adafruit learning system

TensorFlow Lite for EdgeBadge Quickstart

Created by lady ada

Last updated on 2019-12-10 02:51:40 AM UTC

Overview

Machine learning has come to the 'edge' - small microcontrollers that can run a very miniature version of TensorFlow Lite to do ML computations.

But you don't need super complex hardware to start developing your own TensorFlow models! We've curated a simple kit to dip your toes into machine learning waters.

Kit includes:

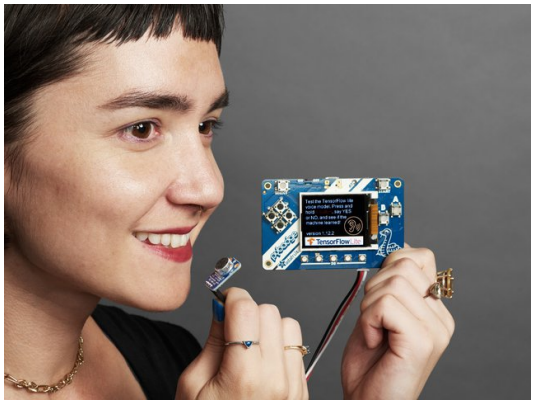
- Adafruit PyBadge with SAMD51 Cortex M4F processor @ 120MHz, with display, speaker and buttons (https://adafru.it/EOm)
- Electret Microphone Amplifier - MAX4466 with Adjustable Gain (https://adafru.it/eQw)
- JST PH 3-Pin to Female Socket Cable - 200mm (https://adafru.it/Fmh)
- Lithium Ion Polymer Battery with Short Cable - 3.7V 350mAh (https://adafru.it/F7A)

The kit uses our PyBadge as your edge processor. It's a compact board - it's credit card sized. It's powered by our favorite chip, the ATSAMD51, with 512KB of flash and 192KB of RAM. We add 2 MB of QSPI flash for file storage, handy for TensorFlow Lite files, images, fonts, sounds, or other assets.

You can plug in a microphone into the ports at the bottom, to add microphone input for micro speech recognition. Our Arduino library has some demos you can get started with to recognize various word pairs like "yes/no", "up/down" and "cat/dog". **TensorFlow Lite for microcontrollers is very cutting-edge so expect to see a lot of development happening in this area, with lots of code and process changes.**

Parts required

You can get everything you need minus tools in this kit:

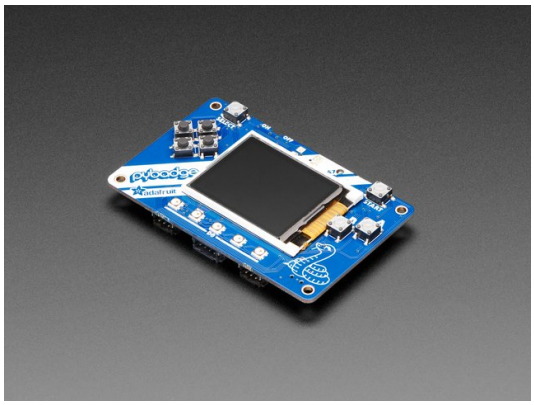


TensorFlow Lite for Microcontrollers Kit

OUT OF STOCK

Out Of Stock

Or as individual parts:



Adafruit PyBadge for MakeCode Arcade, CircuitPython or Arduino

OUT OF STOCK

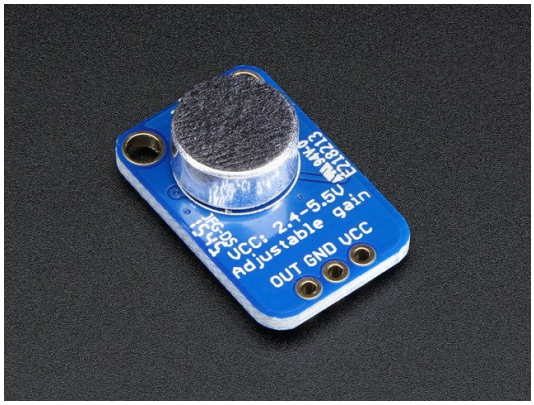
Out Of Stock

JST PH 3-Pin to Female Socket Cable - 200mm

$1.25

IN STOCK

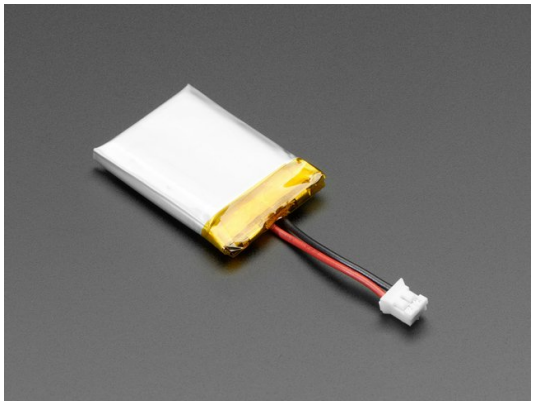
Add To Cart



Electret Microphone Amplifier - MAX4466 with Adjustable Gain

OUT OF STOCK

Out Of Stock



Lithium Ion Polymer Battery with Short Cable - 3.7V 420mAh

$6.95

IN STOCK

Add To Cart

Setup For Compiling Examples

We're going to be using the popular Arduino IDE to compile and load code. Start by following the PyBadge setup guide to

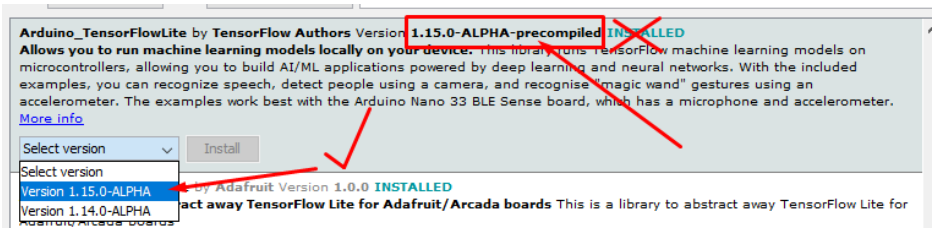
1. Install the latest desktop Arduino IDE (https://adafru.it/Fmm)
2. Install Adafruit SAMD board support package (https://adafru.it/Fmn) (If programming a SAMD board like the Edge/PyBadge)
3. Install Adafruit nRF52 board support package (https://adafru.it/Hwb) (If programming an nRF52 board like the Circuit Playground Bluefruit)
4. Install all the Arcada Libraries (yes there's a lot of them!) (https://adafru.it/EUk)

TensorFlow Libraries

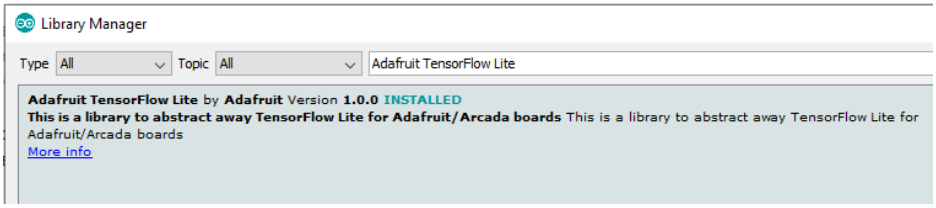
Now install the Arduino TensorFlow library with the library manager

Make sure you **don't pick the *pre-compiled* release version**

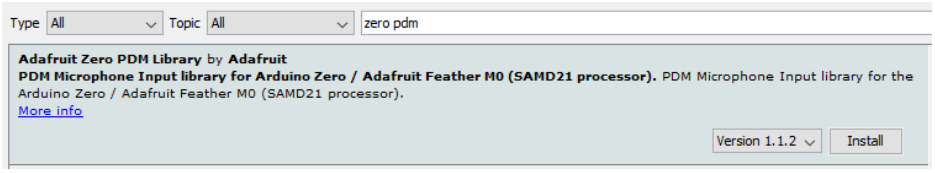
If you see 'precompiled' in the name, install the non-precompiled version from the dropdown



Next, install **Adafruit TensorFlow Lite**



And finally, for the speech demos, grab the Adafruit **Zero PDM** library

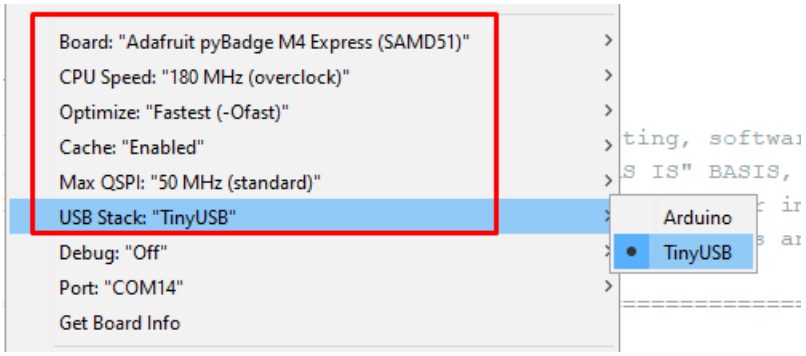


Select Board

Almost ready! Before we're ready to compile some examples!

Plug in the board into your computer with a known-good data/sync cable. Select the right board in the Tools download

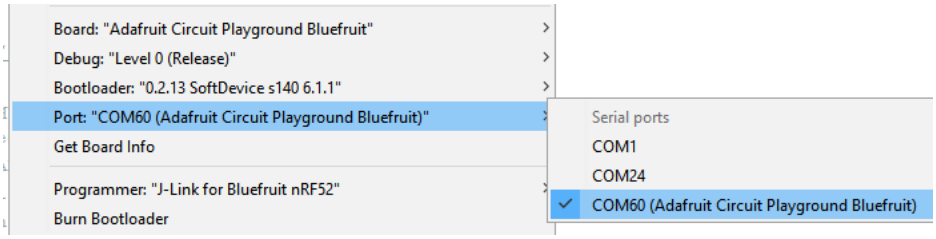
For PyBadge/EdgeBadge



For some examples you will want to set **Optimize** to **Fastest** and set **CPU Speed** to 180MHz (overclocking). This will give 6-10x speedup. For the first few examples, it isn't necessary. Make sure to select **USB Stack: TinyUSB**

For Circuit Playground Bluefruit

You can use the default settings:



Sine Wave Demo

This is the "hello world" demo of TensorFlow Lite. It has a simple model that has been trained to generate a sine wave when a linear input is given. It's a good way to verify you have a working toolchain!

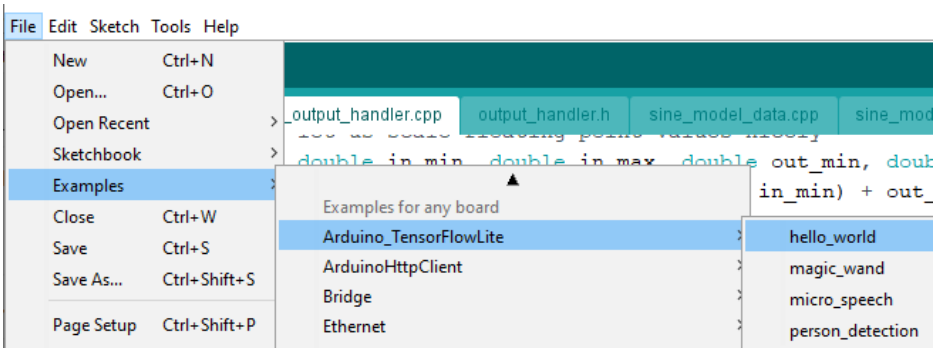
If you want to load demo this immediately to your PyBadge/EdgeBadge, here is the UF2 files which you can 'drag-n-drop' onto your **BOOT** diskdrive to load the example (follow the instructions here on how to load UF2 files if you've never done it before (https://adafru.it/GuD))

https://adafru.it/GuE

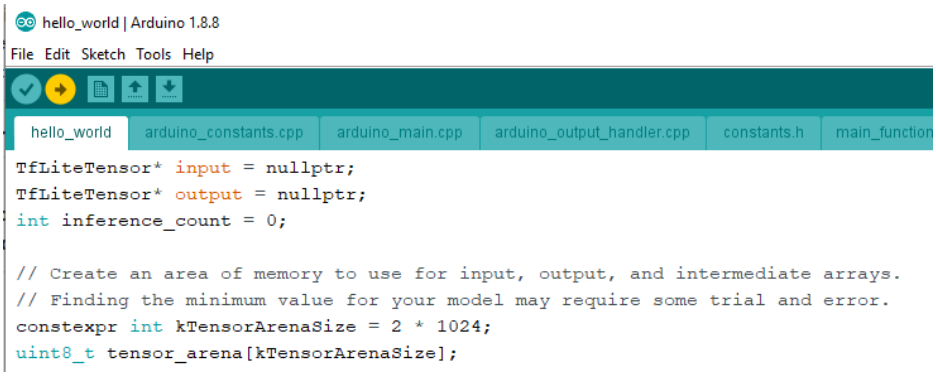
https://adafru.it/GuE

Serial plotter sine wave demo compile & upload

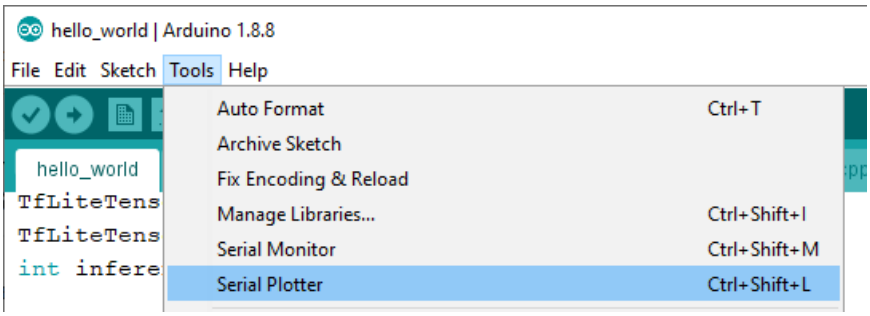
Let's start with the plain Arduino TensorFlow demo. **Don't forget you have to perform all the steps in the previous page for installing Arduino IDE, Adafruit SAMD support, libraries, and board/port selection!**



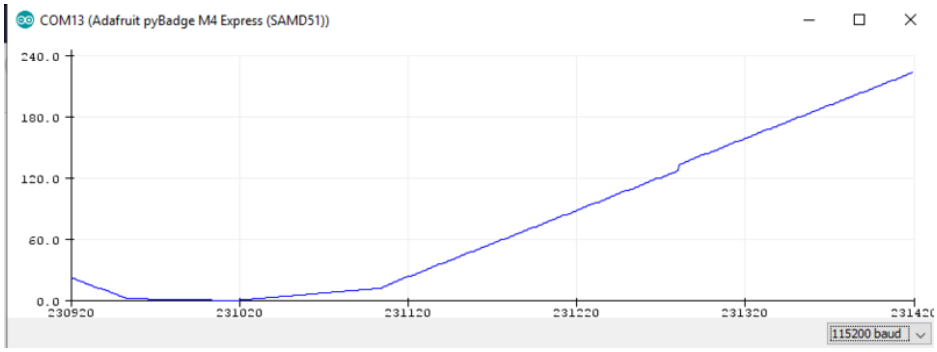
Compile & upload this example!



Upon success, you may see the LED on the board pulsing. The best way to see the output is to select the **Serial Plotter**



You'll see a sine wave on the plotter!



If you want to see a more sinusoidal output go to **arduino_constants.cpp**

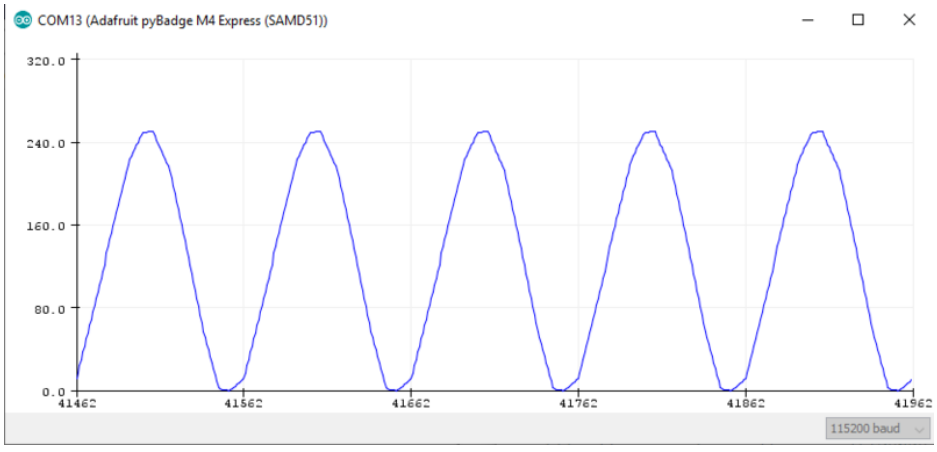
and change

```
const int kInferencesPerCycle = 1000;
```

to

```
const int kInferencesPerCycle = 100;
```

Then re-upload

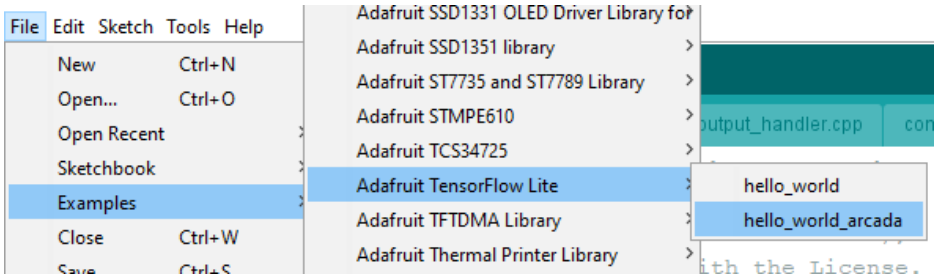


Arcada display output sine demo compile & upload

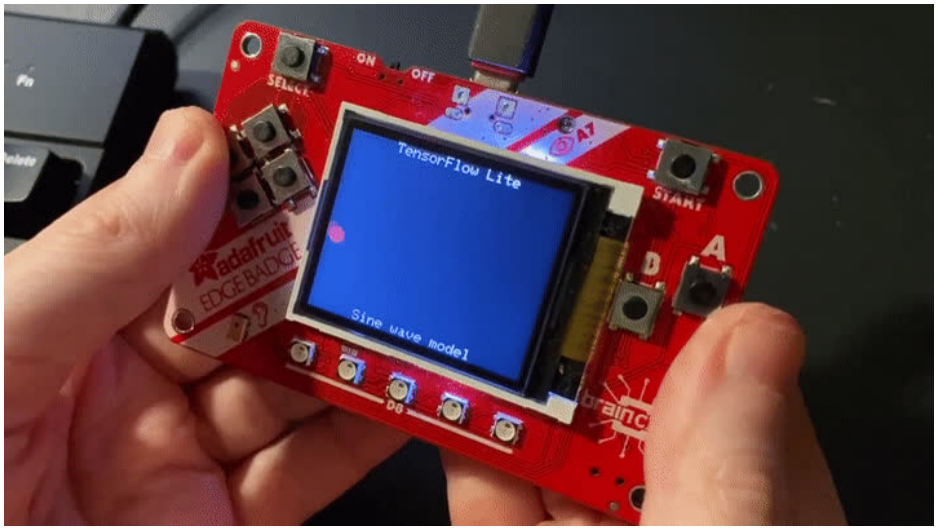
Arcada is our library for handling displays and input - we have so many different boards and displays, we need a unifying library that would handle displays, filesystems, buttons, etc. For many boards, you don't need to do anything

special to figure out the pinouts or part numbers!

Load up the **Adafruit_TFLite->hello_world_arcada example**



You can upload this sketch to your board and you'll get an animated ball on the screen.



The majority of the work is in this file that initializes the display on the first inference, then draws a ball (while erasing the last location) on every successful inference.

```
/* Copyright 2019 The TensorFlow Authors. All Rights Reserved.

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you may not use this file except in compliance with the License.
You may obtain a copy of the License at

    http://www.apache.org/licenses/LICENSE-2.0

Unless required by applicable law or agreed to in writing, software
distributed under the License is distributed on an "AS IS" BASIS,
WITHOUT WARRANTIES OR CONDITIONS OF ANY KIND, either express or implied.
See the License for the specific language governing permissions and
limitations under the License.
==============================================================================*/

#include "output_handler.h"
#include "Arduino.h"
#include "Adafruit_Arcada.h"
extern Adafruit_Arcada arcada;

// The pin of the Arduino's built-in LED
```

```
int led = LED_BUILTIN;

// Track whether the function has run at least once
bool initialized = false;

// helper function to let us scale floating point values nicely
double mapf(double x, double in_min, double in_max, double out_min, double out_max) {
    return (x - in_min) * (out_max - out_min) / (in_max - in_min) + out_min;
}

// Animates a dot across the screen to represent the current x and y values
void HandleOutput(tflite::ErrorReporter* error_reporter, float x_value,
                  float y_value) {
  // Do this only once
  if (!initialized) {
    // Add some text to describe what's up!
    arcada.display->fillScreen(ARCADA_BLACK);
    arcada.display->setTextColor(ARCADA_WHITE);
    arcada.display->setTextSize(1);
    const char *header = "TensorFlow Lite";
    const char *footer = "Sine wave model";
    arcada.display->setCursor((arcada.display->width()-strlen(header)*6)/2, 0);
    arcada.display->print(header);
    arcada.display->setCursor((arcada.display->width()-strlen(footer)*6)/2, arcada.display->height()-
8);
    arcada.display->print(footer);
    initialized = true;
  }

  // map the x input value (0-2*PI) and the y value (-1.5 to 1.5)
  // to the size of the display
  float pixel_x, pixel_y;
  static float last_pixel_x, last_pixel_y;
  pixel_x = mapf(x_value, 0, 2*3.1415, 0, arcada.display->width());
  pixel_y = mapf(y_value, -1.75, 1.75, 0, arcada.display->height());
  if (pixel_x == 0) {
     // clear the screen
     arcada.display->fillRect(0, 10, arcada.display->width(), arcada.display->width()-20,
ARCADA_BLACK);
  }

  arcada.display->fillCircle(pixel_x, pixel_y, 3, ST77XX_RED);
  last_pixel_x = pixel_x;
  last_pixel_y = pixel_y;

  // slow it down so we can see the ball!
  delay(3);
}
```

Customized Wave Demo

The sine wave demo is great to do initial experimentation with training new simple single input->output models.

Google TensorFlow has a great guide here

https://adafru.it/G-D

https://adafru.it/G-D

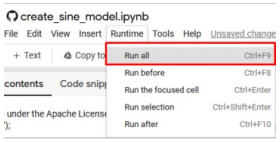
The detailed part of the tutorial is in this colab script. Colab is great because its fully hosted, runs in any web-browser without using your CPU to do the training!

Re-creating the Default Sine Wave Model

Visit the colab script here:

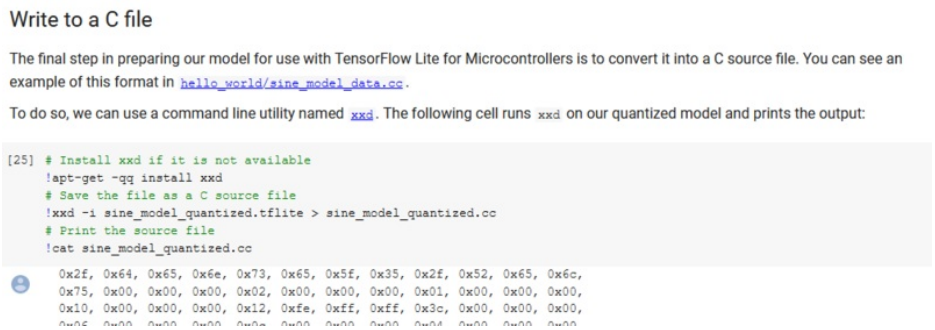
https://adafru.it/G-E

https://adafru.it/G-E



And **run all** the script!

It may take a few minutes. When its complete you'll get an array of data at the bottom:



Grab that text starting with

```
unsigned char sine_model_quantized_tflite[] = {
```

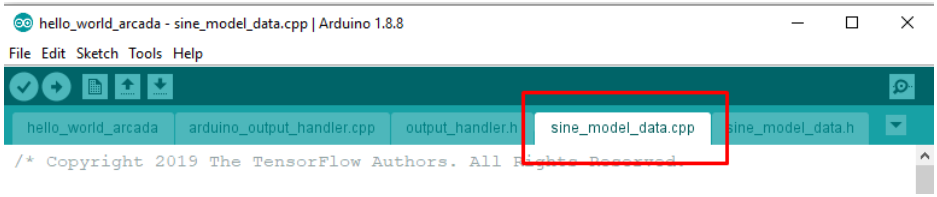
and ending with

```
unsigned int sine_model_quantized_tflite_len = 2640;
```

(the number may vary)

```
unsigned char sine_model_quantized_tflite[] = {
  0x18, 0x00, 0x00, 0x00, 0x54, 0x46, 0x4c, 0x33, 0x00, 0x00, 0x0e, 0x00,
  0x18, 0x00, 0x04, 0x00, 0x08, 0x00, 0x0c, 0x00, 0x10, 0x00, 0x14, 0x00,
  0x0e, 0x00, 0x00, 0x00, 0x03, 0x00, 0x00, 0x00, 0x10, 0x0a, 0x00, 0x00,
  0xb8, 0x05, 0x00, 0x00, 0xa0, 0x05, 0x00, 0x00, 0x04, 0x00, 0x00, 0x00,
  ....more here....
  0x00, 0x00, 0x00, 0x00, 0x02, 0x00, 0x00, 0x00, 0x01, 0x00, 0x00, 0x00,
  0x01, 0x00, 0x00, 0x00, 0x01, 0x00, 0x00, 0x00, 0x10, 0x00, 0x00, 0x00,
  0x00, 0x00, 0x0a, 0x00, 0x0c, 0x00, 0x07, 0x00, 0x00, 0x00, 0x08, 0x00,
  0x0a, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x09, 0x03, 0x00, 0x00, 0x00
};
unsigned int sine_model_quantized_tflite_len = 2640;
```

Now visit the **hello_world_arcada** sketch and fine the **sine_model_data** tab:

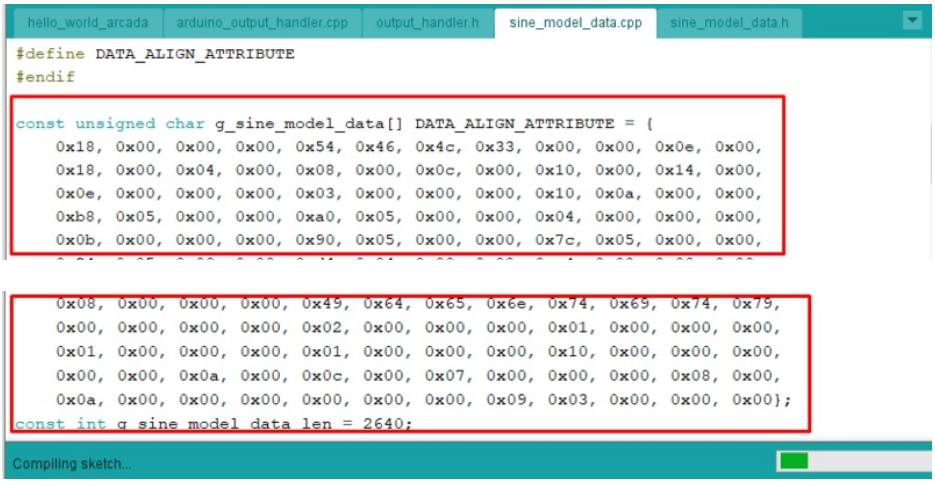


And paste that output from the notebook, replacing the

`unsigned char sine_model_quantized_tflite[] = {`

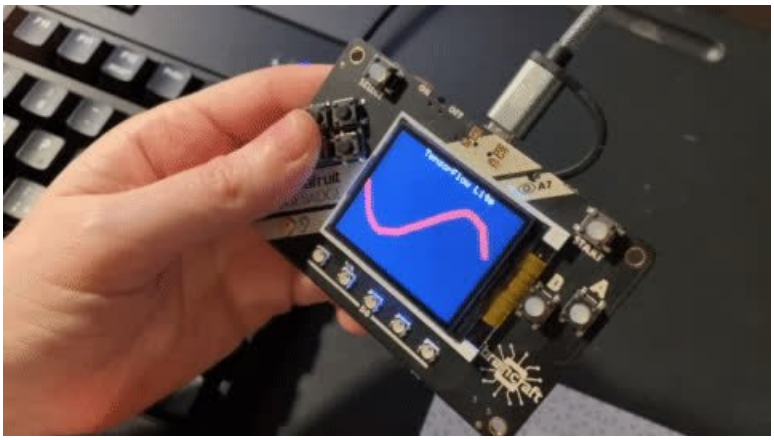
down to

`const int g_sine_model_data_len = 2640;`



Before you can compile, don't forget to change the declaration of the array from 'unsigned char sine_model_quantized_tflite' to 'unsigned const char g_sine_model_data' and the length variable from 'unsigned int sine_model_quantized_tflite_len' to 'const int g_sine_model_data_len'

Recompile and upload to your badge or Circuit Playground Bluefruit, you should get the exact same sine wave demo!



OK maybe not so exciting. Lets try changing the model.

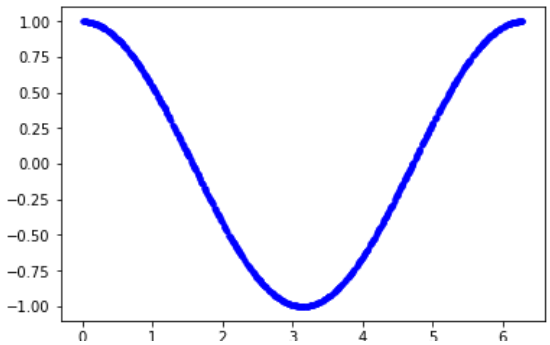
Creating a Cosine Wave Model

Let's get *wild and crazy* now, by making a cosine wave model. Find the line in the script where we create the `y_values` from the `x_values`

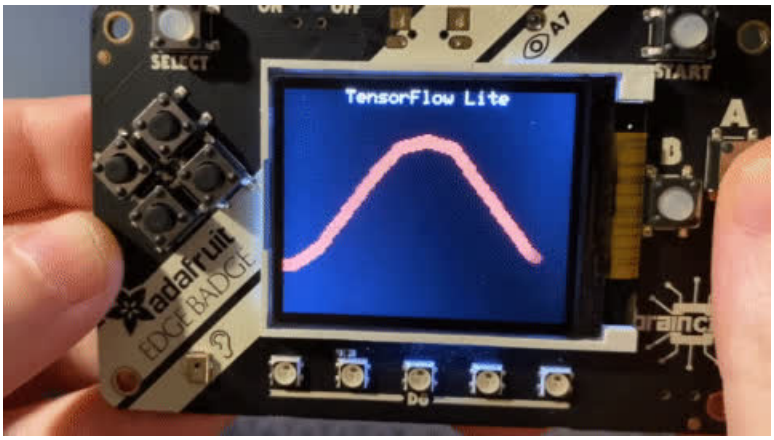
```
# Shuffle the values to guarantee they're not in order
np.random.shuffle(x_values)

# Calculate the corresponding sine values
y_values = np.sin(x_values)

# Plot our data. The 'b.' argument tells the library to print blue dots.
plt.plot(x_values, y_values, 'b.')
plt.show()
```

And change it to a **cos** function!

```
# Calculate the corresponding sine values
y_values = np.cos(x_values)

# Plot our data. The 'b.' argument tells the library to print blue dots.
plt.plot(x_values, y_values, 'b.')
plt.show()
```

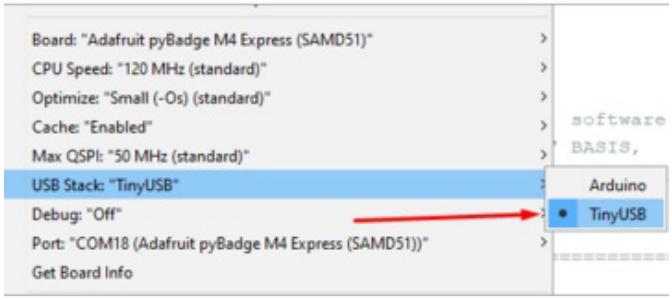


Run the colab script from this point down (or the whole thing) to get a brand new `unsigned char sine_model_quantized_tflite` array and follow the steps you did before to replace the model array in the **hello_world** sketch with your new model. Re-upload to now get cosine wave output, which looks like the plot above

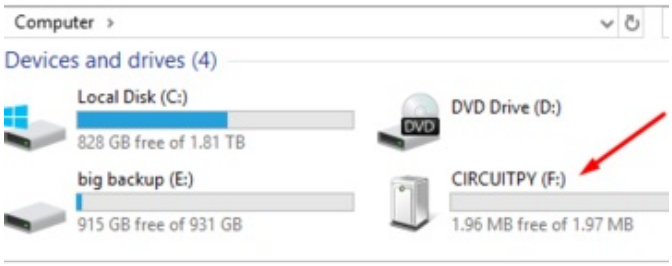


Loading Models From Internal Storage

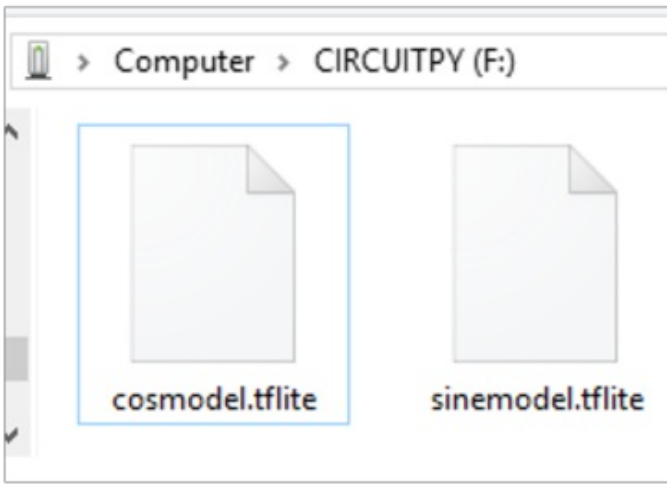
The PyBadge/EdgeBadge/Circuit Playground Bluefruit have 2MB of internal storage. We can use that to store TensorFlow models, so that we don't have to go through the recompilation step above. Instead, the model is loaded from that storage flash, we can read/write to the flash over USB by dragging-and-dropping, just like a USB key!



Upload the **hello_world_arcada** sketch. If you have a PyBadge/EdgeBadge, this time make sure to select **TinyUSB** as the USB stack since that will activate mass storage support. You don't have to specifically select TinyUSB for nRF52 (e.g. Circuit Playground Bluefruit)



Now when you upload, on reset you'll get a new disk drive appearing on your computer, it'll probably be name CIRCUITPY but you can rename it if you like.



Download this models zip file and drag the two .tflite files to CIRCUITPY

https://adafru.it/G-F

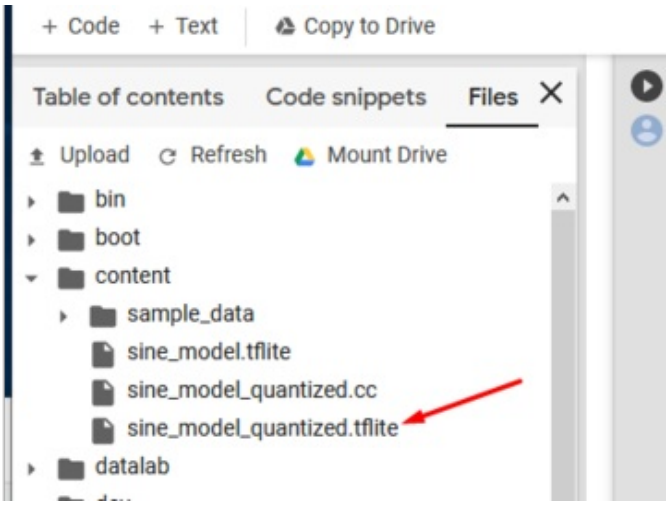
https://adafru.it/G-F

Rename one of the files to **model.tflite** - when this file is available to read, this will tell our sketch to load the model from disk instead of from memory!

Once you've renamed the file, click the **reset** button, you should get an alert like this:

Once you've renamed the file, click the **reset** button, you should get an alert like this. Press the **A** button on the badge or Circuit Playground Bluefruit (its the left button) to begin the model inference run.

Once you've proved that you're running one of the files, try renaming the *other* model file to **model.tflite** and reset. That way you can prove that its running from the disk.



You can go back to the colab script you ran, and look in the **Files** tab to find the `sine_model_quantized.tflite` file that is converted in the last stage. You can download that file directly.

Try creating new **tflite** files that model different functions!

Gesture Demo

The PyBadge has a built-in accelerometer (LIS3DH) which you can use to detect tilt and motion. The accelerometer outputs 3 axes of acceleration data, and we can use that to train and infer gestures using TensorFlow!

If you want to load demo this immediately to your PyBadge, here is a UF2 file, which you can 'drag-n-drop' onto your BADGEBOOT diskdrive to load the example (follow the instructions here on how to load UF2 files if you've never done it before (https://adafru.it/GuD))

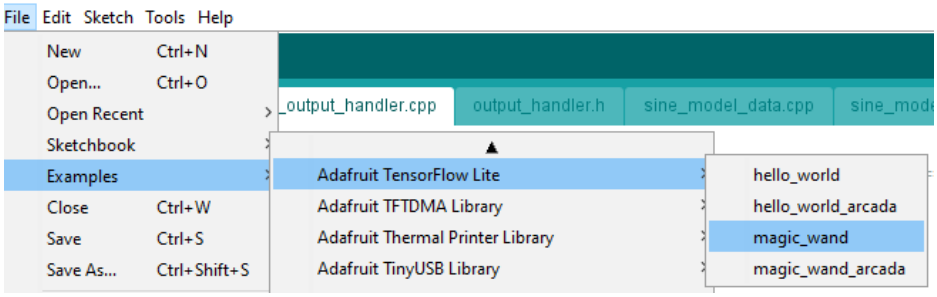
https://adafru.it/GRE

https://adafru.it/GRE

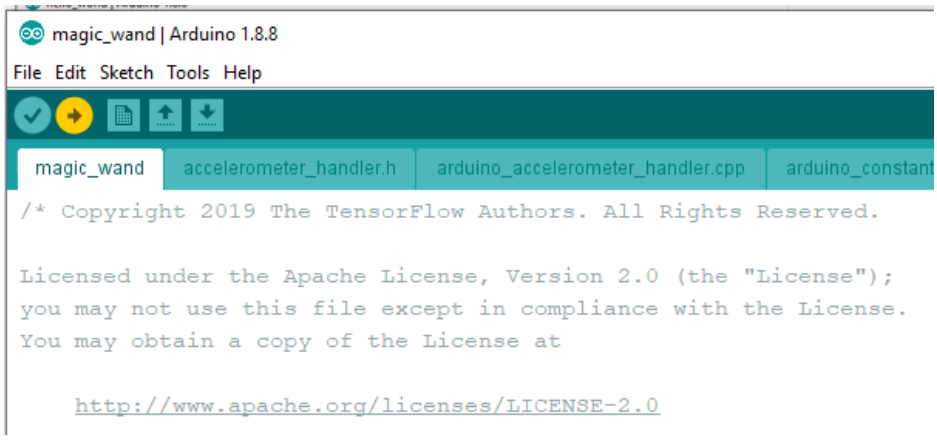
Serial out gesture demo compile & upload

Let's start with the plain Arduino TensorFlow demo. **Don't forget you have to perform all the steps in the previous page for installing Arduino IDE, Adafruit SAMD support, libraries, and board/port selection!**

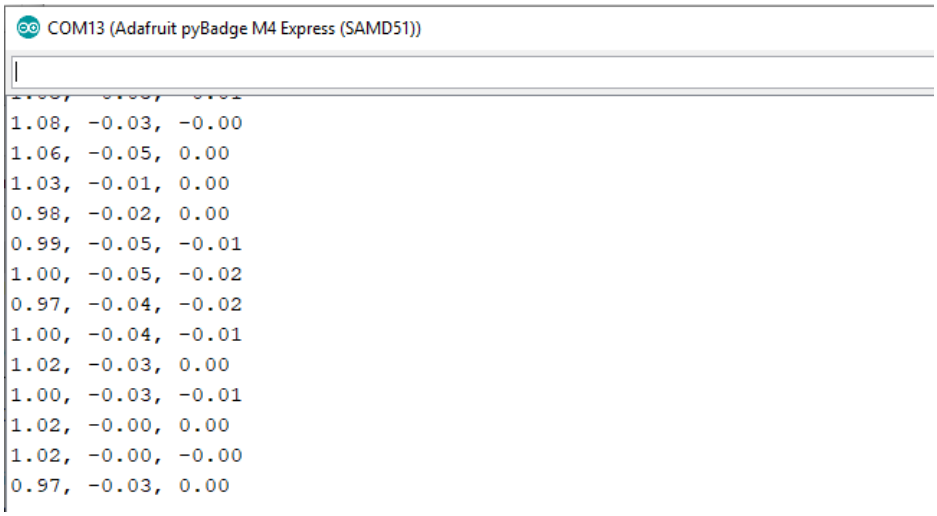
We adapted the default gesture demo to use the LIS3DH, so you *cannot* use the example in the Arduino TensorFlowLite library Instead, use the one in `Adafruit TensorFlow Lite` called `magic_wand`



Compile & upload this example!

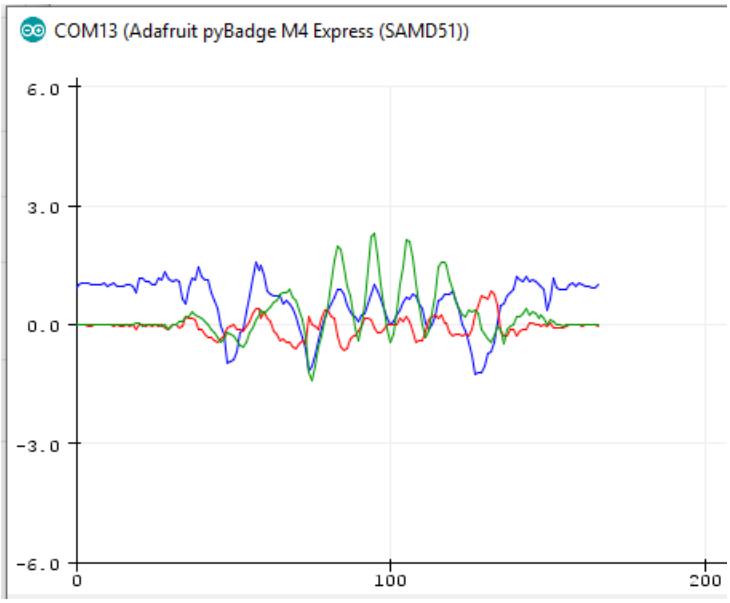


Upon success, you may see the LED on the board pulsing. The best way to see the output is to select the **Serial Monitor**



You'll see steaming data coming out on the Serial Monitor. This is the 3 axis accelerometer data. We output it so that you can have some more debugging data which can be really handy when training/debugging gestures. You can also plot it with the Serial Plotter if you like (close the Monitor first)

Move and twist the badge to see the red/green/blue lines change.

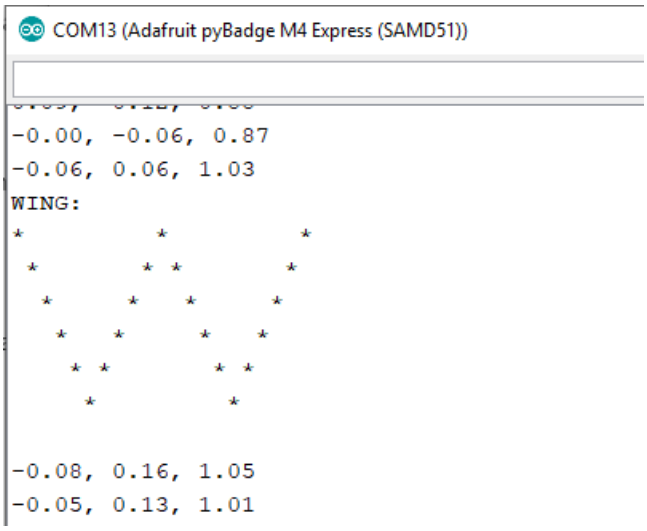


Close the Plotter and re-open the monitor to see the streaming data again. This time, with the **screen facing you, and the USB port pointing to the ceiling** perform one of three gestures:

Wing

This gesture is a **W** starting at your top left, going down, up, down up to your top right

When that gesture is detected you'lll see the front NeoPixels turn yellow, and the following print out on the Serial Monitor:



Ring

This gesture is a **O** starting at top center, then moving clockwise in a circle to the right, then down, then left and back to when you started in the top center

When that gesture is detected you'll see the front NeoPixels turn purple, and the following print out on the Serial Monitor:

```
-0.07, -0.34, 0.91
-0.09, -0.28, 0.93
RING:
            *
        *       *
      *           *
     *             *
      *           *
        *       *
            *


-0.21, -0.16, 0.92
-0.23, -0.17, 0.91
```

Slope

This gesture is an ***L*** starting at your top right, moving diagonally to your bottom left, then straight across to bottom right.

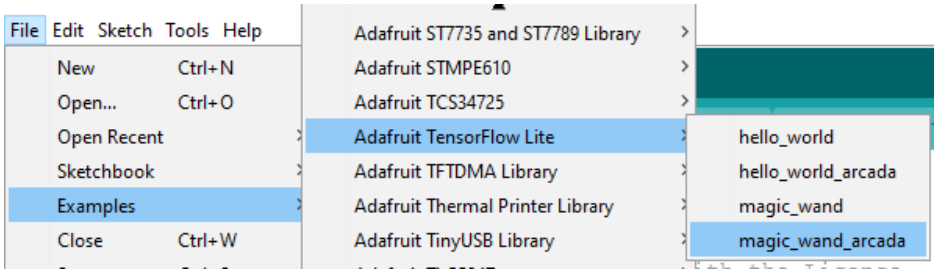
When that gesture is detected you'll see the front NeoPixels turn light blue, and the following print out on the Serial Monitor:

```
0.26, -0.01, 0.91
SLOPE:
          *
         *
        *
       *
      *
     *
    *
   *
  * * * * * * * * *

0.28, 0.00, 0.94
```

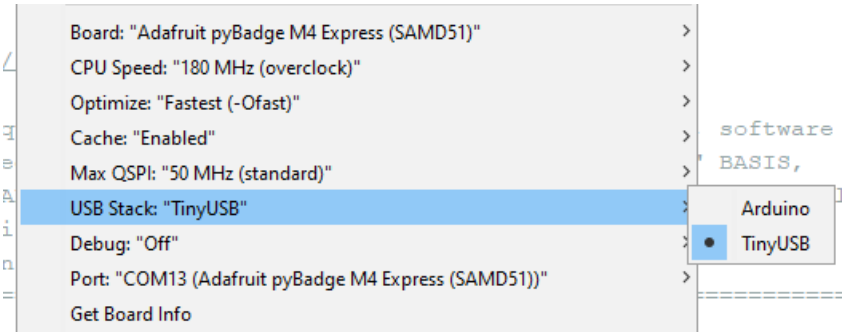
Arcada display output gesture demo compile & upload

Arcada is our library for handling displays and input - we have so many different boards and displays, we need a unifying library that would handle displays, filesystems, buttons, etc. For many boards, you don't need to do anything special to figure out the pinouts or part numbers!

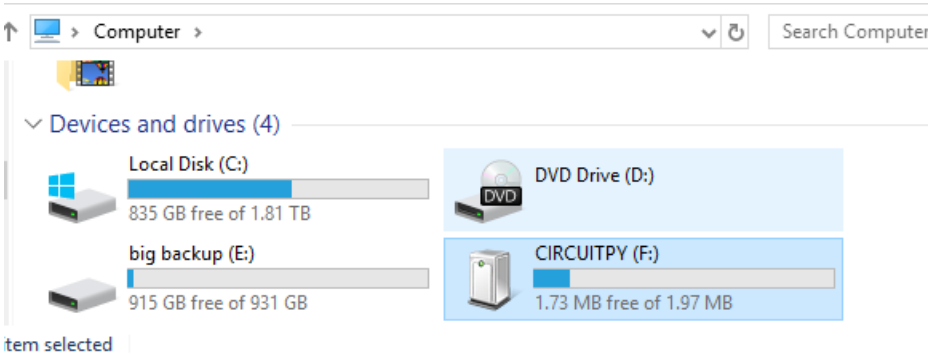
Load up the **Adafruit_TFLite->magic_wand_arcada example**



Make sure you have TinyUSB selected as the USB stack!



You can upload this sketch to your board. After upload it will show up on your computer as a disk drive called CIRCUITPY (unless you changed it)

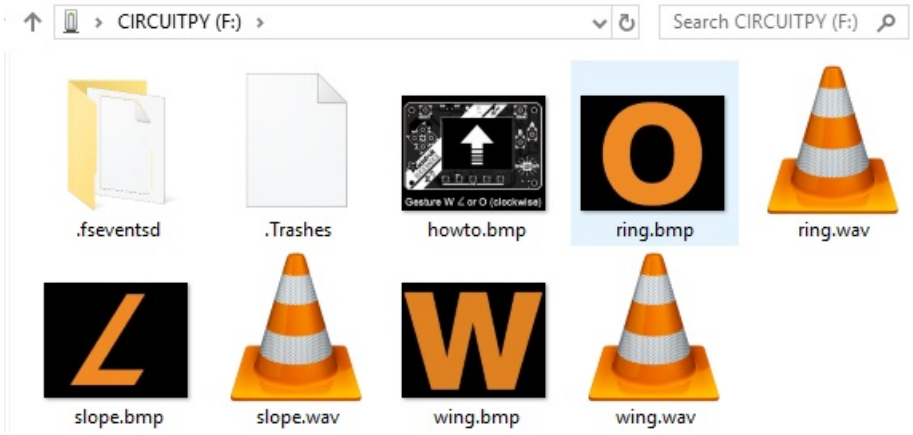


Click this button to download the gesture images and audio clips

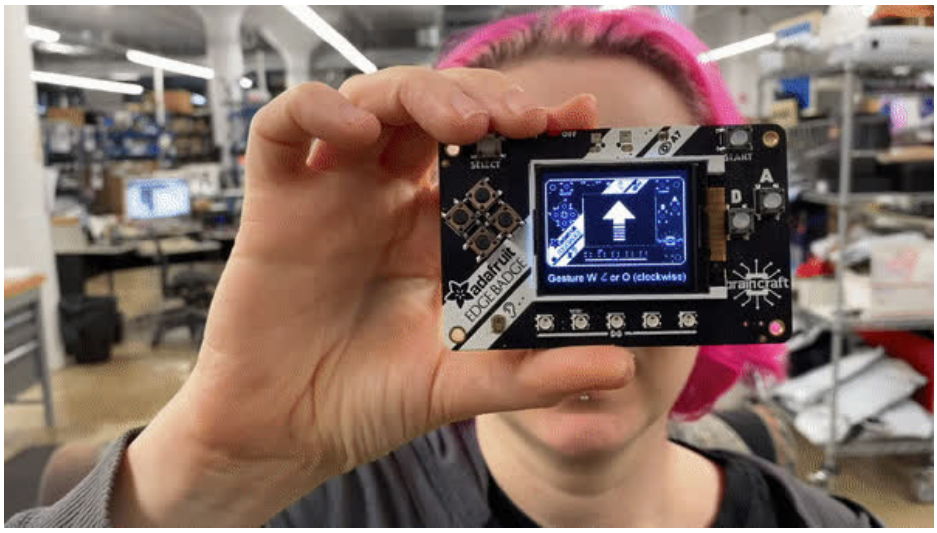
https://adafru.it/GRC

https://adafru.it/GRC

Navigate through the zip file to `examples\magic_wand_arcada\badge_files` then drag the files directly onto the **CIRCUITPY** drive like so:



Click **reset** on the Badge to restart, and you should get the graphics displaying so that you can run the demo untethered!



Setup and configuration of the accelerometer and screen is done in the **accelerometer_handler**

```
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    http://www.apache.org/licenses/LICENSE-2.0

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distributed under the License is distributed on an "AS IS" BASIS,
WITHOUT WARRANTIES OR CONDITIONS OF ANY KIND, either express or implied.
See the License for the specific language governing permissions and
limitations under the License.
==============================================================================*/

#include "accelerometer_handler.h"

#include <Arduino.h>
#include "Adafruit_Arcada.h"
extern Adafruit_Arcada arcada;

/* this is a little annoying to figure out, as a tip - when
 * holding the board straight, output should be (0, 0, 1)
 * tiling the board 90* left, output should be (0, 1, 0)
 * tilting the board 90* forward, output should be (1, 0, 0);
 */

#if defined(ADAFRUIT_PYBADGE_M4_EXPRESS)
// holding up with screen/neopixels facing you
const int X_POSITION = 1;
const int Y_POSITION = 2;
const int Z_POSITION = 0;
const bool INVERT_X = true;
const bool INVERT_Y = true;
const bool INVERT_Z = false;
#endif

#if defined(ARDUINO_NRF52840_CIRCUITPLAY)
// holding up with gizmo facing you
const int X_POSITION = 1;
const int Y_POSITION = 2;
const int Z_POSITION = 0;
const bool INVERT_X = true;
const bool INVERT_Y = true;
const bool INVERT_Z = false;
#endif

#include "constants.h"

// A buffer holding the last 200 sets of 3-channel values
float save_data[600] = {0.0};
// Most recent position in the save_data buffer
int begin_index = 0;
// True if there is not yet enough data to run inference
bool pending_initial_data = true;
// How often we should save a measurement during downsampling
int sample_every_n;
```

```
int sample_every_n;
// The number of measurements since we last saved one
int sample_skip_counter = 1;

uint32_t last_reading_stamp = 0;

TfLiteStatus SetupAccelerometer(tflite::ErrorReporter* error_reporter) {
  // Wait until we know the serial port is ready
  //while (!Serial) { yield(); }

  arcada.pixels.setBrightness(50); // Set BRIGHTNESS to about 1/5 (max = 255)

  arcada.accel.setRange(LIS3DH_RANGE_4_G);
  arcada.accel.setDataRate(LIS3DH_DATARATE_25_HZ);
  float sample_rate = 25;

  // Determine how many measurements to keep in order to
  // meet kTargetHz
  sample_every_n = static_cast<int>(roundf(sample_rate / kTargetHz));

  error_reporter->Report("Magic starts!");

  return kTfLiteOk;
}

bool ReadAccelerometer(tflite::ErrorReporter* error_reporter, float* input,
                       int length, bool reset_buffer) {
  // Clear the buffer if required, e.g. after a successful prediction
  if (reset_buffer) {
    memset(save_data, 0, 600 * sizeof(float));
    begin_index = 0;
    pending_initial_data = true;
  }
  // Keep track of whether we stored any new data
  bool new_data = false;
  // Loop through new samples and add to buffer
  while (arcada.accel.haveNewData()) {
    float x, y, z;

    // Read each sample, removing it from the device's FIFO buffer
    sensors_event_t event;

    if (! arcada.accel.getEvent(&event)) {
      error_reporter->Report("Failed to read data");
      break;
    }

    // Throw away this sample unless it's the nth
    if (sample_skip_counter != sample_every_n) {
      sample_skip_counter += 1;
      continue;
    }

    float values[3] = {0, 0, 0};
    values[X_POSITION] = event.acceleration.x / 9.8;
    values[Y_POSITION] = event.acceleration.y / 9.8;
    values[Z_POSITION] = event.acceleration.z / 9.8;

    x = values[0];
    y = values[1];
```

```
    z = values[2];

    if (INVERT_X) {
      x *= -1;
    }
    if (INVERT_Y) {
      y *= -1;
    }
    if (INVERT_Z) {
      z *= -1;
    }
    Serial.print(x, 2);
    Serial.print(", "); Serial.print(y, 2);
    Serial.print(", "); Serial.println(z, 2);

    last_reading_stamp = millis();
    // Write samples to our buffer, converting to milli-Gs
    save_data[begin_index++] = x * 1000;
    save_data[begin_index++] = y * 1000;
    save_data[begin_index++] = z * 1000;

    // Since we took a sample, reset the skip counter
    sample_skip_counter = 1;
    // If we reached the end of the circle buffer, reset
    if (begin_index >= 600) {
      begin_index = 0;
    }
    new_data = true;
  }

  // Skip this round if data is not ready yet
  if (!new_data) {
    return false;
  }

  // Check if we are ready for prediction or still pending more initial data
  if (pending_initial_data && begin_index >= 200) {
    pending_initial_data = false;
  }

  // Return if we don't have enough data
  if (pending_initial_data) {
    return false;
  }

  // Copy the requested number of bytes to the provided input tensor
  for (int i = 0; i < length; ++i) {
    int ring_array_index = begin_index + i - length;
    if (ring_array_index < 0) {
      ring_array_index += 600;
    }
    input[i] = save_data[ring_array_index];
  }

  return true;
}
```

While the LED/Display output is done in the **output_handler.cpp**

```
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    http://www.apache.org/licenses/LICENSE-2.0

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distributed under the License is distributed on an "AS IS" BASIS,
WITHOUT WARRANTIES OR CONDITIONS OF ANY KIND, either express or implied.
See the License for the specific language governing permissions and
limitations under the License.
==============================================================================*/

#include "output_handler.h"

#include "Arduino.h"
#include "Adafruit_Arcada.h"

extern Adafruit_Arcada arcada;


void HandleOutput(tflite::ErrorReporter* error_reporter, int kind) {
  // The first time this method runs, set up our LED
  static int last_kind = -1;

  static bool is_initialized = false;
  if (!is_initialized) {
    pinMode(LED_BUILTIN, OUTPUT);
    is_initialized = true;
  }
  // Toggle the LED every time an inference is performed
  static int count = 0;
  ++count;
  if (count & 1) {
    digitalWrite(LED_BUILTIN, HIGH);
  } else {
    digitalWrite(LED_BUILTIN, LOW);
  }

  // Print some ASCII art for each gesture
  if (kind == 0) {
    error_reporter->Report(
        "WING:\n\r*         *         *\n\r *       * *       "
        "*\n\r  *     *   *     *\n\r   *   *     *   *\n\r    * *       "
        "* *\n\r     *         *\n\r");
    ImageReturnCode stat = arcada.drawBMP((char *)"wing.bmp", 0, 0);
    if (stat != IMAGE_SUCCESS) {
      arcada.display->fillScreen(ARCADA_BLACK);
      arcada.display->setCursor(20, 20);
      arcada.display->setTextColor(ARCADA_YELLOW);
      arcada.display->setTextSize(ceil(arcada.display->width() / 30));
      arcada.display->print("WING");
    }
    arcada.WavPlayComplete("wing.wav");
    arcada.pixels.fill(arcada.pixels.Color(50, 50, 0));
    arcada.pixels.show();
  } else if (kind == 1) {
```

```
    error_reporter->Report(
        "RING:\n\r          *\n\r       *     *\n\r     *         *\n\r "
        "   *           *\n\r     *         *\n\r       *     *\n\r      "
        "    *\n\r");
    ImageReturnCode stat = arcada.drawBMP((char *)"ring.bmp", 0, 0);
    if (stat != IMAGE_SUCCESS) {
      arcada.display->fillScreen(ARCADA_BLACK);
      arcada.display->setCursor(20, 20);
      arcada.display->setTextColor(ARCADA_PURPLE);
      arcada.display->setTextSize(ceil(arcada.display->width() / 30));
      arcada.display->print("RING");
    }
    arcada.WavPlayComplete("ring.wav");
    arcada.pixels.fill(arcada.pixels.Color(50, 0, 50));
    arcada.pixels.show();
  } else if (kind == 2) {
    error_reporter->Report(
        "SLOPE:\n\r        *\n\r       *\n\r      *\n\r     *\n\r    "
        "*\n\r   *\n\r  *\n\r * * * * * * * *\n\r");
    ImageReturnCode stat = arcada.drawBMP((char *)"slope.bmp", 0, 0);
    if (stat != IMAGE_SUCCESS) {
      arcada.display->fillScreen(ARCADA_BLACK);
      arcada.display->setCursor(20, 20);
      arcada.display->setTextColor(ARCADA_BLUE);
      arcada.display->setTextSize(ceil(arcada.display->width() / 40));
      arcada.display->print("SLOPE");
    }
    arcada.WavPlayComplete("slope.wav");
    arcada.pixels.fill(arcada.pixels.Color(0, 50, 50));
    arcada.pixels.show();
  } else {
    if (last_kind <= 2) {
      // re-draw intro
      ImageReturnCode stat = arcada.drawBMP((char *)"howto.bmp", 0, 0);
      if (stat != IMAGE_SUCCESS) {
        arcada.display->fillScreen(ARCADA_BLACK);
        arcada.display->setCursor(0, 0);
        arcada.display->setTextColor(ARCADA_WHITE);
        arcada.display->setTextSize(ceil(arcada.display->width() / 180.0));
        arcada.display->println("With screen facing");
        arcada.display->println("you, move board in");
        arcada.display->println("the shape of a");
        arcada.display->println("W, clockwise O or L");
      }
      arcada.pixels.fill(0);
      arcada.pixels.show();
    }
  }
  last_kind = kind;
}
```

Micro Speech Demo

The EdgeBadge has a built-in microphone which you can use to detect audio and speech. If you have PyBadge or some other microcontroller board, you can assemble and attach an external microphone which will give you audio input (https://adafru.it/GUb). The mic outputs monophonic digital sound waves, and we can use that to train and infer gestures using TensorFlow!

If you want to load demo this immediately to your EdgeBadge or PyBadge, here is a UF2 file, which you can 'drag-n-drop' onto your BADGEBOOT diskdrive to load the example (follow the instructions here on how to load UF2 files if you've never done it before (https://adafru.it/GuD))

https://adafru.it/GUc

https://adafru.it/GUc

OR

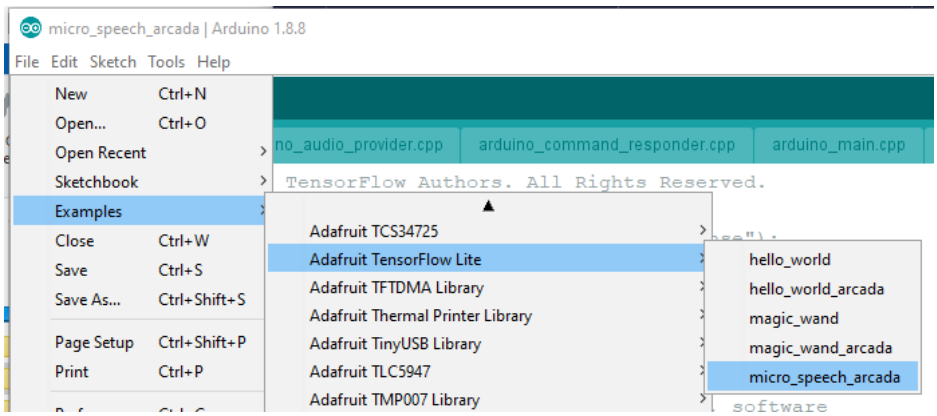
https://adafru.it/GUe

https://adafru.it/GUe

Micro speech demo compile & upload

Don't forget you have to perform all the steps in the previous page for installing Arduino IDE, Adafruit SAMD support, libraries, and board/port selection!

We adapted the default speech demo to use various kinds of audio input, so you *cannot* use the example in the Arduino TensorFlowLite library Instead, use the one in `Adafruit TensorFlow Lite` called `micro_speech_arcada`



Before you compile & upload this example...

Visit the `arduino_audio_provider.cpp` tab and look at the top area for this section

```
//#define USE_EXTERNAL_MIC A8  // D2 on pybadge
#define USE_EDGEBADGE_PDMMIC
//#define AUDIO_OUT A0         // uncomment to 'echo' audio to A0 for debugging
#define DEFAULT_BUFFER_SIZE 512
```

If you're using a PyBadge with external microphone, and its connected to D2, uncomment

`//#define USE_EXTERNAL_MIC A8 // D2 on pybadge`

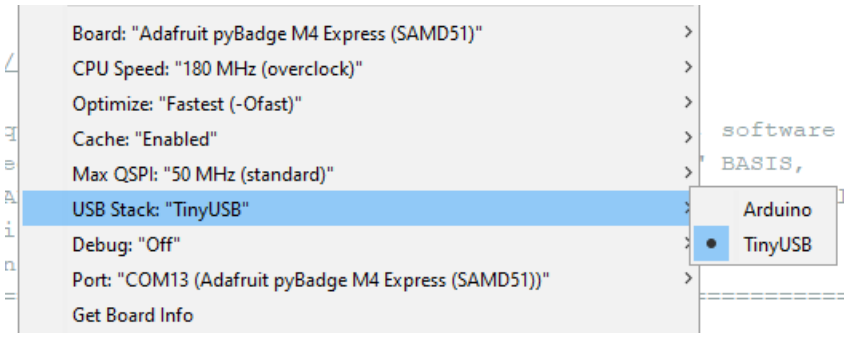
and comment out

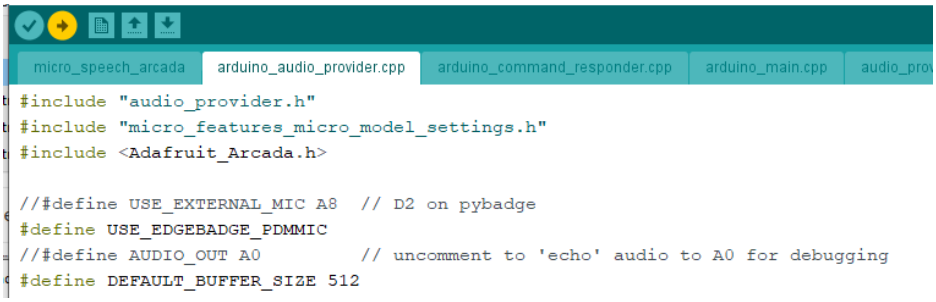
`#define USE_EDGEBADGE_PDMMIC`

before compiling!

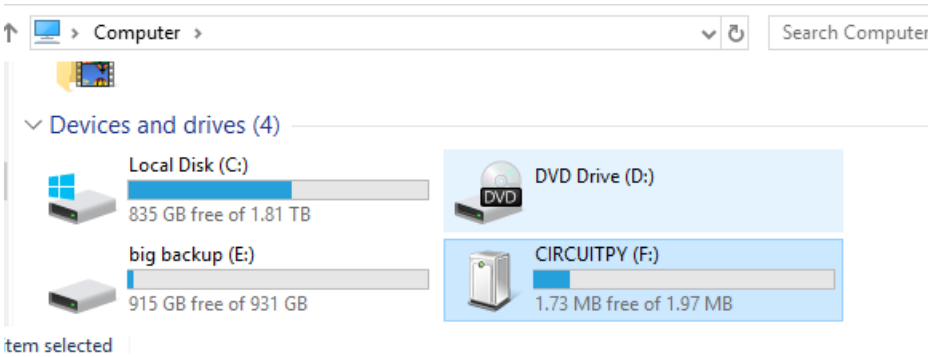
OK *now* you can compile and upload.

Make sure you have TinyUSB selected as the USB stack!





You can upload this sketch to your board. After upload it will show up on your computer as a disk drive called CIRCUITPY (unless you changed it)

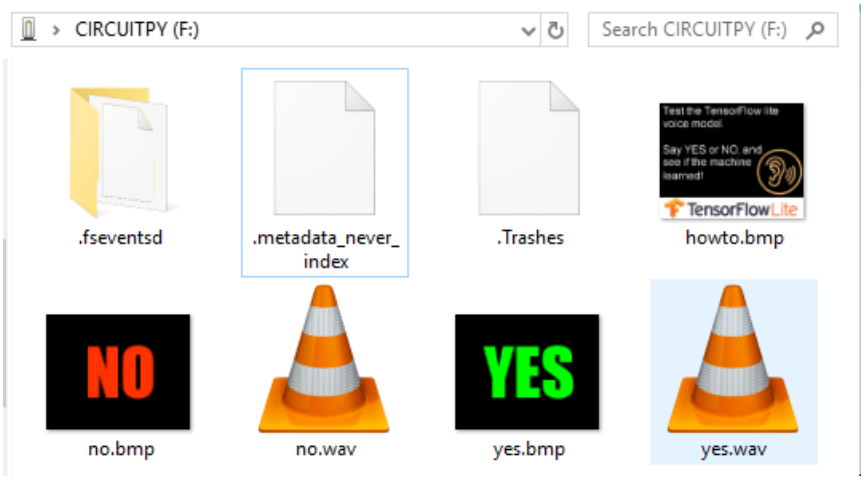


Click this button to download the detection/info images and audio clips

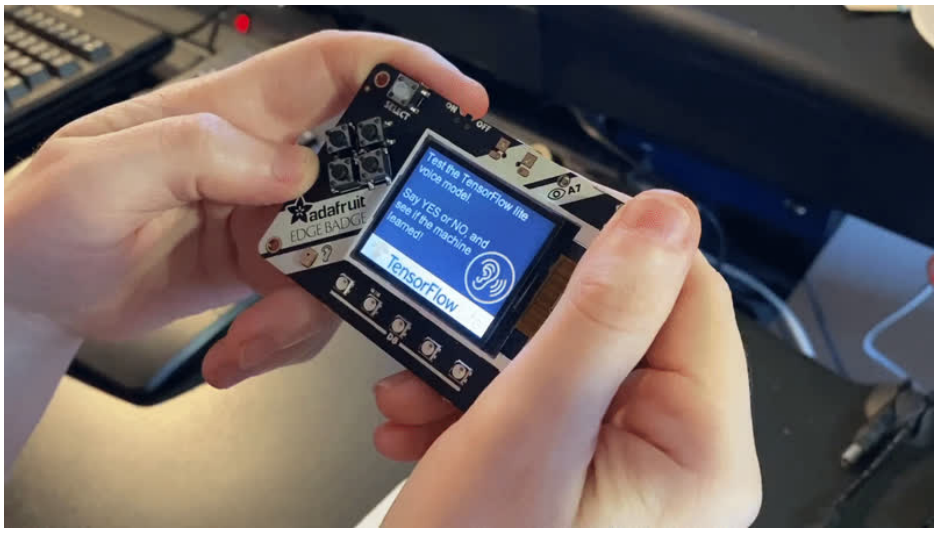
https://adafru.it/GUd

https://adafru.it/GUd

Navigate through the zip file to `examples\micro_speech_arcada\badge_files` then drag the files directly onto the **CIRCUITPY** drive like so:



Click **reset** on the Badge to restart, and you should get the graphics displaying so that you can run the demo untethered!



Setup and configuration of the microphone and screen is done in the **audio_provider**

```
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distributed under the License is distributed on an "AS IS" BASIS,
WITHOUT WARRANTIES OR CONDITIONS OF ANY KIND, either express or implied
```

```
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==============================================================================*/

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distributed under the License is distributed on an "AS IS" BASIS,
WITHOUT WARRANTIES OR CONDITIONS OF ANY KIND, either express or implied.
See the License for the specific language governing permissions and
limitations under the License.
==============================================================================*/

#include "audio_provider.h"
#include "micro_features_micro_model_settings.h"
#include <Adafruit_Arcada.h>

//#define USE_EXTERNAL_MIC A8  // D2 on pybadge
#define USE_EDGEBADGE_PDMMIC
//#define AUDIO_OUT A0         // uncomment to 'echo' audio to A0 for debugging
#define DEFAULT_BUFFER_SIZE 512

#if defined(USE_EDGEBADGE_PDMMIC)
  #include <Adafruit_ZeroPDMSPI.h>
  #define PDM_SPI            SPI2    // PDM mic SPI peripheral
  #define TIMER_CALLBACK     SERCOM3_0_Handler
  Adafruit_ZeroPDMSPI pdmspi(&PDM_SPI);
#endif

extern Adafruit_Arcada arcada;

namespace {
bool g_is_audio_initialized = false;
// An internal buffer able to fit 16x our sample size
constexpr int kAudioCaptureBufferSize = DEFAULT_BUFFER_SIZE * 16;
int16_t g_audio_capture_buffer[kAudioCaptureBufferSize];
// A buffer that holds our output
int16_t g_audio_output_buffer[kMaxAudioSampleSize];
// Mark as volatile so we can check in a while loop to see if
// any samples have arrived yet.
volatile int32_t g_latest_audio_timestamp = 0;
// Our callback buffer for collecting a chunk of data
volatile int16_t recording_buffer[DEFAULT_BUFFER_SIZE];

volatile int max_audio = -32768, min_audio = 32768;
}  // namespace


void CaptureSamples();

void TIMER_CALLBACK() {
  static bool ledtoggle = false;
  static uint32_t audio_idx = 0;
```

```
  int32_t sample = 0;

#if defined(USE_EDGEBADGE_PDMMIC)
  uint16_t read_pdm;
  if (!pdmspi.decimateFilterWord(&read_pdm)) {
    return; // not ready for data yet!
  }
  sample = read_pdm;
#endif

  if (audio_idx >= DEFAULT_BUFFER_SIZE) {
    CaptureSamples();
    max_audio = -32768, min_audio = 32768;
    audio_idx = 0;
  }

  // tick tock test
  //digitalWrite(LED_BUILTIN, ledtoggle);
  //ledtoggle = !ledtoggle;
#if defined(USE_EXTERNAL_MIC)
  sample = analogRead(USE_EXTERNAL_MIC);
  sample -= 2047; // 12 bit audio unsigned  0-4095 to signed -2048-~2047
#endif
#if defined(USE_EDGEBADGE_PDMMIC)
  sample -= 32676; // from 0-65535 to -32768 to 32768
#endif
#if defined(AUDIO_OUT)
  analogWrite(AUDIO_OUT, sample+2048);
#endif

  recording_buffer[audio_idx] = sample;
  max_audio = max(max_audio, sample);
  min_audio = min(min_audio, sample);
  audio_idx++;
}

TfLiteStatus InitAudioRecording(tflite::ErrorReporter* error_reporter) {
  //while (!Serial) yield();
  Serial.begin(115200);

  // Hook up the callback that will be called with each sample
#if defined(USE_EXTERNAL_MIC)
  arcada.timerCallback(kAudioSampleFrequency, TIMER_CALLBACK);
  analogReadResolution(12);
#endif
#if defined(USE_EDGEBADGE_PDMMIC)
  pdmspi.begin(kAudioSampleFrequency);
  Serial.print("Final PDM frequency: "); Serial.println(pdmspi.sampleRate);
#endif
#if defined(AUDIO_OUT)
  analogWriteResolution(12);
#endif
  // Block until we have our first audio sample
  while (!g_latest_audio_timestamp) {
  }

  return kTfLiteOk;
}
```

```
void CaptureSamples() {
  // This is how many bytes of new data we have each time this is called
  const int number_of_samples = DEFAULT_BUFFER_SIZE;
  // Calculate what timestamp the last audio sample represents
  const int32_t time_in_ms =
      g_latest_audio_timestamp +
      (number_of_samples / (kAudioSampleFrequency / 1000));
  // Determine the index, in the history of all samples, of the last sample
  const int32_t start_sample_offset =
      g_latest_audio_timestamp * (kAudioSampleFrequency / 1000);
  // Determine the index of this sample in our ring buffer
  const int capture_index = start_sample_offset % kAudioCaptureBufferSize;
  // Read the data to the correct place in our buffer, note 2 bytes per buffer entry
  memcpy(g_audio_capture_buffer + capture_index, (void *)recording_buffer, DEFAULT_BUFFER_SIZE*2);
  // This is how we let the outside world know that new audio data has arrived.
  g_latest_audio_timestamp = time_in_ms;

  int peak = (max_audio - min_audio);
  Serial.printf("pp %d\n", peak);
  //int normalized = map(peak, 20, 2000, 0, 65535);
  //arcada.pixels.setPixelColor(0, arcada.pixels.gamma32(arcada.pixels.ColorHSV(normalized)));
  //arcada.pixels.show();
}

TfLiteStatus GetAudioSamples(tflite::ErrorReporter* error_reporter,
                             int start_ms, int duration_ms,
                             int* audio_samples_size, int16_t** audio_samples) {
  // Set everything up to start receiving audio
  if (!g_is_audio_initialized) {
    TfLiteStatus init_status = InitAudioRecording(error_reporter);
    if (init_status != kTfLiteOk) {
      return init_status;
    }
    g_is_audio_initialized = true;
  }
  // This next part should only be called when the main thread notices that the
  // latest audio sample data timestamp has changed, so that there's new data
  // in the capture ring buffer. The ring buffer will eventually wrap around and
  // overwrite the data, but the assumption is that the main thread is checking
  // often enough and the buffer is large enough that this call will be made
  // before that happens.

  // Determine the index, in the history of all samples, of the first
  // sample we want
  const int start_offset = start_ms * (kAudioSampleFrequency / 1000);
  // Determine how many samples we want in total
  const int duration_sample_count =
      duration_ms * (kAudioSampleFrequency / 1000);
  for (int i = 0; i < duration_sample_count; ++i) {
    // For each sample, transform its index in the history of all samples into
    // its index in g_audio_capture_buffer
    const int capture_index = (start_offset + i) % kAudioCaptureBufferSize;
    // Write the sample to the output buffer
    g_audio_output_buffer[i] = g_audio_capture_buffer[capture_index];
  }

  // Set pointers to provide access to the audio
  *audio_samples_size = kMaxAudioSampleSize;
  *audio_samples = g_audio_output_buffer;
```

```
  audio_samples = g_audio_output_buffer;

  return kTfLiteOk;
}

int32_t LatestAudioTimestamp() { return g_latest_audio_timestamp; }
```

While the LED/Display/audio output is done in the **command_responder.cpp**

```
/* Copyright 2019 The TensorFlow Authors. All Rights Reserved.

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distributed under the License is distributed on an "AS IS" BASIS,
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See the License for the specific language governing permissions and
limitations under the License.
==============================================================================*/

#include "command_responder.h"

#include "Arduino.h"

#include <Adafruit_Arcada.h>
extern Adafruit_Arcada arcada;

// Toggles the built-in LED every inference, and lights a colored LED depending
// on which word was detected.
void RespondToCommand(tflite::ErrorReporter* error_reporter,
                      int32_t current_time, const char* found_command,
                      uint8_t score, bool is_new_command) {
  static bool is_initialized = false;
  if (!is_initialized) {
    pinMode(LED_BUILTIN, OUTPUT);
    // Pins for the built-in RGB LEDs on the Arduino Nano 33 BLE Sense
    is_initialized = true;
  }
  static int32_t last_command_time = 0;
  static int count = 0;
  static int certainty = 220;

  if (is_new_command) {
    error_reporter->Report("Heard %s (%d) @%dms", found_command, score,
                           current_time);
    if (found_command[0] == 'y') {
      last_command_time = current_time;
      ImageReturnCode stat = arcada.drawBMP((char *)"yes.bmp", 0, 0);
      if (stat != IMAGE_SUCCESS) {
        arcada.display->fillScreen(ARCADA_BLACK);
        arcada.display->setCursor(20, 20);
        arcada.display->setTextColor(ARCADA_GREEN);
        arcada.display->setTextSize(ceil(arcada.display->width() / 30));
        arcada.display->print("YES");
      }
```

```
    }
    arcada.WavPlayComplete("yes.wav");
    arcada.pixels.fill(arcada.pixels.Color(0, 50, 0));
    arcada.pixels.show();
  }

  if (found_command[0] == 'n') {
    last_command_time = current_time;
    ImageReturnCode stat = arcada.drawBMP((char *)"no.bmp", 0, 0);
    if (stat != IMAGE_SUCCESS) {
      arcada.display->fillScreen(ARCADA_BLACK);
      arcada.display->setCursor(20, 20);
      arcada.display->setTextColor(ARCADA_RED);
      arcada.display->setTextSize(ceil(arcada.display->width() / 30));
      arcada.display->print("NO");
    }
    arcada.WavPlayComplete("no.wav");
    arcada.pixels.fill(arcada.pixels.Color(50, 0, 0));
    arcada.pixels.show();
  }

  if (found_command[0] == 'u') {
    last_command_time = current_time;
    last_command_time = current_time;
    ImageReturnCode stat = arcada.drawBMP((char *)"no.bmp", 0, 0);
    if (stat != IMAGE_SUCCESS) {
      arcada.display->fillScreen(ARCADA_BLACK);
      arcada.display->setCursor(20, 20);
      arcada.display->setTextColor(ARCADA_LIGHTGREY);
      arcada.display->setTextSize(ceil(arcada.display->width() / 30));
      arcada.display->print("???");
    }
    arcada.pixels.fill(arcada.pixels.Color(10, 10, 10));
    arcada.pixels.show();
  }
}

// If last_command_time is non-zero but was 1 seconds ago, zero it
// and switch off the LED.
if (last_command_time != 0) {
  if (last_command_time < (current_time - 1000)) {
    last_command_time = 0;
    // draw intro
    ImageReturnCode stat = arcada.drawBMP((char *)"howto.bmp", 0, 0);
    if (stat != IMAGE_SUCCESS) {
      arcada.display->fillScreen(ARCADA_BLACK);
      arcada.display->setCursor(0, 0);
      arcada.display->setTextColor(ARCADA_WHITE);
      arcada.display->setTextSize(ceil(arcada.display->width() / 180.0));
      arcada.display->println("Hold microphone/badge");
      arcada.display->println("approx. 6-8\" away from");
      arcada.display->println("mouth and say either");
      arcada.display->println("     YES or NO    ");
    }
    arcada.pixels.fill(arcada.pixels.Color(0, 0, 0));
    arcada.pixels.show();
  }
  // If it is non-zero but <3 seconds ago, do nothing.
  return;
}
```

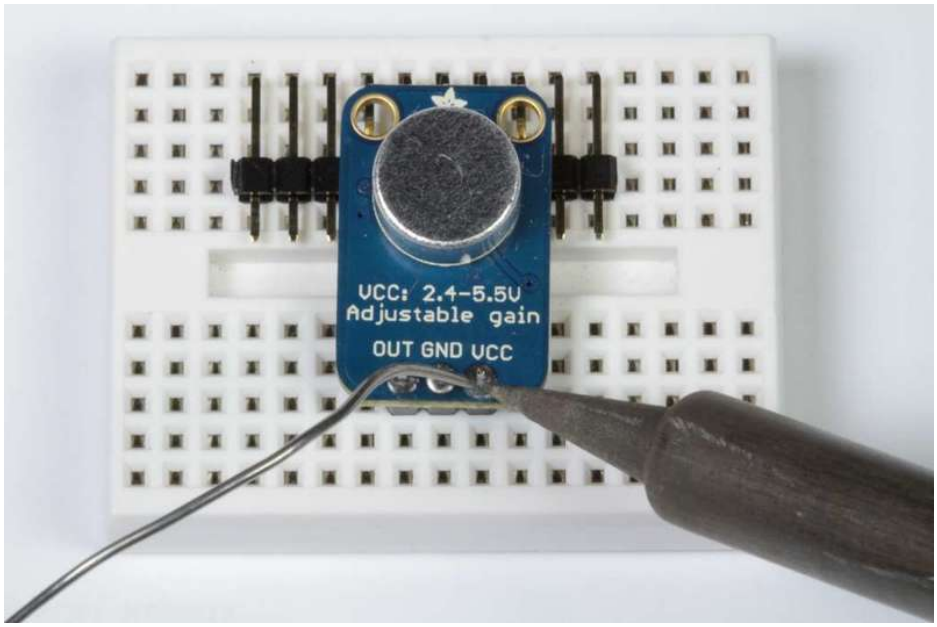
```
  // Otherwise, toggle the LED every time an inference is performed.
  ++count;
  if (count & 1) {
    digitalWrite(LED_BUILTIN, HIGH);
  } else {
    digitalWrite(LED_BUILTIN, LOW);
  }
}
```

Ext. Mic Assembly

If you have an EDGEBADGE with built in mic OR your PyBadge kit came already with a microphone and cable kit, you can skip this step!

Step 1 - Solder Headers onto Microphone

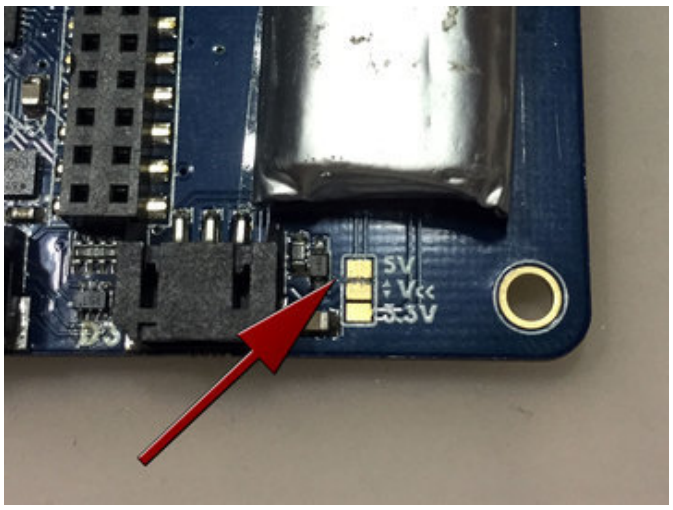
You'll need to plug into your microphone, so visit this guide for step by step instructions on soldering the headers on (https://adafru.it/Fmj)



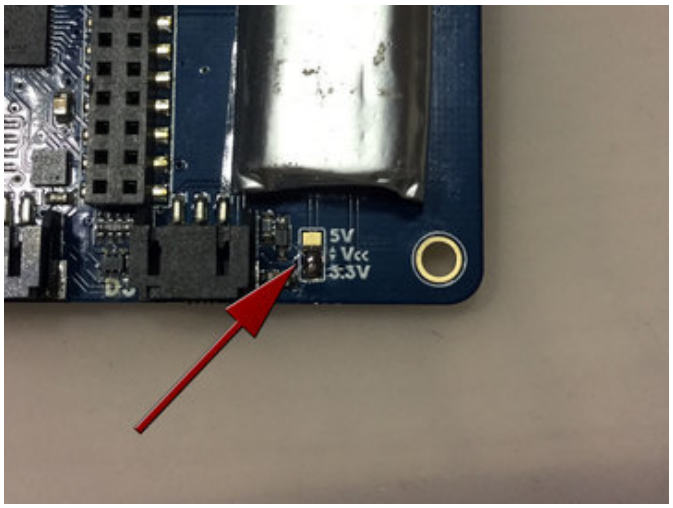
Step 2 - Connect JST PH Cable to Microphone

Connect **Red** to **VCC**, **Black** to **GND** and **White** to **OUT**

Step 3 - Cut and solder the 3V selection jumper on the back of the PyBadge or PyGamer

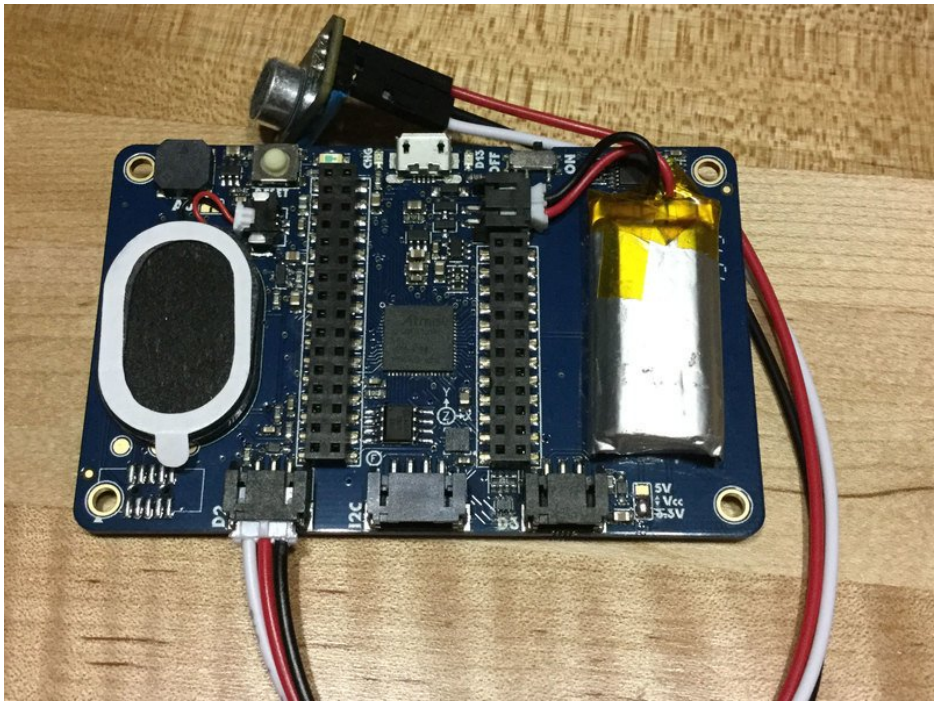


On the back of your board, find the STEMMA cable voltage selection jumper. Cut the trace from **Vcc** to **5V**



Then solder in the **Vcc** to **3V** pads

Step 4 - Plug in Microphone into D2



More PyBadge Projects

More PyBadge Projects (http://adafru.it/4200)

Troubleshooting

error: macro "max" requires 2 arguments, but only 1 given = (_M_b.max() - _M_b.min() < std::numeric_limits<_Eresult_type>::max()

If you're getting complaints about **min()** and **max()** having wrong number of arguments, make sure you've updated to the latest **Adafruit SAMD Boards** package in the boards manager. Also make sure you have the latest libraries while you're at it

"uses VFP register arguments and libtensorflowlite.a does not" error

If you get mysterious compilation errors about VFP registers or SerialUSB missing, check you have not installed the *pre-compiled* version of the TensorFlow library

```
ld.exe: error: C:\Users\ladyada\AppData\Local\Temp\arduino_build_570572/magic_wand_arcada.ino.elf uses
VFP register arguments,
C:\Users\ladyada\Dropbox\ArduinoSketches\libraries\Arduino_TensorFlowLite\src\cortex-
m4\libtensorflowlite.a(error_reporter.cpp.o) does not
ld.exe: failed to merge target specific data of file
C:\Users\ladyada\Dropbox\ArduinoSketches\libraries\Arduino_TensorFlowLite\src\cortex-
m4\libtensorflowlite.a(error_reporter.cpp.o)
ld.exe: error: C:\Users\ladyada\AppData\Local\Temp\arduino_build_570572/magic_wand_arcada.ino.elf uses
VFP register arguments,
C:\Users\ladyada\Dropbox\ArduinoSketches\libraries\Arduino_TensorFlowLite\src\cortex-
m4\libtensorflowlite.a(micro_error_reporter.cpp.o) does not
ld.exe: failed to merge target specific data of file
C:\Users\ladyada\Dropbox\ArduinoSketches\libraries\Arduino_TensorFlowLite\src\cortex-
m4\libtensorflowlite.a(micro_error_reporter.cpp.o)
```

In the library manager, select the latest **not precompiled** version!