

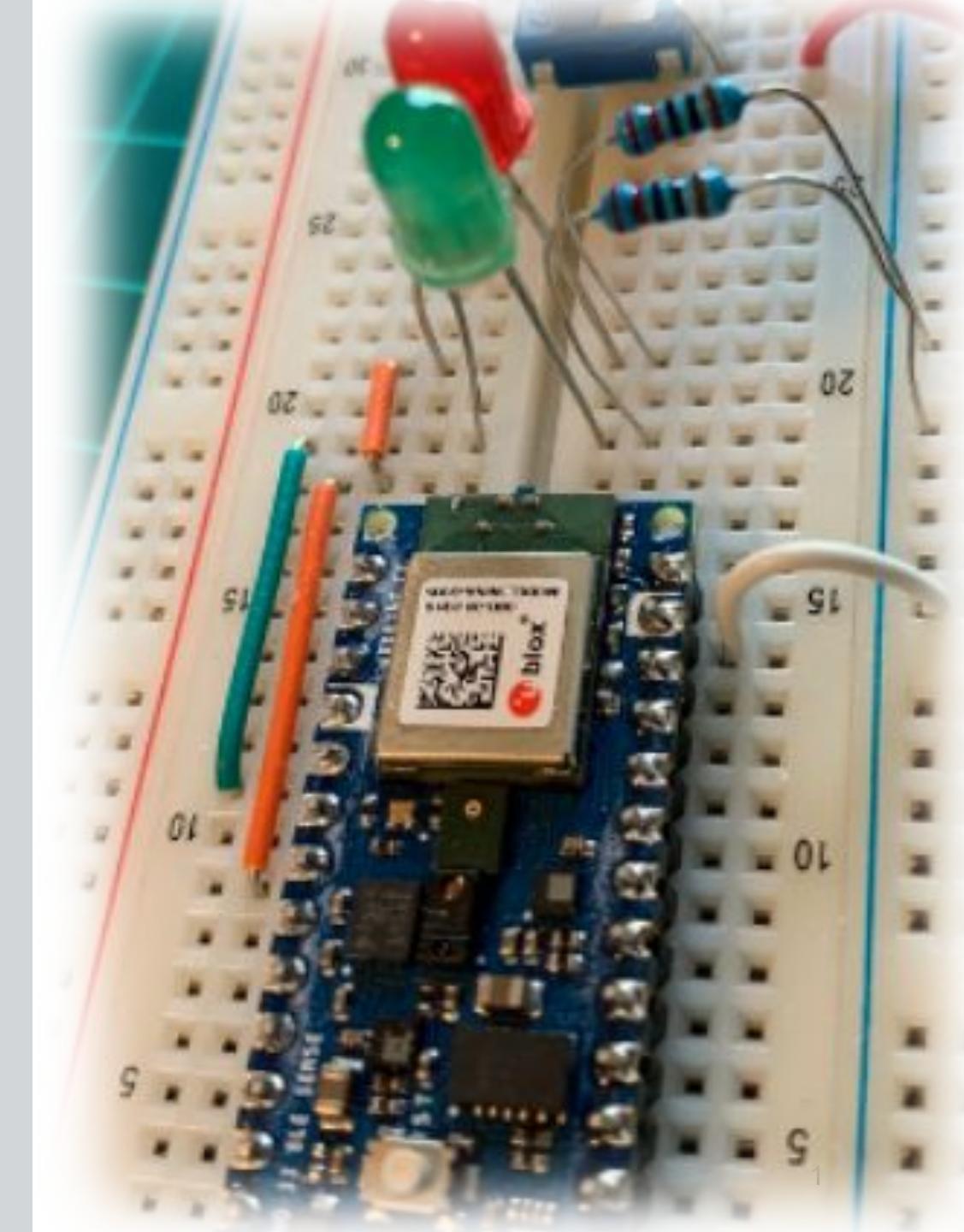
# IESTI01 – TinyML

## Embedded Machine Learning

24. KeyWord Spotting (KWS)  
Edge Impulse Studio



Prof. Marcelo Rovai  
UNIFEI



# Nano-33 BLE Keyword Spotting (KWS) Project

<https://studio.edgeimpulse.com/public/38744/latest>



Select project - Edge Impulse

studio.edgeimpulse.com/studio/select-project

EDGE IMPULSE

MJRoBot (Marcelo Rovai)

# Select project

Create project

Enter a name for your new project

IESTI01\_Keyword\_Spotting\_project

Cancel Create new project

MJRoBot (Marcelo Rovai) / Sound-Classification-Blender-Faucet

MJRoBot (Marcelo Rovai) / oi\_rovis\_kws

MJRoBot (Marcelo Rovai) / Eggs AI

MJRoBot (Marcelo Rovai) / Accelerometer-Nano-Ble-IoT

3

EDGE IMPULSE Home API Reference Log In

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- API and SDK references
- What is embedded ML, anyway?
- Frequently asked questions

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- ST B-L475E-IOT01A
- Arduino Nano 33 BLE Sense**
- Eta Compute ECM3532 AI Sensor
- Eta Compute ECM3532 AI Vision
- OpenMV Cam H7 Plus
- Himax WE-I Plus
- Nordic Semi nRF52840 DK
- Nordic Semi nRF5340 DK
- SiLabs Thunderboard Sense 2
- Sony's Spresense
- Arduino Portenta H7 + Vision shield (preview)
- Raspberry Pi 4
- NVIDIA Jetson Nano
- Mobile phone
- Porting guide

**COMMUNITY BOARDS**

- Seeed Wio Terminal
- Agora Product Development Kit

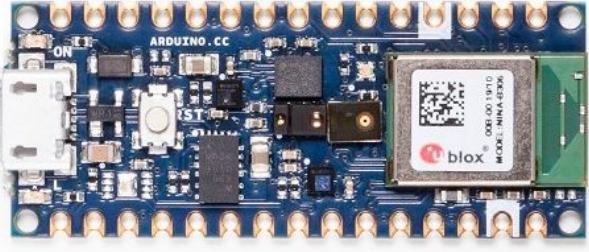
**EDGE IMPULSE FOR LINUX**

- Edge Impulse for Linux
- Linux Node.js SDK
- Linux Go SDK
- Linux C++ SDK
- Linux Python SDK

## Arduino Nano 33 BLE Sense

The Arduino Nano 33 BLE Sense is a tiny development board with a Cortex-M4 microcontroller, motion sensors, a microphone and BLE - and it's fully supported by Edge Impulse. You'll be able to sample raw data, build models, and deploy trained machine learning models directly from the studio. It's available for around 30 USD from [Arduino](#) and a wide range of distributors.

The Edge Impulse firmware for this development board is open source and hosted on GitHub: [edgeimpulse/firmware-arduino-nano-33-ble-sense](#).



**Arduino Nano 33 BLE Sense**

### Installing dependencies

To set this device up in Edge Impulse, you will need to install the following software:

1. [Edge Impulse CLI](#).
2. [Arduino CLI](#).
  - Here's an [instruction video for Windows](#).
  - The [Arduino website](#) has instructions for macOS and Linux.
3. On Linux:
  - GNU Screen: install for example via `sudo apt install screen`.

A large blue arrow points from the note below to the "2. Arduino CLI." section of the dependency list.

**Note that the 1. Edge Impulse CLI is not necessary for Arduino Nano-33 if you use WebUSB.**

**DOCUMENTATION**

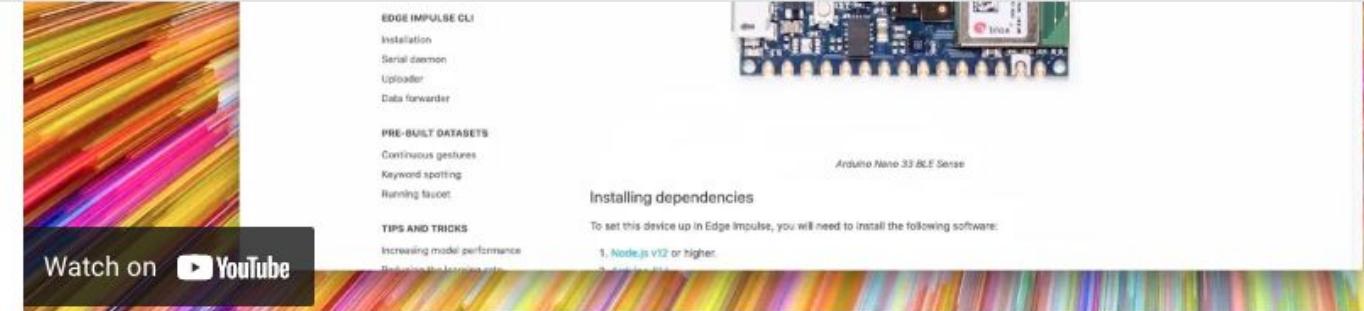
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**COMMUNITY BOARDS**

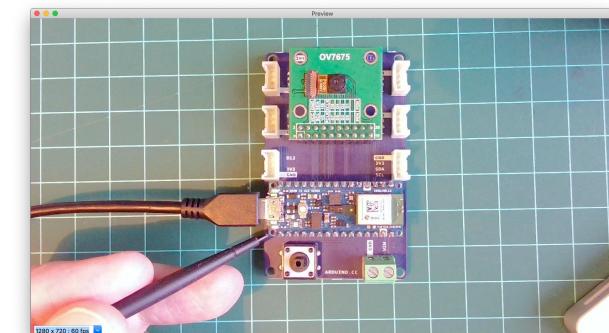
- Seeed Wio Terminal
- Agora Product Development Kit



The screenshot shows the Edge Impulse website with the Arduino Nano 33 BLE Sense development board highlighted. The board is a small blue PCB with various components and a green LED. The website interface includes sections for 'EDGE IMPULSE CLI', 'PRE-BUILT DATABASES', and 'TIPS AND TRICKS'. A 'Watch on YouTube' button is visible at the bottom left.

**1. Connect the development board to your computer**

Use a micro-USB cable to connect the development board to your computer. Then press RESET twice to launch into the bootloader. The on-board LED should start pulsating to indicate this.



*Press RESET twice quickly to launch the bootloader on the Arduino Nano 33 BLE Sense.*

**2. Update the firmware**

The development board does not come with the right firmware yet. To update the firmware:

1. [Download the latest Edge Impulse firmware](#), and unzip the file.
2. Open the flash script for your operating system (`flash_windows.bat`, `flash_mac.command` or `flash_linux.sh`) to flash the firmware.
3. Wait until flashing is complete, and press the RESET button once to launch the new firmware.

**3. Setting keys**

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**DEVELOPMENT BOARDS**

- Overview

ST B-L475E-IOT01A

**Arduino Nano 33 BLE Sense**

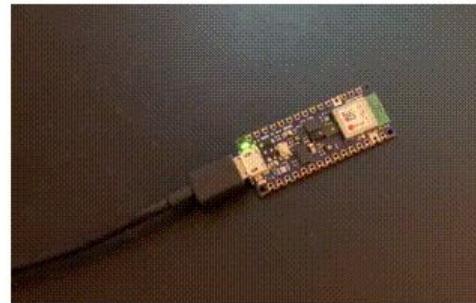
- Eta Compute ECM3532 AI Sensor
- Eta Compute ECM3532 AI Vision
- OpenMV Cam H7 Plus
- Himax WE-I Plus
- Nordic Semi nRF52840 DK
- Nordic Semi nRF5340 DK
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**1. Connect the development board to your computer**

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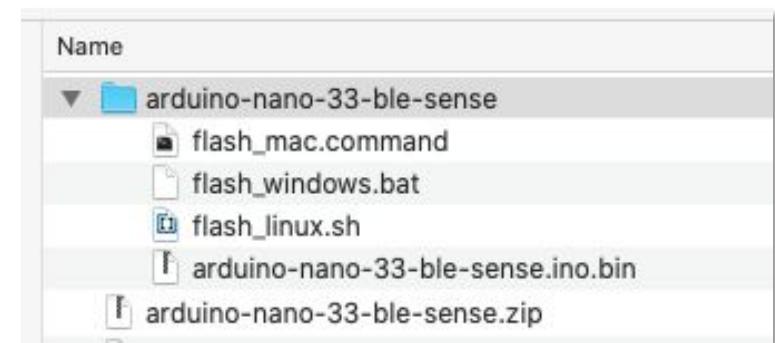
**1**

*Press RESET twice quickly to launch the bootloader on the Arduino Nano 33 BLE Sense.*

**2. Update the firmware**

The development board does not come with the right firmware yet. To update the firmware:

1. [Download the latest Edge Impulse firmware](#), and unzip the file.
2. Open the flash script for your operating system ( `flash_windows.bat` , `flash_mac.command` or `flash_linux.sh` ) to flash the firmware.
3. Wait until flashing is complete, and press the RESET button once to launch the new firmware.

**3. Setting keys**

# MacOS

```
mjrovai — flash_mac.command — 124x43
Last login: Mon Jun 28 08:58:22 on ttys002
You have new mail.
/Users/mjrovai/Downloads/arduino-nano-33-ble-sense/flash_mac.command ; exit;

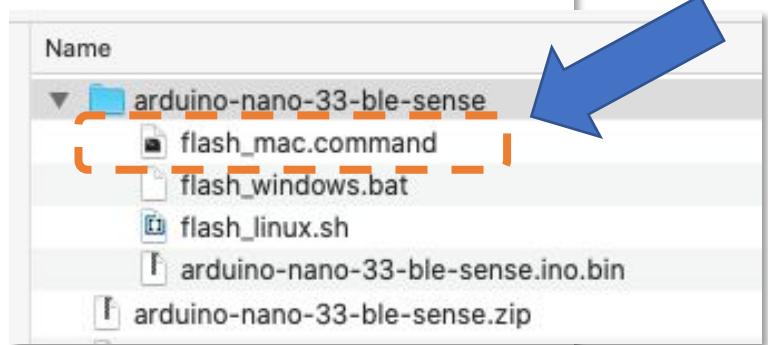
The default interactive shell is now zsh.
To update your account to use zsh, please run `chsh -s /bin/zsh`.
For more details, please visit https://support.apple.com/kb/HT208050.
(base) MacBook-Pro-de-Marcelo:~ mjrovai$ /Users/mjrovai/Downloads/arduino-nano-33-ble-sense/flash_mac.command ; exit;
Finding Arduino Mbed core...
Finding Arduino Mbed OK
Finding Arduino Nano 33 BLE...
Finding Arduino Nano 33 BLE OK
Flashing board...
Device      : nRF52840-QIAA
Version     : Arduino Bootloader (SAM-BA extended) 2.0 [Arduino:IKXYZ]
Address     : 0x0
Pages       : 256
Page Size   : 4096 bytes
Total Size  : 1024KB
Planes      : 1
Lock Regions: 0
Locked      : none
Security    : false
Erase flash

Done in 0.001 seconds
Write 525440 bytes to flash (129 pages)
[=====] 100% (129/129 pages)
Done in 20.533 seconds

Flashed your Arduino Nano 33 BLE development board.
To set up your development with Edge Impulse, run 'edge-impulse-daemon'
To run your impulse on your development board, run 'edge-impulse-run-impulse'
logout
Saving session...
...copying shared history...
...saving history...truncating history files...
...completed.

[Process completed]
```

1. Press Nano-33 Reset button Twice  
2. With Nano-33 LED Flashing:



3.Nano-33 LED Stop Flashing

# Windows 10

```
Prompt de Comando
Microsoft Windows [versão 10.0.19041.1052]
(c) Microsoft Corporation. Todos os direitos reservados.

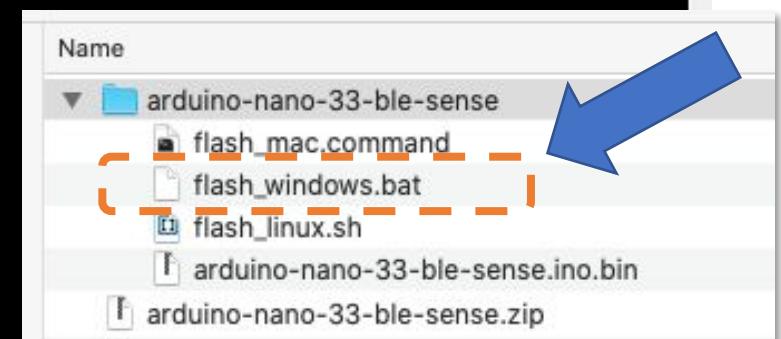
C:\Users\GUILH>arduino-cli
Arduino Command Line Interface (arduino-cli).

Usage:
  arduino-cli [command]

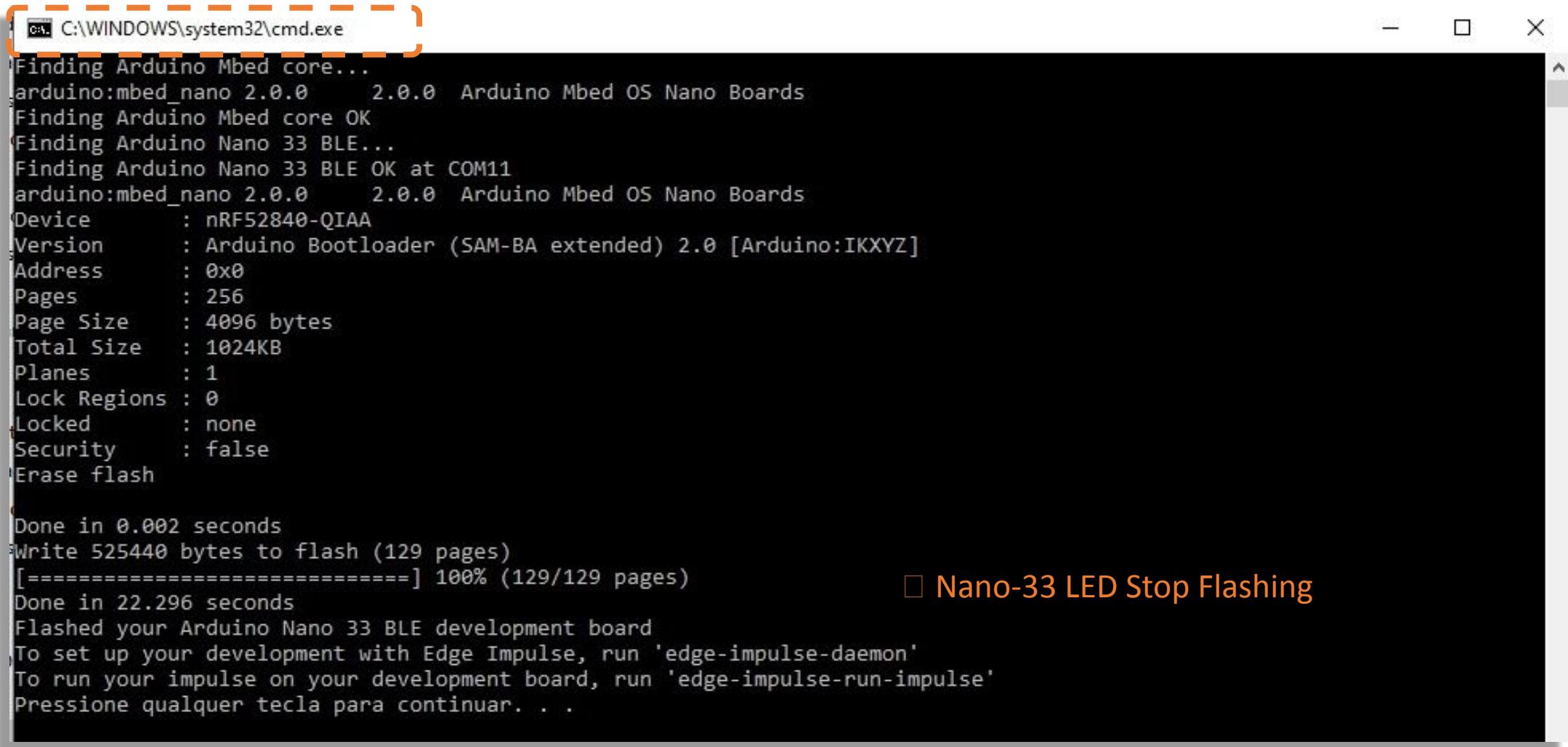
Examples:
  arduino-cli <command> [flags...]

Available Commands:
  board           Arduino board commands.
  burn-bootloader Upload the bootloader.
  cache           Arduino cache commands.
  compile         Compiles Arduino sketches.
  completion     Generates completion scripts
  config          Arduino configuration commands.
  core            Arduino core operations.
  daemon          Run as a daemon on port 50051
  debug           Debug Arduino sketches.
  help            Help about any command
  lib              Arduino commands about libraries.
  outdated        Lists cores and libraries that can be upgraded
  sketch          Arduino CLI sketch commands.
  update          Updates the index of cores and libraries
  upgrade         Upgrades installed cores and libraries.
  upload          Upload Arduino sketches.
  version         Shows version number of Arduino CLI.
```

1. Press Nano-33 Reset button Twice
2. With Nano-33 LED Flashing:



# Windows 10



```
C:\WINDOWS\system32\cmd.exe
Finding Arduino Mbed core...
arduino:mbed_nano 2.0.0      2.0.0  Arduino Mbed OS Nano Boards
Finding Arduino Mbed core OK
Finding Arduino Nano 33 BLE...
Finding Arduino Nano 33 BLE OK at COM11
arduino:mbed_nano 2.0.0      2.0.0  Arduino Mbed OS Nano Boards
Device      : nRF52840-QIAA
Version     : Arduino Bootloader (SAM-BA extended) 2.0 [Arduino:IKXYZ]
Address     : 0x0
Pages       : 256
Page Size   : 4096 bytes
Total Size  : 1024KB
Planes      : 1
Lock Regions: 0
Locked      : none
Security    : false
Erase flash

Done in 0.002 seconds
Write 525440 bytes to flash (129 pages)
[=====] 100% (129/129 pages)
Done in 22.296 seconds
Flashed your Arduino Nano 33 BLE development board
To set up your development with Edge Impulse, run 'edge-impulse-daemon'
To run your impulse on your development board, run 'edge-impulse-run-impulse'
Pressione qualquer tecla para continuar. . .
```

Nano-33 LED Stop Flashing

Follow this [video](#) to install the Arduino CLI on Windows 10 and add the 'arduino-cli' binary to your PATH. **This makes the CLI available from any location through the command prompt.**

The screenshot shows the Edge Impulse Studio interface. On the left, a sidebar lists project options like Dashboard, Devices, Data acquisition, and ImpulseNet. The main area displays a "Data acquisition - IESTI01\_Key" project titled "POTTING\_PROJECT". A modal dialog box is open, asking for permission to connect to a serial port. It lists several ports: cu.Bluetooth-Incoming-Port, cu.MALS, cu.RovaisAirPods-Wireless, cu.SOC, and Nano 33 BLE (cu.usbmodem144301) - Paired. The last one is selected and highlighted in blue. Below the dialog are buttons for "Cancel" and "Connect". A large orange arrow labeled "3" points from this dialog to the "Let's collect some data" button at the bottom of the main screen.

studio.edgeimpulse.com wants to connect to a serial port

cu.Bluetooth-Incoming-Port  
cu.MALS  
cu.RovaisAirPods-Wireless  
cu.SOC  
Nano 33 BLE (cu.usbmodem144301) - Paired

Cancel Connect

3

No data collected yet

Let's collect some data

RECORDING PROJECT

RECORD NEW DATA

2

Connect using WebUSB

No devices connected to the remote management API.

RAW DATA

Click on a sample to load...

Do not forget to connect the Nano with your PC serial via Arduino-CLI, before starting collecting data.

1 →

Name

arduino-nano-33-ble-sense

- flash\_mac.command
- flash\_windows.bat
- flash\_linux.sh
- arduino-nano-33-ble-sense.ino.bin

arduino-nano-33-ble-sense.zip

# OPTIONAL

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## COMMUNITY BOARDS

- Seeed Wio Terminal
- Agora Product Development Kit

## EDGE IMPULSE FOR LINUX

# Installation

## If WebUSB force browser to close, install Edge Impulse CLI

This Edge Impulse CLI is used to control local devices, act as a proxy to synchronise data for devices that don't have an internet connection, and to upload and convert local files. The CLI consists of seven tools:

- [edge-impulse-daemon](#) - configures devices over serial, and acts as a proxy for devices that do not have an IP connection.
- [edge-impulse-uploader](#) - allows uploading and signing local files.
- [edge-impulse-data-forwarder](#) - a very easy way to collect data from any device over a serial connection, and forward the data to Edge Impulse.
- [edge-impulse-run-impulse](#) - show the impulse running on your device.
- [edge-impulse-blocks](#) - create organizational transformation blocks.
- [eta-flash-tool](#) - to flash the Eta Compute ECM3532 AI Sensor.
- [himax-flash-tool](#) - to flash the Himax WE-I Plus.

Connect to devices without the CLI? Recent versions of Google Chrome and Microsoft Edge can connect directly to fully-supported development boards, without the CLI. See [this blog post](#) for more information.

WebUSB

### Installation - macOS and Windows

1. Install [Python 3](#) on your host computer.
2. Install [Node.js](#) v14 or higher on your host computer.
  - For Windows users, install the Additional Node.js tools when prompted. You may skip this setup if you have Visual Studio 2015 or more.
3. Install the CLI tools via:

```
npm install -g edge-impulse-cli --force
```

You should now have the tools available in your PATH.

### Installation - Linux/Ubuntu and Raspbian OS

# Edge Impulse CLI

- edge-impulse-daemon --clean
- Enter EI Studio credentials
- Select Project name
- Give a name for your device (optional)

```
mjrovai — node -e sudo — 80x40
Last login: Sun Jul  4 12:18:24 on ttys001
You have new mail.

The default interactive shell is now zsh.
To update your account to use zsh, please run `chsh -s /bin/zsh`.
For more details, please visit https://support.apple.com/kb/HT208050.
[(base) MacBook-Pro-de-Marcelo:~ mjrovai$ sudo edge-impulse-daemon --clean
[Password:
Edge Impulse serial daemon v1.12.2
[?] What is your user name or e-mail address (edgeimpulse.com)? rovai@mjrobot.org
[?] What is your password? [hidden]
Endpoints:
  WebSocket: wss://remote-mgmt.edgeimpulse.com
  API: https://studio.edgeimpulse.com/v1
  Ingestion: https://ingestion.edgeimpulse.com

[SER] Connecting to /dev/tty.usbmodem144301
[SER] Serial is connected, trying to read config...
[SER] Clearing configuration
[SER] Clearing configuration OK
[SER] Retrieved configuration
[SER] Device is running AT command version 1.3.0

? To which project do you want to connect this device? MJRobot (Marcelo Rovai)
IESTI01 Keyword Spotting project
Setting upload host in device... OK
Configuring remote management settings... OK
Configuring API key in device... OK
Configuring HMAC key in device... OK
[SER] Device is not connected to remote management API, will use daemon
[WS ] Connecting to wss://remote-mgmt.edgeimpulse.com
[WS ] Connected to wss://remote-mgmt.edgeimpulse.com
[?] What name do you want to give this device? nano
[WS ] Device "nano" is now connected to project "IESTI01_Keyword_Spotting_project"
[WS ] Go to https://studio.edgeimpulse.com/studio/38744/acquisition/training to
build your machine learning model!
```

Devices - IESTI01\_Keyword\_Sp x +

◀ ▶ C studio.edgeimpulse.com/studio/38744/devices

EDGE IMPULSE MJRoBot (Marcelo Roval)

Dashboard Devices Data acquisition Impulse design Create impulse Retrain model Live classification Model testing Versioning Deployment

DEVICES (IESTI01\_KEYWORD\_SPOTTING\_PROJECT)

Your devices

+ Connect a new device

These are devices that are connected to the Edge Impulse remote management API, or have posted data to the ingestion SDK.

NAME	ID	TYPE	SENSORS	REMOT...	LAST SEEN
 nano	36:17:55:F9:70:F7	ARDUINO_NANO33BLE	Built-in accelerometer, Built-i...	●	Today, 12:21:41

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GETTING STARTED Documentation Forums



Data acquisition - IESTI01\_ +

studio.edgeimpulse.com/studio/38744/acquisition/training?page=1

 **EDGE IMPULSE**

**DATA ACQUISITION (IESTI01\_KEYWORD\_SPOTTING\_PROJECT)**

**Training data** **Test data**

**Did you know?** You can capture data from any device or development board, or upload your existing datasets - Show options X

**DATA COLLECTED** -  **LABELS** 0

**Collected data**

No data collected yet

 [Let's collect some data](#)

**Record new data**

**Device** 36:17:55:F9:70:F7

**Label** unifei **Sample length (ms.)** 10000

**Sensor** Built-in microphone **Frequency** 16000Hz

**Start sampling**

**RAW DATA**  
Click on a sample to load...

Dashboard  
Devices  
**Data acquisition**  
Impulse design  
Create impulse  
Retrain model  
Live classification  
Model testing  
Versioning  
Deployment

**GETTING STARTED**  
Documentation  
Forums

MJRoBot (Marcelo Rovai) 

Data acquisition - IESTI01\_ x

studio.edgeimpulse.com/studio/38744/acquisition/training?page=1

## EDGE IMPULSE

DATA COLLECTED  
10s

LABELS  
1

Collected data

SAMPLE NAME	LABEL	ADDED	LENGTH
unifei.29js37tq	unifei	Today, 18:22:34	10s

Device ?  
36:17:55:F9:70:F7

Label  
unifei

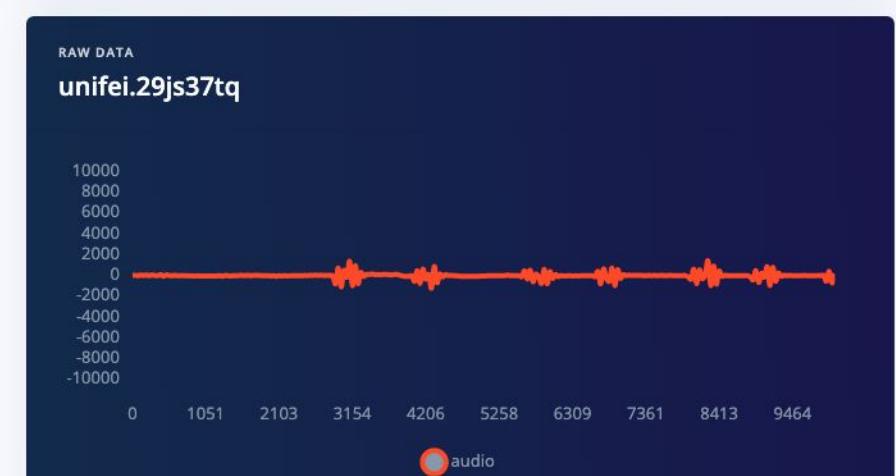
Sample length (ms.)  
10000

Sensor  
Built-in microphone

Frequency  
16000Hz

Start sampling

RAW DATA  
**unifei.29js37tq**



audio

0:10 / 0:10

0 1051 2103 3154 4206 5258 6309 7361 8413 9464

Data acquisition - IESTI01

studio.edgeimpulse.com/studio/38744/acquisition/training?page=1

### EDGE IMPULSE

DATA COLLECTED  
10s

LABELS  
1

Collected data

SAMPLE NAME	LABEL	ADDED	LENGTH
unifei.29js37tq	unifei	Today, 18:22:34	10s

Rename  
Edit label  
Move to test set  
Crop sample  
**Split sample**  
Download  
Download (.WAV)  
Delete

Record new data

Device ?  
36:17:55:F9:70:F7

Label  
unifei

Sample length (ms.)  
10000

Sensor  
Built-in microphone

Frequency  
16000Hz

Start sampling

RAW DATA  
unifei.29js37tq

audio

▶ 0:10 / 0:10 🔍 ⏪ ⏹

<https://studio.edgeimpulse.com/studio/38744/acquisition/training?page=1#>

The screenshot shows the Edge Impulse Studio Data Acquisition interface. On the left, a sidebar lists various project management and documentation links. The main area displays a summary of collected data: 10s of data and 1 label. A central modal window titled "Split sample 'unifei.29js37tq'" shows an audio waveform with several segments highlighted. A "Set segment length (ms.): 1000" input field and an "Apply" button are present. The waveform has time markers at 0, 1013, 2027, 3041, 4054, 5068, 6082, 7096, 8109, and 9123. Below the waveform, a play button, a progress bar at 0:00 / 0:00, and a volume icon are visible. At the bottom of the modal, there are "Cancel" and "Split" buttons, along with a "Shift samples" checkbox. To the right of the modal, a "Record new data" section includes a "Device" dropdown, a "Sample length (ms.)" input set to 10000, a "Frequency" dropdown set to 16000Hz, and a "Start sampling" button. Below these controls, a smaller preview window shows a 10-second audio clip.

Data acquisition - IESTI01

studio.edgeimpulse.com/studio/38744/acquisition/training?page=1

### EDGE IMPULSE

- Dashboard
- Devices
- Data acquisition**
- Impulse design
- Create impulse
- Retrain model
- Live classification
- Model testing
- Versioning
- Deployment

#### DATA COLLECTED

6s

LABELS 1

#### Collected data

SAMPLE NAME	LABEL	ADDED	LENGTH	⋮
unifei.29js37tq.s6	unifei	Today, 18:28:22	1s	⋮
unifei.29js37tq.s5	unifei	Today, 18:28:22	1s	⋮
unifei.29js37tq.s4	unifei	Today, 18:28:22	1s	⋮
unifei.29js37tq.s3	unifei	Today, 18:28:22	1s	⋮
unifei.29js37tq.s2	unifei	Today, 18:28:22	1s	⋮
unifei.29js37tq.s1	unifei	Today, 18:28:22	1s	⋮

RAW DATA  
unifei.29js37tq.s6

Start sampling

Record new data

Device ?  
36:17:55:F9:70:F7

Label  
unifei

Sample length (ms.)  
10000

Sensor  
Built-in microphone

Frequency  
16000Hz

0:00 / 0:00

18

Data acquisition - IESTI01\_Key... [+](#)

studio.edgeimpulse.com/studio/38744/acquisition/training?page=1

EDGE IMPULSE

DATA ACQUISITION (IESTI01\_KEYWORD\_SPOTTING\_PROJECT)

Training data Test data

Did you know? You can capture data from any device or development board, or upload your existing datasets - [Show options](#)

DATA COLLECTED 1m 37s

LABELS 1

Collected data

Device ? Connect using WebUSB

Device nano

Label unifei Sample length (ms.) 10000

Sensor Built-in microphone Frequency 16000Hz

Start sampling

RAW DATA Click on a sample to load...

DATA COLLECTED 1m 37s

LABELS 1

Collected data

SAMPLE NAME	LABEL	ADDED	LENGTH	⋮
unifei.29lq8ugs	unifei	Today, 12:29:12	10s	⋮
unifei.29lq80v9	unifei	Today, 12:28:42	10s	⋮
unifei.29lq760p	unifei	Today, 12:28:14	10s	⋮
unifei.29lq6a2p	unifei	Today, 12:27:46	10s	⋮
unifei.29lq5fvd	unifei	Today, 12:27:19	10s	⋮
unifei.29lq4m8v	unifei	Today, 12:26:53	10s	⋮
unifei.29lq3t92	unifei	Today, 12:26:27	10s	⋮
unifei.29lq286o	unifei	Today, 12:25:33	10s	⋮
unifei.29jskg44	unifei	Yesterday, 18:31...	10s	⋮
unifei.29js37tq.s6	unifei	Yesterday, 18:28...	1s	⋮

DATA COLLECTED 1m 37s

LABELS 1

Collected data

SAMPLE NAME	LABEL	ADDED	LENGTH	⋮
unifei.29lq8ugs	unifei	Today, 12:29:12	10s	⋮
unifei.29lq80v9	unifei	Today, 12:28:42	10s	⋮
unifei.29lq760p	unifei	Today, 12:28:14	10s	⋮
unifei.29lq6a2p	unifei	Today, 12:27:46	10s	⋮
unifei.29lq5fvd	unifei	Today, 12:27:19	10s	⋮
unifei.29lq4m8v	unifei	Today, 12:26:53	10s	⋮
unifei.29lq3t92	unifei	Today, 12:26:27	10s	⋮
unifei.29lq286o	unifei	Today, 12:25:33	10s	⋮
unifei.29jskg44	unifei	Yesterday, 18:31...	10s	⋮
unifei.29js37tq.s6	unifei	Yesterday, 18:28...	1s	⋮

Data acquisition - IESTI01\_Key | Uaiirrior | UNIFEI

studio.edgeimpulse.com/studio/38744/acquisition/training?page=2

### EDGE IMPULSE

DATA COLLECTED  
4m 37s

LABELS  
3

Collected data

SAMPLE NAME	LABEL	ADDED	LENGTH
silence.29lss69b.s4	silence	Today, 13:24:24	1s
silence.29lss69b.s3	silence	Today, 13:24:24	1s
silence.29lss69b.s2	silence	Today, 13:24:24	1s
silence.29lss69b.s1	silence	Today, 13:24:24	1s
silence.29lss69b.s9	silence	Today, 13:24:12	1s
silence.29lss69b.s8	silence	Today, 13:24:12	1s
silence.29lss69b.s7	silence	Today, 13:24:12	1s
silence.29lss69b.s6	silence	Today, 13:24:12	1s
silence.29lss69b.s5	silence	Today, 13:24:12	1s
silence.29lss69b.s4	silence	Today, 13:24:12	1s
silence.29lss69b.s3	silence	Today, 13:24:12	1s
silence.29lss69b.s2	silence	Today, 13:24:12	1s

RAW DATA  
**silence.29lt3rm7.s2**

0 104 208 312 416 520 624 728 832 936

audio

▶ 0:00 / 0:00 🔊 ⏮

Record new data

Device ?  
nano

Label  
silence

Sample length (ms.)  
10000

Sensor  
Built-in microphone

Frequency  
16000Hz

Start sampling

CREATE IMPULSE (IESTI01\_KEYWORD\_SPOTTING\_PROJECT)

An impulse takes raw data, uses signal processing to extract features, and then uses a learning block to classify new data.

**Time series data**

Axes: audio

Window size: 1000 ms.

Window increase: 500 ms.

Zero-pad data:

Add a processing block

Add a learning block

Output features

Save impulse

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Create impulse - IESTI01\_Keyw Ualrrorr | UNIFEI

studio.edgeimpulse.com/studio/38744/create-impulse

**EDGE IMPULSE**

CREATE IMPULSE (IESTI01)

**Add a processing block**

An impulse takes

DESCRIPTION	AUTHOR	RECOMMENDED
<b>Audio (MFCC)</b> Extracts features from audio signals using Mel Frequency Cepstral Coefficients, great for human voice.	Edgelimpulse Inc. ★	<b>Add</b>
<b>Spectrogram</b> <small>EXPERIMENTAL</small> Extracts a spectrogram from audio or sensor data, great for non-voice audio or data with continuous frequencies.	Edgelimpulse Inc. ★	<b>Add</b>
<b>Flatten</b> Flatten an axis into a single value, useful for slow-moving averages like temperature data, in combination with other blocks.	Edgelimpulse Inc.	<b>Add</b>
<b>Image</b> Preprocess and normalize image data, and optionally reduce the color depth.	Edgelimpulse Inc.	<b>Add</b>
<b>Audio (MFE)</b> <small>EXPERIMENTAL</small> Extracts a spectrogram from audio signals using Mel-filterbank energy features, great for non-voice audio.	Edgelimpulse Inc.	<b>Add</b>
<b>Spectral Analysis</b> Great for analyzing repetitive motion, such as data from accelerometers. Extracts the frequency and power characteristics of a signal over time.	Edgelimpulse Inc.	<b>Add</b>
<b>Audio (Syntiant)</b> <small>EXPERIMENTAL</small> Syntiant only. Compute log Mel-filterbank energy features from an audio signal.	Edgelimpulse Inc.	<b>Add</b>
<b>Raw Data</b> Use data without pre-processing. Useful if you want to use deep learning to learn features.	Edgelimpulse Inc.	<b>Add</b>

MJRoBot (Marcelo Roval)

**Output features** ✓

**Save Impulse**

Time series data

Axes  
audio

Window size

Window increase

Zero-pad data

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Create impulse - IESTI01\_Keyw X Ualrrorr | UNIFEI x +

studio.edgeimpulse.com/studio/38744/create-impulse

EDGE IMPULSE

CREATE IMPULSE (IESTI01\_KEYWORD\_SPOTTING\_PROJECT)

An impulse takes raw data, uses signal processing to extract features, and then uses a learning block to classify new data.

Dashboard

Devices

Data acquisition

Impulse design

Create impulse

Retrain model

Live classification

Model testing

Versioning

Deployment

GETTING STARTED

Documentation

Forums

Time series data

Axes: audio

Window size: 1000 ms.

Window increase: 500 ms.

Zero-pad data:

Audio (MFCC)

Name: MFCC

Input axes:  audio

Neural Network (Keras)

Name: NN Classifier

Input features:  MFCC

Output features: 3 (iesti, silence, unifei)

Output features

3 (iesti, silence, unifei)

Save impulse

Add a processing block

Add a learning block

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MJRoBot (Marcelo Rova)



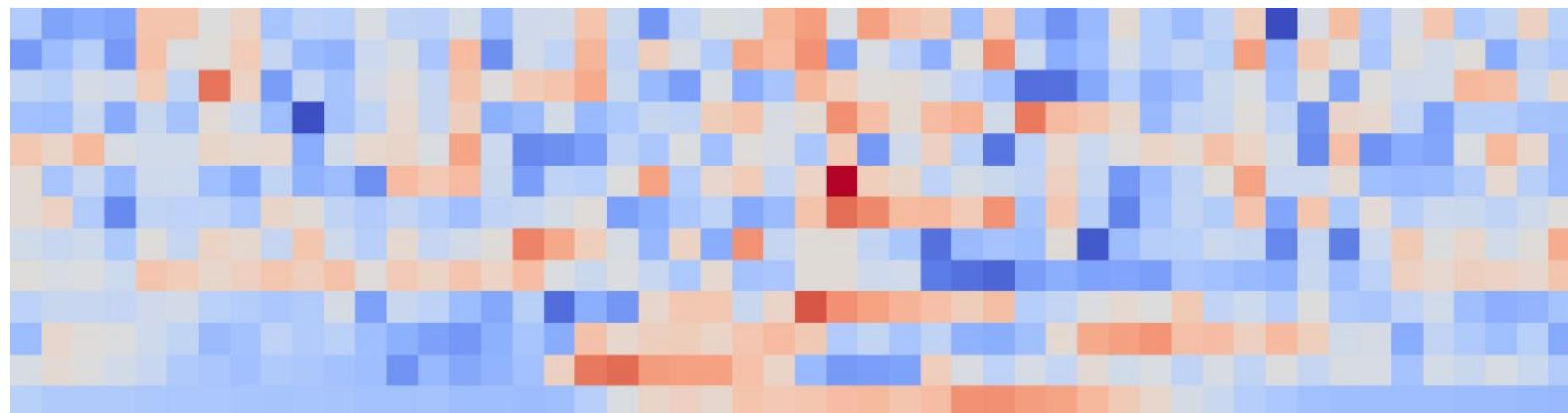
Raw data



1 second of Sound raw data



MFCC



Dim =  $13 \times 50$   
= 650

50 slots

MFCC - IESTI01\_Keyword\_Spot Ualrrior | UNIFEI

studio.edgeimpulse.com/studio/38744/dsp/mfcc/3/generate-features

**EDGE IMPULSE**

MFCC (IESTI01\_KEYWORD\_SPOTTING\_PROJECT)

Parameters Generate features

**Training set**

Data in training set 4m 37s

Classes 3 (iesti, silence, unifei)

Window length 1000 ms.

Window increase 500 ms.

Training windows 253

Generate features

**Feature generation output**

```
still running...
Sun Jul 4 17:29:51 2021 Construct embedding
completed 0 / 500 epochs
completed 50 / 500 epochs
completed 100 / 500 epochs
completed 150 / 500 epochs
completed 200 / 500 epochs
completed 250 / 500 epochs
completed 300 / 500 epochs
completed 350 / 500 epochs
completed 400 / 500 epochs
completed 450 / 500 epochs
Sun Jul 4 17:29:54 2021 Finished embedding
Reducing dimensions for visualizations OK
Job completed
```

**Feature explorer (253 samples)**

X Axis: Visualization layer 1, Y Axis: Visualization layer 2, Z Axis: Visualization layer 3

**On-device performance**

PROCESSING TIME 217 ms.

PEAK RAM USAGE 17 KB

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NN Classifier - IESTI01\_Keyword\_Spotting

studio.edgeimpulse.com/studio/38744/learning/keras/5

MJRoBot (Marcelo Rovai)

### NN CLASSIFIER (iesti01\_KEYWORD\_SPOTTING\_PROJECT)

#1 Click to set a description for this version

#### Neural Network settings

##### Training settings

Number of training cycles: 100

Learning rate: 0.005

Minimum confidence rating: 0.60

##### Audio training options

Data augmentation:

##### Neural network architecture

Architecture presets: 1D Convolutional (Default) 2D Convolutional

**Input layer (650 features)**

- Reshape layer (13 columns)
- 1D conv / pool layer (8 neurons, 3 kernel size, 1 layer)
- Dropout (rate 0.25)
- 1D conv / pool layer (16 neurons, 3 kernel size, 1 layer)
- Dropout (rate 0.25)
- Flatten layer
- Add an extra layer

**Output layer (3 features)**

**Start training**

#### Training output

Saving best performing model...  
 Converting TensorFlow Lite float32 model...  
 Converting TensorFlow Lite int8 quantized model with float32 input and output...  
 Converting TensorFlow Lite int8 quantized model with int8 input and output...  
 Calculating performance metrics...  
 Profiling float32 model...  
 Profiling float32 model (tflite)...  
 Profiling float32 model (EON)...  
 Profiling int8 model...  
 Profiling int8 model (tflite)...  
 Profiling int8 model (EON)...

Model training complete  
**Job completed**

#### Model

Model version: Quantized (int8)

##### Last training performance (validation set)

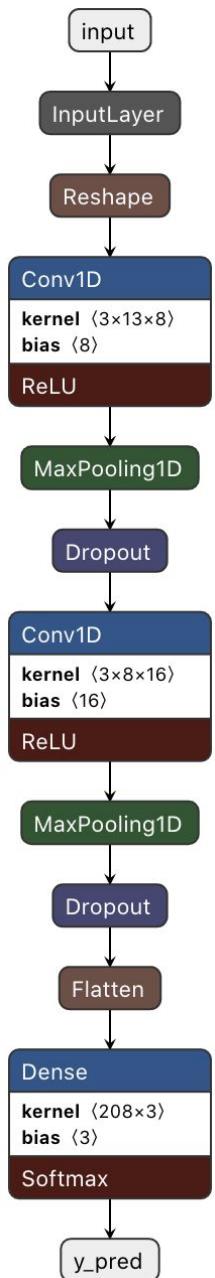
ACCURACY 100.0%	LOSS 0.02
--------------------	--------------

##### Confusion matrix (validation set)

	IESTI	SILENCE	UNIFEI
IESTI	100%	0%	0%
SILENCE	0%	100%	0%
UNIFEI	0%	0%	100%
F1 SCORE	1.00	1.00	1.00

##### Feature explorer (full training set)

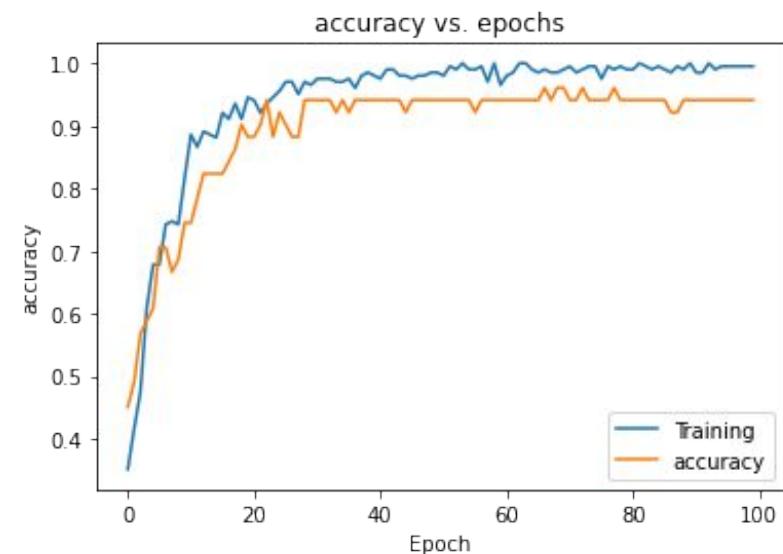
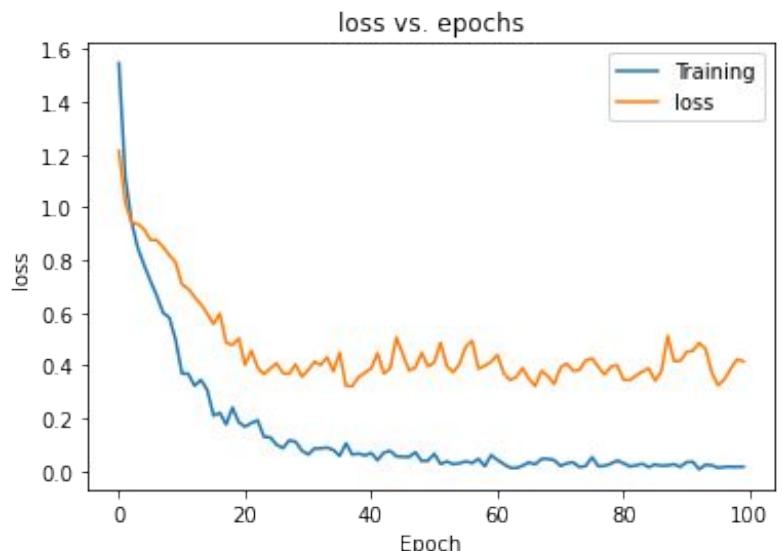
Legend:  
● iesti - correct  
● silence - correct  
● unifei - correct



Model: "sequential"

Layer (type)	Output Shape	Param #
reshape (Reshape)	(None, 50, 13)	0
conv1d (Conv1D)	(None, 50, 8)	320
max_pooling1d (MaxPooling1D)	(None, 25, 8)	0
dropout (Dropout)	(None, 25, 8)	0
conv1d_1 (Conv1D)	(None, 25, 16)	400
max_pooling1d_1 (MaxPooling1 (None, 13, 16)		0
dropout_1 (Dropout)	(None, 13, 16)	0
flatten (Flatten)	(None, 208)	0
y_pred (Dense)	(None, 3)	627

Total params: 1,347  
Trainable params: 1,347  
Non-trainable params: 0



Live classification - IESTI01\_Ke

studio.edgeimpulse.com/studio/38744/classification#load-sample-35698157

### EDGE IMPULSE

#### Classify new data

Device: nano  
Sensor: Built-in microphone  
Sample length (ms.): 10000  
Frequency: 16000Hz

[Start sampling](#)

#### Classify existing test sample

testing.29lu6v0r (iesti)

[Load sample](#)

#### Classification result

##### Summary

Name	testing.29lu6v0r
Expected outcome	silence
CATEGORY	COUNT
iesti	1
silence	16
unifei	1
uncertain	1

##### Detailed result

TIMESTAMP	TESTI	SILENCE	UNIFEI
0	0	1.00	0
500	0	1.00	0
1000	0	1.00	0
1500	0	1.00	0
2000	0.19	0.59	0.22
2500	0	1.00	0
3000	0.01	0.95	0.03

##### Raw DATA

testing.29lu6v0r (audio)

0:01 / 0:01

##### Raw features

```
1, 0, -2, -4, -6, -6, -4, 1, -1, -1, -1, 1, -1, -3, -2, -1, -1, -2, -2, 1, -1, -1, -1, -2, -3, -3, -2, -3, 2, 2, 2, 3, 2, 2, 2, 5, 7, -
```

##### MFCC (272 samples)

X Axis: Visualization layer 1  
Y Axis: Visualization layer 2  
Z Axis: Visualization layer 3

classified  
iesti  
silence  
unifei  
classification 4

##### Processed features

```
1.1280, -0.0686, -0.0853, 1.2996, 0.1440, -1.0248, -0.3983, -0.7610, -1.0223, -0.1558, 0.1156, -0.5995, 0.0343, 0.9696, 0.6107, 0.4964, 0.9162, -
```

Model testing - IESTI01\_Keywo

studio.edgeimpulse.com/studio/38744/validation

**EDGE IMPULSE**

**MODEL TESTING (IESTI01\_KEYWORD\_SPOTTING\_PROJECT)**

This lists all test data. You can manage this data through Data acquisition.

**Test data**

Set the 'expected outcome' for each sample to the desired outcome to automatically score the impulse.

SAMPLE NAME	EXPECTED OUTCOME	LENGTH	ACCURACY	RESULT
testing.29lufkik	silence	10s	84%	16 silence, 1 iesti, 1 unifei, 1 unc...
testing.29lu6v0r	iesti	10s	52%	10 iesti, 4 silence, 3 unifei, 2 unc...
testing.29lu1guk	unifei	10s	57%	11 unifei, 3 iesti, 3 silence, 2 unc...
silence.29lspi7j.s10	silence	1s	100%	1 silence
silence.29lspi7j.s9	silence	1s	100%	1 silence
silence.29lspi7j.s8	silence	1s	100%	1 silence
silence.29lspi7j.s7	silence	1s	100%	1 silence
silence.29lspi7j.s6	silence	1s	100%	1 silence
silence.29lspi7j.s5	silence	1s	100%	1 silence
silence.29lspi7j.s4	silence	1s	100%	1 silence
silence.29lspi7j.s3	silence	1s	100%	1 silence
silence.29lspi7j.s2	silence	1s	100%	1 silence
silence.29lspi7j.s1	silence	1s	100%	1 silence
silence.29lt4rkv.s9	silence	1s	100%	1 silence
silence.29lt4rkv.s8	silence	1s	100%	1 silence
silence.29lt4rkv.s7	silence	1s	100%	1 silence
silence.29lt4rkv.s6	silence	1s	100%	1 silence

**Model testing output**

Created features  
Generating features for MFCC OK  
Classifying data for NN Classifier...  
Copying features from DSP block...  
Copying features from DSP block OK  
Classifying data for float32 model...  
Scheduling job in cluster...  
Job started  
Classifying data for NN Classifier OK

**Job completed**

**Model testing results**

ACCURACY **80.56%**

	IESTI	SILENCE	UNIFEI	UNCERTAIN
IESTI	69.7%	12.1%	12.1%	6.1%
SILENCE	2.6%	92.1%	2.6%	2.6%
UNIFEI	8.1%	8.1%	78.4%	5.4%

**Feature explorer**

Legend:

- iesti - correct
- silence - correct
- unifei - correct
- iesti - incorrect
- silence - incorrect
- unifei - incorrect

Deployment - IESTI01\_Keyword

studio.edgeimpulse.com/studio/38744/deployment

## EDGE IMPULSE

- Dashboard
- Devices
- Data acquisition
- Impulse design
  - Create impulse
  - MFCC
  - NN Classifier
- Retrain model
- Live classification
- Model testing
- Versioning
- Deployment

### GETTING STARTED

- Documentation
- Forums



Eta Compute ECM3532 AI Vision



SiLabs Thunderboard Sense 2



Himax WE-i Plus


Nordic nRF52840 DK + IKS02A1



Nordic nRF5340 DK + IKS02A1



Sony's Spresense


Linux boards

**Select optimizations (optional)**

Model optimizations can increase on-device performance but may reduce accuracy. Click below to analyze optimizations and see the recommended choices for your target. Or, just click Build to use the currently selected options.

**Enable EON™ Compiler** Same accuracy, up to 50% less memory. Open source.

Available optimizations for NN Classifier													
<b>Quantized (int8) ★</b> <input checked="" type="button"/> Currently selected This optimization is recommended for best performance.	RAM USAGE <b>4.4K</b> FLASH USAGE <b>30.2K</b> LATENCY <b>4 ms</b> ACCURACY <b>81.48%</b>												
CONFUSION MATRIX <table border="1"> <tr> <td>69.7</td> <td>12.1</td> <td>12.1</td> <td>6.1</td> </tr> <tr> <td>2.6</td> <td><b>94.7</b></td> <td>2.6</td> <td>0</td> </tr> <tr> <td>8.1</td> <td>8.1</td> <td><b>78.4</b></td> <td>5.4</td> </tr> </table>		69.7	12.1	12.1	6.1	2.6	<b>94.7</b>	2.6	0	8.1	8.1	<b>78.4</b>	5.4
69.7	12.1	12.1	6.1										
2.6	<b>94.7</b>	2.6	0										
8.1	8.1	<b>78.4</b>	5.4										
<b>Unoptimized (float32)</b> <input type="button"/> Click to select	RAM USAGE <b>8.0K</b> FLASH USAGE <b>33.2K</b> LATENCY <b>18 ms</b> ACCURACY <b>80.56%</b>												
CONFUSION MATRIX <table border="1"> <tr> <td>69.7</td> <td>12.1</td> <td>12.1</td> <td>6.1</td> </tr> <tr> <td>2.6</td> <td><b>92.1</b></td> <td>2.6</td> <td>2.6</td> </tr> <tr> <td>8.1</td> <td>8.1</td> <td><b>78.4</b></td> <td>5.4</td> </tr> </table>		69.7	12.1	12.1	6.1	2.6	<b>92.1</b>	2.6	2.6	8.1	8.1	<b>78.4</b>	5.4
69.7	12.1	12.1	6.1										
2.6	<b>92.1</b>	2.6	2.6										
8.1	8.1	<b>78.4</b>	5.4										

Estimate for Cortex-M4F 80MHz (ST IoT Discovery Kit)

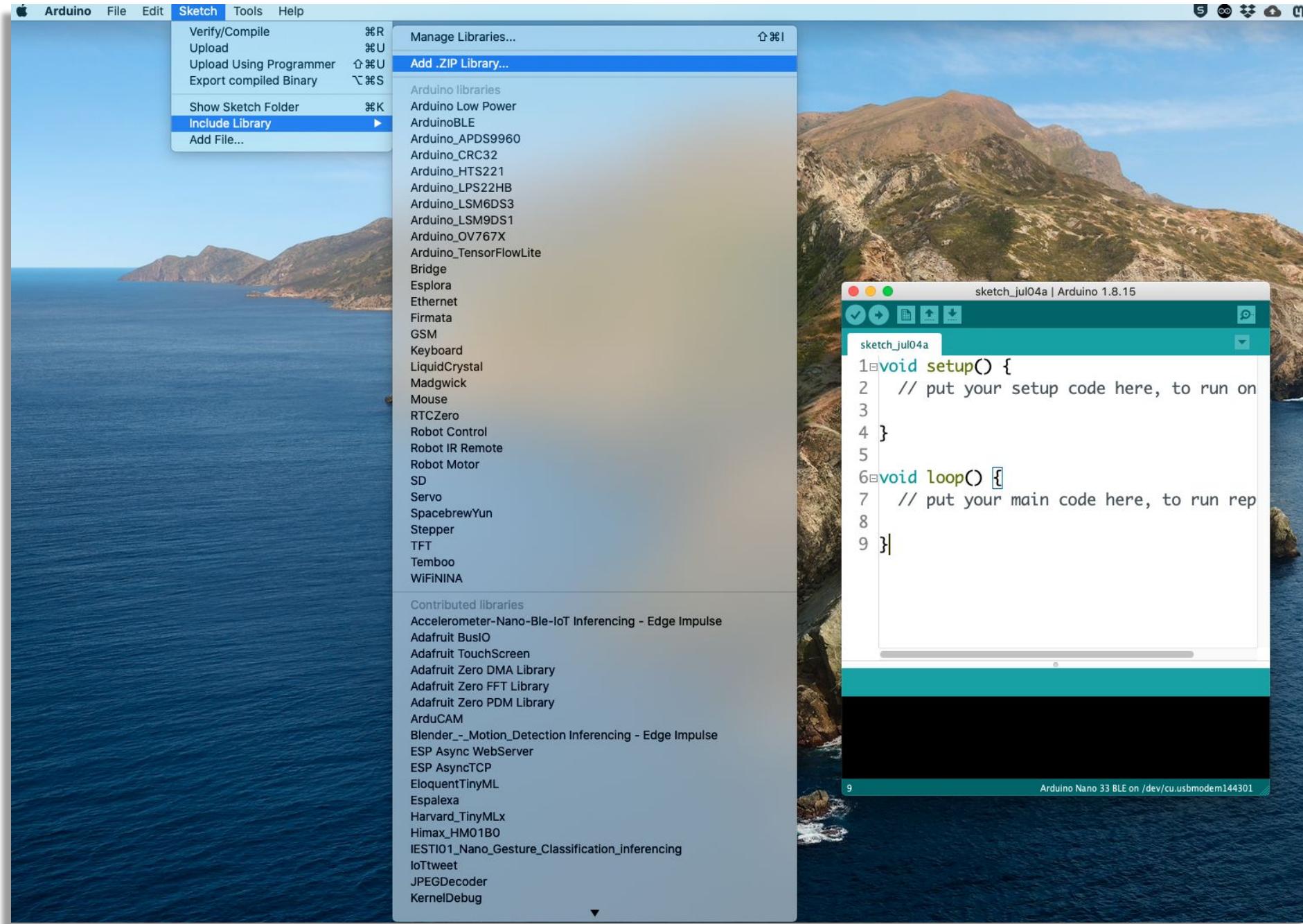
**Build**

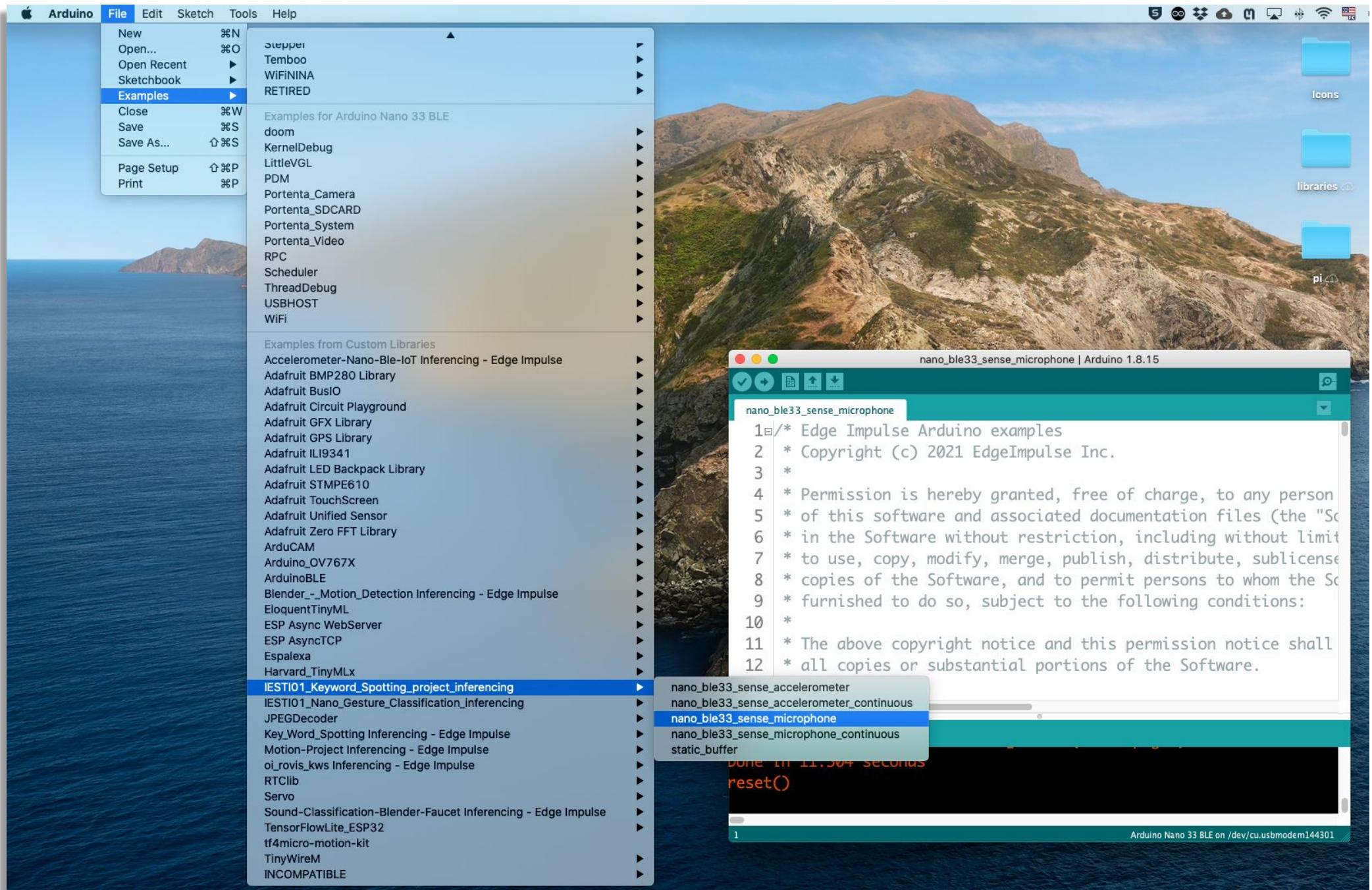
**Build output**

```

Creating job... OK (ID: 1051368)
Generating features for MFCC...
Not generating new features: features already generated and no options or files have changed.
Generating features for MFCC OK

Classifying data for NN Classifier...
Copying features from DSP block...
Copying features from DSP block OK
Classifying data for float32 model...
Classifying data for int8 model...
Scheduling job in cluster...
Scheduling job in cluster...
Job started
Job started
Job completed
  
```

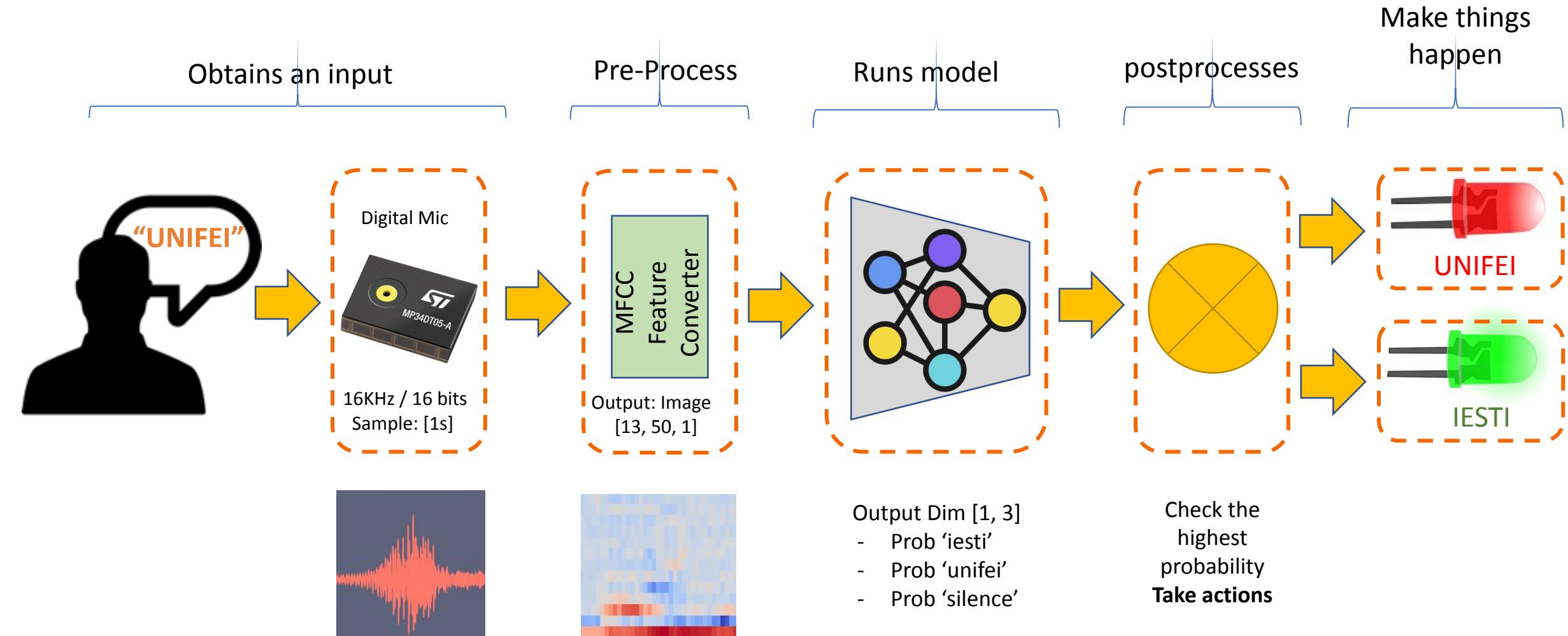




```
Starting inferencing in 2 seconds...
Recording...
Recording done
Predictions (DSP: 201 ms., Classification: 6 ms., Anomaly: 0 ms.):
  iesti: 0.00000
  silence: 0.99609
  unifei: 0.00000
Starting inferencing in 2 seconds...
Recording...
Recording done
Predictions (DSP: 201 ms., Classification: 6 ms., Anomaly: 0 ms.):
  iesti: 0.00391
  silence: 0.01562
  unifei: 0.98047
Starting inferencing in 2 seconds...
```

Autoscroll  Show timestamp Both NL & CR 115200 baud Clear output

# KeyWord Spotting (KWS) - Inference



Project Video: <https://youtu.be/XnFYz-RSNe8>

```
nano_ble33_sense_microphone_leds | Arduino 1.8.15

42 /**
43  * @brief      Arduino setup function
44 */
45 void setup()
46{
47     Serial.begin(115200);
48     while (!Serial);
49
50     Serial.println("IESTI01 - KWS Project");
51     // Pins for the built-in RGB LEDs on the Arduino Nano 33 BLE Sense
52     pinMode(LED_R, OUTPUT);
53     pinMode(LED_G, OUTPUT);
54     pinMode(LED_B, OUTPUT);
55
56     // Ensure the LED is off by default.
57     // Note: The RGB LEDs on the Arduino Nano 33 BLE
58     // Sense are on when the pin is LOW, off when HIGH.
59     digitalWrite(LED_R, HIGH);
60     digitalWrite(LED_G, HIGH);
61     digitalWrite(LED_B, HIGH);
62
63     // summary of inferencing settings (from model_metadata.h)
64     ei_printf("Inferencing settings:\n");
65     ei_printf("\tInterval: %.2f ms.\n", (float)EI_CLASSIFIER_INTERVAL_MS);
66     ei_printf("\tFrame size: %d\n", EI_CLASSIFIER_DSP_INPUT_FRAME_SIZE);
67     ei_printf("\tSample length: %d ms.\n", EI_CLASSIFIER_RAW_SAMPLE_COUNT / 16);
68     ei_printf("\tNo. of classes: %d\n", sizeof(ei_classifier_inferencing_categories) / sizeof(ei_class
69
70     if (microphone_inference_start(EI_CLASSIFIER_RAW_SAMPLE_COUNT) == false) {
71         ei_printf("ERR: Failed to setup audio sampling\r\n");
72         return;
73     }
74 }
```

Done uploading.

```
[=====] 98% (70/71 pages)write(addr=0x34,size=0x1000)
writeBuffer(scr_addr=0x34, dst_addr=0x46000, size=0x1000)
[=====] 100% (71/71 pages)
```

```
77 */
78 * @brief      Special Postprocess function for RGB LEDs
79 */
80
81 void turn_off_leds(){
82     digitalWrite(LED_R, HIGH);
83     digitalWrite(LED_G, HIGH);
84     digitalWrite(LED_B, HIGH);
85 }
86
87 /*
88 * iesti: [0] ==> Green ON
89 * Silence: [1] ==> All OFF
90 * unifei: [2] ==> Red ON
91 */
92
93 void turn_on_leds(int pred_index) {
94     switch (pred_index)
95     {
96     case 0:
97         turn_off_leds();
98         digitalWrite(LED_G, LOW);
99         break;
100
101    case 1:
102        turn_off_leds();
103        break;
104
105    case 2:
106        turn_off_leds();
107        digitalWrite(LED_R, LOW);
108        break;
109    }
110 }
111
```

Done uploading.

```
[=====] 98% (70/71 pages)write(addr=0x34, size=0x1000)
writeBuffer(scr_addr=0x34, dst_addr=0x46000, size=0x1000)
[=====] 100% (71/71 pages)
```

nano\_ble33\_sense\_microphone\_leds | Arduino 1.8.15

```
112 void Loop()
113 {
114     ei_printf("Starting inferencing in 2 seconds...\n");
115     delay(2000);
116     ei_printf("Recording...\n");
117
118     bool m = microphone_inference_record();
119     if (!m) {
120
121         ei_printf("Recording done\n");
122
123         signal_t signal;
124         signal.total_length = EI_CLASSIFIER_RAW_SAMPLE_COUNT;
125         signal.get_data = &microphone_audio_signal_get_data;
126         ei_impulse_result_t result = { 0 };
127
128         EI_IMPULSE_ERROR r = run_classifier(&signal, &result, debug_nn);
129         if (r != EI_IMPULSE_OK) {
130
131             // print the predictions
132             ei_printf("Predictions ");
133             ei_printf("(DSP: %d ms., Classification: %d ms., Anomaly: %d ms.)",
134                     result.timing.dsp, result.timing.classification, result.timing.anomaly);
135             ei_printf(": \n");
136
137             int pred_index = 0;      // Initialize pred_index
138             float pred_value = 0;    // Initialize pred_value
139
140             for (size_t ix = 0; ix < EI_CLASSIFIER_LABEL_COUNT; ix++) {
141                 // ei_printf("%s: %.5f\n", result.classification[ix].label, result.classification[ix].value);
142                 if (result.classification[ix].value > pred_value){
143                     pred_index = ix;
144                     pred_value = result.classification[ix].value;
145                 }
146             }
147             ei_printf(": \n");
148             ei_printf(" PREDICTION: ==> %s with probability %.2f\n",
149                     result.classification[pred_index].label, pred_value);
150             ei_printf(": \n");
151             turn_on_leds (pred_index);
152
153         }
154     }
155 }
```

Done uploading.

```
[=====] 98% (70/71 pages)write(addr=0x34,size=0x1000)
writeBuffer(scr_addr=0x34, dst_addr=0x46000, size=0x1000)
[=====] 100% (71/71 pages)
```

115 Arduino Nano 33 BLE on /dev/cu.usbmodem144301

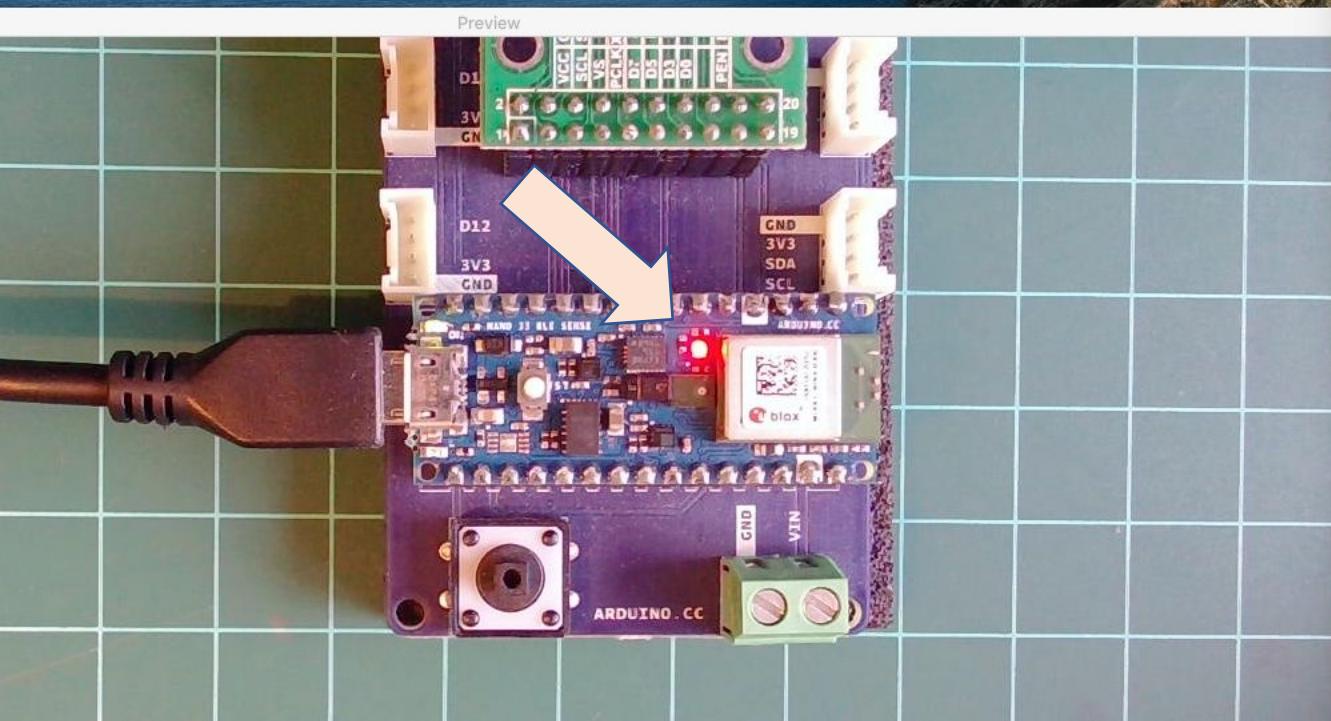
Recording...  
 Recording done  
 Predictions (DSP: 195 ms., Classification: 6 ms., Anomaly: 0 ms.):  
 :  
 PREDICTION: ==> silence with probability 1.00  
 :  
 Starting inferencing in 2 seconds...  
 Recording...  
 Recording done  
 Predictions (DSP: 195 ms., Classification: 6 ms., Anomaly: 0 ms.):  
 :  
 PREDICTION: ==> unifei with probability 0.92  
 :  
 Starting inferencing in 2 seconds...

 Autoscroll  Show timestamp

Both NL &amp; CR

115200 baud

Clear output



nano\_ble33\_sense\_microphone\_leds | Arduino 1.8.15

```

130 signal.get_data = &microphone_audio_signal_get_data;
131 ei_impulse_result_t result = { 0 };
132
133 EI_IMPULSE_ERROR r = run_classifier(&signal, &result, debug_nn);
134 if (r != EI_IMPULSE_OK) {
135   ei_printf("ERR: Failed to run classifier (%d)\n", r);
136   return;
137 }
138
139 // print the predictions
140 ei_printf("Predictions ");
141 ei_printf("(DSP: %d ms., Classification: %d ms., Anomaly: %d ms.)",
142   result.timing.dsp, result.timing.classification, result.timing.anoma
143 ei_printf(": \n");
144
145 int pred_index = 0;      // Initialize pred_index
146 float pred_value = 0;    // Initialize pred_value
147
148 for (size_t ix = 0; ix < EI_CLASSIFIER_LABEL_COUNT; ix++) {
149   // ei_printf("  %s: %.5f\n", result.classification[ix].label, resu
150   if (result.classification[ix].value > pred_value){
151     pred_index = ix;
152     pred_value = result.classification[ix].value;
153   }
154 }
155 ei_printf(": \n");
156 ei_printf("  PREDICTION: ==> %s with probability %.2f\n",
157   result.classification[pred_index].label, pred_value);
158 ei_printf(": \n");
159 turn_on_leds (pred_index);
160

```

Done uploading.

```

[=====] 98% (70/71 pages)write(addr=0x34, size=0x1000)
writeBuffer(scr_addr=0x34, dst_addr=0x46000, size=0x1000)
[=====] 100% (71/71 pages)
Done in 11.279 seconds
reset()

```

157

Arduino Nano 33 BLE on /dev/cu.usbmodem144301

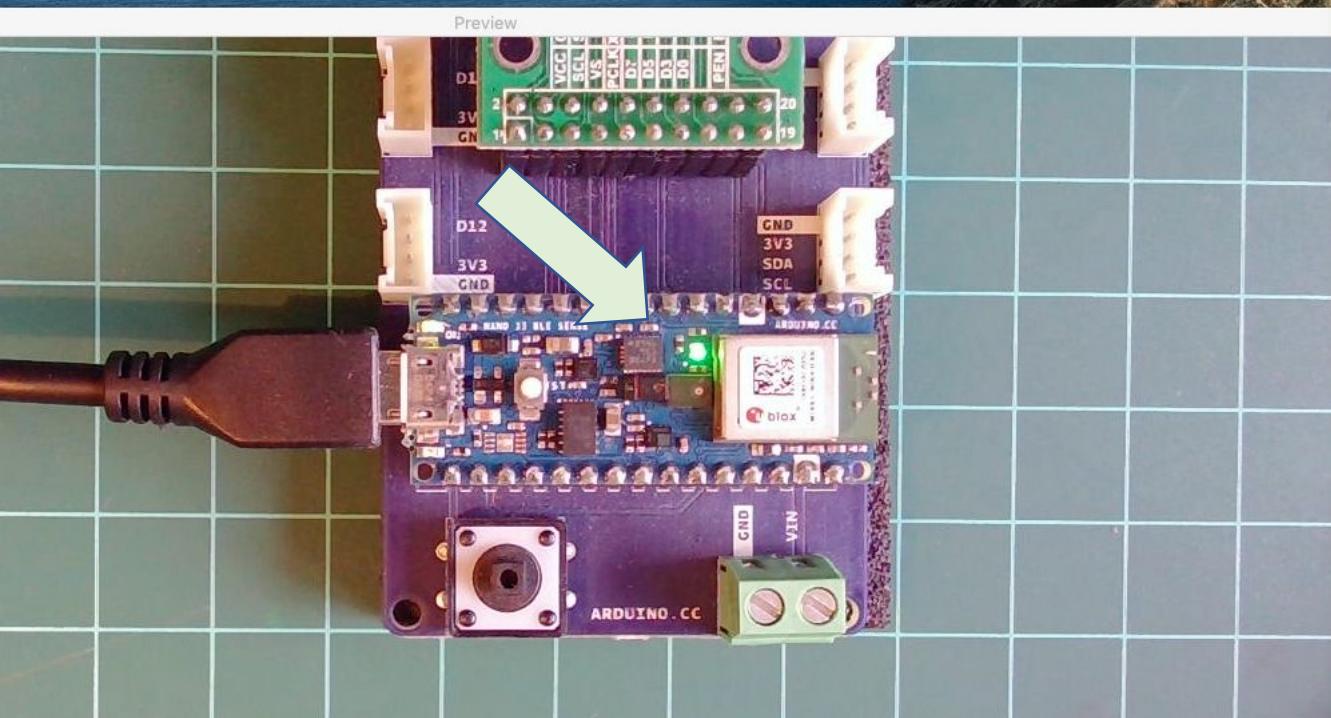
Recording...  
 Recording done  
 Predictions (DSP: 196 ms., Classification: 7 ms., Anomaly: 0 ms.):  
 :  
 PREDICTION: ==> silence with probability 1.00  
 :  
 Starting inferencing in 2 seconds...  
 Recording...  
 Recording done  
 Predictions (DSP: 195 ms., Classification: 6 ms., Anomaly: 0 ms.):  
 :  
 PREDICTION: ==> iesti with probability 0.82  
 :  
 Starting inferencing in 2 seconds...

 Autoscroll  Show timestamp

Both NL &amp; CR

115200 baud

Clear output



```
nano_ble33_sense_microphone_leds | Arduino 1.8.15

130 signal.get_data = &microphone_audio_signal_get_data;
131 ei_impulse_result_t result = { 0 };
132
133 EI_IMPULSE_ERROR r = run_classifier(&signal, &result, debug_nn);
134 if (r != EI_IMPULSE_OK) {
135   ei_printf("ERR: Failed to run classifier (%d)\n", r);
136   return;
137 }
138
139 // print the predictions
140 ei_printf("Predictions ");
141 ei_printf("(DSP: %d ms., Classification: %d ms., Anomaly: %d ms.)",
142   result.timing.dsp, result.timing.classification, result.timing.anoma
143 ei_printf(": \n");
144
145 int pred_index = 0;      // Initialize pred_index
146 float pred_value = 0;    // Initialize pred_value
147
148 for (size_t ix = 0; ix < EI_CLASSIFIER_LABEL_COUNT; ix++) {
149   // ei_printf("%s: %.5f\n", result.classification[ix].label, resu
150   if (result.classification[ix].value > pred_value){
151     pred_index = ix;
152     pred_value = result.classification[ix].value;
153   }
154 }
155 ei_printf(": \n");
156 ei_printf(" PREDICTION: ==> %s with probability %.2f\n",
157   result.classification[pred_index].label, pred_value);
158 ei_printf(": \n");
159 turn_on_leds (pred_index);

Done uploading.
[=====] 98% (70/71 pages)write(addr=0x34, size=0x1000)
writeBuffer(scr_addr=0x34, dst_addr=0x46000, size=0x1000)
[=====] 100% (71/71 pages)
Done in 11.279 seconds
reset()
```

# KWS Classifier Project

## Looking “Under the hood”



ei-iesti01\_keyword\_spotting\_project-nn-classifier.ipynb

# Reading Material

# Main references

- [Harvard School of Engineering and Applied Sciences - CS249r: Tiny Machine Learning](#)
- [Professional Certificate in Tiny Machine Learning \(TinyML\) – edX/Harvard](#)
- [Introduction to Embedded Machine Learning - Coursera/Edge Impulse](#)
- [Computer Vision with Embedded Machine Learning - Coursera/Edge Impulse](#)
- Fundamentals textbook: “[Deep Learning with Python](#)” by François Chollet
- Applications & Deploy textbook: “[TinyML](#)” by Pete Warden, Daniel Situnayake
- Deploy textbook “[TinyML Cookbook](#)” by Gian Marco Iodice

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Thanks



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