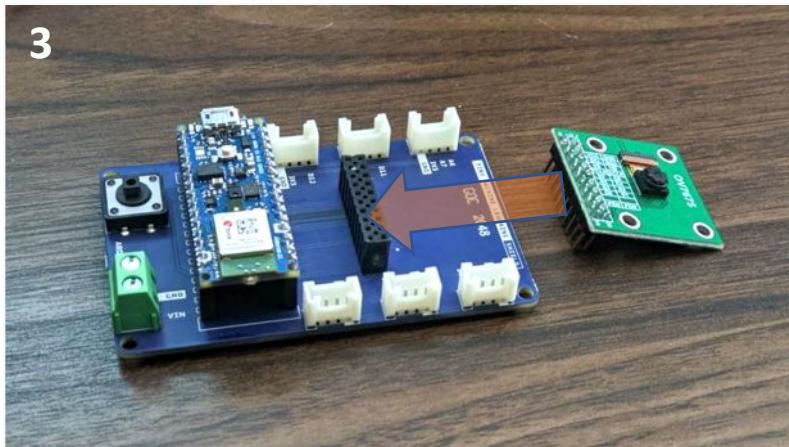
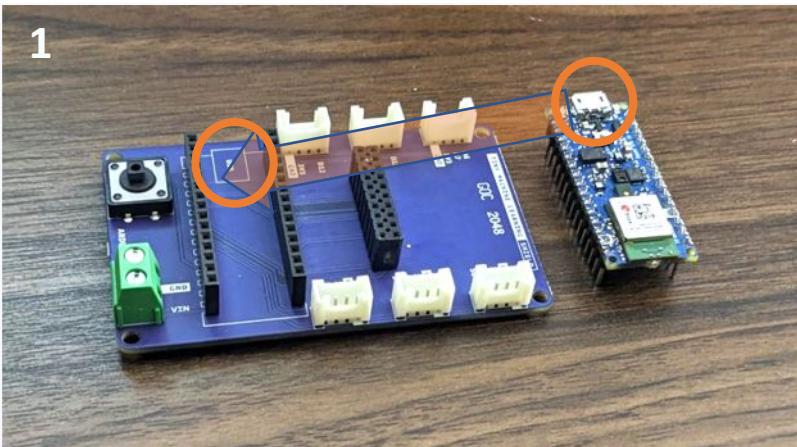
- Proprietary connection system from SeeedStudio, similar to JST PH-type connectors
- Large catalog of sensors, actuators available at seeedstudio.com
- Be sure to check the voltage requirements and pinout of any new Grove module for compatibility with this shield before purchasing or connecting said module

TinyML Kit Installation

- Hardware Set-up
- Software Set-up



Installing the Hardware



Installing the Arduino IDE 2.0

The screenshot shows the Arduino website's software section. At the top, there are tabs for PROFESSIONAL, EDUCATION, STORE, HARDWARE, SOFTWARE (which is selected), CLOUD, DOCUMENTATION, COMMUNITY, BLOG, and ABOUT. Below this, there's a search bar and a sign-in button.

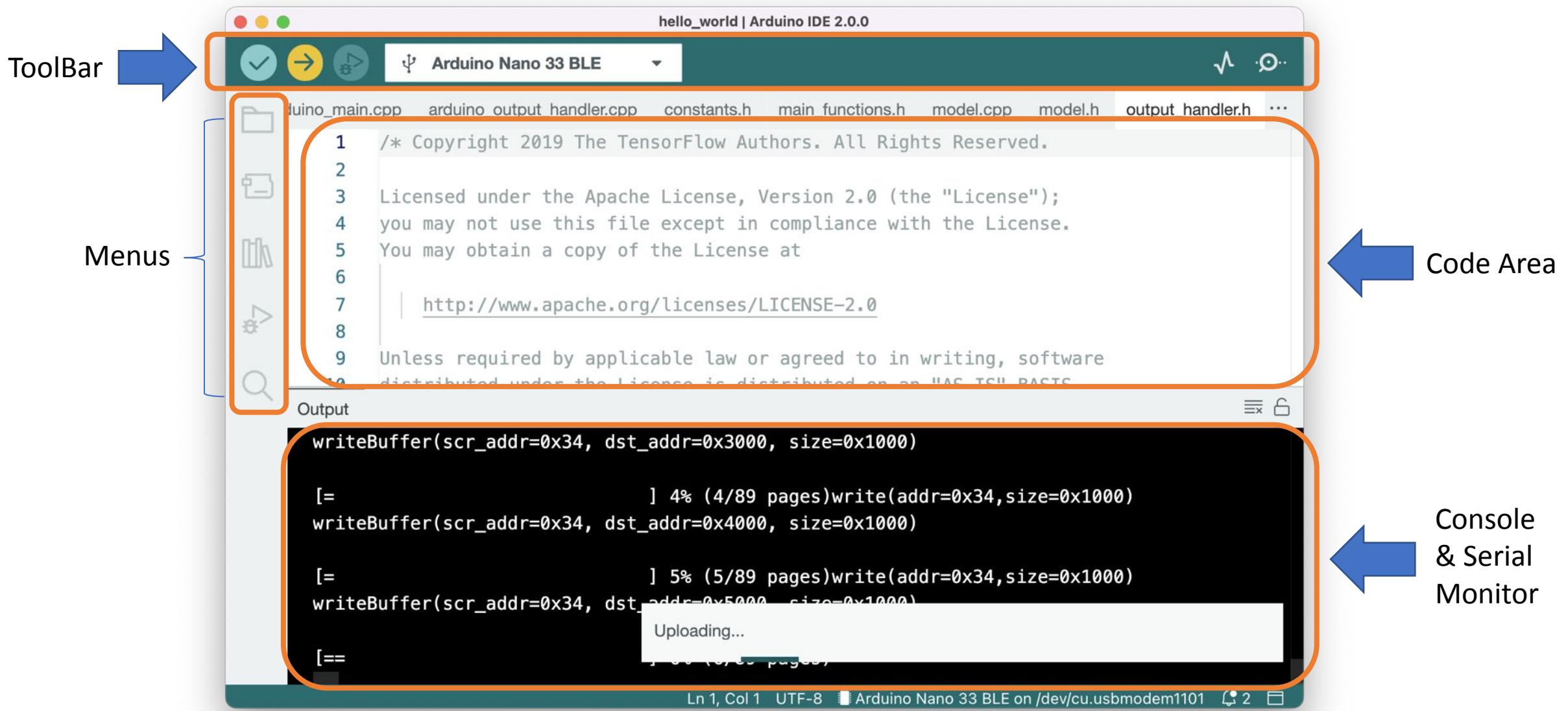
The main content area features the Arduino Web Editor, which allows users to code online and save sketches in the cloud. It includes sections for CODE ONLINE and GETTING STARTED, and a preview of a sketchbook interface.

Below the editor, there's a large heading "Downloads". On the left, there's a summary of the Arduino IDE 2.0, its features (faster, more powerful, modern editor, autocomplete, navigation, live debugger), and a link to the documentation. It also mentions nightly builds and source code availability on GitHub.

On the right, under the heading "DOWNLOAD OPTIONS", there are links for Windows (Win 10 and newer, 64 bits; MSI installer; ZIP file), Linux (AppImage 64 bits (X86-64); ZIP file 64 bits (X86-64)), and macOS (10.14: "Mojave" or newer, 64 bits). This entire "DOWNLOAD OPTIONS" section is highlighted with an orange rounded rectangle.

A "Help" button is located at the bottom right of the download section.

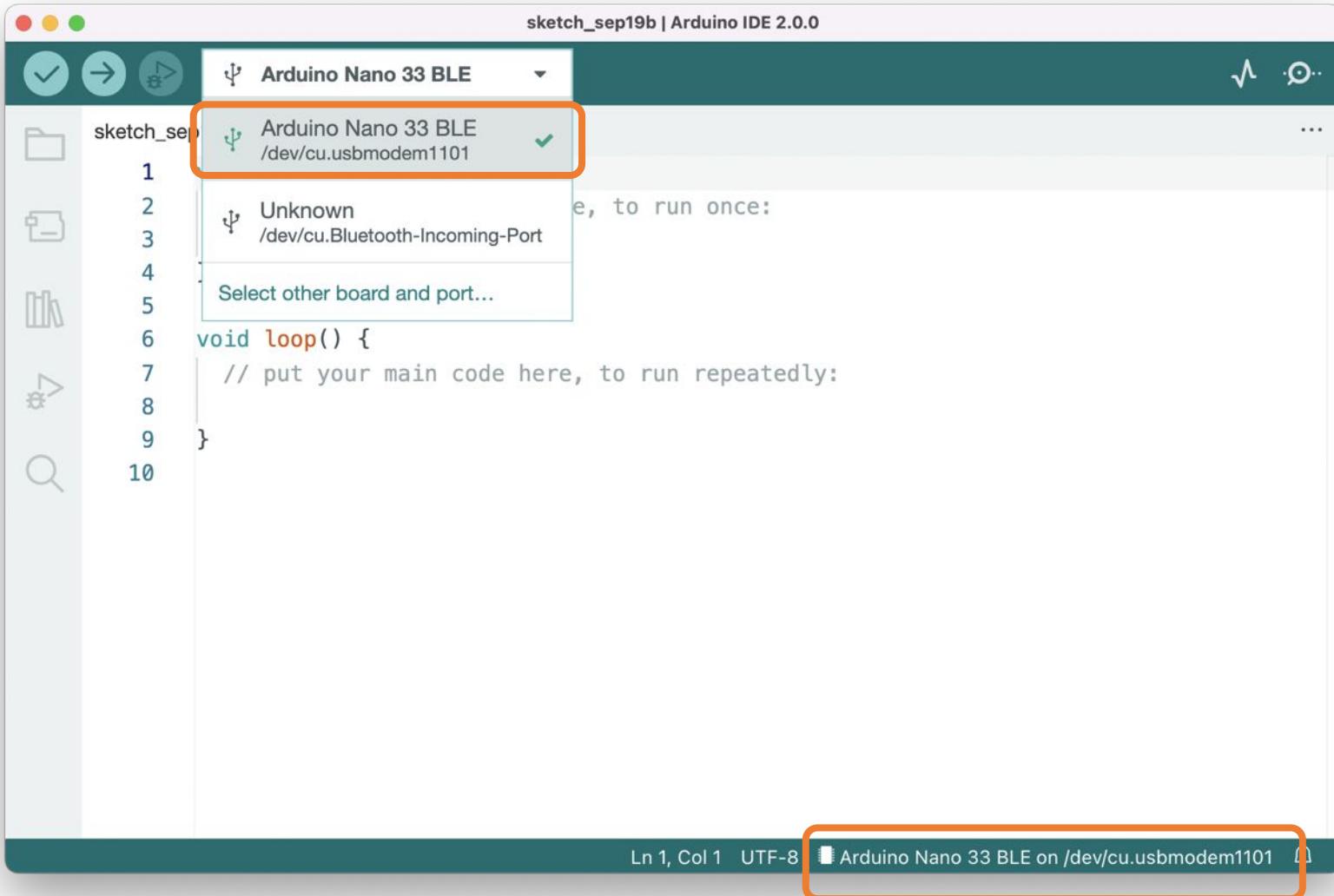
The Arduino IDE 2.0



Installing the Board Files



Select Board and Port



Installing Sensor and Auxilary Libraries

IMU library

The screenshot shows the Arduino IDE 2.0.0 interface with a sketch titled "sketch_sep19a.ino". The code includes setup() and loop() functions. In the Library Manager, the "LSM9DS1" library is selected and highlighted with an orange box. Below it, the "Arduino_LSM9DS1" library by Arduino is listed as installed. A blue arrow points from the "LSM9DS1" section towards the "Harvard_TinyMLx" library in the next screenshot.

```
sketch_sep19a | Arduino IDE 2.0.0
Arduino Nano 33 BLE
LIBRARY MANAGER
sketch_sep19a.ino
1 void setup() {
2 // put your setup code here, to run once:
3
4 }
5
6 void loop() {
7 // put your main code here, to run repeatedly:
8
9 }
10
```

Shield and Camera libraries

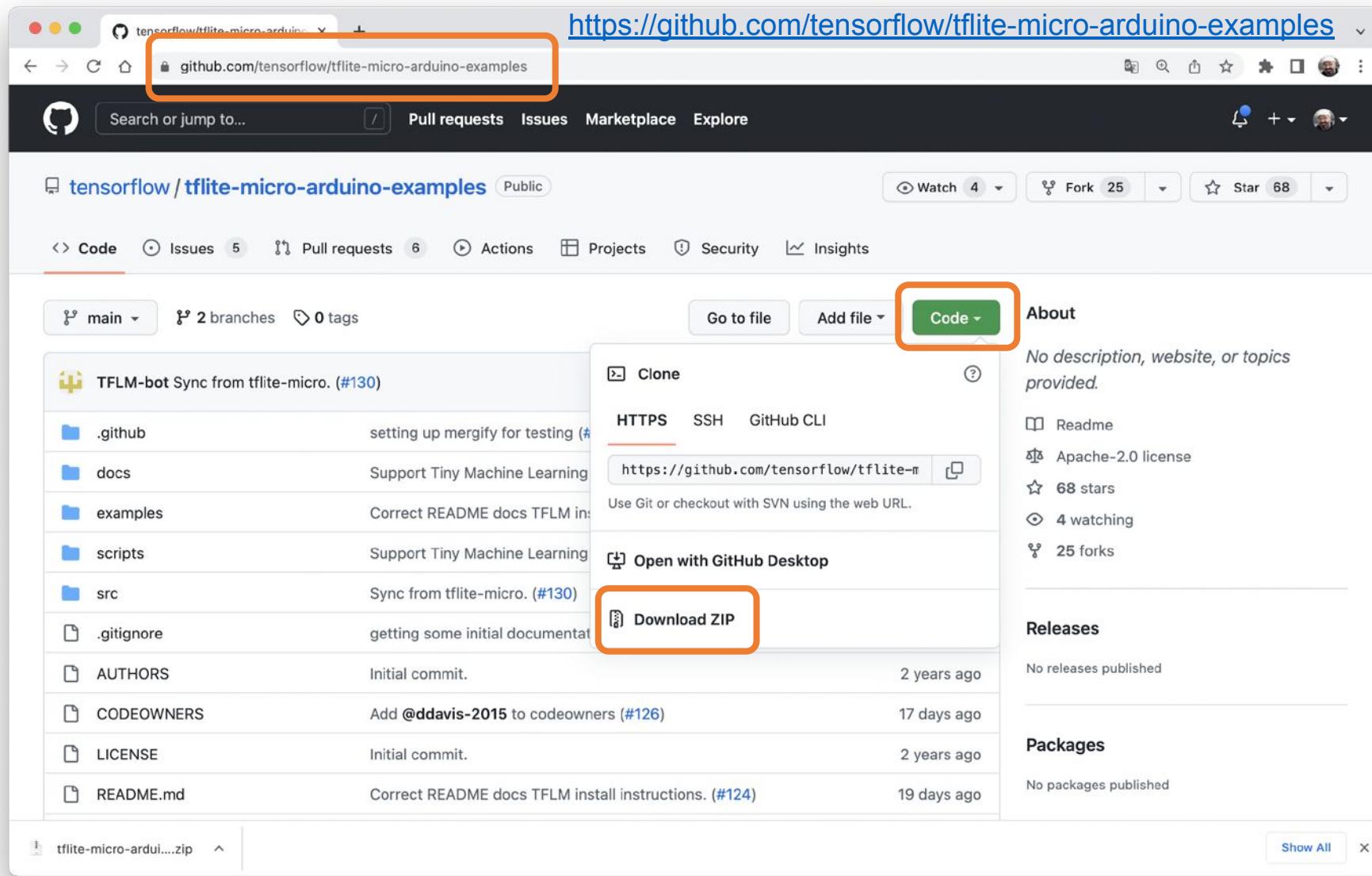
The screenshot shows the Arduino IDE 2.0.0 interface with a sketch titled "sketch_sep20a.ino". The code includes setup() and loop() functions. In the Library Manager, the "harvard" library is selected and highlighted with an orange box. Below it, the "Harvard_TinyMLx" library by TinyMLx Authors is listed as installed. A callout box highlights the library's description, which mentions it supports the TinyML Shield and includes examples for the Arduino Nano 33 BLE Sense board and the Tiny Machine Learning Kit. It also notes the inclusion of a modified version of the Arduino_OV767X library and TensorFlow_Lite examples. A text overlay at the bottom right states "Includes the OV767X library".

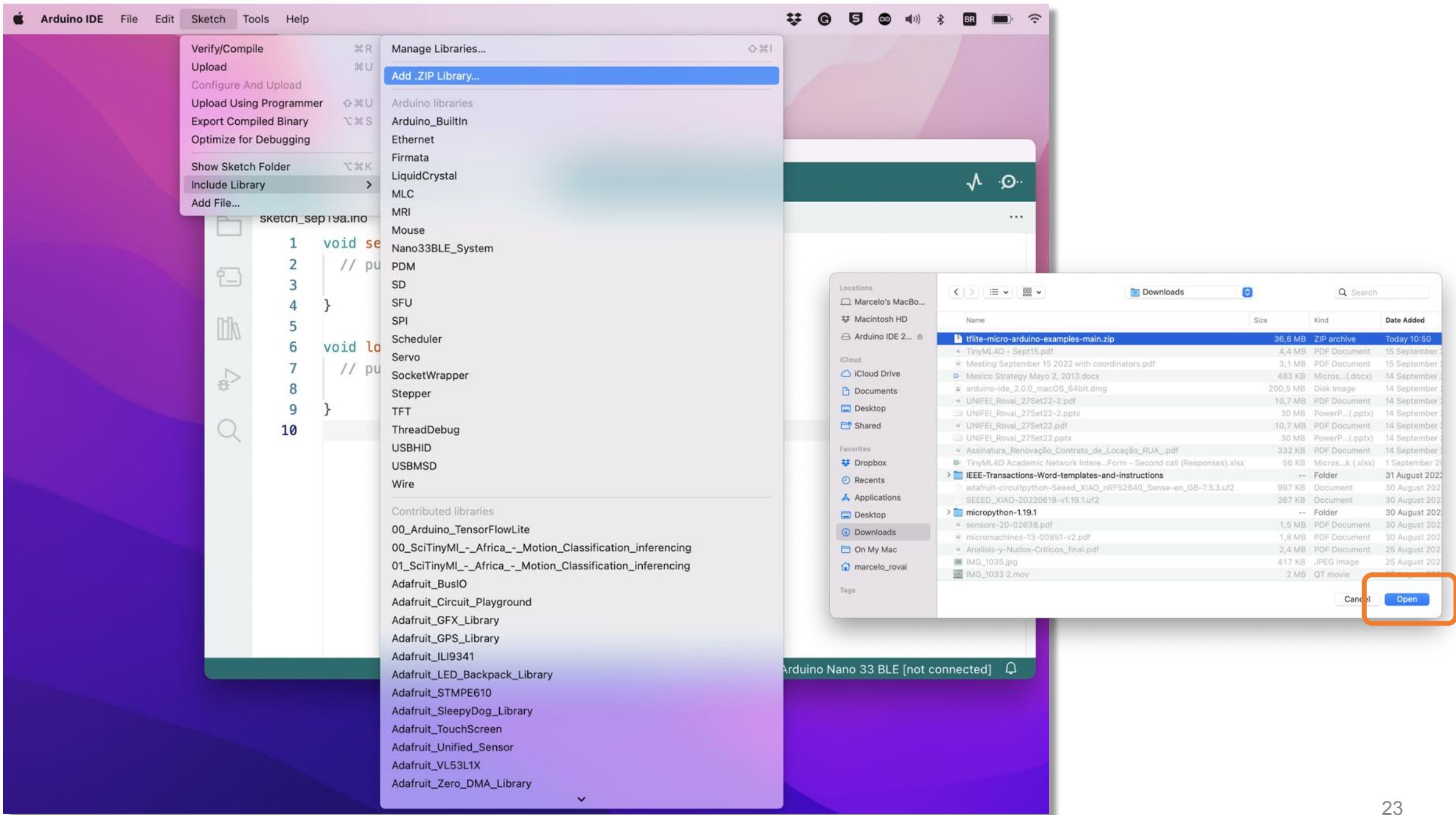
```
sketch_sep20a | Arduino IDE 2.0.0
Arduino Nano 33 BLE
LIBRARY MANAGER
sketch_sep20a.ino
1 void setup() {
2 // put your setup code here, to run once:
3
4 }
5
6 void loop() {
7 // put your main code here, to run repeatedly:
8
9 }
10
```

indexing: 8/30

Includes the OV767X library

Installing Tensorflow Lite Micro (TFLM) Library





The screenshot shows the Arduino IDE 2.0.0 interface with the title bar "sketch_sep19a | Arduino IDE 2.0.0". The main window displays the code for "sketch_sep19a.ino". The code consists of two functions: "setup()" and "loop()". The "setup()" function contains a single line of code: "// put your setup code here, to run once;". The "loop()" function also contains a single line of code: "// put your main code here, to run repeatedly;". The status bar at the bottom indicates "Ln 10, Col 1 UTF-8" and "Arduino Nano 33 BLE [not connected]". A progress bar at the bottom right shows 1% completion.

```
sketch_sep19a.ino
1 void setup() {
2     // put your setup code here, to run once:
3 }
4
5 void loop() {
6     // put your main code here, to run repeatedly:
7 }
8
9 }
```

The screenshot shows the Arduino IDE 2.0.0 interface with the title bar "sketch_sep19a | Arduino IDE 2.0.0". The main window displays the same code as the first screenshot. Below the code editor, there is an "Output" window. The output window shows the message "Library installed". The status bar at the bottom indicates "Ln 10, Col 1 UTF-8" and "Arduino Nano 33 BLE [not connected]".

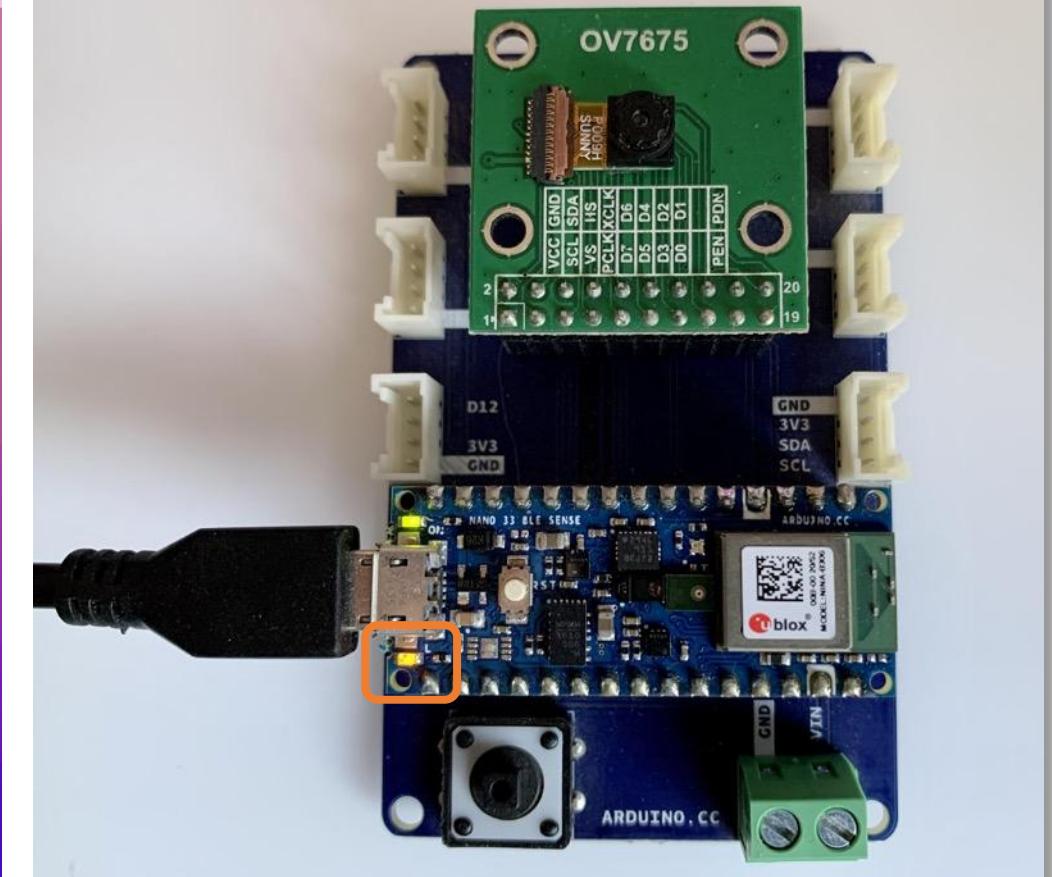
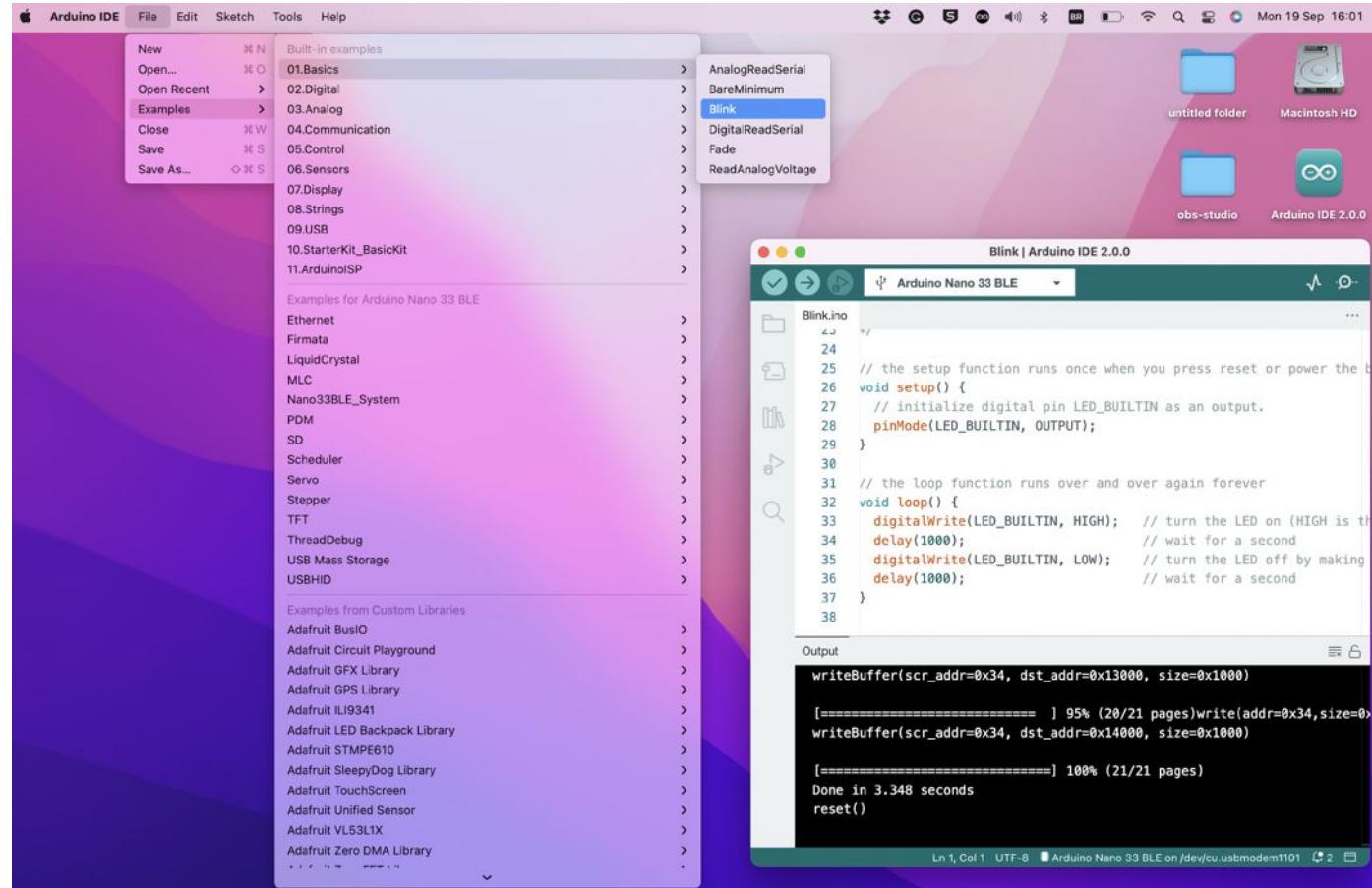
```
sketch_sep19a.ino
1 void setup() {
2     // put your setup code here, to run once:
3 }
4
5 void loop() {
6     // put your main code here, to run repeatedly:
7 }
8
9 }
```

TinyML Kit Test

- MCU test (Blink)
- Sensors Test (IMU, MIC, CAMERA)



MCU installation test (Blink)



Testing IMU

Arduino IDE Menu -> Files/Examples/Harvard_TinyMLx/test_IMU

```
test_IMU.ino
76 if (imuIndex == 0) { // testing accelerometer
77     if (IMU.accelerationAvailable()) {
78         IMU.readAcceleration(x, y, z);
79
80         Serial.print("Ax:");
81         Serial.print(x);
82         Serial.print(',');
83         Serial.print("Ay:");
84         Serial.print(y);
85         Serial.print(',');
86         Serial.print("Az:");
87         Serial.println(z);
88     }
89 }
```

Output: Message (⌘ + Enter to send message to 'Arduino Nano 33 BLE' on '/dev/cu.usbmodem1101')

Welcome to the IMU test for the built-in IMU on the Nano 33 BLE Sense

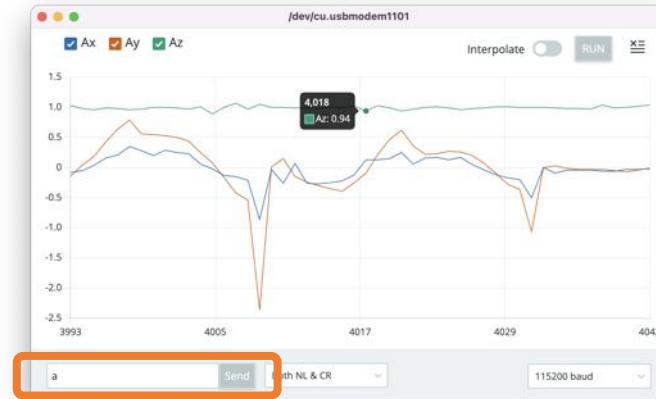
Available commands:

- a - display accelerometer readings in g's in x, y, and z directions
- g - display gyroscope readings in deg/s in x, y, and z directions
- m - display magnetometer readings in uT in x, y, and z directions

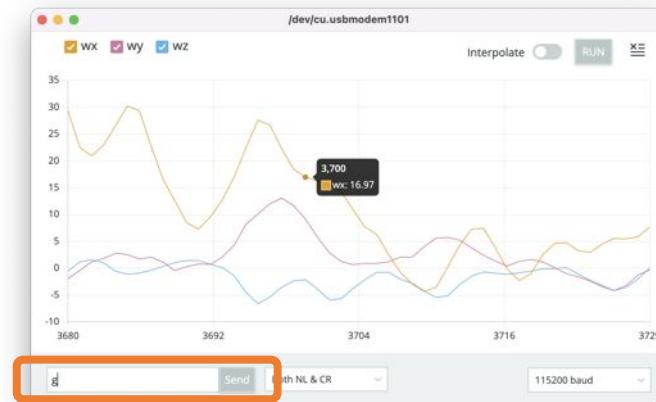
Ax:0.05,Ay:-0.03,Az:0.99
Ax:0.05,Ay:-0.03,Az:0.99

Ln 116, Col 8 UTF-8 Arduino Nano 33 BLE on /dev/cu.usbmodem1101 2

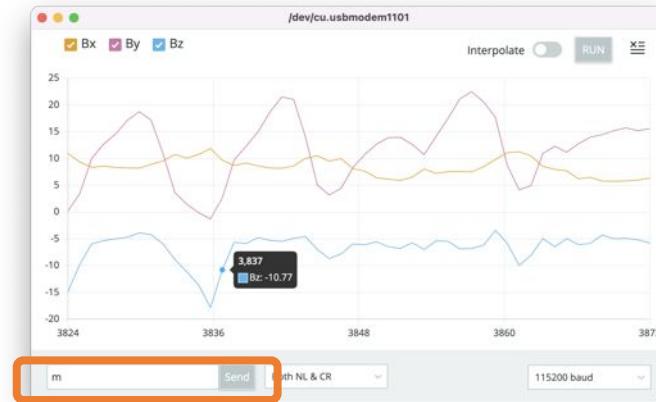
a ->



g ->



m ->



Note: To be shown simultaneously on Plotter, variables must be separated by coma (Change the sketch)

Testing Microphone

Arduino IDE Menu -> Files/Examples/Harvard_TinyMLx/test_microphone

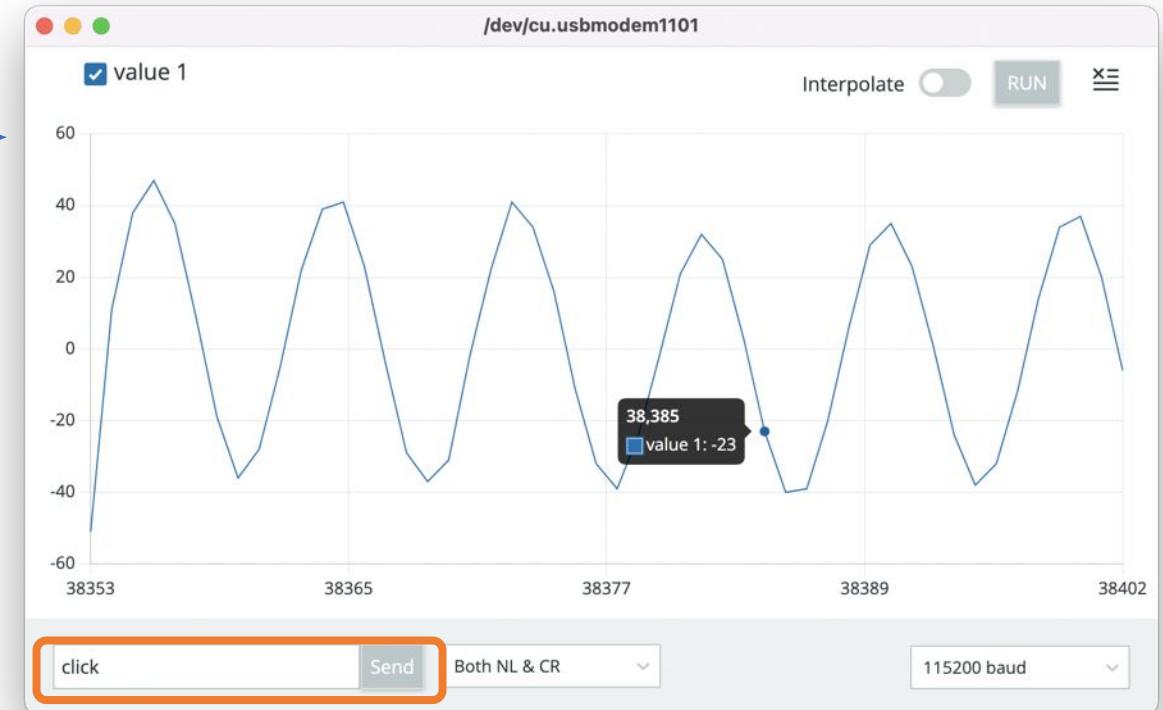
The screenshot shows the Arduino IDE 2.0.0 interface. The top bar displays "test_microphone | Arduino IDE 2.0.0" and "Arduino Nano 33 BLE". The left sidebar shows the file structure with "test_microphone.ino" selected. The main code editor contains the following code:

```
test_microphone.ino
1  /*
2   * Active Learning Labs
3   * Harvard University
4   * tinyMLx - Built-in Microphone Test
5   */
6
7 #include <PDM.h>
8 #include <TinyMLShield.h>
9
10 // PDM buffer
11 short sampleBuffer[256];
12 volatile int samplesRead;
13
14 bool record = false;
```

The bottom section shows the Serial Monitor with the following output:

```
Welcome to the microphone test for the built-in microphone on the Nano 33 BLE Sense
Use the on-shield button or send the command 'click' to start and stop an audio recording
Open the Serial Plotter to view the corresponding waveform
```

At the bottom, it says "indexing: 17/31".

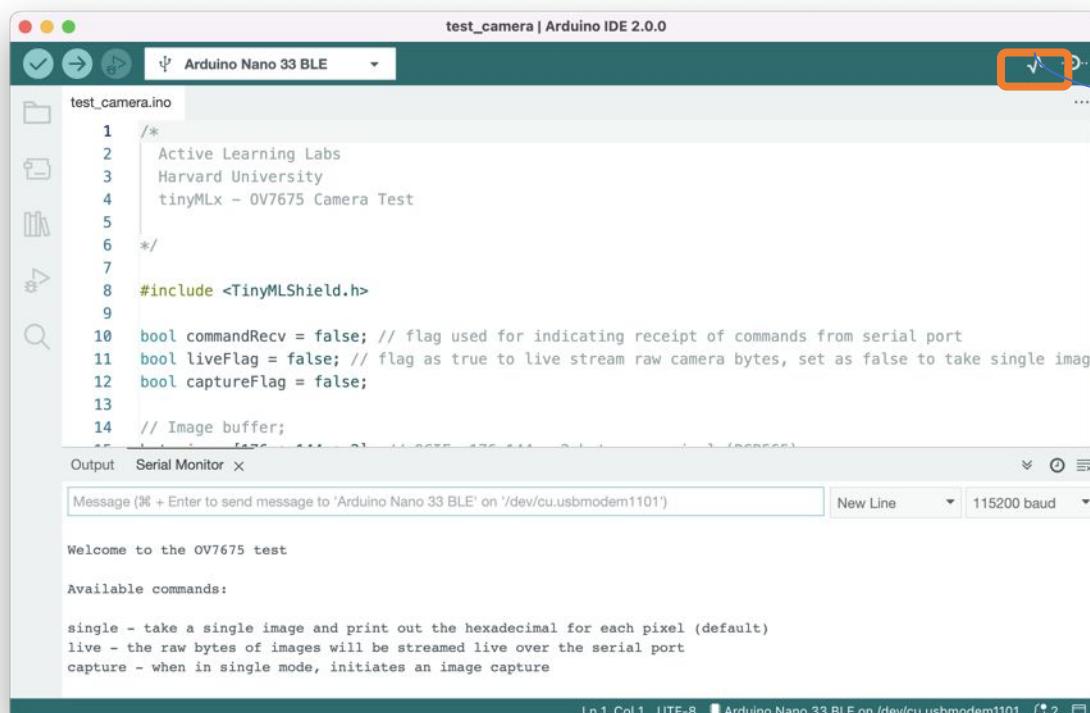


Note: Press the button on shield or send “click” as a command to start/stop sound record



Testing Camera

Arduino IDE Menu -> Files/Examples/Harvard_TinyMLx/test_camera



```
test_camera | Arduino IDE 2.0.0
test_camera.ino
1  /*
2   Active Learning Labs
3   Harvard University
4   tinyMLx - OV7675 Camera Test
5
6 */
7
8 #include <TinyMLShield.h>
9
10 bool commandRecv = false; // flag used for indicating receipt of commands from serial port
11 bool liveFlag = false; // flag as true to live stream raw camera bytes, set as false to take single image
12 bool captureFlag = false;
13
14 // Image buffer;
```

Output Serial Monitor x

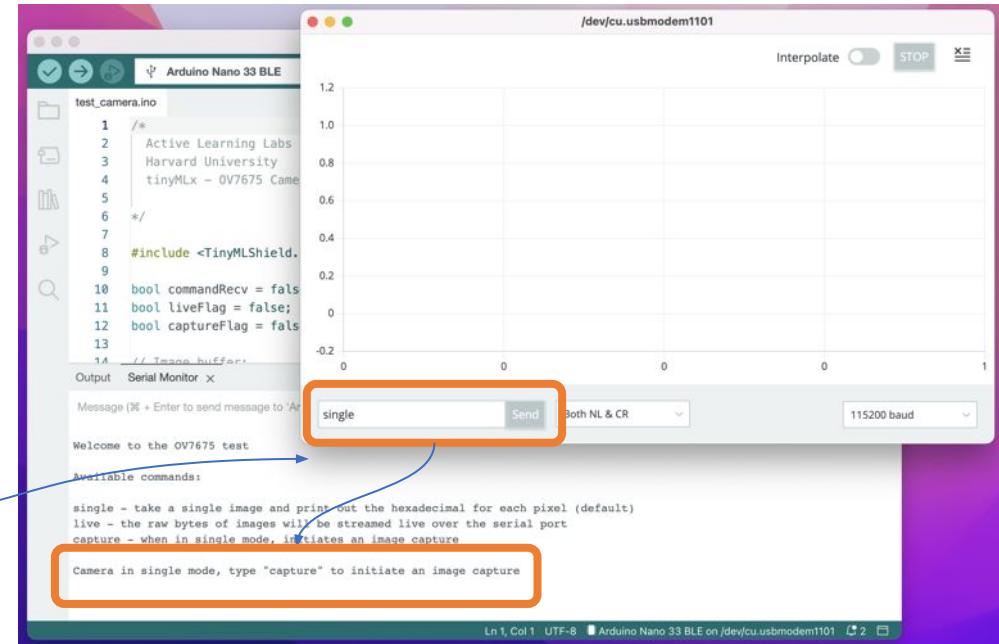
Message (% + Enter to send message to 'Arduino Nano 33 BLE' on '/dev/cu.usbmodem1101') New Line 115200 baud

Welcome to the OV7675 test

Available commands:

single - take a single image and print out the hexadecimal for each pixel (default)
live - the raw bytes of images will be streamed live over the serial port
capture - when in single mode, initiates an image capture

Ln 1, Col 1 UTF-8 ■ Arduino Nano 33 BLE on /dev/cu.usbmodem1101 2



Arduino Nano 33 BLE

test_camera.ino

```
1  /*
2   Active Learning Labs
3   Harvard University
4   tinyMLx - OV7675 Camera
5
6 */
7
8 #include <TinyMLShield.h>
9
10 bool commandRecv = false;
11 bool liveFlag = false;
12 bool captureFlag = false;
13
14 // Image buffer;
```

Output Serial Monitor x

Message (% + Enter to send message to 'Arduino Nano 33 BLE' on '/dev/cu.usbmodem1101') Send Both NL & CR 115200 baud

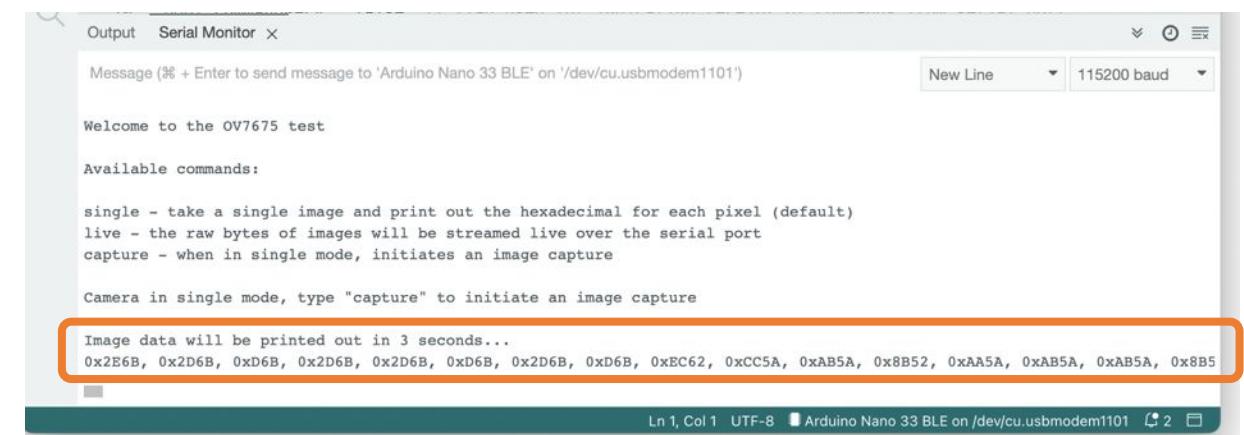
Welcome to the OV7675 test

Available commands:

single - take a single image and print out the hexadecimal for each pixel (default)
live - the raw bytes of images will be streamed live over the serial port
capture - when in single mode, initiates an image capture

Camera in single mode, type "capture" to initiate an image capture

Ln 1, Col 1 UTF-8 ■ Arduino Nano 33 BLE on /dev/cu.usbmodem1101 2



Output Serial Monitor x

Message (% + Enter to send message to 'Arduino Nano 33 BLE' on '/dev/cu.usbmodem1101') New Line 115200 baud

Welcome to the OV7675 test

Available commands:

single - take a single image and print out the hexadecimal for each pixel (default)
live - the raw bytes of images will be streamed live over the serial port
capture - when in single mode, initiates an image capture

Camera in single mode, type "capture" to initiate an image capture

Image data will be printed out in 3 seconds...
0x2E6B, 0x2D6B, 0xD6B, 0x2D6B, 0x2D6B, 0xD6B, 0x2D6B, 0xD6B, 0xEC62, 0xCC5A, 0xAB5A, 0x8B52, 0xAA5A, 0xAB5A, 0xAB5A, 0x8B5

Ln 1, Col 1 UTF-8 ■ Arduino Nano 33 BLE on /dev/cu.usbmodem1101 2

Note: Press the button on shield or send “capture” as a command to capture a image



Testing Camera



```
Output Serial Monitor X

Message (% + Enter to send message to 'Arduino Nano 33 BLE' on '/dev/cu.usbmodem1101')
New Line ▾ 115200

Welcome to the OV7675 test

Available commands:

single - take a single image and print out the hexadecimal for each pixel (default)
live - the raw bytes of images will be streamed live over the serial port
capture - when in single mode, initiates an image capture

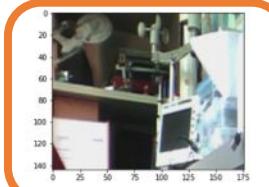
Camera in single mode, type "capture" to initiate an image capture

Image data will be printed out in 3 seconds...
0x2E6B, 0x2D6B, 0xD6B, 0x2D6B, 0x2D6B, 0xD6B, 0x2D6B, 0xD6B, 0xEC62, 0xCC5A, 0xAB5A, 0x8B52, 0xAA5A, 0xAB5A, 0xAB5A, 0x
```



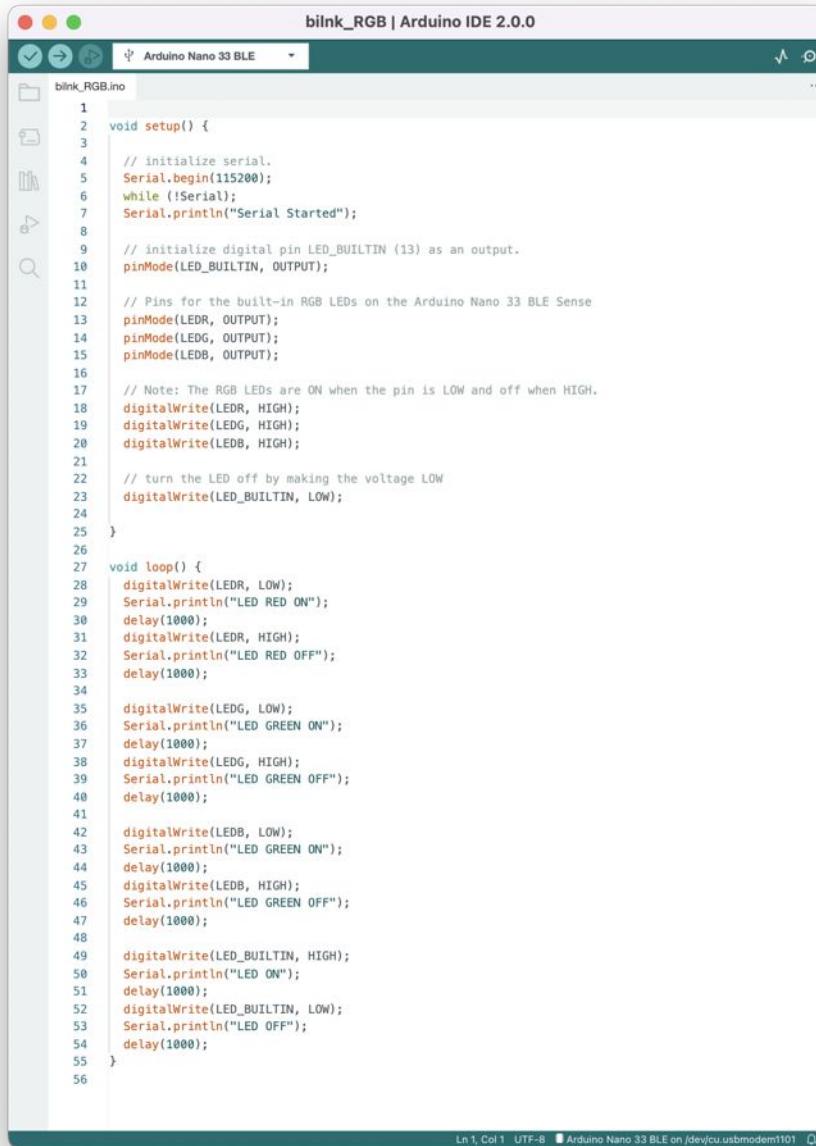
The screenshot shows the Google Colab interface with the following details:

- Title Bar:** OV7675_Image_Viewer.ipynb
- Header:** colab.research.google.com/drive/1RcJN54ByEoF...
- Toolbar:** Back, Forward, Home, Search, etc.
- Code Cell:** Contains the Python code for the OV7675 Image Viewer.
- Output Area:** Displays the captured image from the OV7675 sensor.
- File Menu:** File, Edit, View, Insert, Runtime, Tools, Help.
- Status Bar:** All changes saved.
- Right Panel:** Comment, Share, Settings, Help.



OV7675 Image Viewer.ipynb

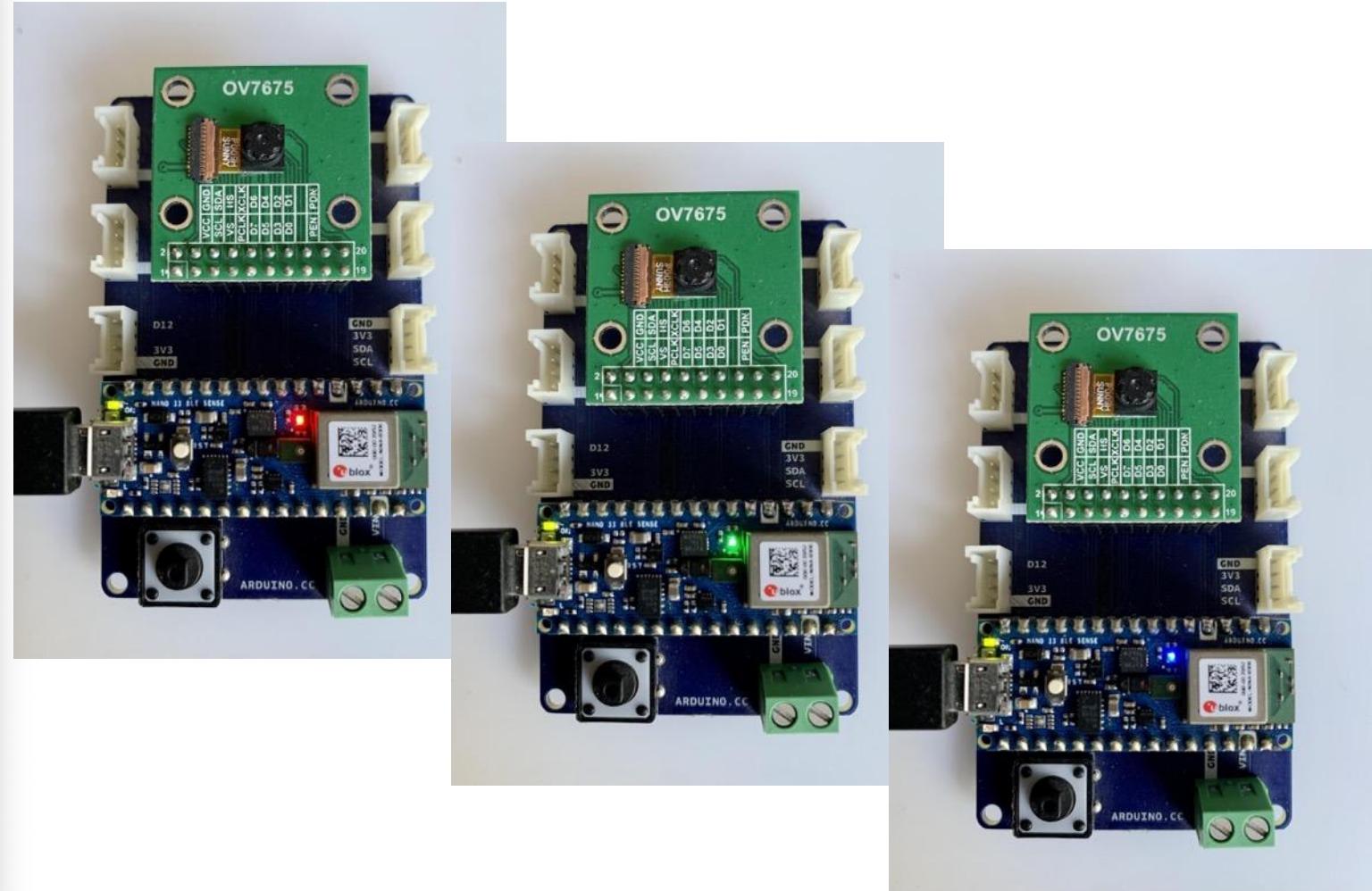
Optional Tests (RGB LEDs)



The screenshot shows the Arduino IDE interface with the file 'blink_RGB.ino' open. The code is as follows:

```
1 void setup() {
2     // initialize serial.
3     Serial.begin(115200);
4     while (!Serial);
5     Serial.println("Serial Started");
6
7     // initialize digital pin LED_BUILTIN (13) as an output.
8     pinMode(LED_BUILTIN, OUTPUT);
9
10    // Pins for the built-in RGB LEDs on the Arduino Nano 33 BLE Sense
11    pinMode(LED_R, OUTPUT);
12    pinMode(LED_G, OUTPUT);
13    pinMode(LED_B, OUTPUT);
14
15    // Note: The RGB LEDs are ON when the pin is LOW and off when HIGH.
16    digitalWrite(LED_R, HIGH);
17    digitalWrite(LED_G, HIGH);
18    digitalWrite(LED_B, HIGH);
19
20    // turn the LED off by making the voltage LOW
21    digitalWrite(LED_BUILTIN, LOW);
22
23 }
24
25 void loop() {
26     digitalWrite(LED_R, LOW);
27     Serial.println("LED RED ON");
28     delay(1000);
29     digitalWrite(LED_R, HIGH);
30     Serial.println("LED RED OFF");
31     delay(1000);
32
33     digitalWrite(LED_G, LOW);
34     Serial.println("LED GREEN ON");
35     delay(1000);
36     digitalWrite(LED_G, HIGH);
37     Serial.println("LED GREEN OFF");
38     delay(1000);
39
40     digitalWrite(LED_B, LOW);
41     Serial.println("LED GREEN ON");
42     delay(1000);
43     digitalWrite(LED_B, HIGH);
44     Serial.println("LED GREEN OFF");
45     delay(1000);
46
47     digitalWrite(LED_BUILTIN, HIGH);
48     Serial.println("LED ON");
49     delay(1000);
50     digitalWrite(LED_BUILTIN, LOW);
51     Serial.println("LED OFF");
52     delay(1000);
53 }
```

At the bottom of the IDE status bar, it says "Ln 1, Col 1 UTF-8" and "Arduino Nano 33 BLE on /dev/cu.usbmodem1101".



Optional Tests (KeyWord Spotting)

micro_speech | Arduino IDE 2.0.0

Arduino Nano 33 BLE

```
1  /* Copyright 2017 The TensorFlow Authors. All Rights Reserved.
2
3 Licensed under the Apache License, Version 2.0 (the "License");
4 you may not use this file except in compliance with the License.
5 You may obtain a copy of the License at
6
7     http://www.apache.org/licenses/LICENSE-2.0
8
9 Unless required by applicable law or agreed to in writing, software
10 distributed under the License is distributed on an "AS IS" BASIS,
11 WITHOUT WARRANTIES OR CONDITIONS OF ANY KIND, either express or implied.
```

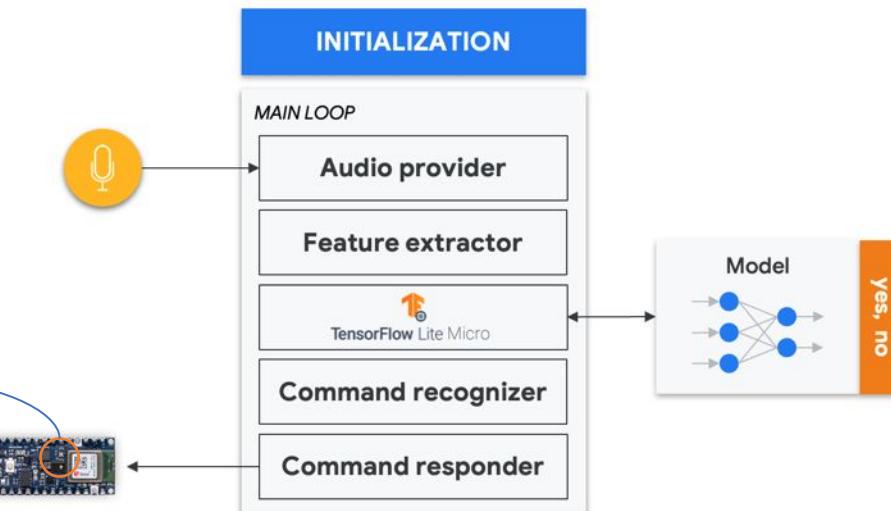
Output Serial Monitor X

Message (% + Enter to send message to 'Arduino Nano 33 BLE' on '/dev/cu.usbmodem1101' New Line 115200 baud

```
Heard yes (210) @39952ms
Heard no (211) @45440ms
Heard yes (203) @48832ms
```

Yes
No
Unknown

Ln 1, Col 1 UTF-8 Arduino Nano 33 BLE on /dev/cu.usbmodem1101 2



Thanks

TinyML4D

An initiative to make Embedded Machine Learning
education available to everyone globally



UNIFEI