

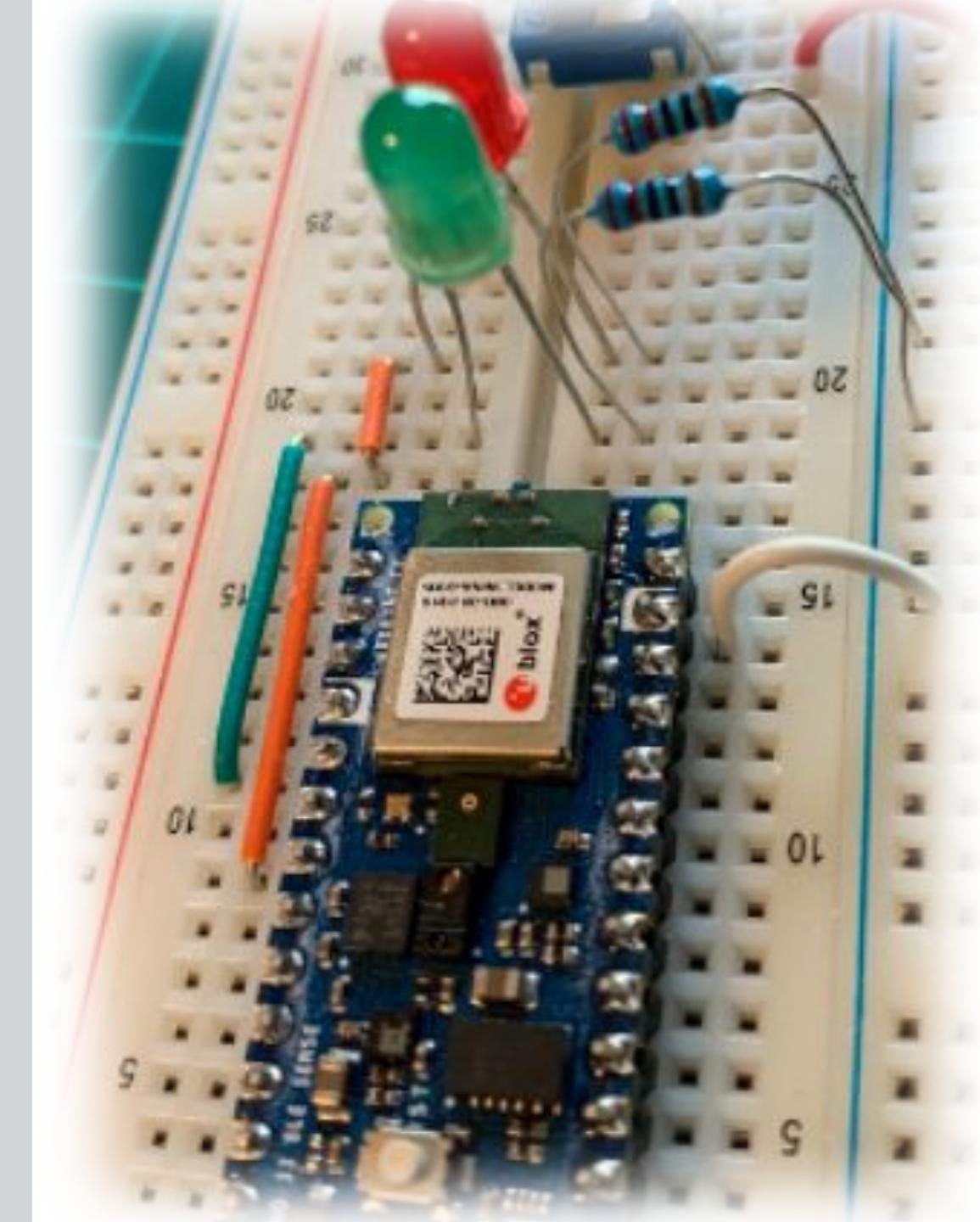
IESTI01 – TinyML

Embedded Machine Learning

22. Anomaly Detection



Prof. Marcelo Rovai
UNIFEI

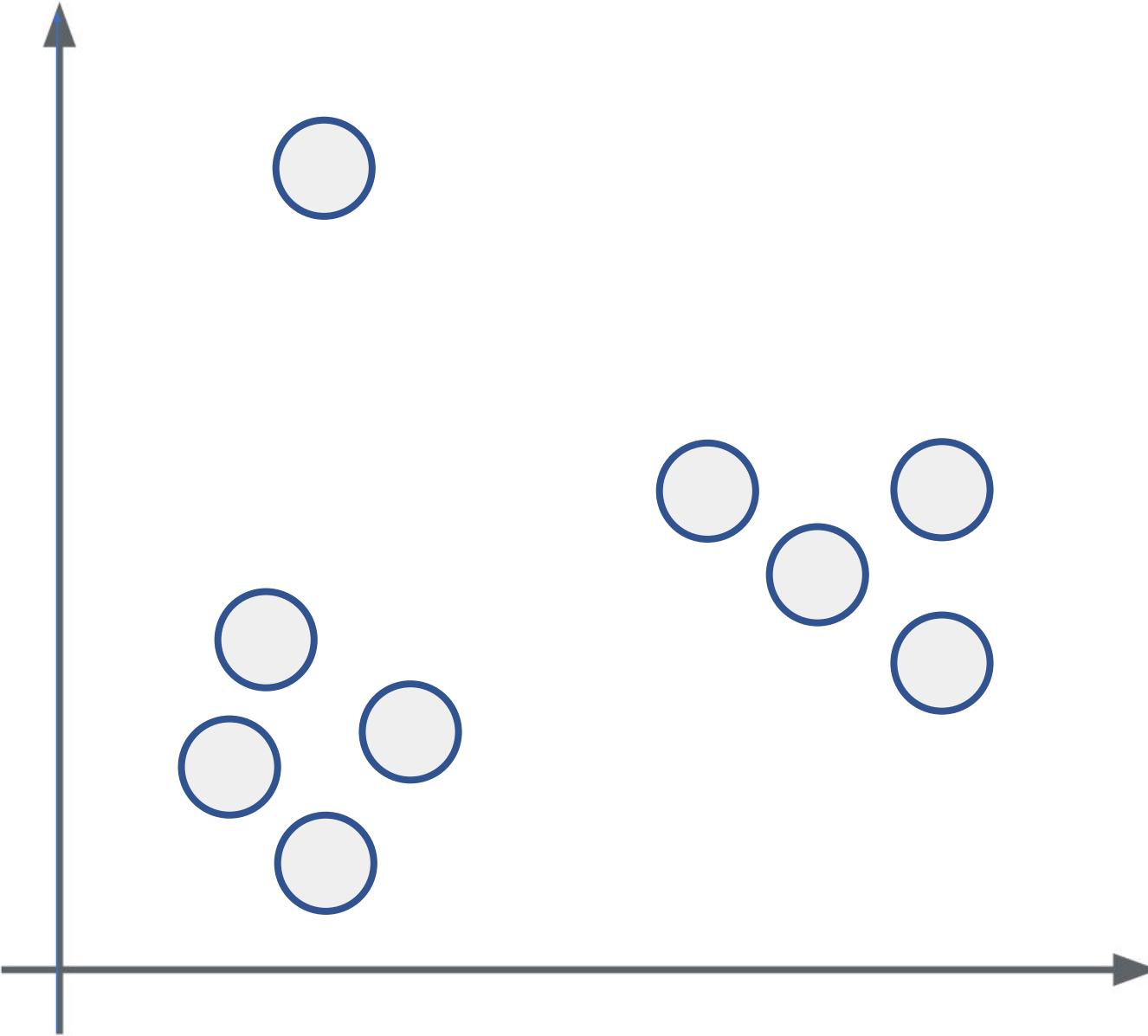


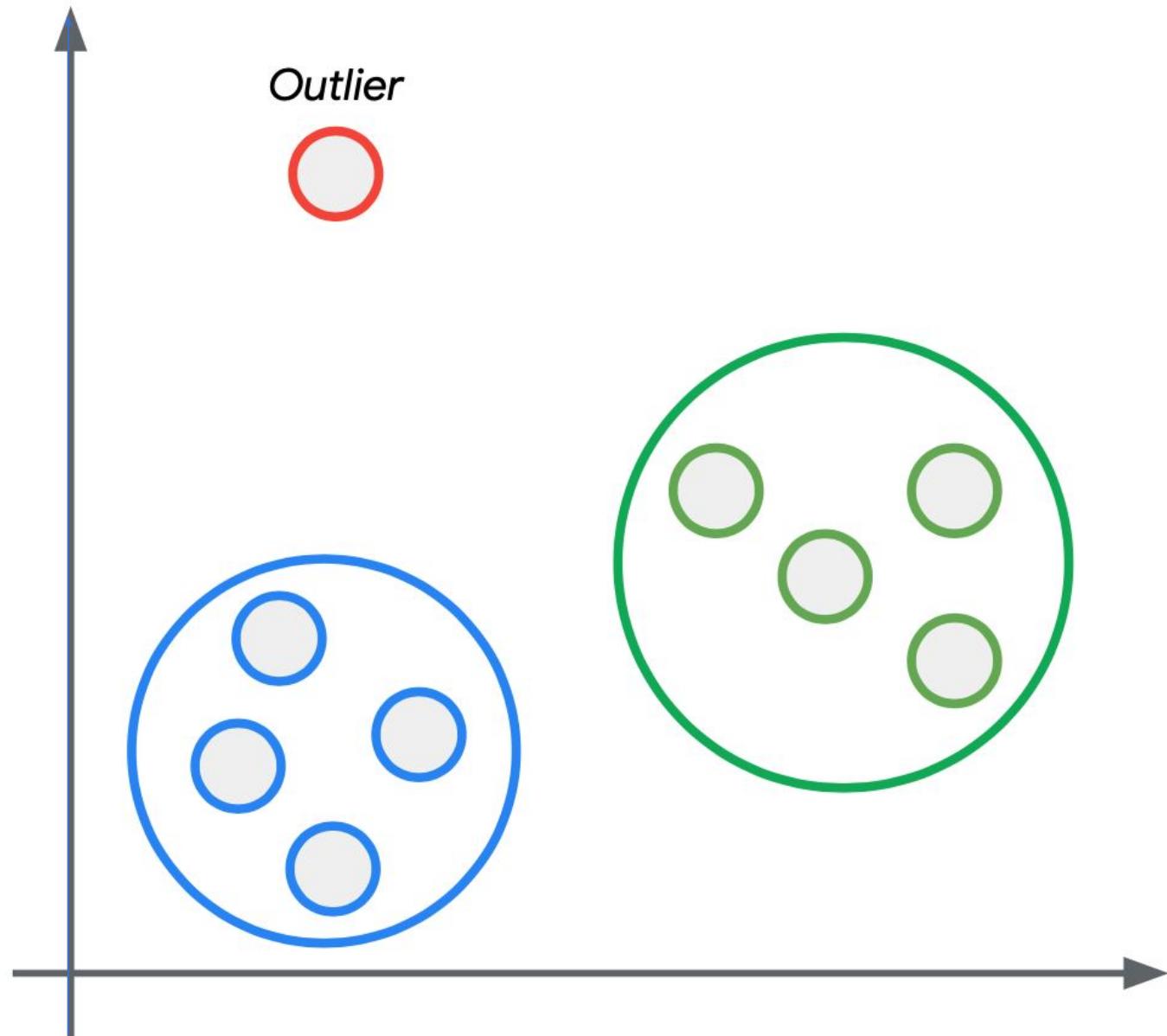
Anomaly Detection



What is Anomaly Detection?

In **data analysis**, **anomaly detection** is the **identification of rare items, events or observations which raise suspicions because they differing significantly from the **majority of the data**.**

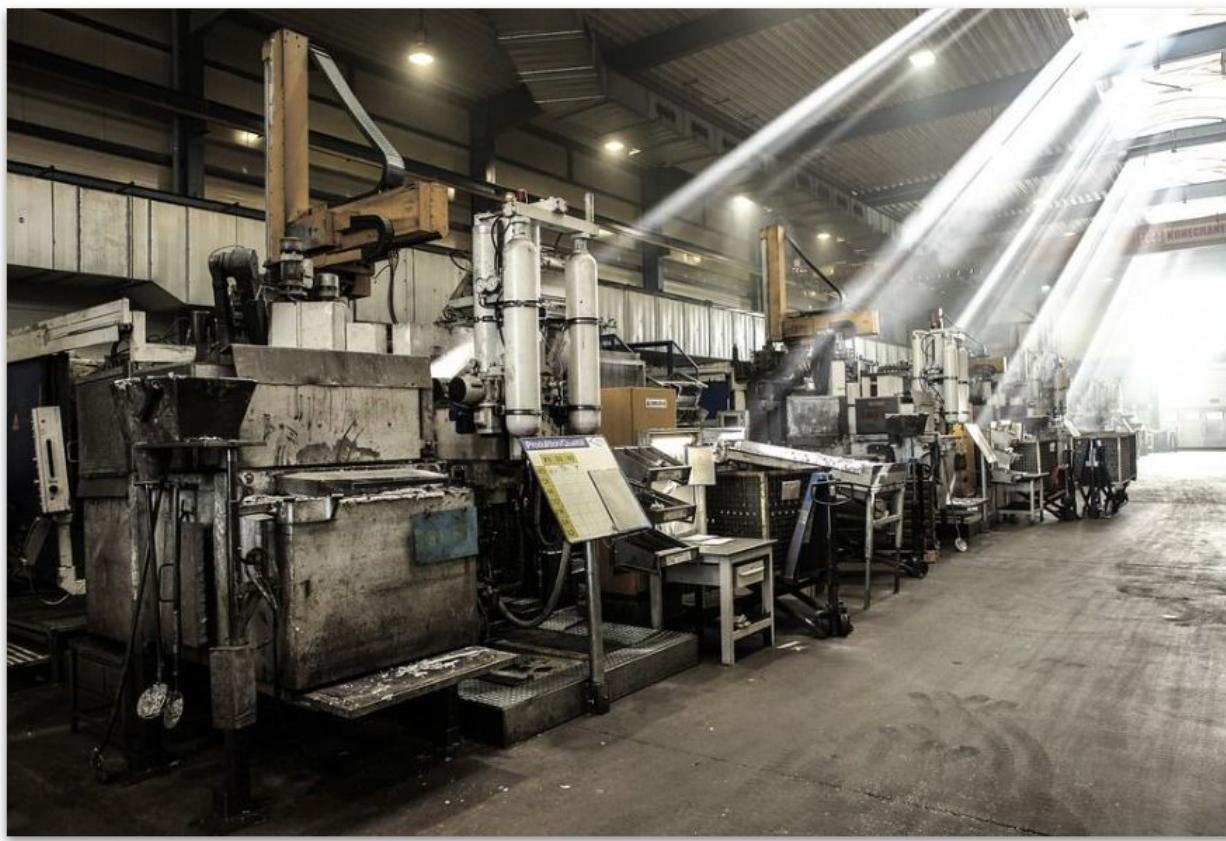




Application: Factory machinery



Application: Factory machinery

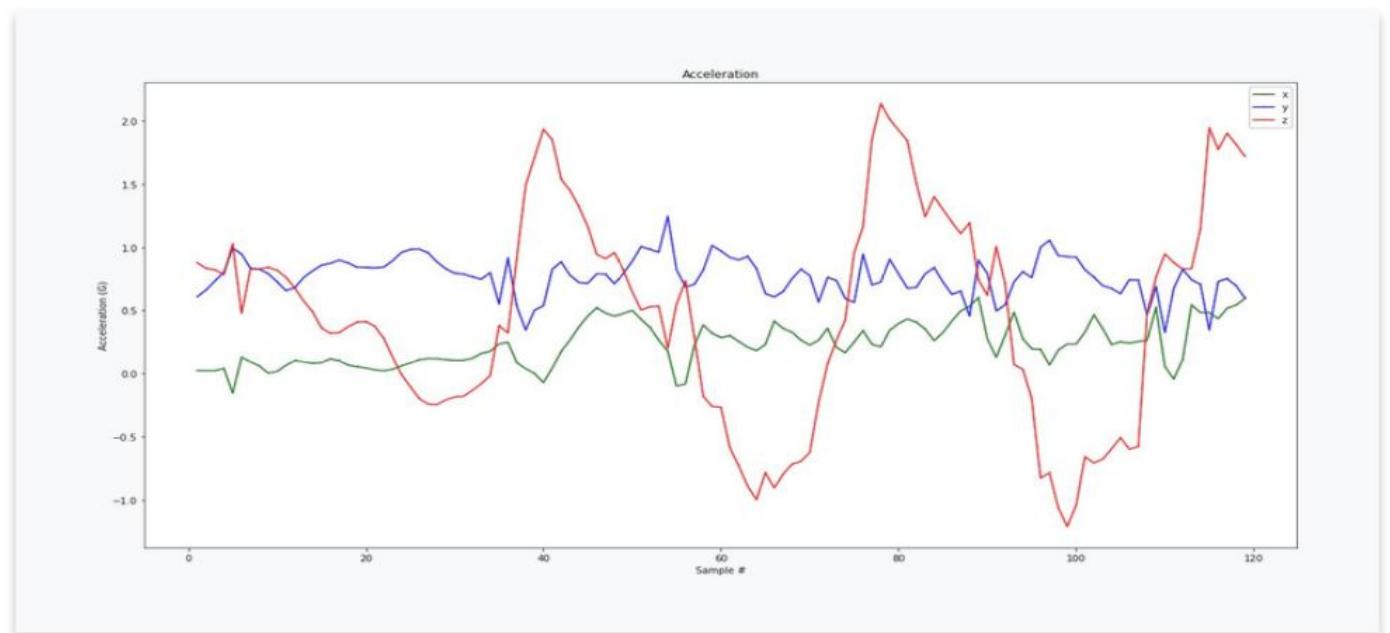
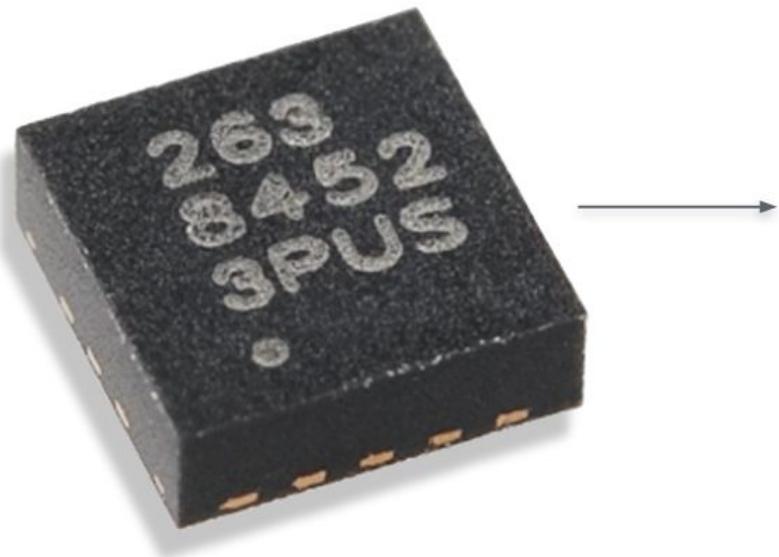


Ball Bearings



Accelerometer

Sensor: Accelerometer



Sensor: Accelerometer

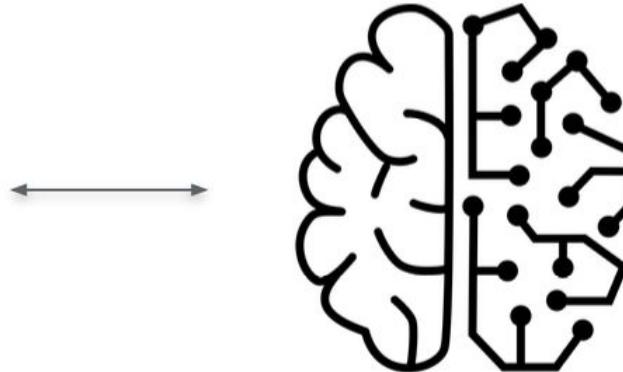
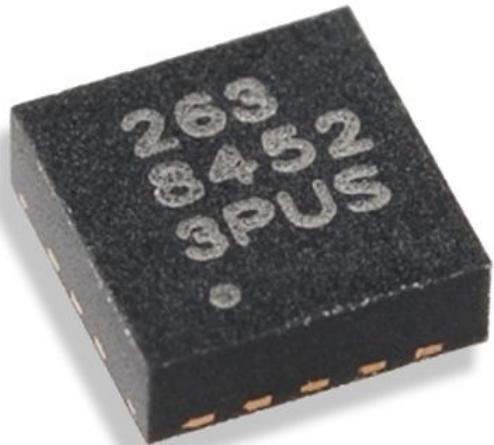


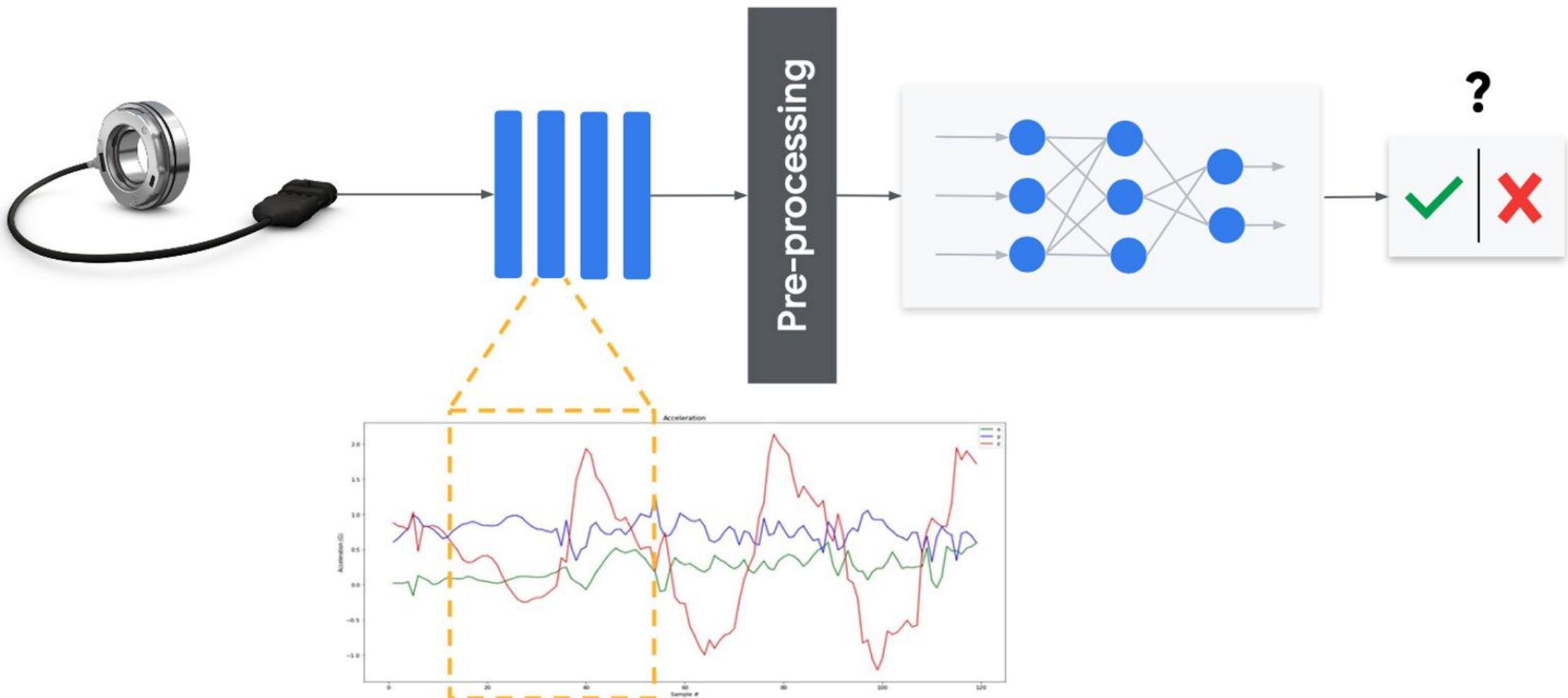
$$2 \text{ bytes} \times 8 \times 20\text{kHz} = 320 \text{ KB / sec}$$

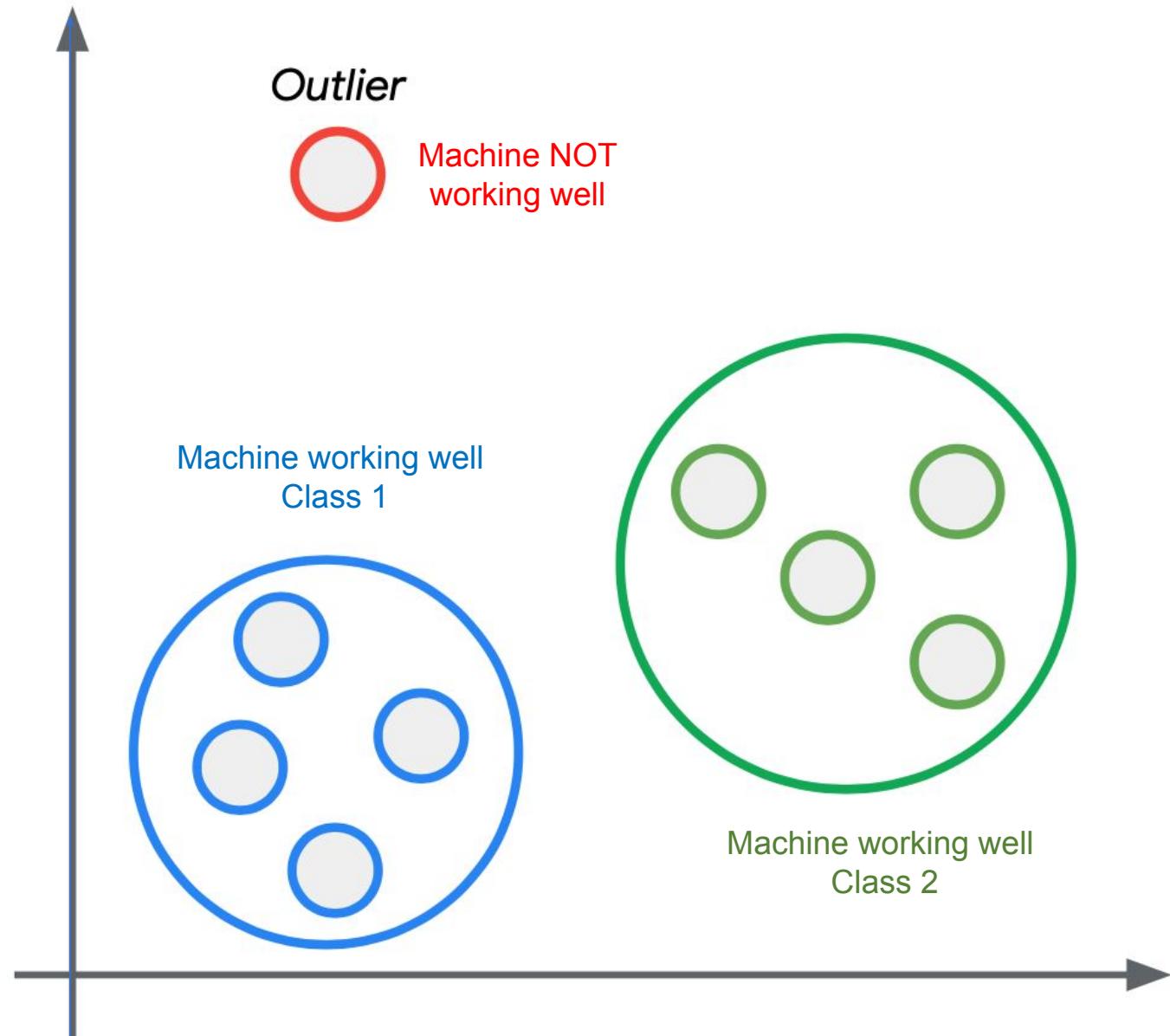
Measurement | Sample Rate
 # Sensors

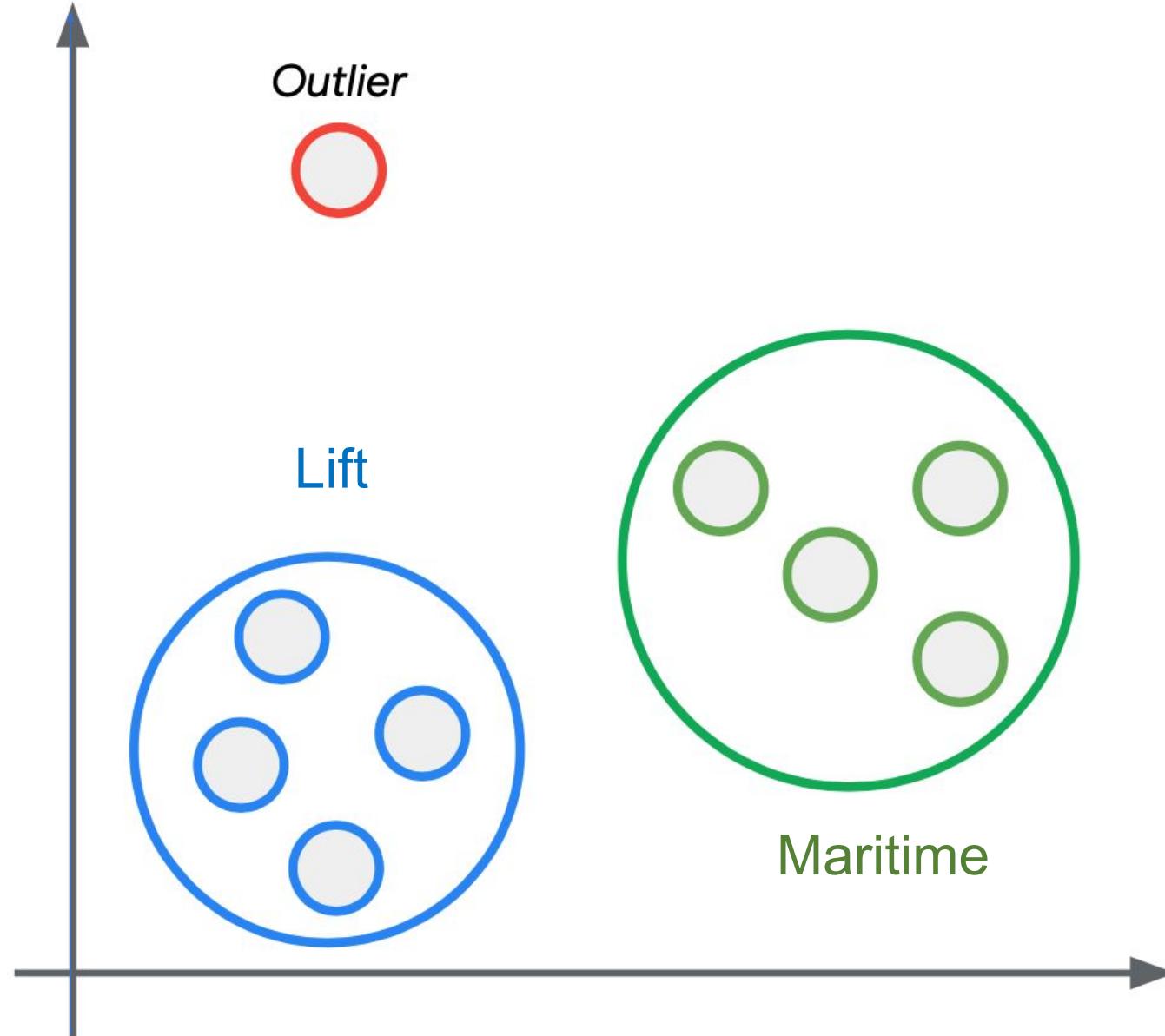
It's too expensive to stream to the cloud

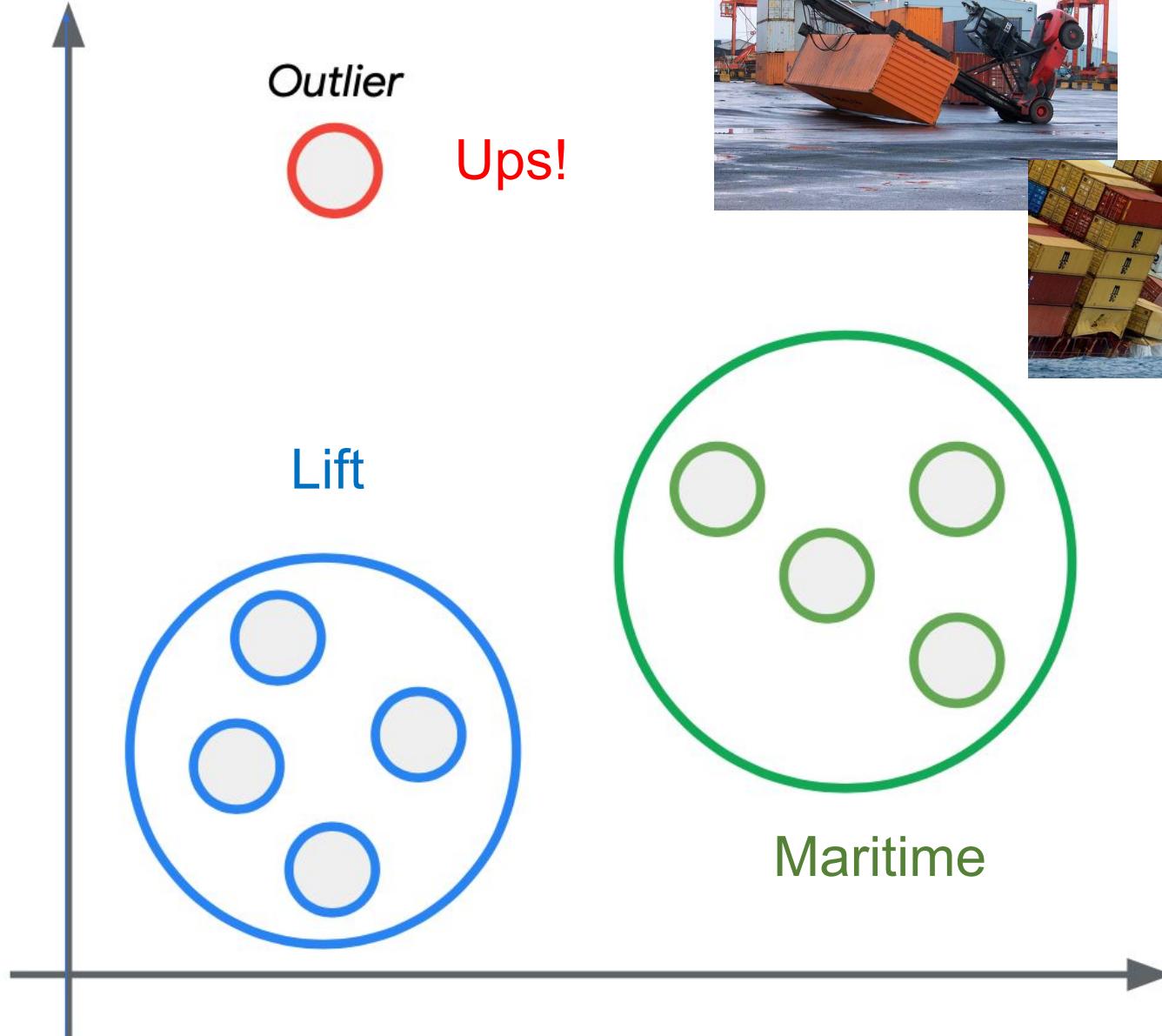
Need “intelligence”
close to sensors



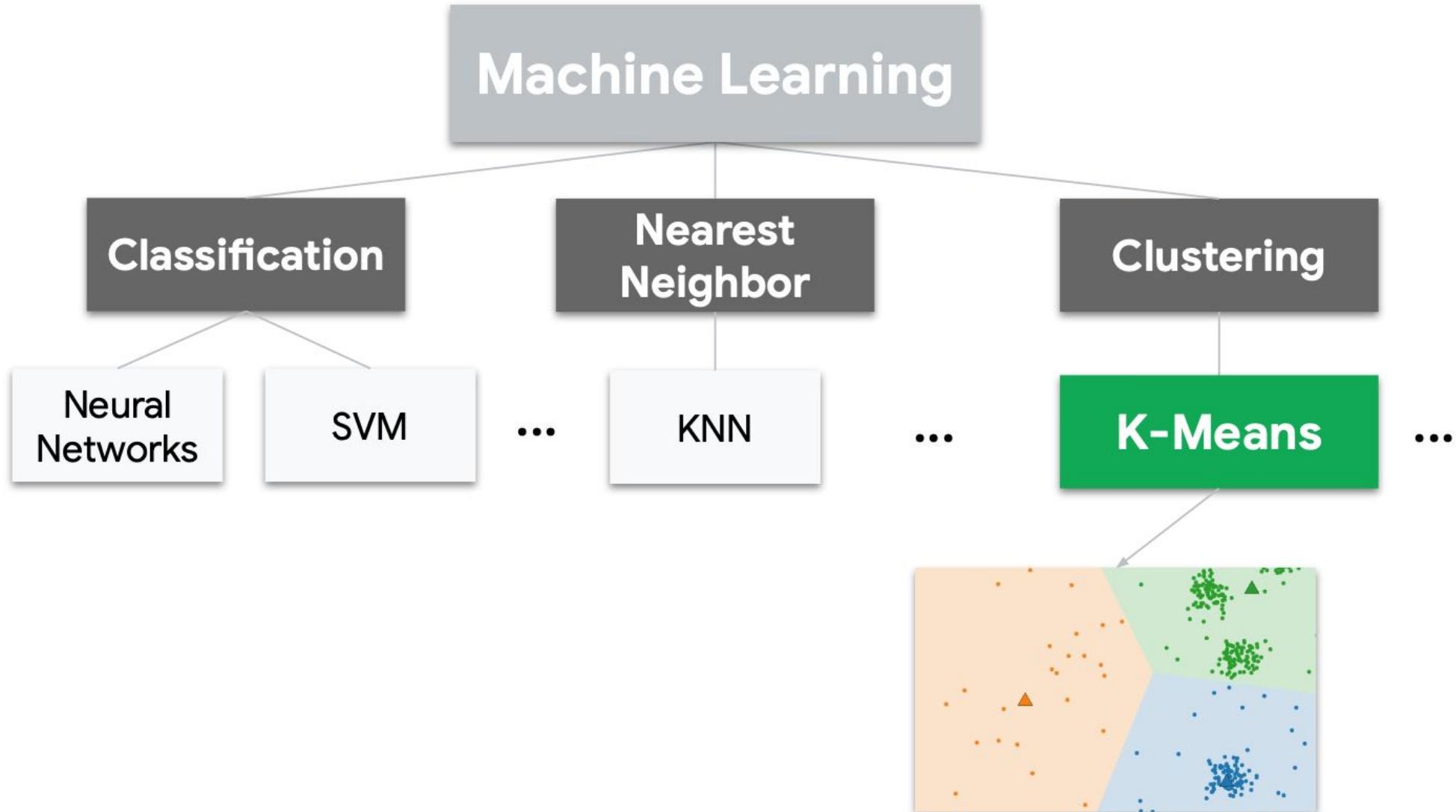








It's not all deep learning

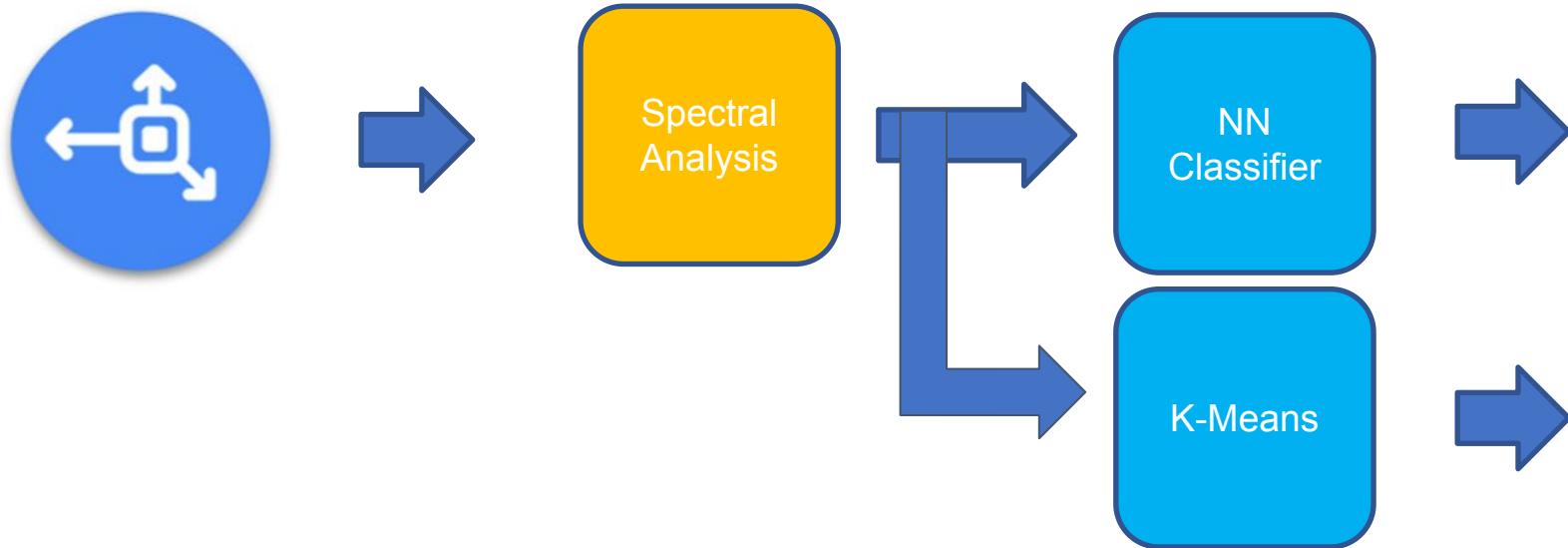


K-means Clustering for Anomaly Detection

Code Time!

Anomaly_Detection_K_means.ipynb





Classes

- Lift
 - Terrestrial
 - Maritime
 - Idle
-
- Anomaly

Motion Classification – Anomaly Detection

Project Time!



Create impulse - IESTI01 - Nano Motion Classification

studio.edgeimpulse.com/studio/61345/create-impulse

MJRoBot (Marcelo Rovai)

EDGE IMPULSE

CREATE IMPULSE (IESTI01 - NANO MOTION CLASSIFICATION)

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

Time series data

Spectral Analysis

Classification (Keras)

Output features

Axes
accX, accY, accZ

Window size

Window increase

Frequency (Hz)
100

Zero-pad data

Add a learning block

Some learning blocks have been hidden based on the data in your project.

DESCRIPTION	AUTHOR	RECOMMENDED
Classification (Keras) Learns patterns from data, and can apply these to new data. Great for categorizing movement or recognizing audio.	EdgImpulse Inc.	
Anomaly Detection (K-means) Find outliers in new data. Good for recognizing unknown states, and to complement classifiers.	EdgImpulse Inc.	
Regression (Keras) Learns patterns from data, and can apply these to new data. Great for predicting numeric continuous values.	EdgImpulse Inc.	

Save Impulse

Dashboard

Devices

Data acquisition

Impulse design

Create impulse

Spectral features

NN Classifier

EON Tuner

Retrain model

Live classification

Model testing

Versioning

Deployment

GETTING STARTED

Documentation

Forums

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Create impulse - IESTI01 - Nano Motion Classification

studio.edgeimpulse.com/studio/61345/create-impulse

MJRoBot (Marcelo Rovai)

EDGE IMPULSE

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: accX, accY, accZ

Window size: 2000 ms.

Window increase: 80 ms.

Frequency (Hz): 100

Zero-pad data:

Spectral Analysis

Name: Spectral features

Input axes: accX, accY, accZ

Classification (Keras)

Name: NN Classifier

Input features: Spectral features

Output features: 4 (idle, lift, maritime, terrestrial)

Output features

5 (idle, lift, maritime, terrestrial, Anomaly score)

Anomaly Detection (K-means)

Name: Anomaly detection

Input features: Spectral features

Output features: 1 (Anomaly score)

Add a processing block

Save Impulse

Anomaly detection - IESTI01 - [X](#)

[studio.edgeimpulse.com/studio/61345/learning/anomaly/15](#)

EDGE IMPULSE

ANOMALY DETECTION (IESTI01 - NANO MOTION CLASSIFICATION)

#1 ▾ Click to set a description for this version

Anomaly detection settings

Cluster count: 32

Axes:

accX RMS ★ accY Spectral Power 0.1 - 0.5
 accX Peak 1 Freq accY Spectral Power 0.5 - 1.0
 accX Peak 1 Height accY Spectral Power 1.0 - 2.0
 accX Peak 2 Freq accY Spectral Power 2.0 - 5.0
 accX Peak 2 Height accZ RMS ★
 accX Peak 3 Freq accZ Peak 1 Freq
 accX Peak 3 Height accZ Peak 1 Height
 accX Spectral Power 0.1 - 0.5 accZ Peak 2 Freq
 accX Spectral Power 0.5 - 1.0 accZ Peak 2 Height
 accX Spectral Power 1.0 - 2.0 accZ Peak 3 Freq
 accX Spectral Power 2.0 - 5.0 accZ Peak 3 Height

Select all axes

Anomaly explorer (3,400 samples)

X Axis: accX RMS **Y Axis:** accY RMS **Test data:** -- No test data

● trained

Training output:

```

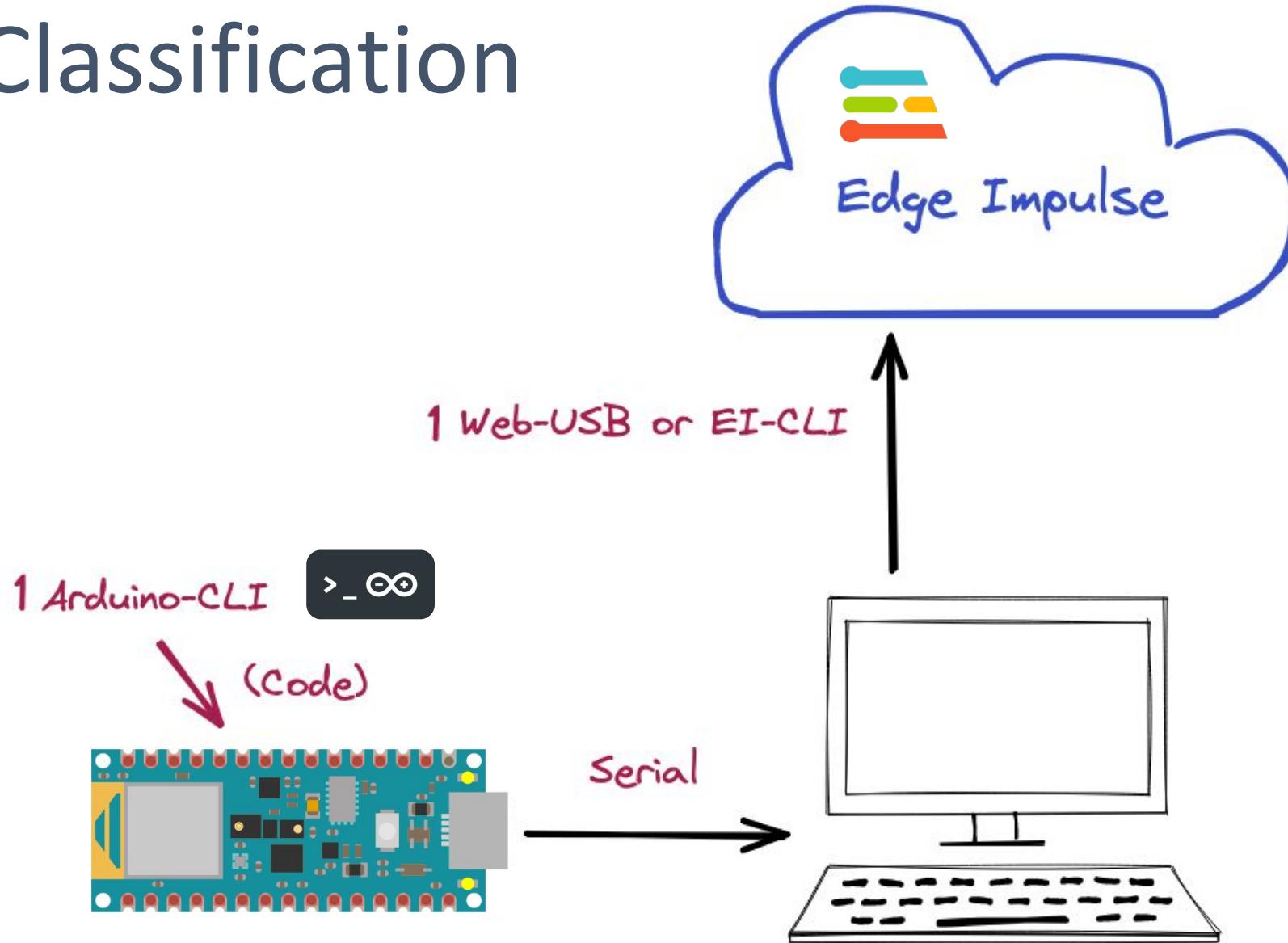
0.6082163453102112, 0.25316372513771057], 'max_error': 0.34954408210594134}, {'center': [-0.5115050673484802, -0.004735563416033983, 0.709574282169342], 'max_error': 0.2947459724666345}, {'center': [0.031501531600952, 1.2126123905181885, 1.129497766494751], 'max_error': 0.6769873962564943}, {'center': [1.391443133354187, 0.902986841171265, 0.8108663558959961], 'max_error': 0.5210900944982784}, {'center': [0.035471659153699875, 1.796299695968628, 1.2969461679458618], 'max_error': 0.5249936584588187}, {'center': [0.10634401440620422, 2.2963626384735107, 0.7528869005052185], 'max_error': 0.44105256183930464}, {'center': [1.645737767219543, 1.7475732564926147, 1.4299843311309814], 'max_error': 0.5520137297917197}, {'center': [2.21975709915161, 2.0978941917419434, 0.7476416230201721], 'max_error': 0.5746162180430946}, {'center': [0.032550420612096786, -0.03719609975814819, 1.5903402566989761], 'max_error': 0.4070282568799601}, {'center': [0.2832728922367096, 2.612391710281372, 1.1812870502471924], 'max_error': 0.43737044666248764}, {'center': [1.6214791536331177, 3.0532443523406982, 1.385027527809143], 'max_error': 0.7516882902121258}, {'center': [0.97450409412384, 1.682228883789062, 1.557731032371521], 'max_error': 0.7167072825903013}, {'center': [3.062652111053467, 0.4566035866737366, 0.4609105587005615], 'max_error': 0.444618109668133}

```

Job completed

Start training

Live Classification



Devices - IESTI01 - Nano Motic Arduino Nano 33 BLE Sense

studio.edgeimpulse.com/studio/61345/devices

EDGE IMPULSE

Devices (IESTI01 - NANO MOTION CLASSIFICATION)

Deleted device (" Nano ")

Your devices

These are devices that are connected to the Edge Impulse studio.

Connect a new device

Collect data

You can collect data from development boards, from your own devices, or by uploading an existing dataset.

Connect a fully supported development board

Get started with real hardware from a wide range of silicon vendors - fully supported by Edge Impulse.

Browse dev boards

Use your mobile phone

Use your computer

Data from any device with the data forwarder

Upload data

Integrate with your cloud

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Devices

Dashboard

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- Create impulse
- Spectral features
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- Anomaly detection

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GETTING STARTED

Documentation

Forums

MJRobot (Marcelo Rovai)

+ Connect a new device

Connect a fully supported development board

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Browse dev boards

Use your mobile phone

Use your computer

Data from any device with the data forwarder

Upload data

Integrate with your cloud

The enterprise version of Edge Impulse integrates directly with the data stored in your cloud platform.

Contact us

Devices - IESTI01 - Nano Motic X Arduino Nano 33 BLE Sense +

docs.edgeimpulse.com/docs/arduino-nano-33-ble-sense

DOCUMENTATION

Getting Started

API and SDK references

What is embedded ML, anyway?

Frequently asked questions

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

Nordic Semi nRF9160 DK

Nordic Semi Thingy:91

SiLabs Thunderboard Sense 2

Sony's Spresense

Syntiant TinyML Board

TI CC1352P Launchpad

Arduino Portenta H7 + Vision shield (preview)

Raspberry Pi 4

NVIDIA Jetson Nano

Mobile phone

Porting guide



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

From a command prompt or terminal, run:

```
edge-impulse-daemon
```

This will start a wizard which will ask you to log in, and choose an Edge Impulse project. If you want to switch projects run the command with `--clean`.

Alternatively, recent versions of Google Chrome and Microsoft Edge can collect data directly from your development board, without the need for the Edge Impulse CLI. See [this blog post](#) for more information.

4. Verifying that the device is connected

That's all! Your device is now connected to Edge Impulse. To verify this, go to [your Edge Impulse project](#), and click Devices. The device will be listed here.

Your devices

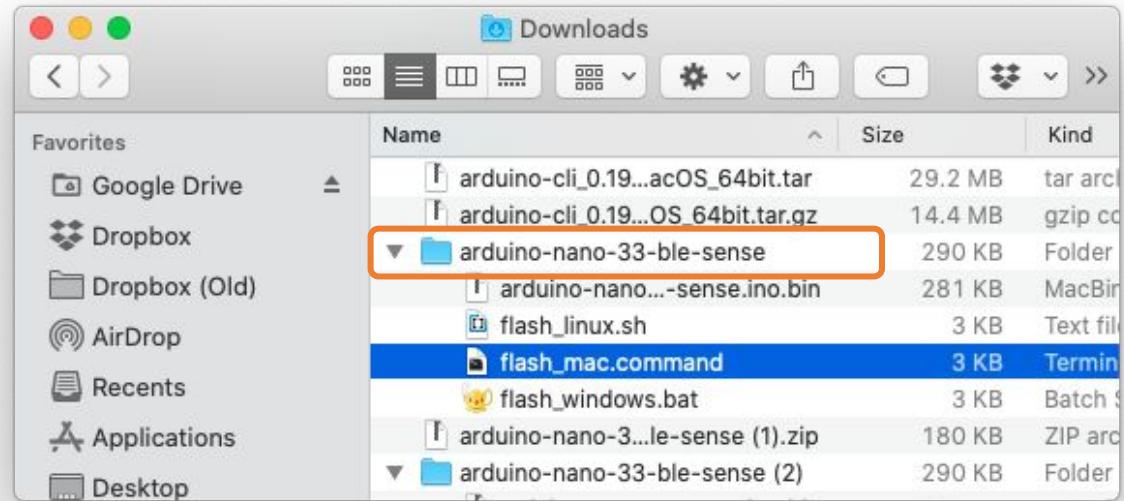
+ Connect a new device

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	REM...	LAST SEEN
 Jan's Nano 33 BLE Sense	51:05:F2:F4:3D:C1	ARDUINO_NANO3...	Built-in accelerometer...	●	Today, 18:40:09

<https://cdn.edgeimpulse.com/firmware/arduino-nano-33-ble-sense.zip>

arduino-nano-33....zip ^ Show All X



```
mjrovai — flash_mac.command — 80x43
Last login: Thu Nov 11 14:24:32 on ttys000
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 280848 bytes to flash (69 pages)
[=====] 100% (69/69 pages)
Done in 10.982 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.
Deleting expired sessions...none found.

[Process completed]
```

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

- cu.Bluetooth-Incoming-Port
- cu.MALS
- cu.RovaisAirPods-Wirelessi
- cu.SOC
- Arduino Nano 33 BLE (cu.usbmodem145101) - Paired**

Cancel Connect

development board, or upload your existing datasets - Show options

TRAIN / TEST SPLIT
80% / 20%

ADDED	LENGTH
Nov 09 2021, 15:06:09	1m 20s
Nov 09 2021, 14:57:35	10s
Nov 09 2021, 14:57:13	10s
Nov 09 2021, 14:56:48	10s
Nov 09 2021, 14:56:31	10s
Nov 09 2021, 14:55:55	10s
Nov 09 2021, 14:55:36	10s
Nov 09 2021, 14:55:19	10s
Nov 09 2021, 14:55:00	10s
Nov 09 2021, 14:41:45	10s
Nov 09 2021, 14:41:26	10s
Nov 09 2021, 14:41:06	10s

Record new data

Connect using WebUSB

No devices connected to the remote management API.

RAW DATA
Click on a sample to load...

ei-iesti01---nano....zip

Show All

The screenshot shows the Edge Impulse Studio interface. On the left, a sidebar lists various project components like Dashboard, Devices, Data acquisition, and Model testing. The 'Data acquisition' section is expanded, showing 'Impulse designs' and a list of datasets. One dataset, 'maritime.json.2jvi5bit', is highlighted with a blue arrow pointing to its row in the main dataset list. The main area displays a list of samples with columns for 'ADDED' and 'LENGTH'. At the top right, there's a purple header bar with user information and a 'Connect using WebUSB' button, which is also highlighted with an orange box and a blue arrow. The bottom navigation bar includes a file named 'ei-iesti01---nano....zip' and a 'Show All' button.

Alternative option with Edge Impulse CLI

```
mjrovai — node /usr/local/bin/edge-impulse-daemon --clean — 80x45
Last login: Mon Nov 15 17:22:34 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$ edge-impulse-daemon --clean
Edge Impulse serial daemon v1.13.16
[?] 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.usbmodem145101
[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 1.6.0

? To which project do you want to connect this device?
MJRoBot (Marcelo Rovai) / IESTI01 - Covid-19: Detection by Cough
MJRoBot (Marcelo Rovai) / TinyML Kit Camera test
MJRoBot (Marcelo Rovai) / Harvard - Person Detection
MJRoBot (Marcelo Rovai) / Wio - Gesture Recognition
MJRoBot (Marcelo Rovai) / Cifar10_Image_Classification
MJRoBot (Marcelo Rovai) / Bean Disease Classifier
MJRoBot (Marcelo Rovai) / SciTinyML-Motion-Anomaly-Project
MJRoBot (Marcelo Rovai) / 1-Hands-On-SciTinyML-Motion-Project
MJRoBot (Marcelo Rovai) / ESP32-Motion-Classification
MJRoBot (Marcelo Rovai) / ESP32_KWS_Project
> MJRoBot (Marcelo Rovai) / IESTI01 - Nano Motion Classification
MJRoBot (Marcelo Rovai) / IESTI01 - Motion Classification Test
MJRoBot (Marcelo Rovai) / ICTP_Mosquito_Sound_Classification
MJRoBot (Marcelo Rovai) / Mosquito Wingbeat Sound Classification
MJRoBot (Marcelo Rovai) / Motion-Project
MJRoBot (Marcelo Rovai) / Blender - Motion Detection
MJRoBot (Marcelo Rovai) / Key_Word_Spotting
MJRoBot (Marcelo Rovai) / Oi_Rovis_Key_Word_Spotting
MJRoBot (Marcelo Rovai) / Sound-Classification-Blender-Faucet
MJRoBot (Marcelo Rovai) / oi_rovvis_kws
(Move up and down to reveal more choices)
```

```
mjrovai — node /usr/local/bin/edge-impulse-daemon --clean — 80x39
Last login: Mon Nov 15 17:22:34 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$ edge-impulse-daemon --clean
Edge Impulse serial daemon v1.13.16
[?] 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.usbmodem145101
[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 1.6.0

? To which project do you want to connect this device? MJRoBot (Marcelo Rovai) /
IESTI01 - Nano Motion Classification
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 - Nano Motion Classification"
[WS ] Go to https://studio.edgeimpulse.com/studio/61345/acquisition/training to
build your machine learning model!
```

Devices - IESTI01 - Nano Motion Classification

studio.edgeimpulse.com/studio/61345/devices

EDGE IMPULSE

DEVICES (IESTI01 - NANO MOTION CLASSIFICATION)

MJRobot (Marcelo Rovai)

Deleted device (" Nano ")

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	REMOTE ...	LAST SEEN
 36:17:55:F9:70:F7	36:17:55:F9:70:F7	ARDUINO_NANO33BLE	Built-in accelerometer, Built-in microphone		Today, 17:45:37

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Collect data

Device 36:17:55:F9:70:F7 is now connected

Get started!

Dashboard

Devices

Data acquisition

Impulse design

- Create impulse
- Spectral features
- NN Classifier
- Anomaly detection

EON Tuner

Retrain model

Live classification

Model testing

Versioning

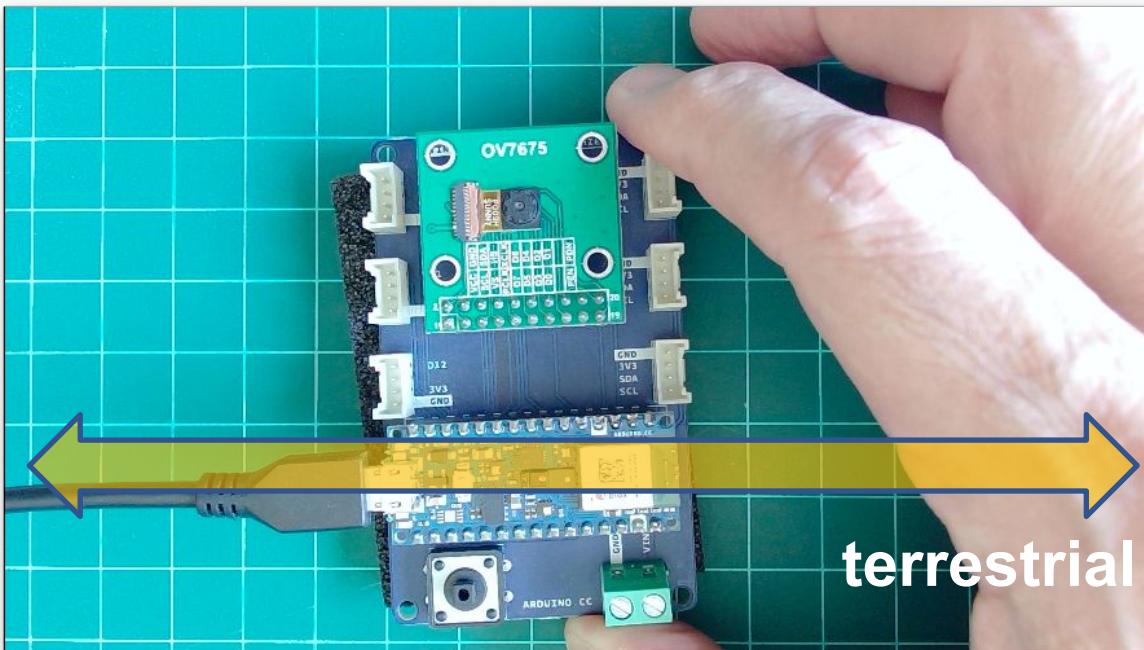
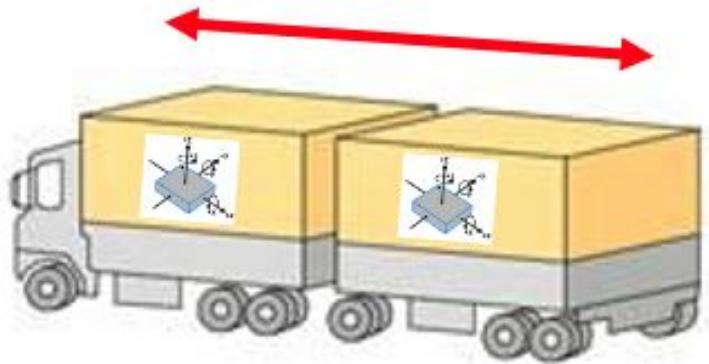
Deployment

GETTING STARTED

Documentation

Forums

Test: terrestrial





Classification result

Summary

Name

Expected outcome

CATEGORY	COUNT
idle	0
lift	0
maritime	7
terrestrial	0
uncertain	0
anomaly	94

Anomaly explorer (3,501 samples)



Distance from closest cluster

accX RMS: 0.2653, accY RMS: 1.3105, accZ RMS: 0.8946

Deploy

DEPLOYMENT (IESTI01 - NANO MOTION CLASSIFICATION)

Deploy your impulse

You can deploy your impulse to any device. This makes the model run without an internet connection, minimizes latency, and runs with minimal power consumption. [Read more.](#)

Create library

Turn your impulse into optimized source code that you can run on any device.

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.

Arduino File Edit Sketch Tools Help

Verify/Compile ⌘R
Upload ⌘U
Upload Using Programmer ⇧⌘U
Export compiled Binary ⌘S
Show Sketch Folder ⌘K
Include Library ► Add .ZIP Library... Manage Libraries...

[SER] Reading from buffer OK
[SER] File is 16273 bytes after decoding
[SER] Uploading to https://ingestion.edgeimpulse.com/api
[SER] Uploading to https://ingestion.edgeimpulse.com/api
[WS] Trying to connect in 1 second...
[SER] Device is not connected to remote management API.
[WS] Connecting to wss://remote-mgmt.edgeimpulse.com
[WS] Connected to wss://remote-mgmt.edgeimpulse.com
[WS] Device "nano" is now connected to project "IESTI01"
[WS] Go to https://studio.edgeimpulse.com/studio/61345
build your machine learning model!
[WS] Trying to connect in 1 second...
[SER] Device is not connected to remote management API.
[WS] Connecting to wss://remote-mgmt.edgeimpulse.com
[WS] Connected to wss://remote-mgmt.edgeimpulse.com
[WS] Device "nano" is now connected to project "IESTI01"
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[SER] Device is not connected to remote management API.
[WS] Connecting to wss://remote-mgmt.edgeimpulse.com
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[SER] Device is not connected to remote management API.
[WS] Connecting to wss://remote-mgmt.edgeimpulse.com
[WS] Connected to wss://remote-mgmt.edgeimpulse.com
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[WS] Go to https://studio.edgeimpulse.com/studio/61345
build your machine learning model!
[WS] Trying to connect in 1 second...
[SER] Device is not connected to remote management API.
[WS] Connecting to wss://remote-mgmt.edgeimpulse.com
[WS] Connected to wss://remote-mgmt.edgeimpulse.com
[WS] Device "nano" is now connected to project "IESTI01"
[WS] Go to https://studio.edgeimpulse.com/studio/61345
build your machine learning model!
[WS] Trying to connect in 1 second...
[SER] Device is not connected to remote management API.
[WS] Connecting to wss://remote-mgmt.edgeimpulse.com
[WS] Connected to wss://remote-mgmt.edgeimpulse.com
[WS] Device "nano" is now connected to project "IESTI01"
[WS] Go to https://studio.edgeimpulse.com/studio/61345
build your machine learning model!

^X^Z [1]+ Stopped edge-impulse-demon --clean
(base) MacBook-Pro-de-Marcelo:~ mjrovai\$

Downloads

Dropbox (Old) Name Size

AirDrop IMG_9735.jpg
Recents IMG_9733.jpg
Applications arduino-nano-3...le-sense (4).zip
Desktop TinyML_Ovverie...ov_2021-2.pptx
Downloads TinyML_Ovverie...Nov_2021-2.pdf
mjrovai Affordable_Bim..._U.pdf.download
elife-27854-v1.pdf

Contributed libraries Accelerometer-Nano-Ble-IoT Inferencing - Edge Impulse
Adafruit BusIO
Adafruit MPU6050
Adafruit TouchScreen
Adafruit Zero DMA Library
Adafruit Zero FFT Library

```
Starting inferencing in 2 seconds...
Sampling...
Predictions (DSP: 20 ms., Classification: 1 ms., Anomaly: 1 ms.):
    idle: 0.00000
    lift: 0.00000
    maritime: 0.99609
    terrestrial: 0.00000
    anomaly score: 0.620

Starting inferencing in 2 seconds...
Sampling...
Predictions (DSP: 20 ms., Classification: 0 ms., Anomaly: 2 ms.):
    idle: 0.00000
    lift: 0.00000
    maritime: 0.99609
    terrestrial: 0.00000
    anomaly score: 1.470
```

Autoscroll Show timestamp

Both NL & CR

115200 baud

Clear output

Pos-processing

Turn on/off LEDS

- Idle : ==> All OFF
- lift: ==> **Green ON**
- maritime: ==> **Red ON**
- terrestrial: ==> **Blue ON**
- Anomaly ==> **LED_BUILTIN ON**

motion_classification_nano_ble33_sense_accelerometer | Arduino 1.8.16

```
36 void setup()
37 {
38     Serial.begin(115200);
39     while (!Serial);
40
41     Serial.println("TESTI01 - Nano Motion Classification - Inferencing Test");
42
43     pinMode(LED_BUILTIN, OUTPUT);
44     pinMode(LED_R, OUTPUT);
45     pinMode(LED_G, OUTPUT);
46     pinMode(LED_B, OUTPUT);
47
48     // Ensure the LED is off by default.
49     digitalWrite(LED_BUILTIN, LOW);
50     digitalWrite(LED_R, HIGH);
51     digitalWrite(LED_G, HIGH);
52     digitalWrite(LED_B, HIGH);
53
54     if (!IMU.begin()) {
55         ei_printf("Failed to initialize IMU!\r\n");
56     }
57     else {
58         ei_printf("IMU initialized\r\n");
59     }
60
61     if (EI_CLASSIFIER_RAW_SAMPLES_PER_FRAME != 3) {
62         ei_printf("ERR: EI_CLASSIFIER_RAW_SAMPLES_PER_FRAME should be equal to 3 (t
63         return;
64     }
65 }
66
```

Done Saving.

[=====] 100% (39/39 pages)

Done in 6.193 seconds

reset()

136

Arduino Nano 33 BLE on /dev/cu.usbmodem145101

motion_classification_nano_ble33_sense_accelerometer | Arduino 1.8.16

```
66
67 void turn_off_leds(){
68     digitalWrite(LED_R, HIGH);
69     digitalWrite(LED_G, HIGH);
70     digitalWrite(LED_B, HIGH);
71 }
72 /*
73
80 void turn_on_leds(int pred_index) {
81     switch (pred_index)
82 {
83     case 0:    // Idle:      [0] ==> All OFF
84         turn_off_leds();
85         break;
86
87     case 1:    // lift:      [1] ==> Green ON
88         turn_off_leds();
89         digitalWrite(LED_G, LOW);
90         break;
91
92     case 2:    // maritime:  [2] ==> Red ON
93         turn_off_leds();
94         digitalWrite(LED_R, LOW);
95         break;
96
97     case 3:    // terrestrial:[3] ==> Blue ON
98         turn_off_leds();
99         digitalWrite(LED_B, LOW);
100        break;
101    }
102 }
```

Done Saving.

...[SERIAL] 0x51, 0x2000, 0x2000

[=====] 100% (39/39 pages)

Done in 6.193 seconds

reset()

97

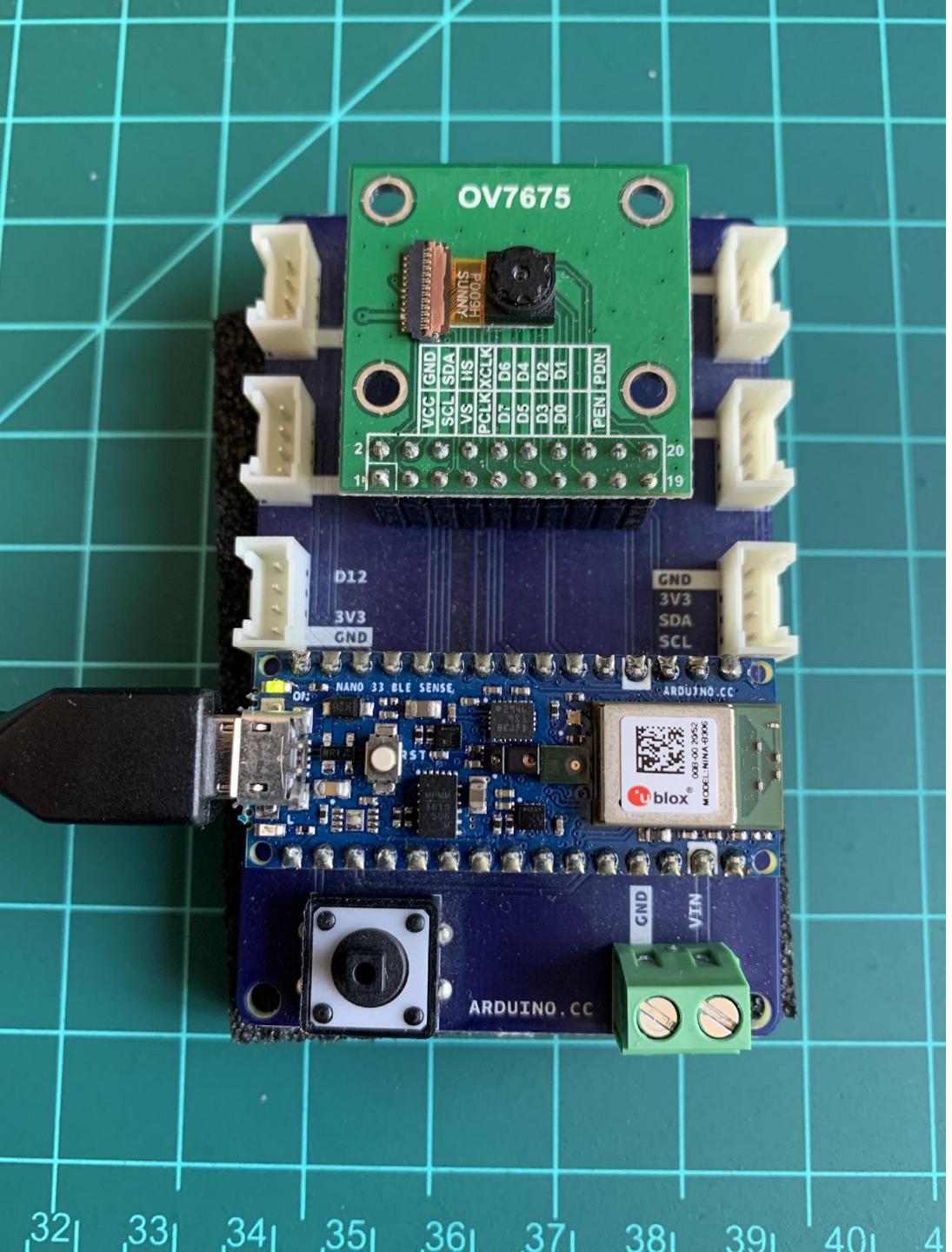
Arduino Nano 33 BLE on /dev/cu.usbmodem145101

```
motion_classification_nano_ble33_sense_accelerometer | Arduino 1.8.16
motion_classification_nano_ble33_sense_accelerometer §

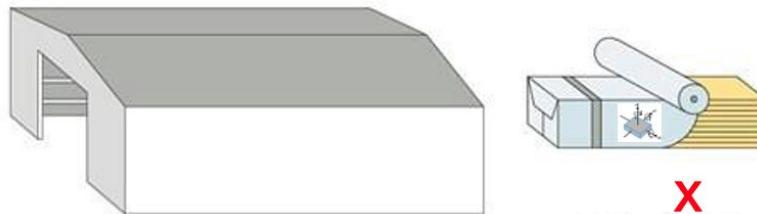
159 // Run the classifier
160 ei_impulse_result_t result = { 0 };
161 err = run_classifier(&signal, &result, debug_nn);
162 if (err != EI_IMPULSE_OK) {
163     ei_printf("ERR: Failed to run classifier (%d)\n", err);
164     return;
165 }
166
167 // print the predictions
168 ei_printf("Predictions ");
169 ei_printf("(DSP: %d ms., Classification: %d ms., Anomaly: %d ms.)",
170         result.timing.dsp, result.timing.classification, result.timing.anomaly);
171 ei_printf(": \n");
172
173 int pred_index = 0;
174 float pred_value = result.classification[0].value;
175
176 for (size_t ix = 0; ix < EI_CLASSIFIER_LABEL_COUNT; ix++) {
177     ei_printf("%s: %.5f\n", result.classification[ix].label, result.classif
178     if (result.classification[ix].value > pred_value){
179         pred_index = ix;
180         pred_value = result.classification[ix].value;
181     }
182 }
183 ei_printf(" Prediction: %s with probability %.2f\n", result.classification[pre
184 turn_on_leds (pred_index);
185
186 #if EI_CLASSIFIER_HAS_ANOMALY == 1
187     ei_printf(" anomaly score: %.3f\n", result.anomaly);
188     if (result.anomaly > 0.5)
189         digitalWrite(LED_BUILTIN, HIGH);
190     else
191         digitalWrite(LED_BUILTIN, LOW);
192 #endif
193 }

Done uploading.
writeBuffer(scr_addr=0x34, dst_addr=0x24000, size=0x1000)
[=====] 94% (37/39 pages) write(addr=0x34, size=0x1000)
writeBuffer(scr_addr=0x34, dst_addr=0x25000, size=0x1000)
[=====] 97% (38/39 pages) write(addr=0x34, size=0x1000)

160 Arduino Nano 33 BLE on /dev/cu.usbmodem145101
```



label: idle



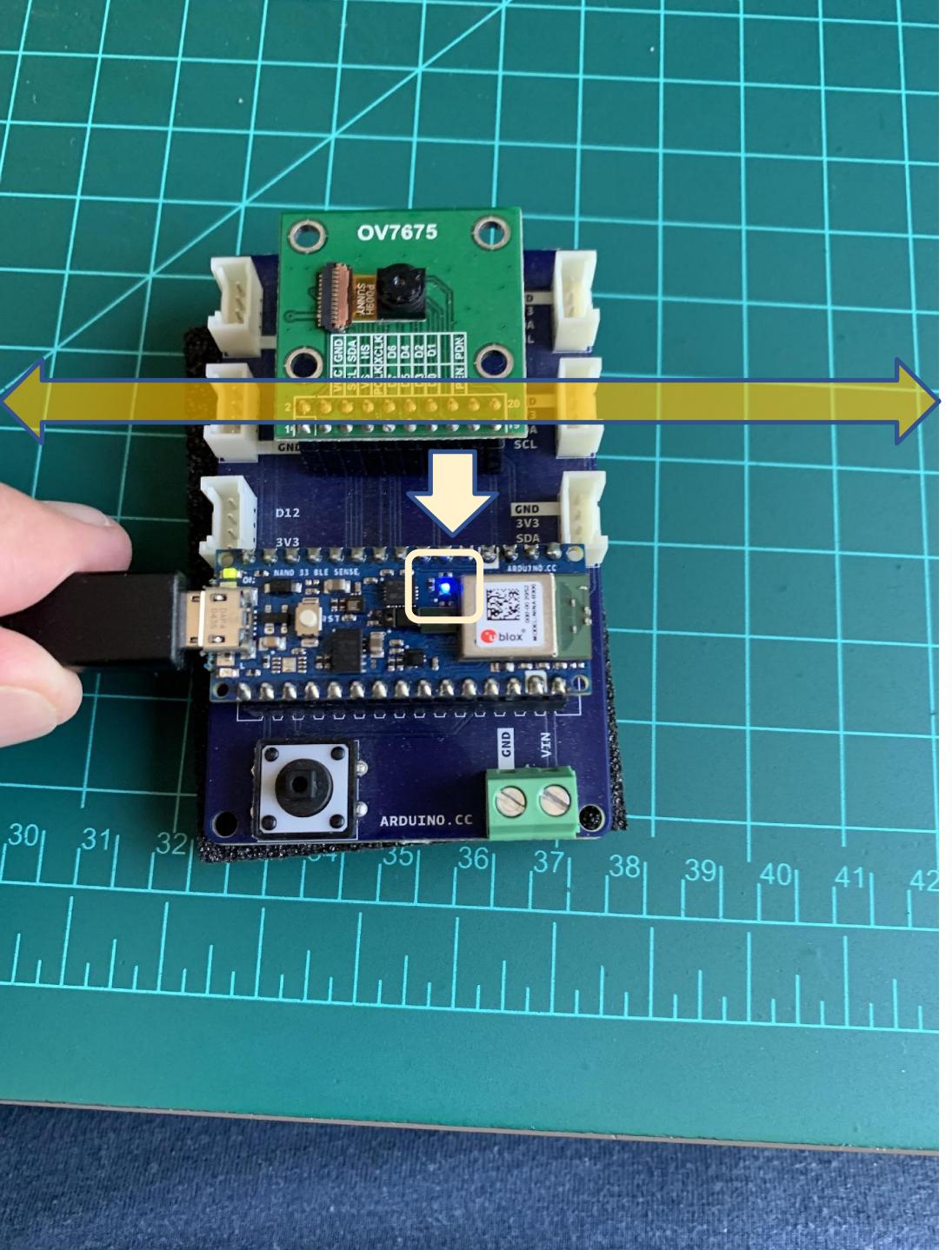
```
/dev/cu.usbmodem145101
Send

IESTI01 - Nano Motion Classification - Inferencing Test
IMU initialized

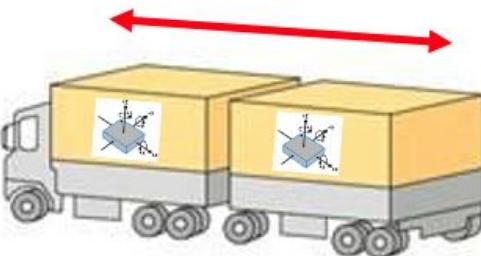
Starting inferencing in 2 seconds...
Sampling...
Predictions (DSP: 20 ms., Classification: 0 ms., Anomaly: 2 ms.):
    idle: 0.99219
    lift: 0.00391
    maritime: 0.00391
    terrestrial: 0.00000
Prediction: idle with probability 0.99
anomaly score: 0.001

Starting inferencing in 2 seconds...
Sampling...
Predictions (DSP: 20 ms., Classification: 1 ms., Anomaly: 1 ms.):
    idle: 0.99219
    lift: 0.00391
    maritime: 0.00391
    terrestrial: 0.00000
Prediction: idle with probability 0.99
anomaly score: -0.001

 Autoscroll  Show timestamp Both NL & CR 115200 baud Clear output
```



label: terrestrial

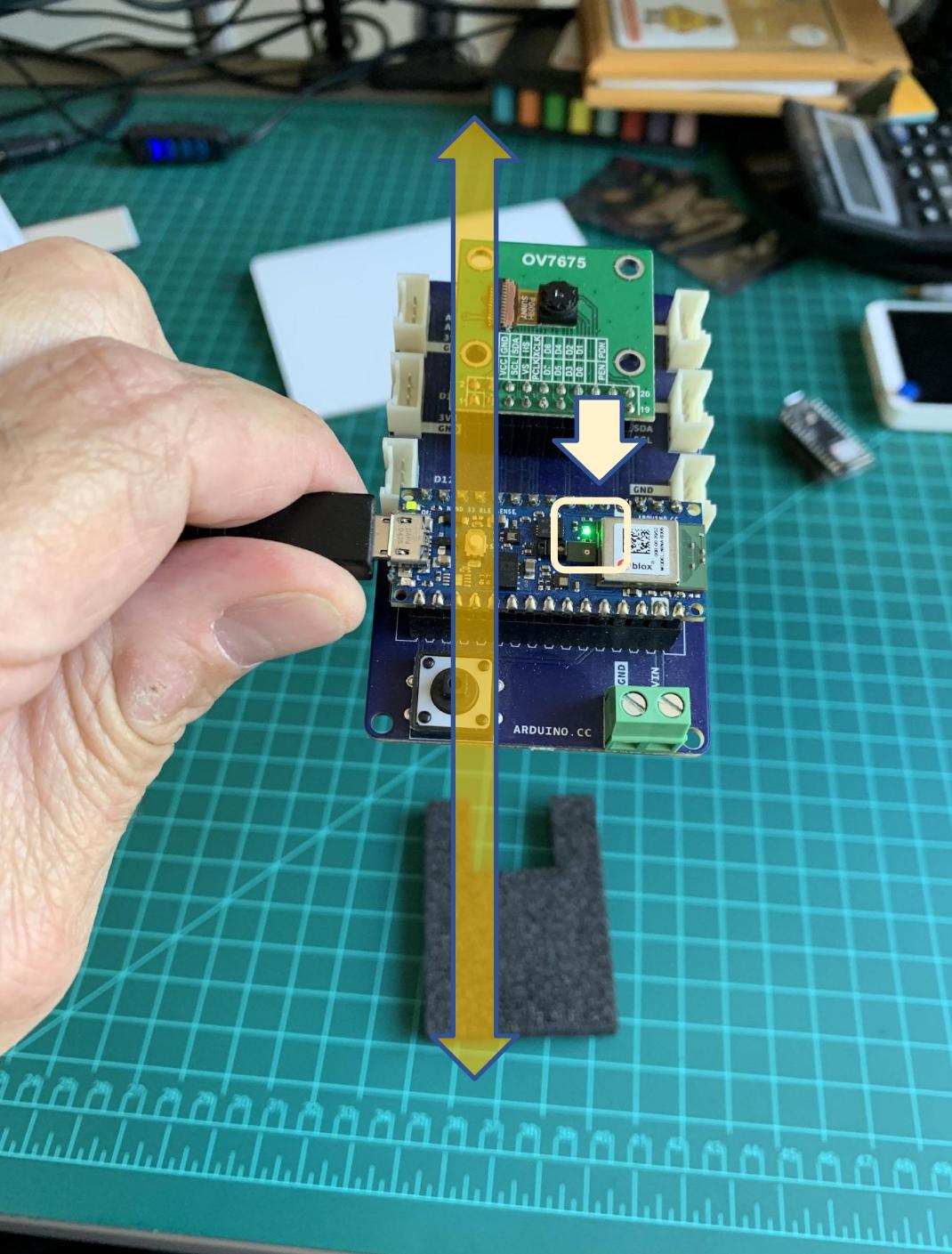


```
/dev/cu.usbmodem145101
Send

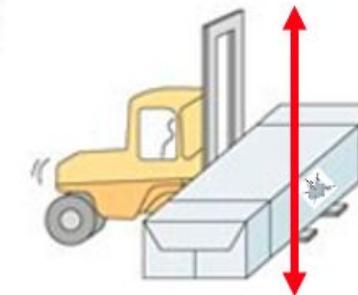
Starting inferencing in 2 seconds...
Sampling...
Predictions (DSP: 20 ms., Classification: 1 ms., Anomaly: 1 ms.):
  idle: 0.00000
  lift: 0.00000
  maritime: 0.00000
  terrestrial: 0.99609
Prediction: terrestrial with probability 1.00
anomaly score: -0.190

Starting inferencing in 2 seconds...
Sampling...
Predictions (DSP: 20 ms., Classification: 0 ms., Anomaly: 2 ms.):
  idle: 0.00000
  lift: 0.00000
  maritime: 0.00000
  terrestrial: 0.99609
Prediction: terrestrial with probability 1.00
anomaly score: -0.096

 Autoscroll  Show timestamp Both NL & CR 115200 baud Clear output
```



label: lift



```
/dev/cu.usbmodem145101
Send

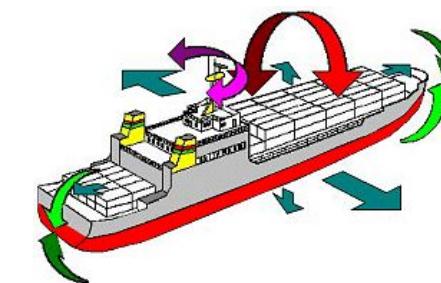
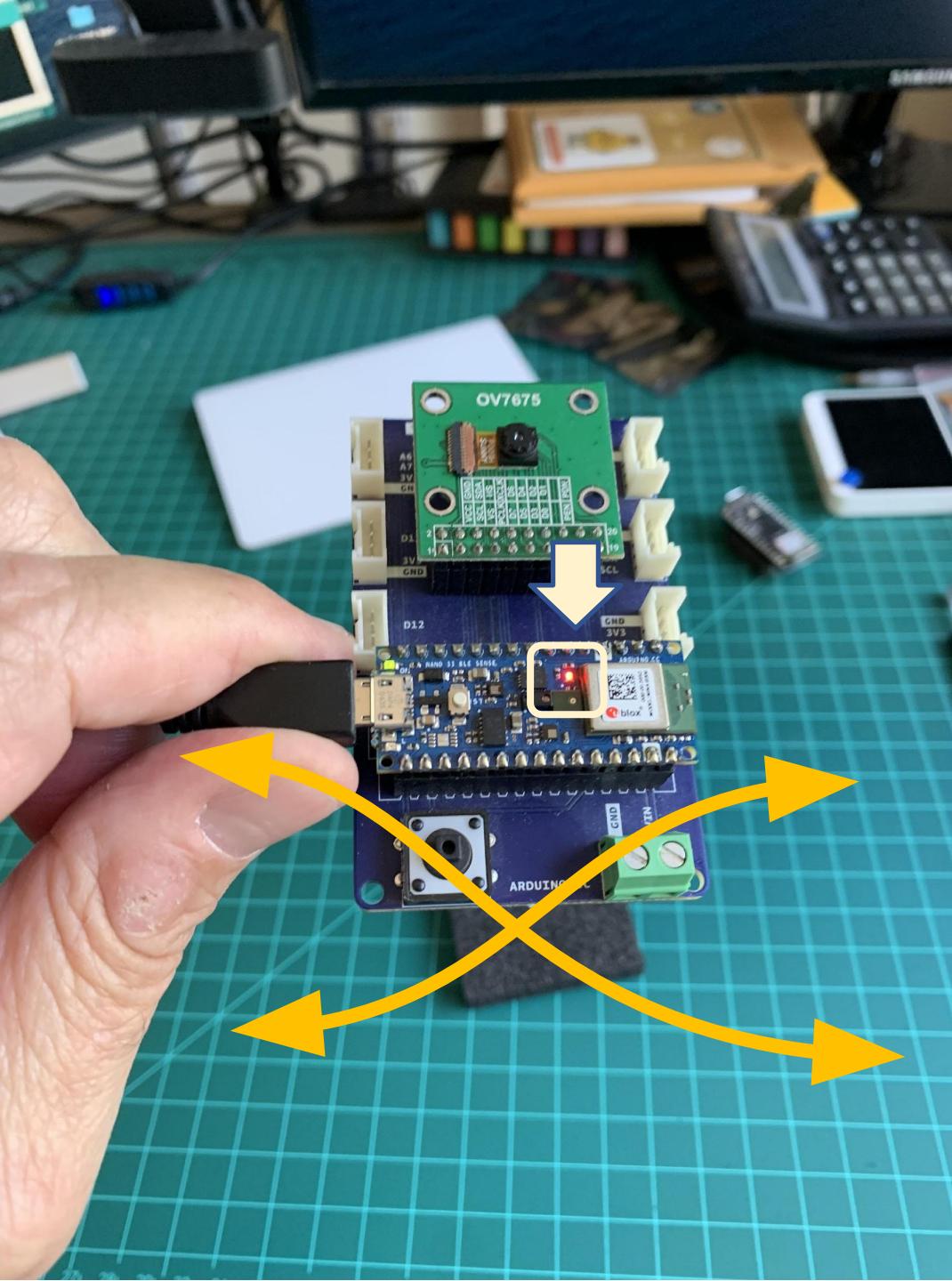
Starting inferencing in 2 seconds...
Sampling...
Predictions (DSP: 20 ms., Classification: 0 ms., Anomaly: 2 ms.):
    idle: 0.00000
    lift: 0.99609
    maritime: 0.00000
    terrestrial: 0.00000
Prediction: lift with probability 1.00
anomaly score: 0.047

Starting inferencing in 2 seconds...
Sampling...
Predictions (DSP: 20 ms., Classification: 1 ms., Anomaly: 1 ms.):
    idle: 0.76172
    lift: 0.12500
    maritime: 0.10547
    terrestrial: 0.00781
Prediction: idle with probability 0.76
anomaly score: 0.874

 Autoscroll  Show timestamp Both NL & CR 115200 baud Clear output
```

A screenshot of a terminal window showing the results of a machine learning inference. The terminal is connected to the port /dev/cu.usbmodem145101 at 115200 baud. The output shows the model is starting to infer in 2 seconds, then sampling. It lists predictions for four categories: idle, lift, maritime, and terrestrial. The 'lift' category has the highest probability of 0.99609. A red box highlights the prediction 'Prediction: lift with probability 1.00' and its anomaly score of 0.047. Below this, another set of predictions is shown for the same categories, with 'idle' having the highest probability of 0.76172. The terminal also includes checkboxes for 'Autoscroll' and 'Show timestamp', and buttons for 'Both NL & CR', '115200 baud', and 'Clear output'.

label: maritime

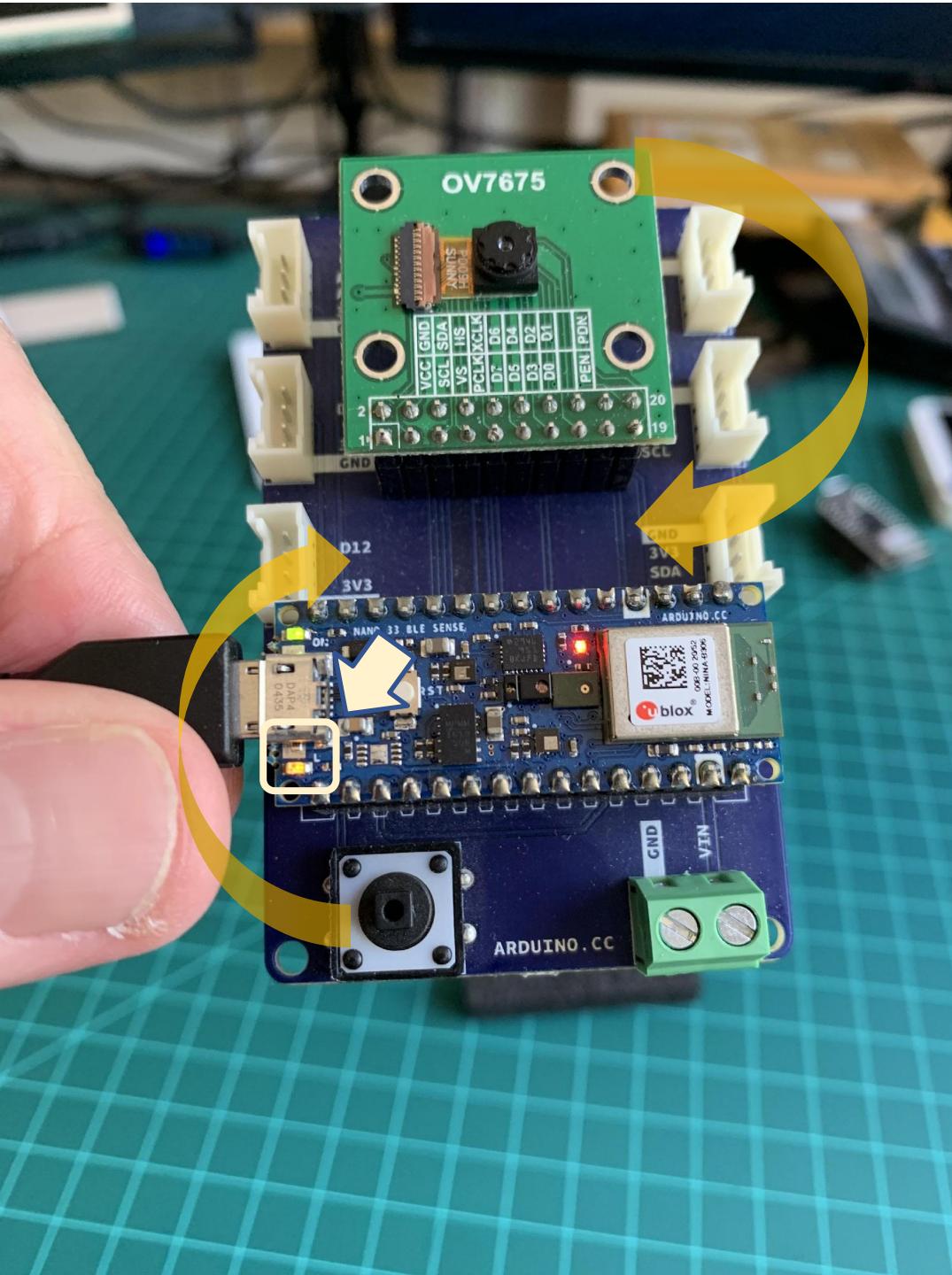


```
Starting inferencing in 2 seconds...
Sampling...
Predictions (DSP: 20 ms., Classification: 0 ms., Anomaly: 2 ms.):
  idle: 0.00391
  lift: 0.29297
  maritime: 0.40625
  terrestrial: 0.29297
Prediction: maritime with probability 0.41
anomaly score: 0.431

Starting inferencing in 2 seconds...
Sampling...
Predictions (DSP: 20 ms., Classification: 0 ms., Anomaly: 1 ms.):
  idle: 0.95312
  lift: 0.03516
  maritime: 0.00781
  terrestrial: 0.00391
Prediction: idle with probability 0.95
anomaly score: 0.247

 Autoscroll  Show timestamp Both NL & CR 115200 baud Clear output
```

label: anomaly



```
/dev/cu.usbmodem145101
Send

Starting inferencing in 2 seconds...
Sampling...
Predictions (DSP: 20 ms., Classification: 1 ms., Anomaly: 1 ms.):
    idle: 0.00781
    lift: 0.12109
    maritime: 0.87109
    terrestrial: 0.00000
Prediction: maritime with probability 0.87
anomaly score: 0.902

Starting inferencing in 2 seconds...
Sampling...
Predictions (DSP: 20 ms., Classification: 1 ms., Anomaly: 1 ms.):
    idle: 0.89453
    lift: 0.08984
    maritime: 0.01172
    terrestrial: 0.00781
Prediction: idle with probability 0.89
anomaly score: 0.248

 Autoscroll  Show timestamp Both NL & CR 115200 baud Clear output
```

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 \(Coursera\)](#)
- [Text Book: "TinyML" by Pete Warden, Daniel Situnayake](#)

I want to thank Shawn Hymel and Edge Impulse, Pete Warden and Laurence Moroney from Google, and especially Harvard professor Vijay Janapa Reddi, Ph.D. student Brian Plancher and their staff for preparing the excellent material on TinyML that is the basis of this course at UNIFEI.

The IESTI01 course is part of the TinyML4D, an initiative to make TinyML education available to everyone globally.

Thanks
And stay safe!



UNIFEI