Image Classification

Hands-On

Prof. Marcelo J. Rovai
UNIFEI – Federal University of Itajuba, Brazil
rovai@unifei.edu.br

Computer Vision Main Types

Image Classification

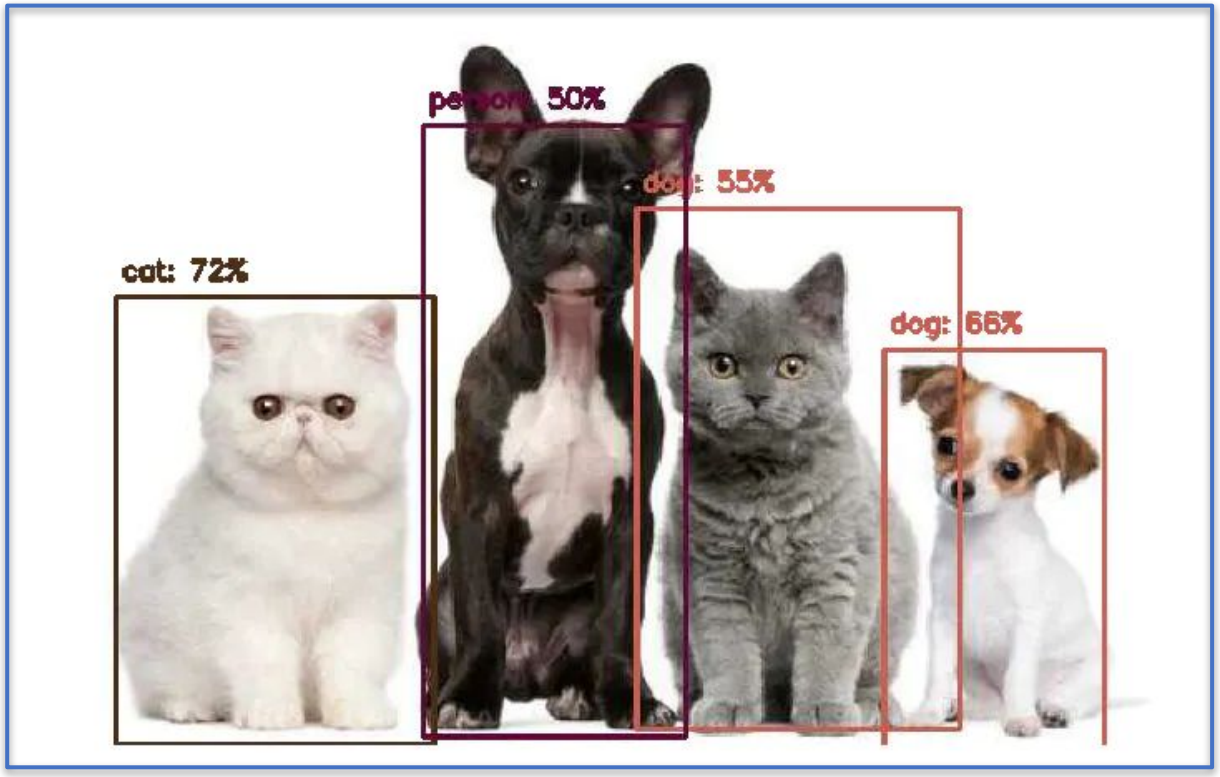
(**Multi-Class** Classification)

Cat: 70%

Dog: 80%

Object Detection

Multi-Label Classification + Object **Localization**



Computer Vision Main Types

Image Classification

(**Multi-Class** Classification)

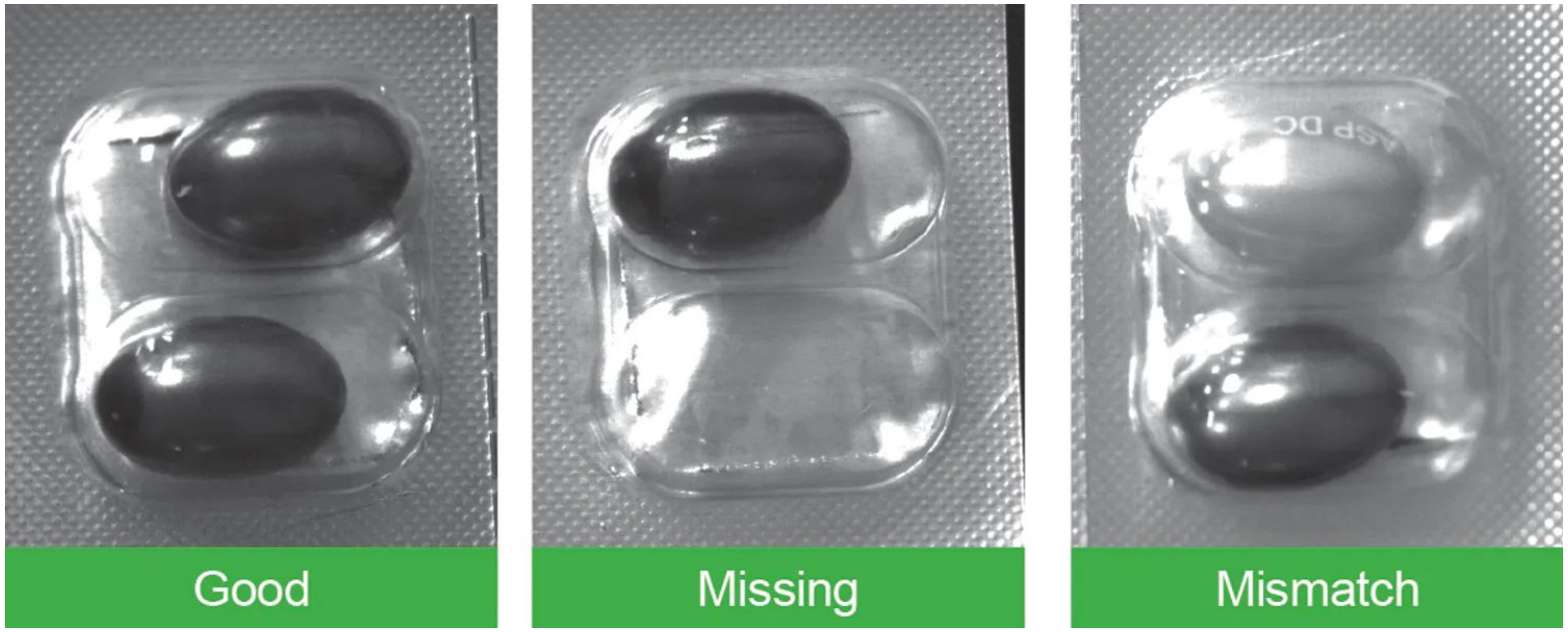
Cat: 70%

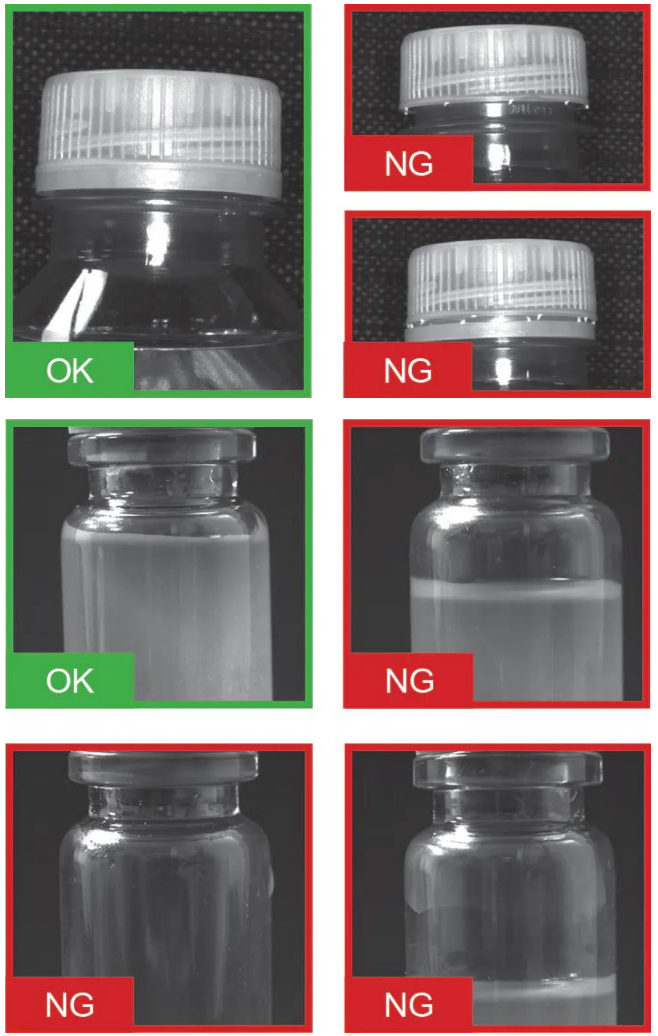
Dog: 80%

Object Detection

Multi-Label Classification + Object **Localization**

Image Classification Project:
Package Inspection





[Deep Learning at the Edge Simplifies Package Inspection]

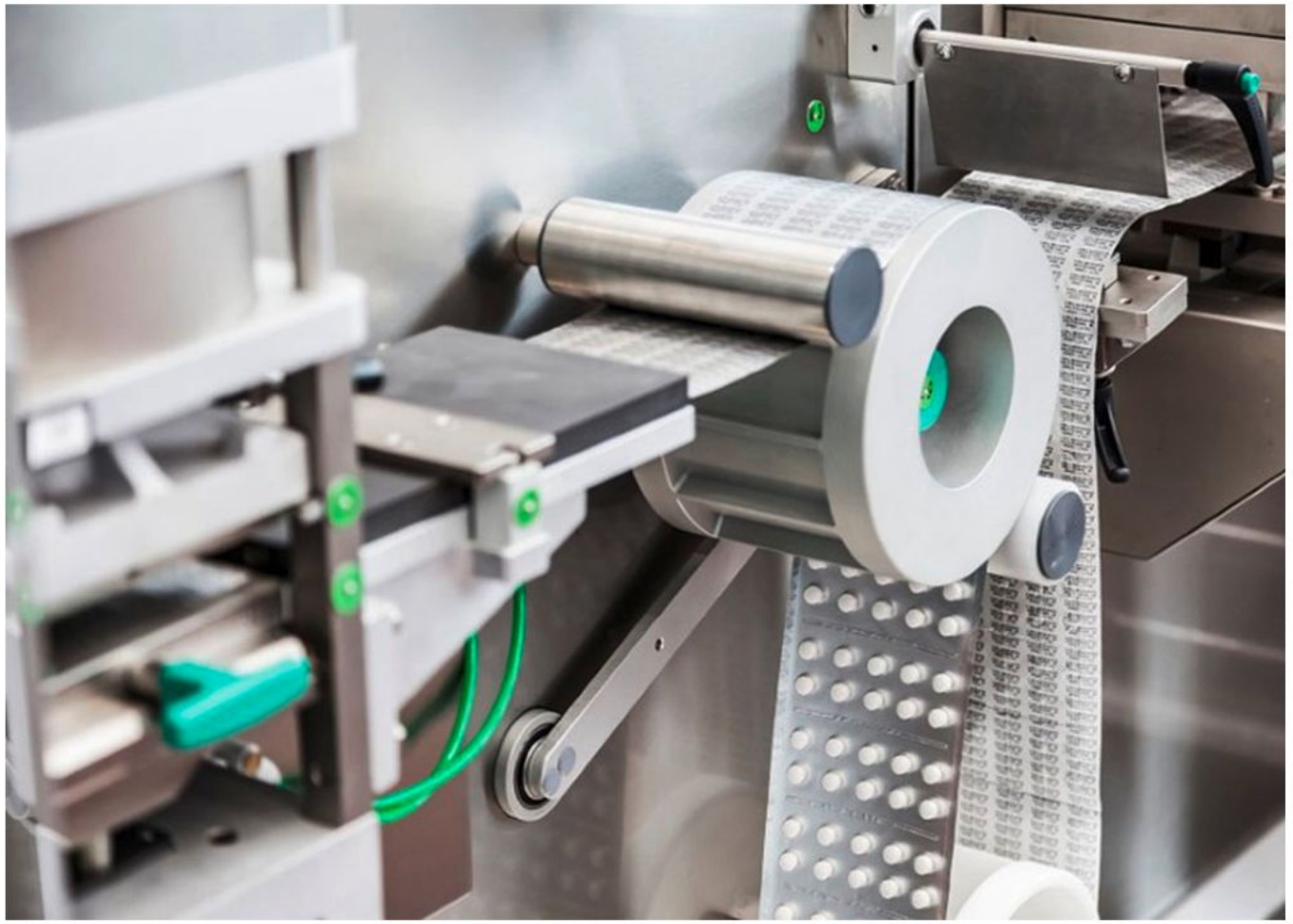


Image Classification Project

Decide a Goal

- Possible Images:
  - medicine
  - background

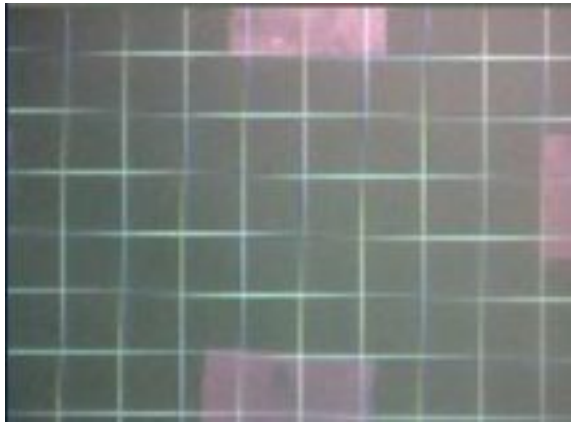
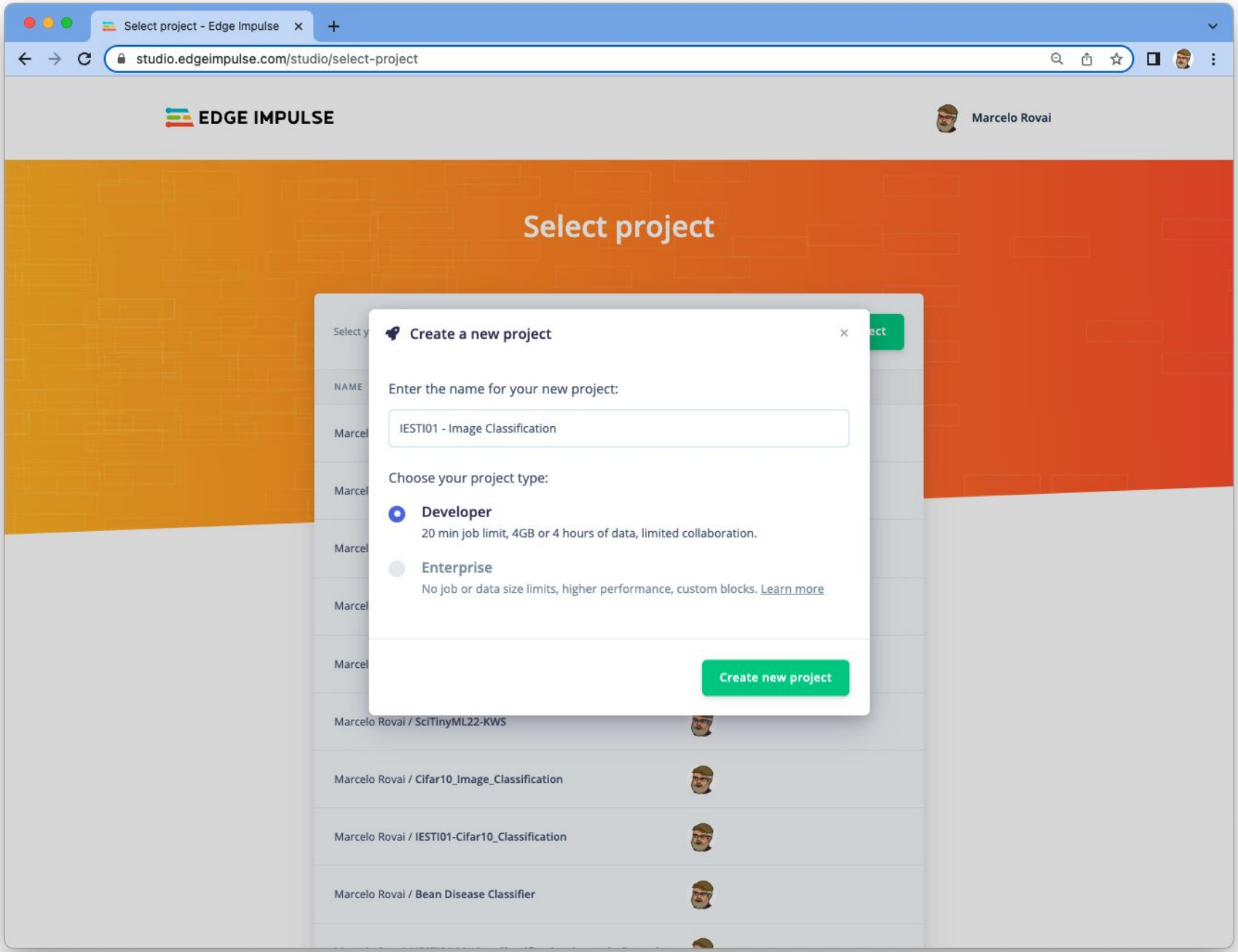
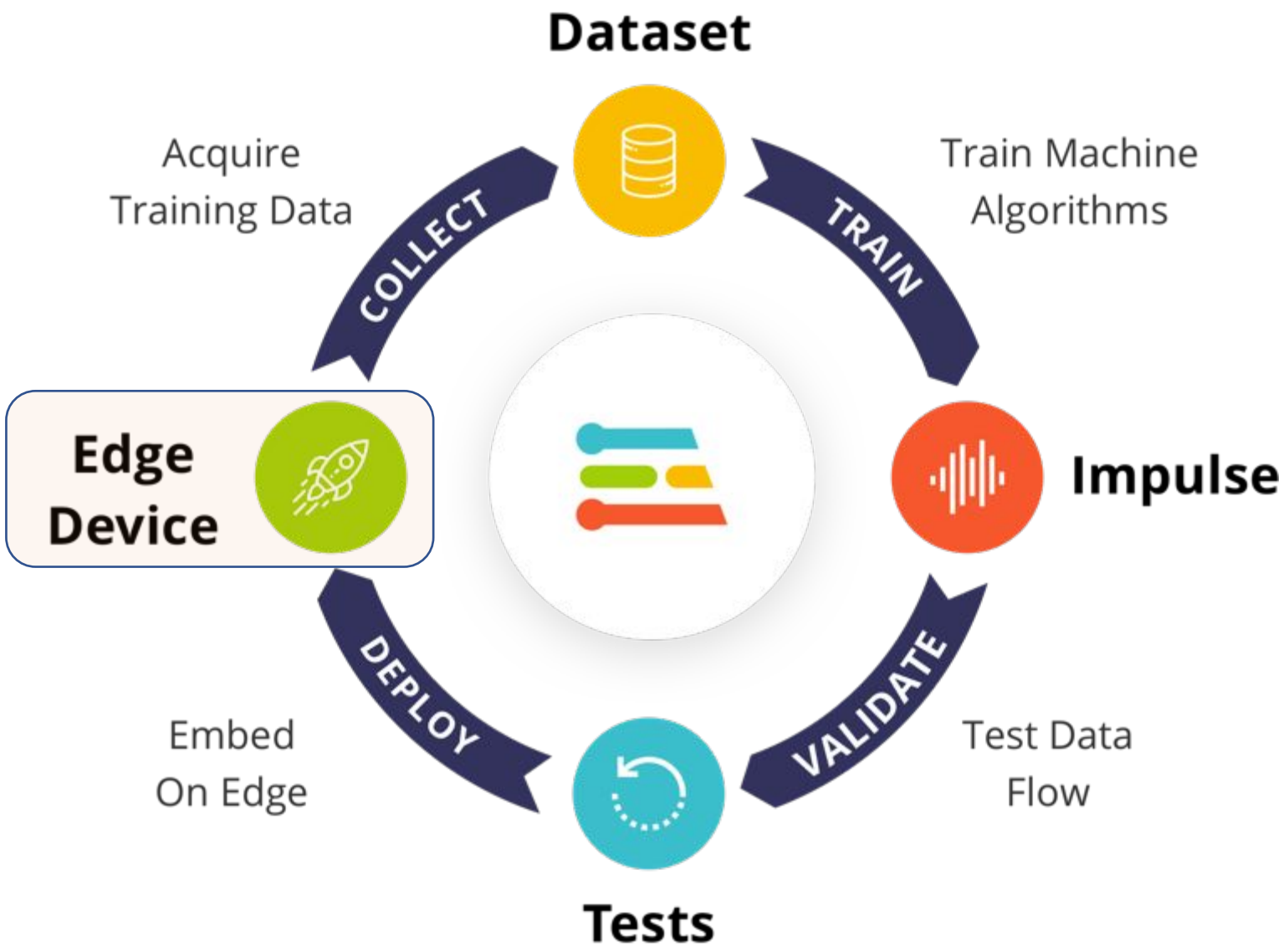


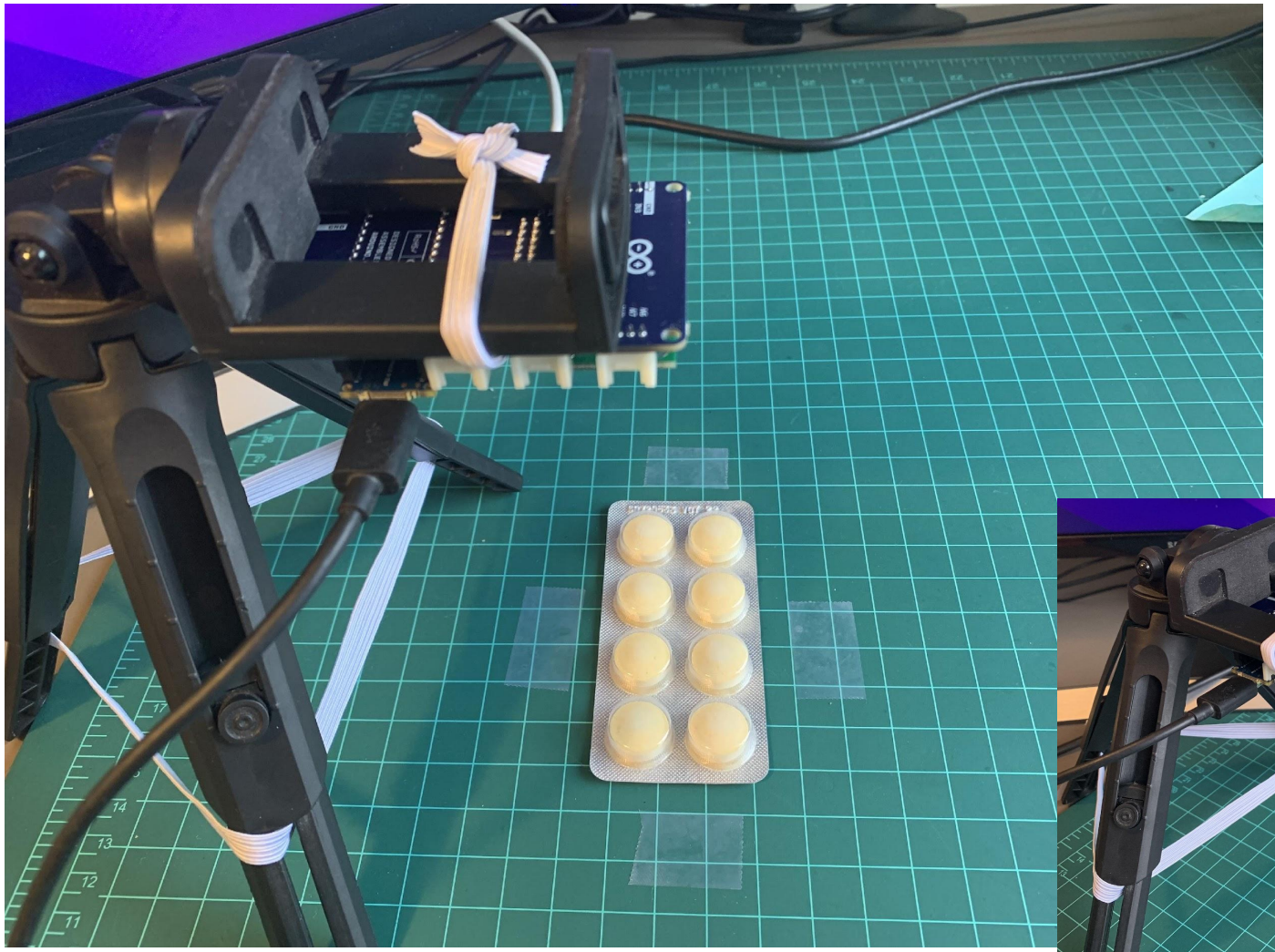
Image Classification Application: Design, Train, Test and Deploy

https://studio.edgeimpulse.com/public/114253/latest


Select project - Edge Impulse
studio.edgeimpulse.com/studio/select-project
EDGE IMPULSE
Marcelo Rovai
Select project
Create a new project
Enter the name for your new project:
IESTI01 - Image Classification
Choose your project type:
Developer
20 min job limit, 4GB or 4 hours of data, limited collaboration.
Enterprise
No job or data size limits, higher performance, custom blocks. Learn more
Create new project
NAME
Marcelo Rovai / SciTinyML22-KWS
Marcelo Rovai / Cifar10_Image_Classification
Marcelo Rovai / IESTI01-Cifar10_Classification
Marcelo Rovai / Bean Disease Classifier

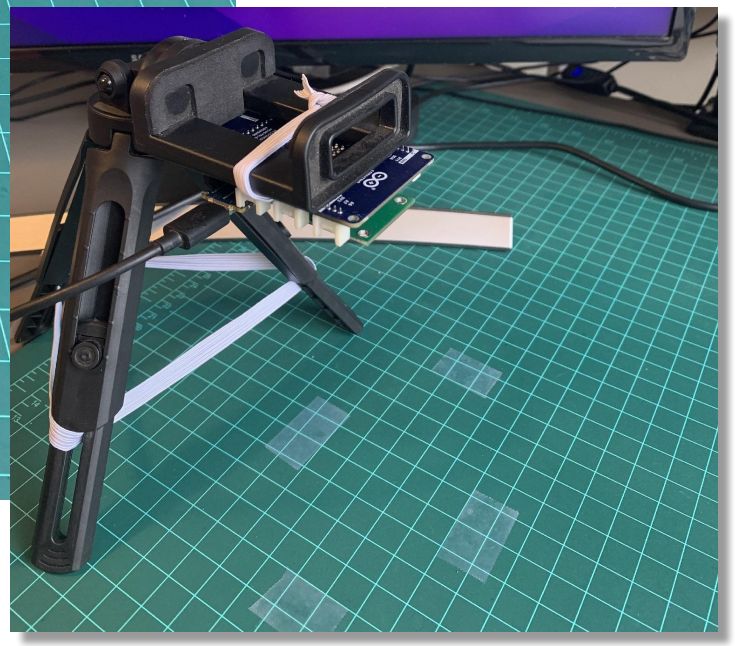


- Pre-Processing Data
- Design a Model
- Train a Model



Label: medicine

Label: background



Arduino CLI

EDGE IMPULSE Home API Reference Log In

Guides > Arduino Nano 33 BLE Sense Search ⌘K

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
- 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

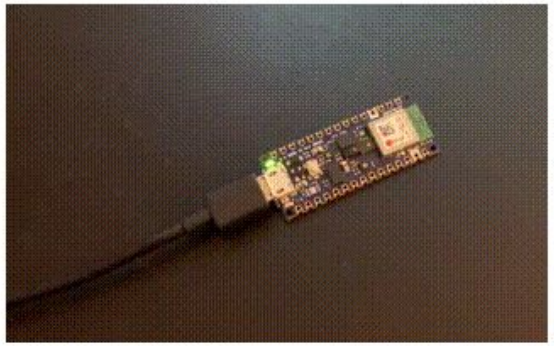
To set this device up in Edge Impulse, you will need to install the following software:

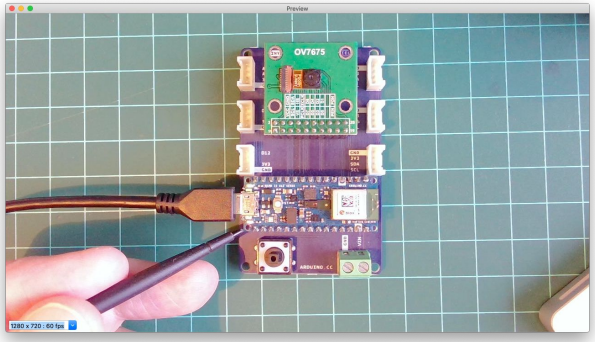
1. Edge Impulse CLI.
2. Arduino CLI.
   - Here's an instruction video for Windows.
   - The Arduino website has instructions for macOS and Linux.
3. On Linux:
   - GNU Screen: install for example via `sudo apt install screen`.

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

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

Nano 33 BLE Sense | Overview

docs/arduino-nano-33-ble-sense

DOCUMENTATION

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

DEVELOPMENT BOARDS

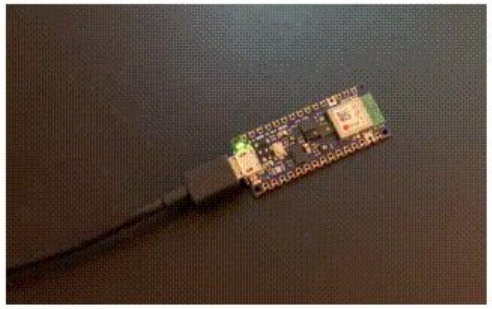
- Overview
- ST B-L475E-IOT01A
- **Arduino Nano 33 BLE Sense**
- Eta Compute ECM3532 AI Sensor
- Eta Compute ECM3532 AI Vision
- OpenMV Cam H7 Plus
- Himax WE-I Plus
- Nordic Semi nRF52840 DK
- Nordic Semi nRF5340 DK
- SiLabs Thunderboard Sense 2
- Sony's Spresense
- Arduino Portenta H7 + Vision shield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

COMMUNITY BOARDS

- Seeed Wio Terminal
- Agora Product Development Kit

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.

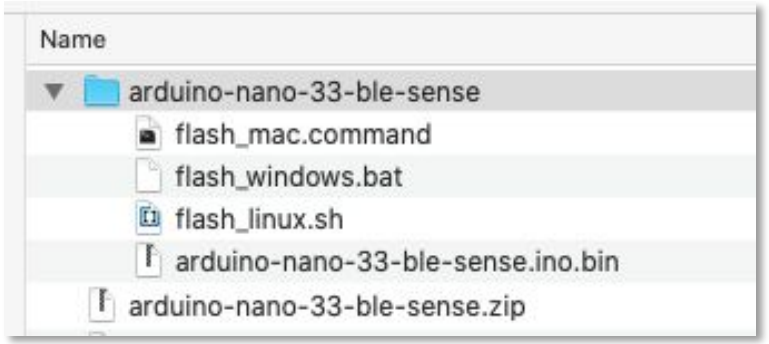
1

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

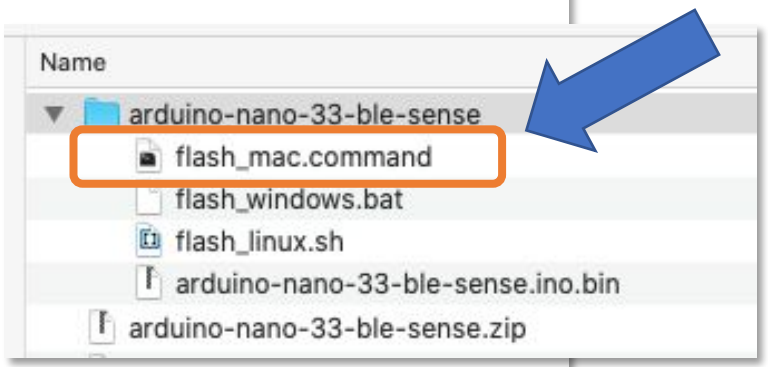


2

MacOS

```
mjrovai — flash_mac.command — 124×43
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:



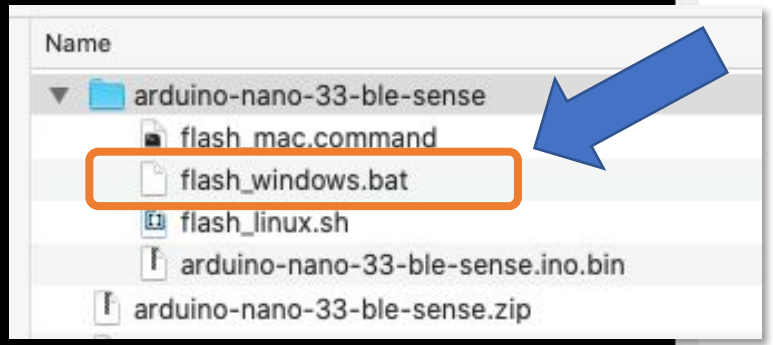
3.Nano-33 LED Stop Flashing

Windows 10

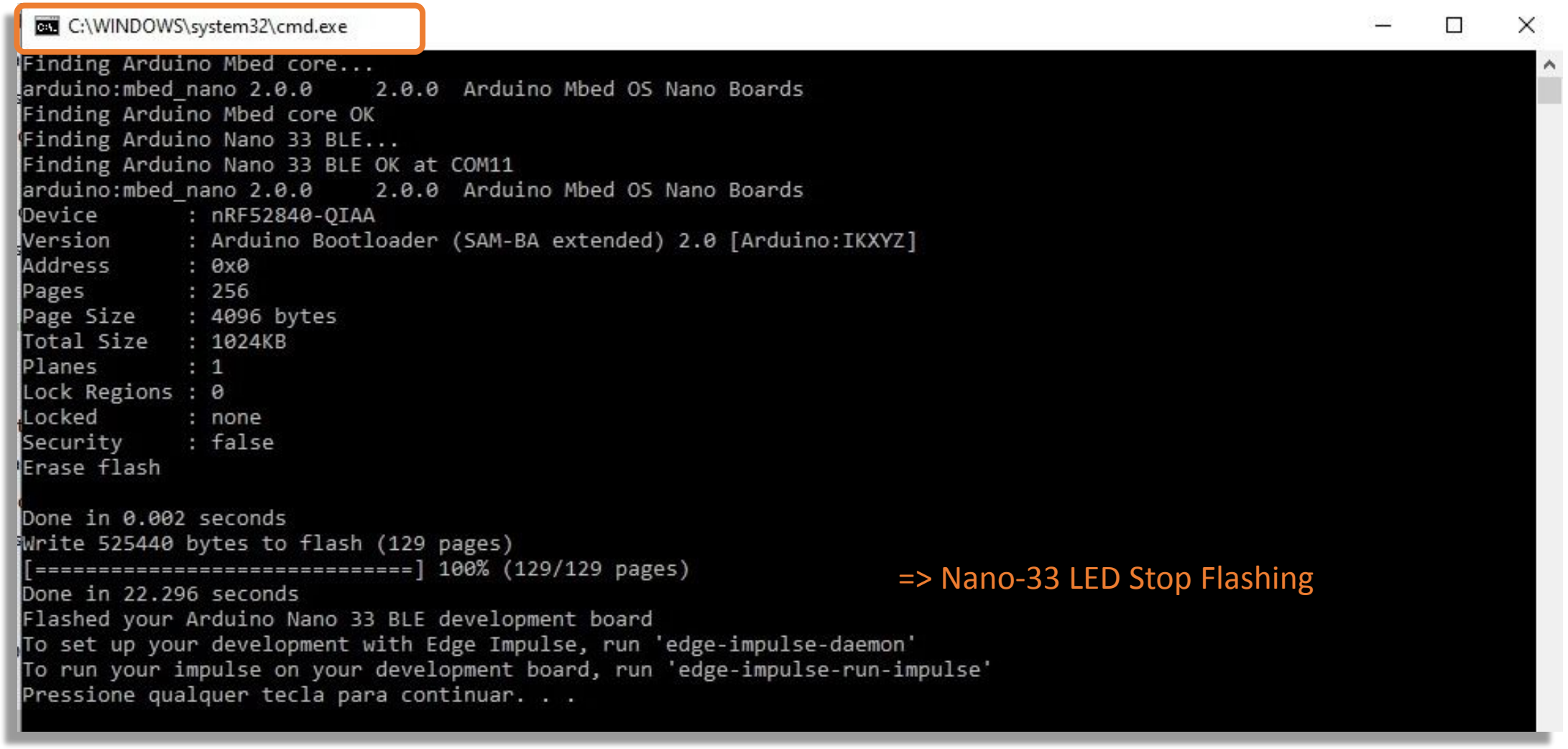
Prompt de Comando

```
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:

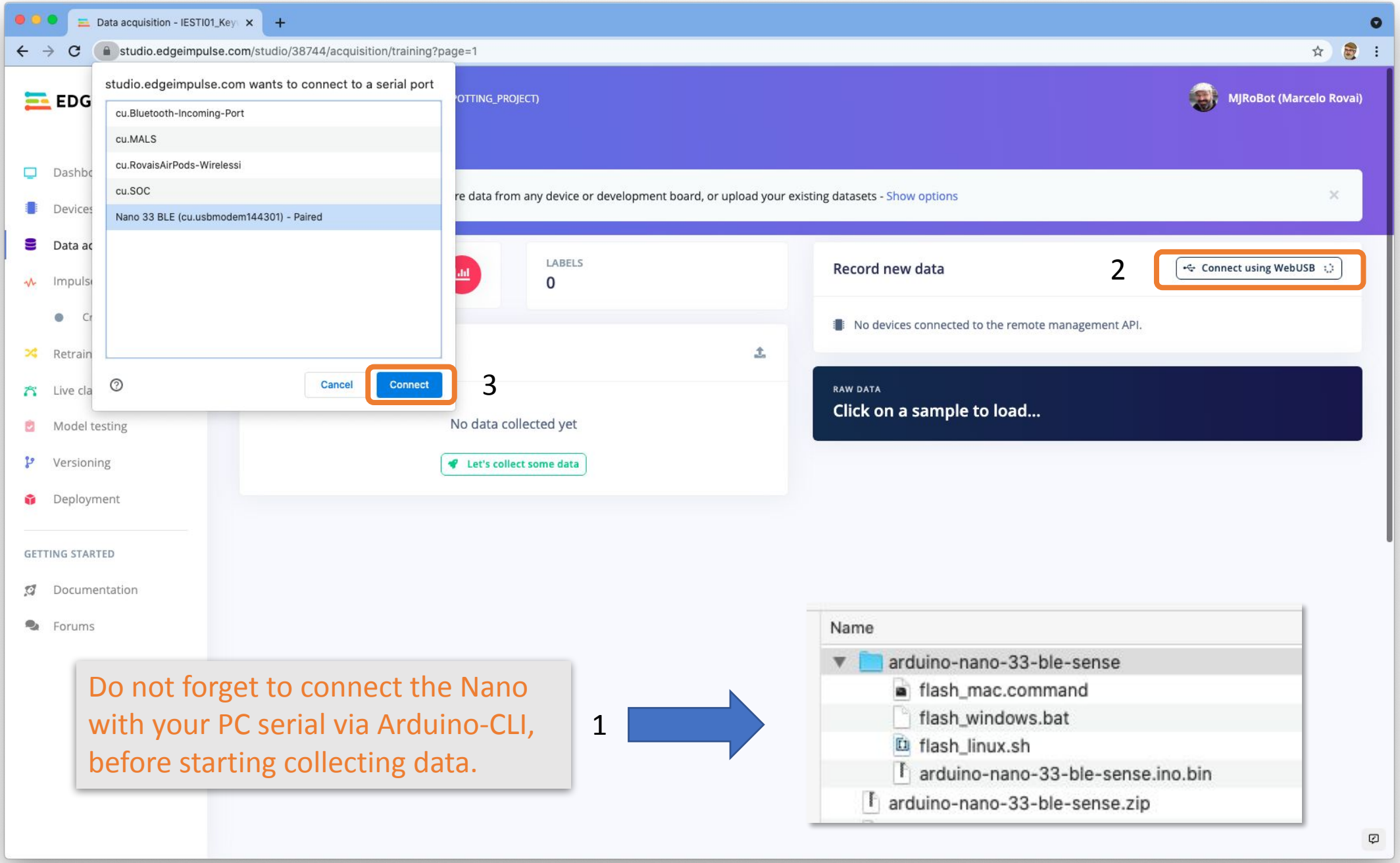


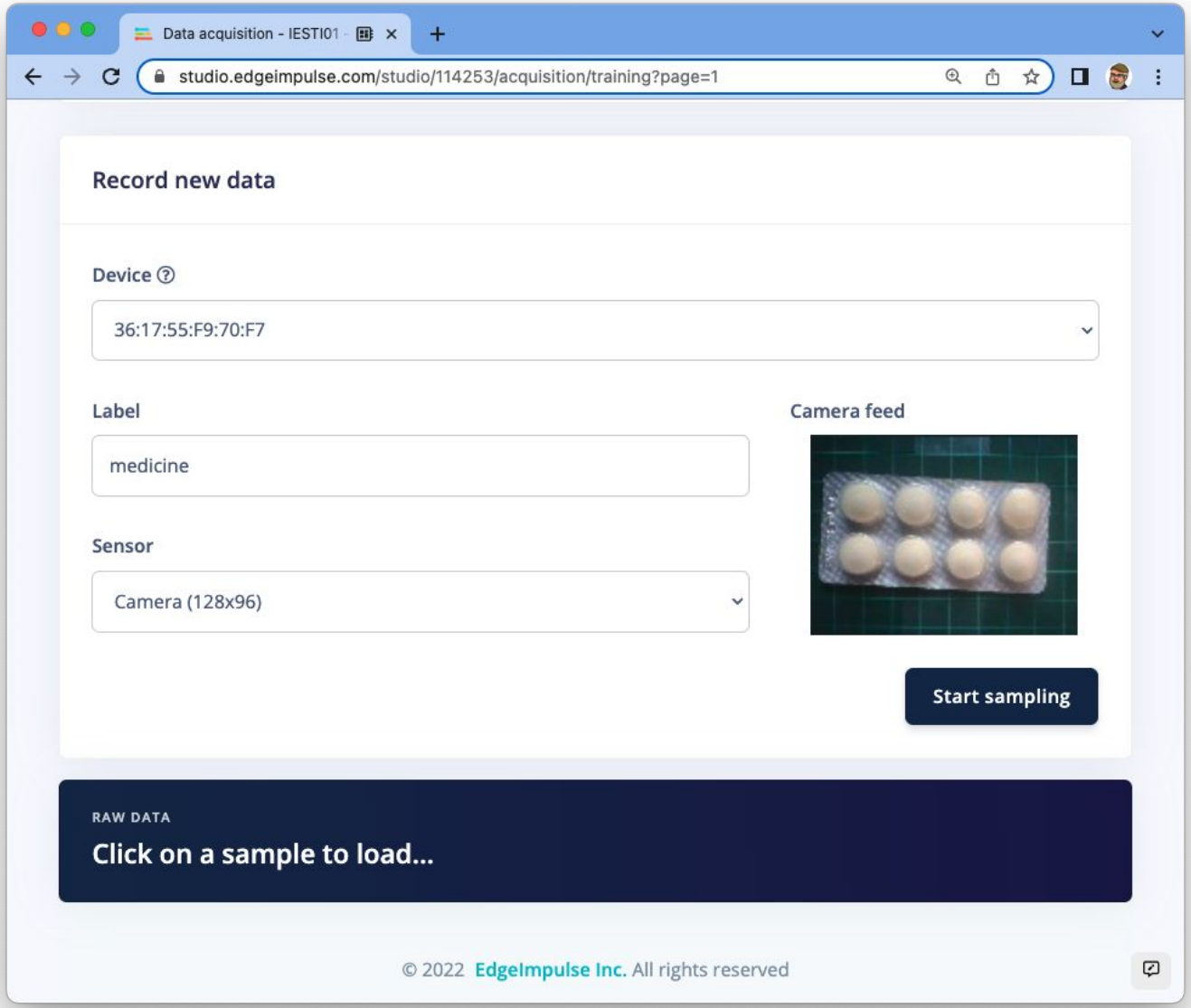
Windows 10

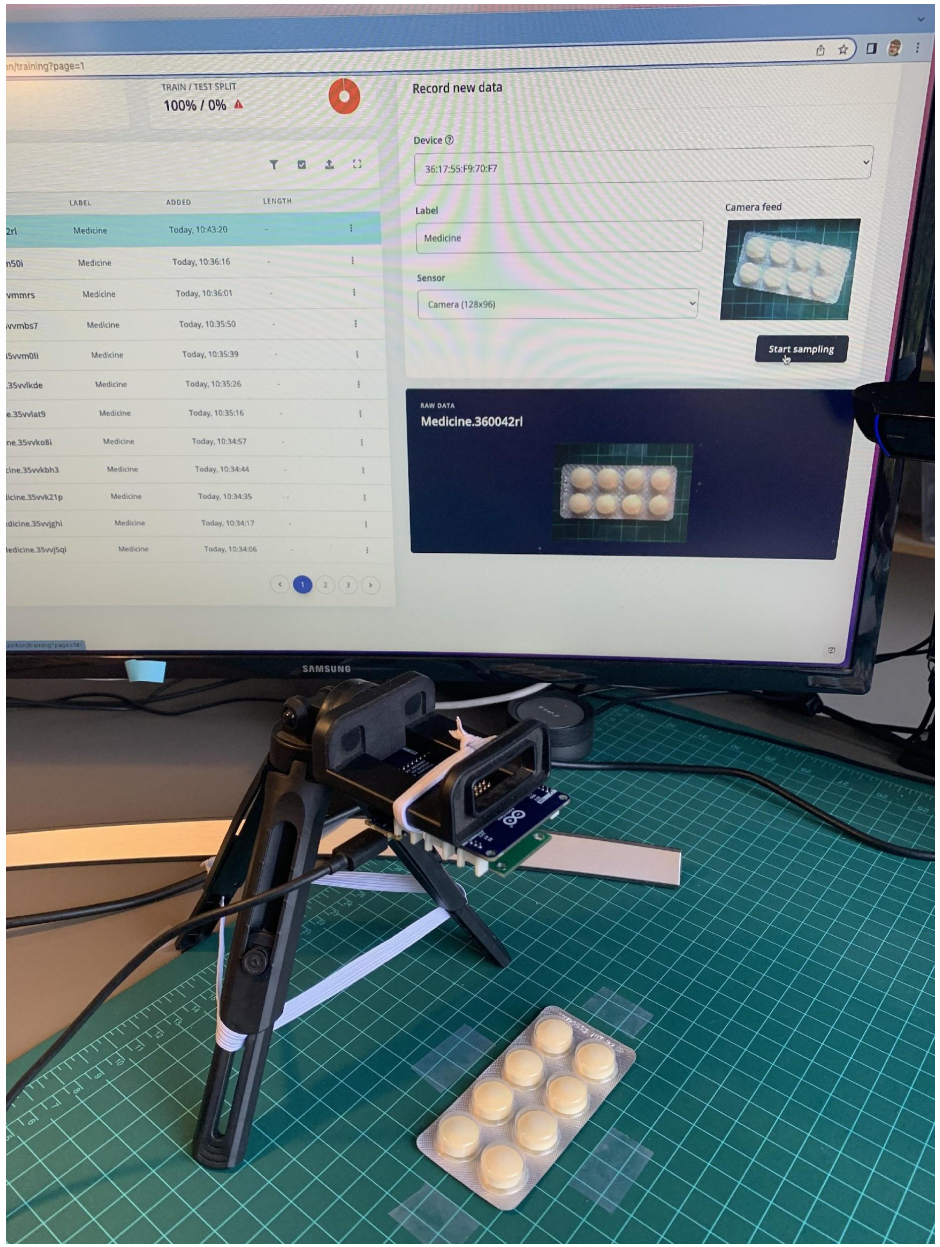


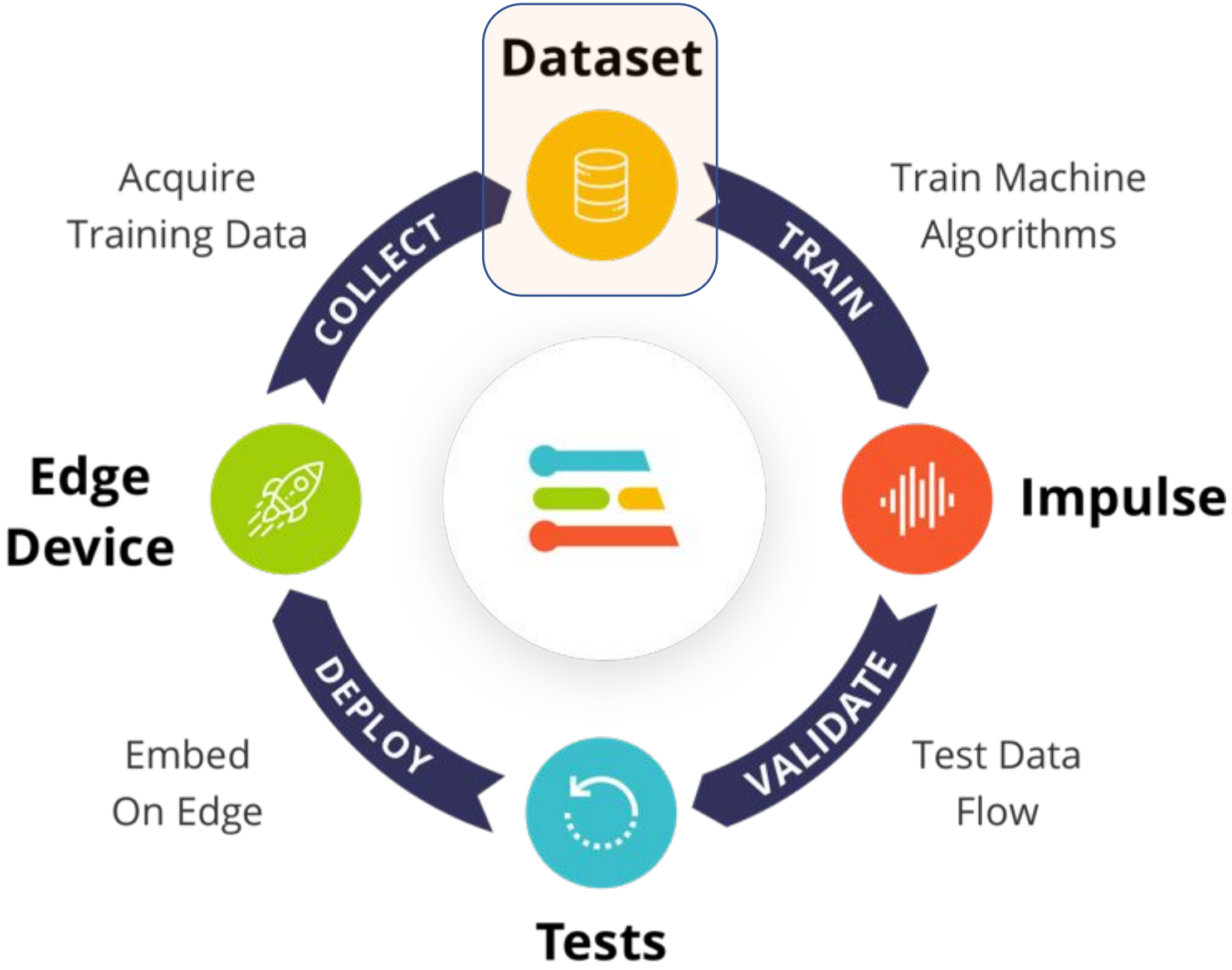
=> Nano-33 LED Stop Flashing

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**.

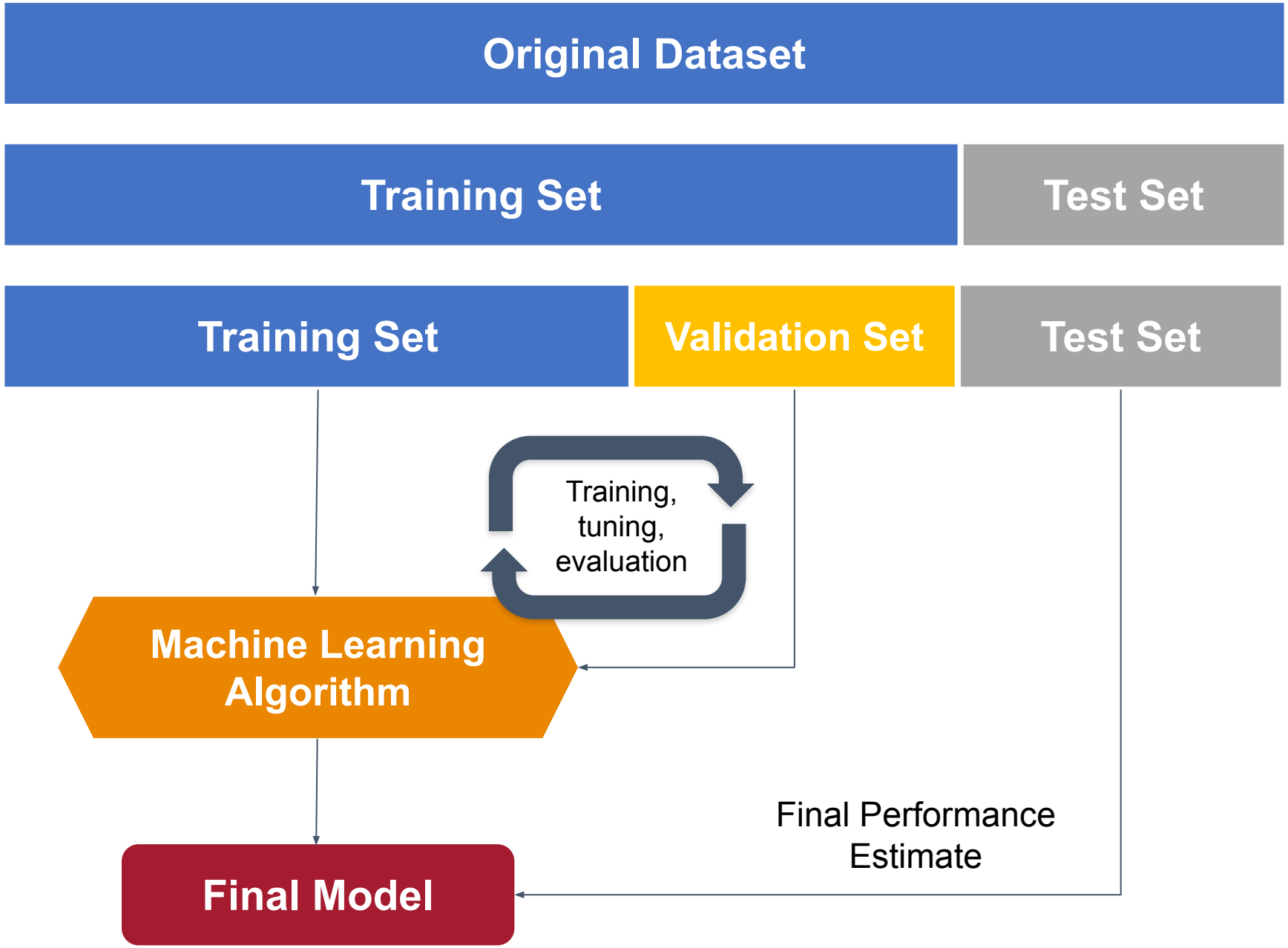

Data acquisition - IESTI01_Key
studio.edgeimpulse.com/studio/38744/acquisition/training?page=1
studio.edgeimpulse.com wants to connect to a serial port
cu.Bluetooth-Incoming-Port
cu.MALS
cu.RovaisAirPods-Wirelessi
cu.SOC
Nano 33 BLE (cu.usbmodem144301) - Paired
Cancel
Connect
3
MJRoBot (Marcelo Rovai)
re data from any device or development board, or upload your existing datasets - Show options
LABELS
0
Record new data
2
Connect using WebUSB
No devices connected to the remote management API.
RAW DATA
Click on a sample to load...
No data collected yet
Let's collect some data
Dashbo
Devices
Data ac
Impulse
Retrain
Live cla
Model testing
Versioning
Deployment
GETTING STARTED
Documentation
Forums
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

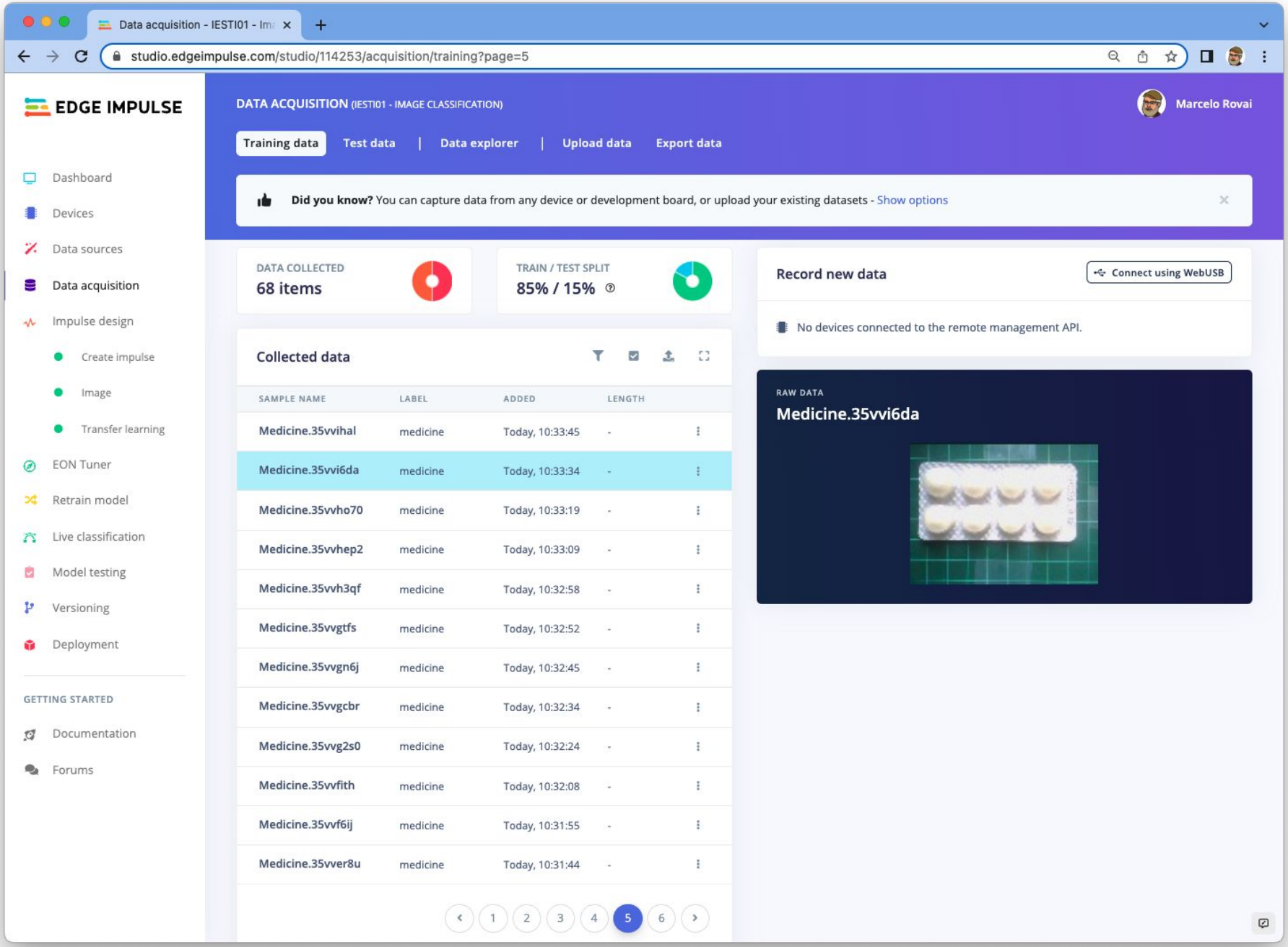

Data acquisition - IESTI01
studio.edgeimpulse.com/studio/114253/acquisition/training?page=1
Record new data
Device
36:17:55:F9:70:F7
Label
medicine
Sensor
Camera (128x96)
Camera feed
Start sampling
RAW DATA
Click on a sample to load...
© 2022 EdgeImpulse Inc. All rights reserved

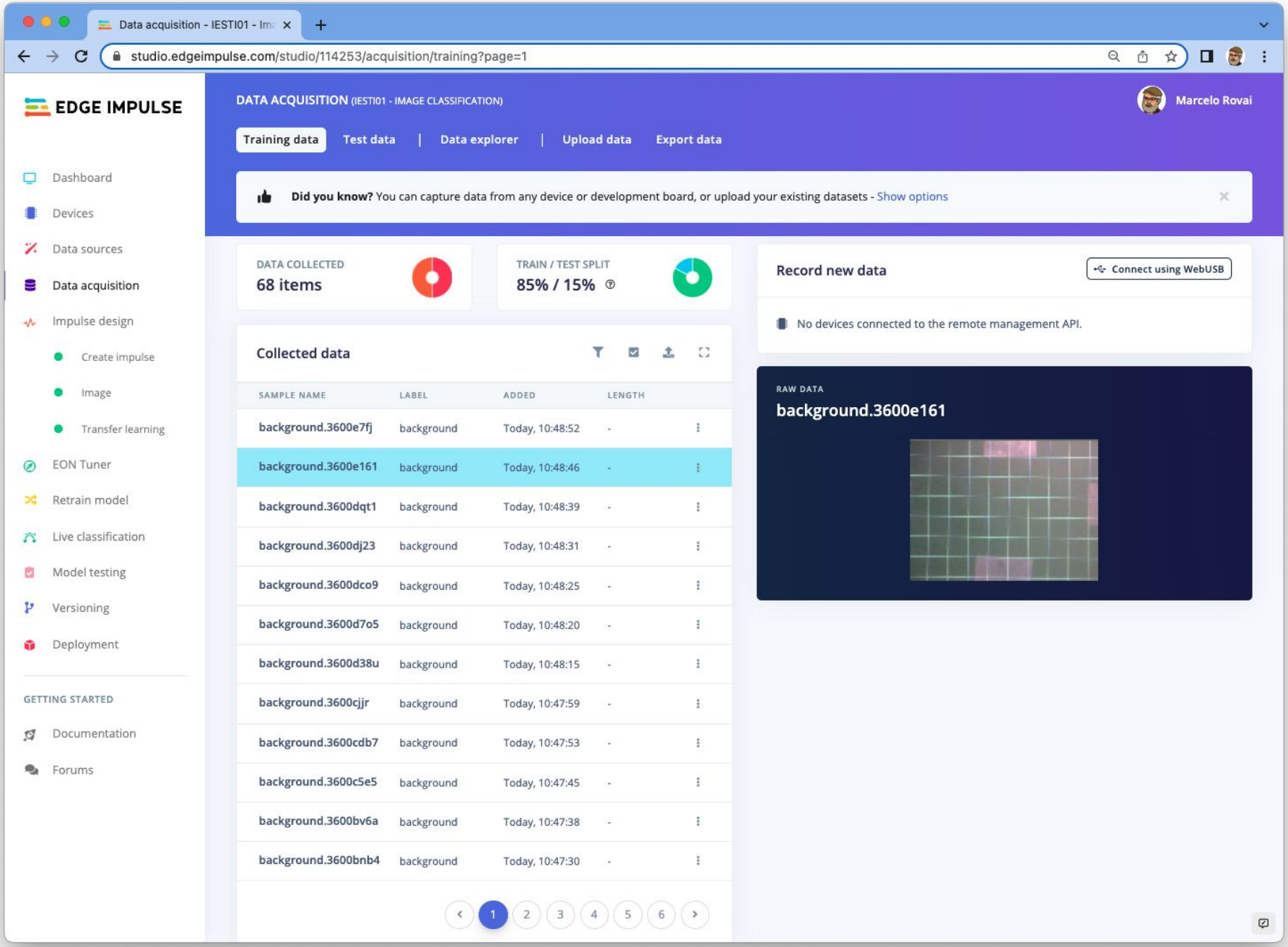

Record new data
Device
36:17:55:F9:70:F7
Label
Medicine
Sensor
Camera (128x96)
Camera feed
Start sampling
RAW DATA
Medicine.360042rl
SAMSUNG

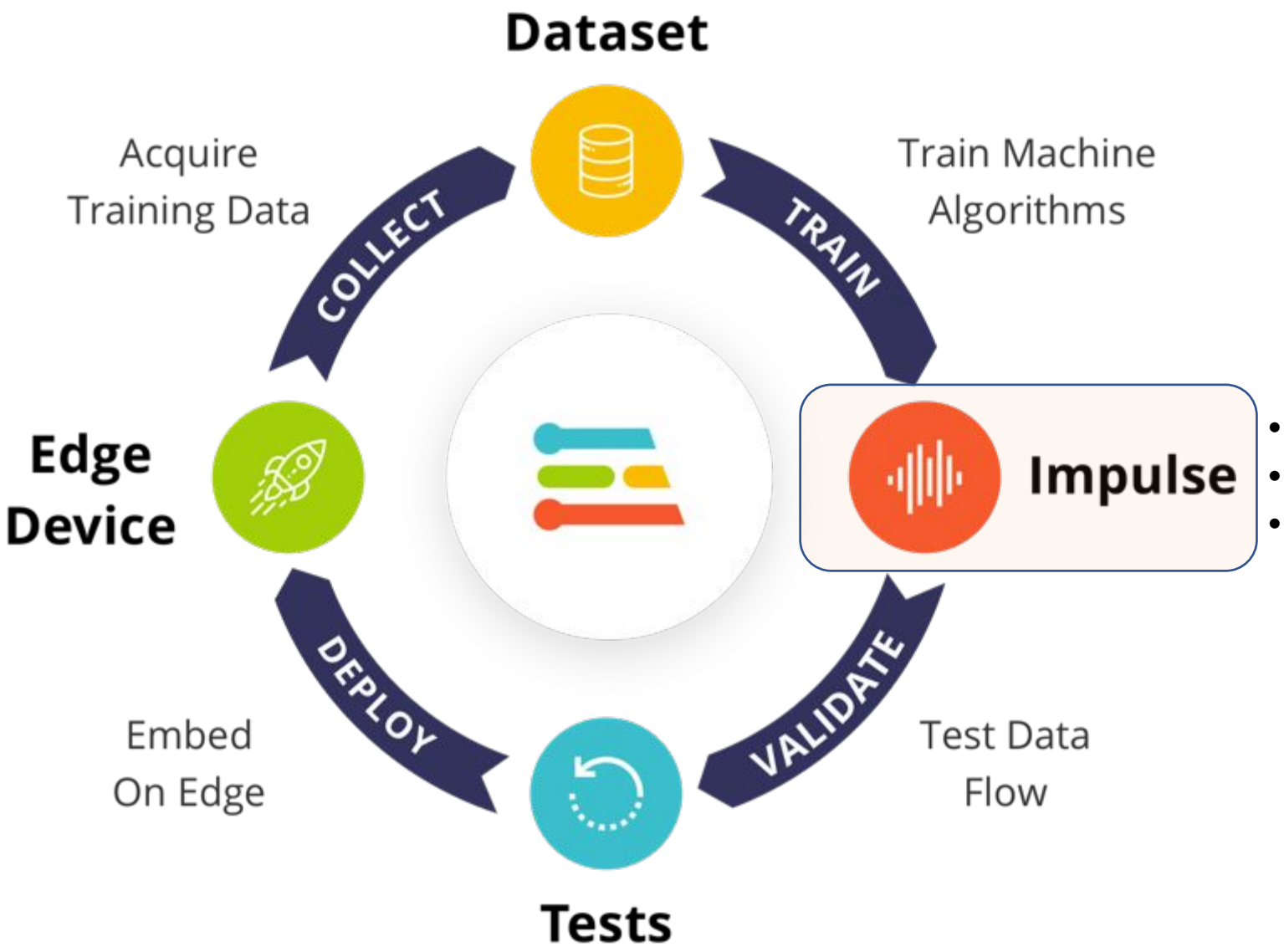


- Pre-Processing Data
- Design a Model
- Train a Model


Original Dataset
Training Set
Test Set
Training Set
Validation Set
Test Set
Training,
tuning,
evaluation
Machine Learning
Algorithm
Final Performance
Estimate
Final Model


Data acquisition - IESTI01 - Im
studio.edgeimpulse.com/studio/114253/acquisition/training?page=5
EDGE IMPULSE
DATA ACQUISITION (IESTI01 - IMAGE CLASSIFICATION)
Marcelo Rovai
Training data
Test data
Data explorer
Upload data
Export data
Dashboard
Devices
Data sources
Data acquisition
Impulse design
Create impulse
Image
Transfer learning
EON Tuner
Retrain model
Live classification
Model testing
Versioning
Deployment
GETTING STARTED
Documentation
Forums
Did you know? You can capture data from any device or development board, or upload your existing datasets - Show options
DATA COLLECTED
68 items
TRAIN / TEST SPLIT
85% / 15%
Record new data
Connect using WebUSB
No devices connected to the remote management API.
Collected data
SAMPLE NAME
LABEL
ADDED
LENGTH
Medicine.35vvihal medicine Today, 10:33:45 -
Medicine.35vvi6da medicine Today, 10:33:34 -
Medicine.35vvho70 medicine Today, 10:33:19 -
Medicine.35vvhep2 medicine Today, 10:33:09 -
Medicine.35vvh3qf medicine Today, 10:32:58 -
Medicine.35vvgtfs medicine Today, 10:32:52 -
Medicine.35vvgn6j medicine Today, 10:32:45 -
Medicine.35vvgcbr medicine Today, 10:32:34 -
Medicine.35vvg2s0 medicine Today, 10:32:24 -
Medicine.35vvfith medicine Today, 10:32:08 -
Medicine.35vvf6ij medicine Today, 10:31:55 -
Medicine.35vver8u medicine Today, 10:31:44 -
1 2 3 4 5 6
RAW DATA
Medicine.35vvi6da

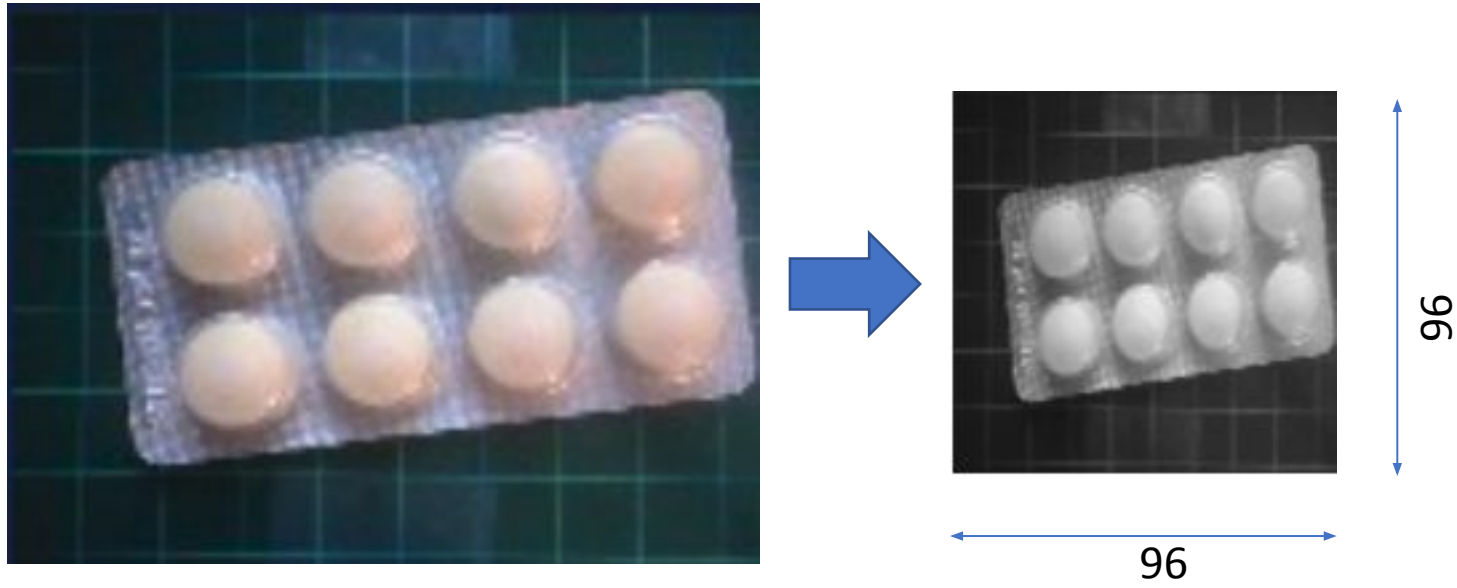

Data acquisition - IESTI01 - Im
studio.edgeimpulse.com/studio/114253/acquisition/training?page=1
EDGE IMPULSE
DATA ACQUISITION (IESTI01 - IMAGE CLASSIFICATION)
Marcelo Rovai
Training data
Test data
Data explorer
Upload data
Export data
Did you know? You can capture data from any device or development board, or upload your existing datasets - Show options
Dashboard
Devices
Data sources
Data acquisition
Impulse design
Create impulse
Image
Transfer learning
EON Tuner
Retrain model
Live classification
Model testing
Versioning
Deployment
GETTING STARTED
Documentation
Forums
DATA COLLECTED
68 items
TRAIN / TEST SPLIT
85% / 15%
Record new data
Connect using WebUSB
No devices connected to the remote management API.
Collected data
SAMPLE NAME
LABEL
ADDED
LENGTH
background.3600e7fj background Today, 10:48:52 -
background.3600e161 background Today, 10:48:46 -
background.3600dqt1 background Today, 10:48:39 -
background.3600dj23 background Today, 10:48:31 -
background.3600dco9 background Today, 10:48:25 -
background.3600d7o5 background Today, 10:48:20 -
background.3600d38u background Today, 10:48:15 -
background.3600cjjr background Today, 10:47:59 -
background.3600cdb7 background Today, 10:47:53 -
background.3600c5e5 background Today, 10:47:45 -
background.3600bv6a background Today, 10:47:38 -
background.3600bnb4 background Today, 10:47:30 -
1 2 3 4 5 6
RAW DATA
background.3600e161



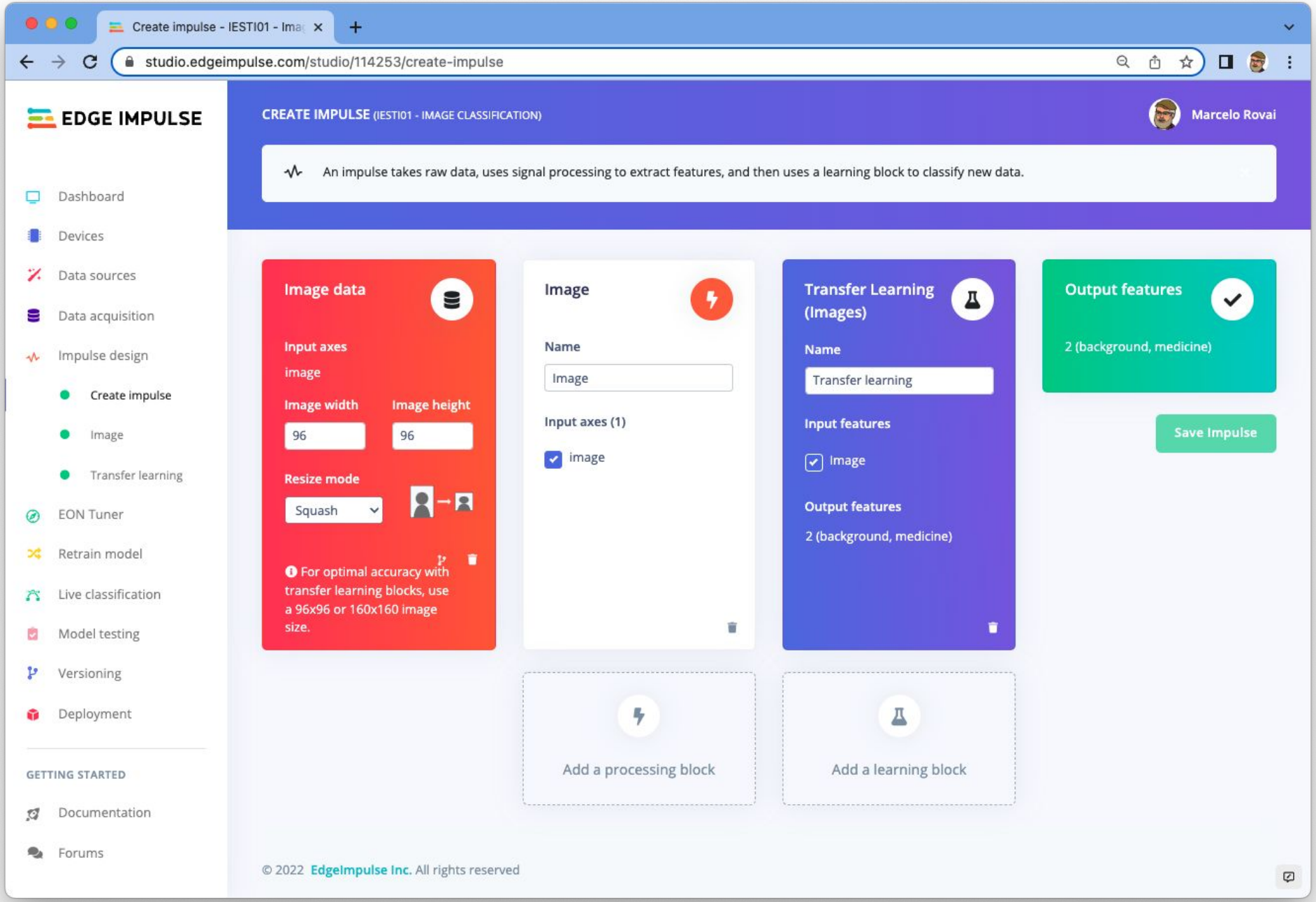
- Pre-Processing Data
- Design a Model
- Train a Model

Data Pre-processing

- Image Pre-Process *:
  - Convert to Grayscale
  - Re-scale 96 x 96



* During Inference, the OV7675 captures the raw image as:
- QQVGA (160 x 120), crop it and resize it to 96x96
- RGB565 and convert it first to RGB888 and after it to Grayscale
- 1FPS


Create impulse - IESTI01 - Ima
studio.edgeimpulse.com/studio/114253/create-impulse
EDGE IMPULSE
Dashboard
Devices
Data sources
Data acquisition
Impulse design
Create impulse
Image
Transfer learning
EON Tuner
Retrain model
Live classification
Model testing
Versioning
Deployment
GETTING STARTED
Documentation
Forums
CREATE IMPULSE (IESTI01 - IMAGE CLASSIFICATION)
Marcelo Rovai
An impulse takes raw data, uses signal processing to extract features, and then uses a learning block to classify new data.
Image data
Input axes
image
Image width
96
Image height
96
Resize mode
Squash
For optimal accuracy with transfer learning blocks, use a 96x96 or 160x160 image size.
Image
Name
Image
Input axes (1)
image
Transfer Learning (Images)
Name
Transfer learning
Input features
Image
Output features
2 (background, medicine)
Output features
2 (background, medicine)
Save Impulse
Add a processing block
Add a learning block
© 2022 EdgeImpulse Inc. All rights reserved

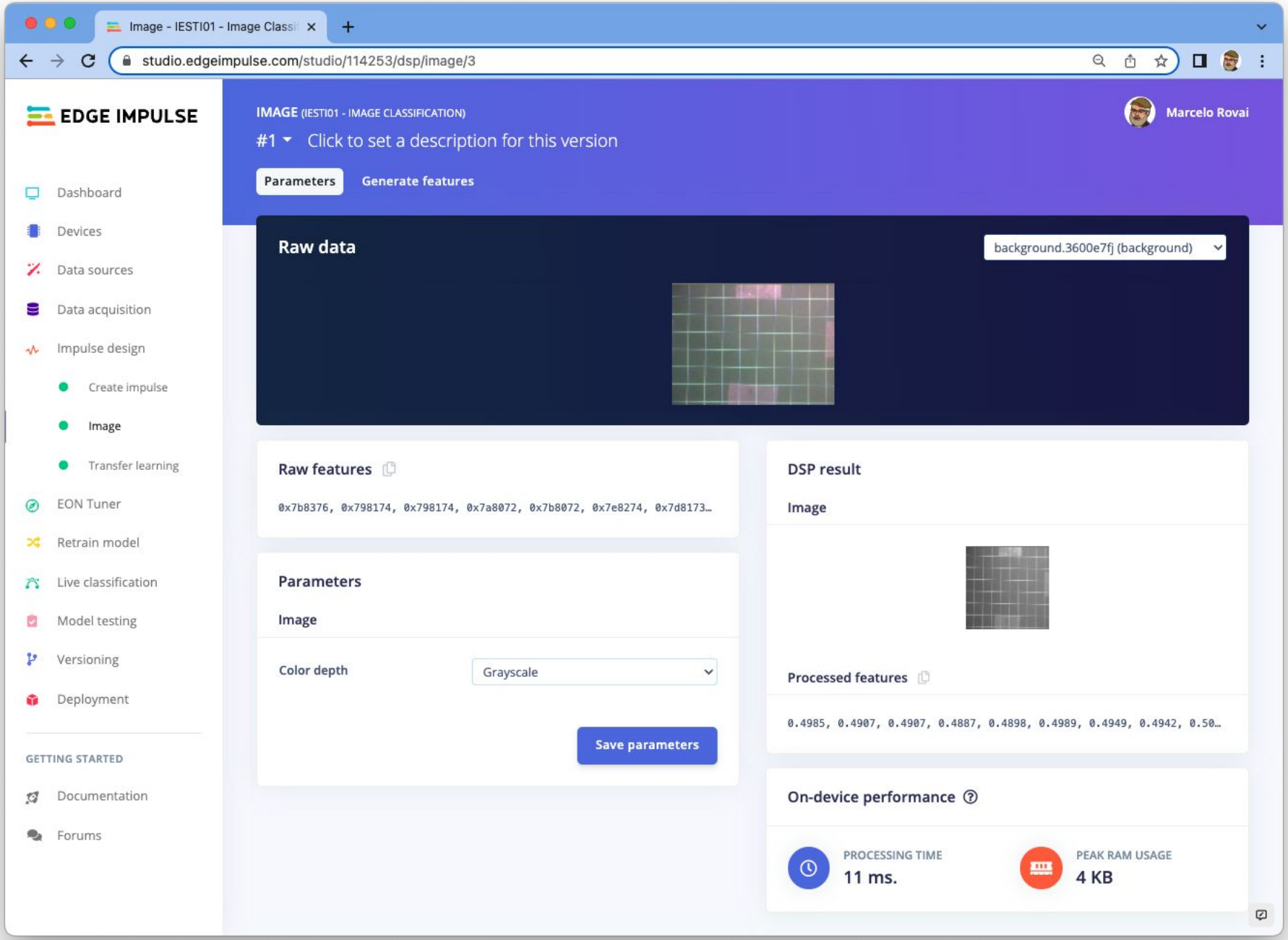


Image - IESTI01 - Image Classi
studio.edgeimpulse.com/studio/114253/dsp/image/3
EDGE IMPULSE
Dashboard
Devices
Data sources
Data acquisition
Impulse design
Create impulse
Image
Transfer learning
EON Tuner
Retrain model
Live classification
Model testing
Versioning
Deployment
GETTING STARTED
Documentation
Forums
IMAGE (IESTI01 - IMAGE CLASSIFICATION)
#1 Click to set a description for this version
Marcelo Rovai
Parameters
Generate features
Raw data
background.3600e7fj (background)
Raw features
0x7b8376, 0x798174, 0x798174, 0x7a8072, 0x7b8072, 0x7e8274, 0x7d8173…
Parameters
Image
Color depth
Grayscale
Save parameters
DSP result
Image
Processed features
0.4985, 0.4907, 0.4907, 0.4887, 0.4898, 0.4989, 0.4949, 0.4942, 0.50…
On-device performance
PROCESSING TIME
11 ms.
PEAK RAM USAGE
4 KB

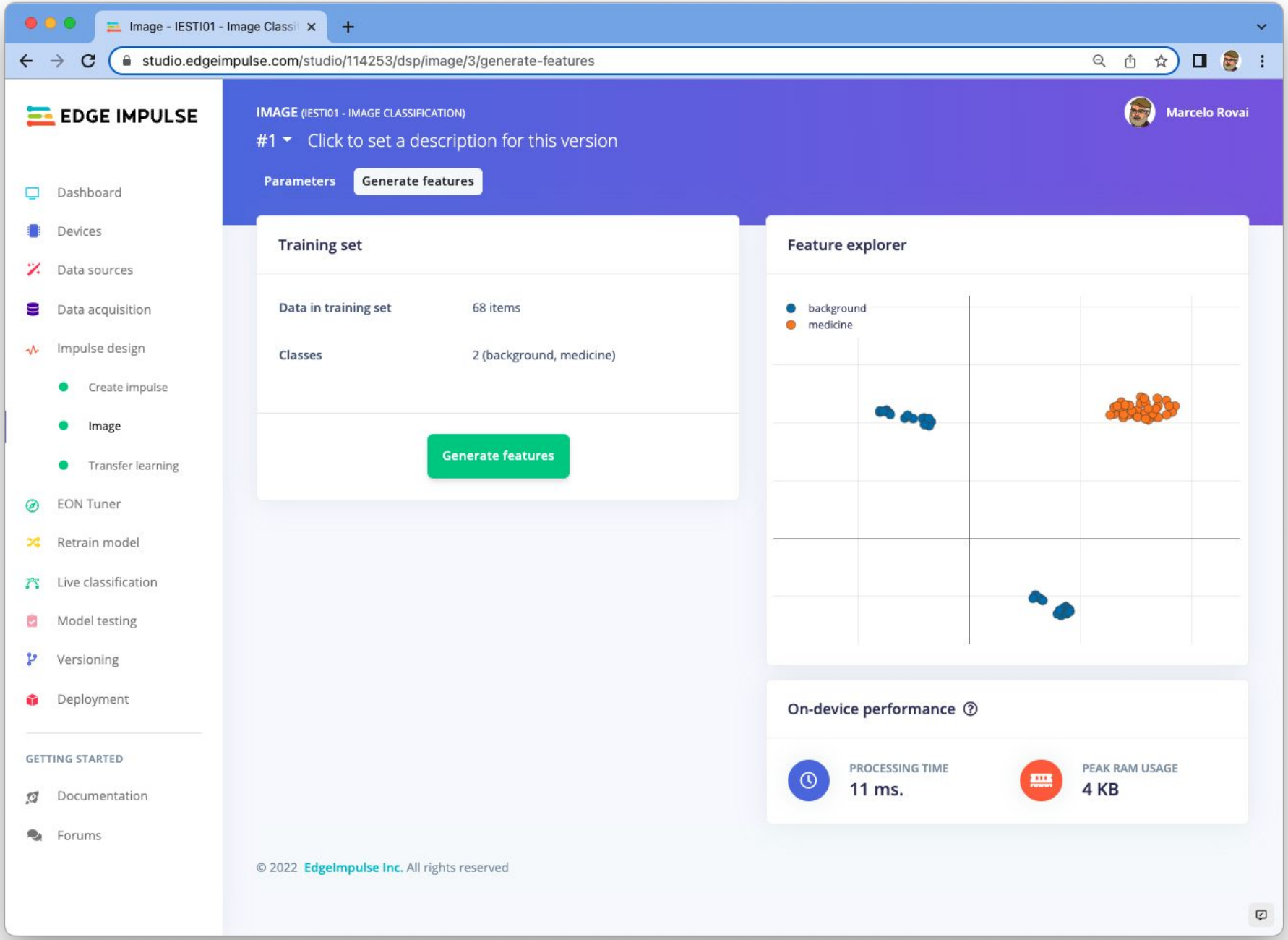


Image - IESTI01 - Image Classi
studio.edgeimpulse.com/studio/114253/dsp/image/3/generate-features
EDGE IMPULSE
IMAGE (IESTI01 - IMAGE CLASSIFICATION)
Marcelo Rovai
#1
Click to set a description for this version
Parameters
Generate features
Dashboard
Devices
Data sources
Data acquisition
Impulse design
Create impulse
Image
Transfer learning
EON Tuner
Retrain model
Live classification
Model testing
Versioning
Deployment
GETTING STARTED
Documentation
Forums
Training set
Data in training set
68 items
Classes
2 (background, medicine)
Generate features
Feature explorer
background
medicine
On-device performance
PROCESSING TIME
11 ms.
PEAK RAM USAGE
4 KB
© 2022 EdgeImpulse Inc. All rights reserved

Model Design

MobileNetV1 96x96 0.25

A pre-trained multi-layer convolutional network designed to efficiently classify images. Uses around 105.9K RAM and 301.6K ROM with default settings and optimizations. Works best with 96x96 input size. Supports both RGB and grayscale.

Model

Image Size

MobileNetV1 96x96 0.2

Alpha

Uses around 83.1K RAM and 218.3K ROM with default settings and optimizations. Works best with 96x96 input size. Supports both RGB and grayscale.

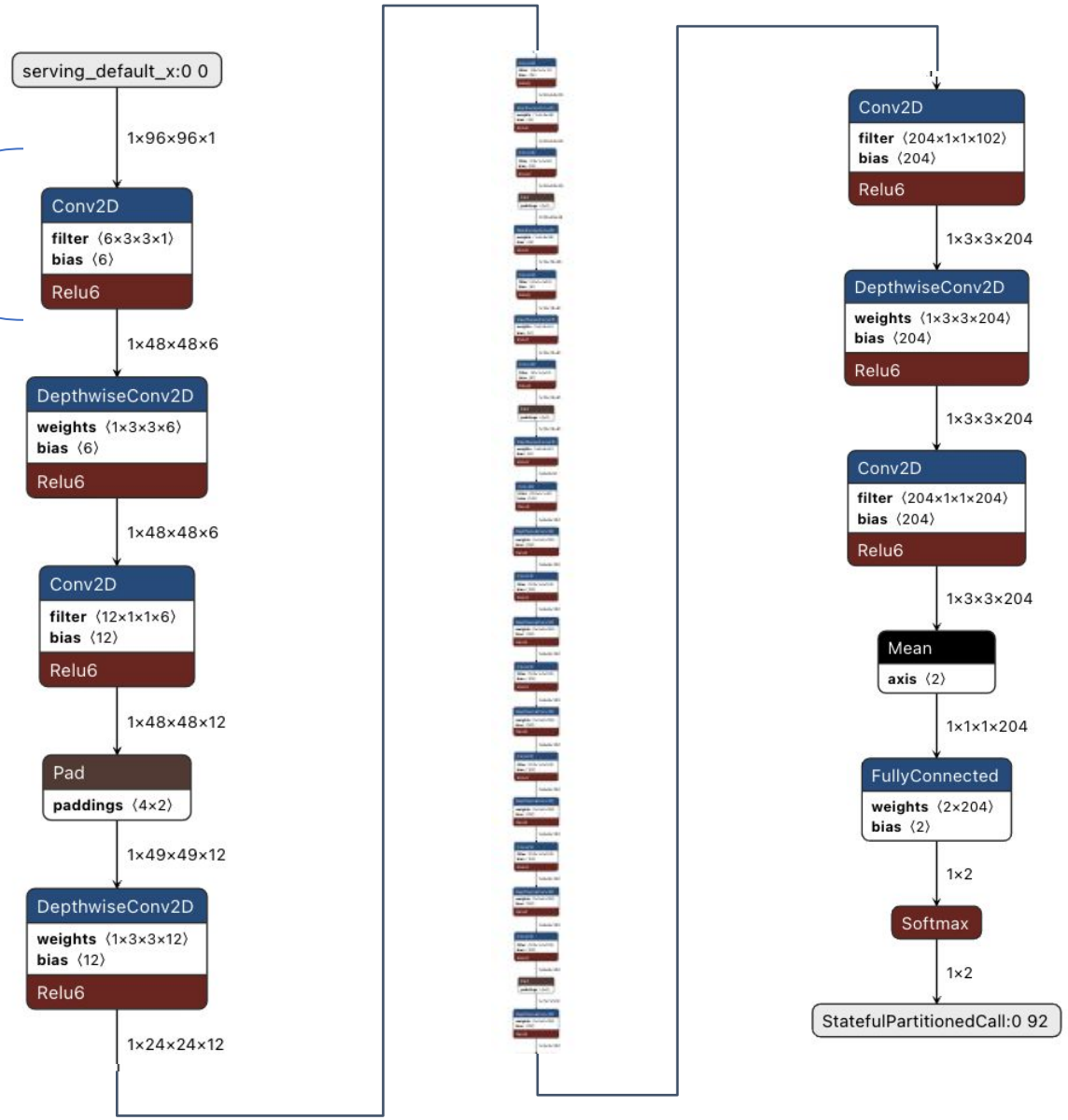
MobileNetV1 96x96 0.1

Uses around 53.2K RAM and 101K ROM with default settings and optimizations. Works best with 96x96 input size. Supports both RGB and grayscale.

Model Design

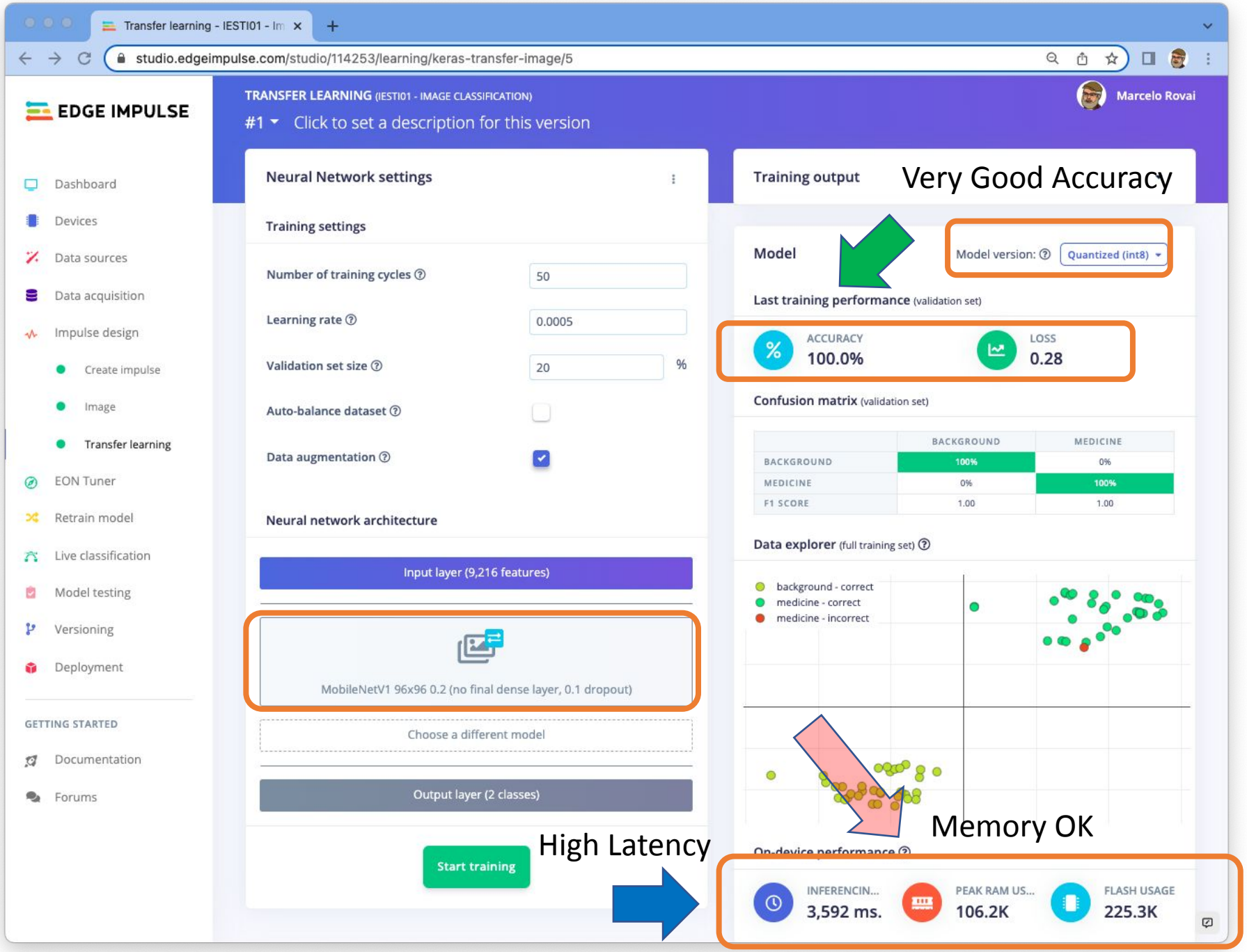
Input layer
(9,216 features
96 x 96)

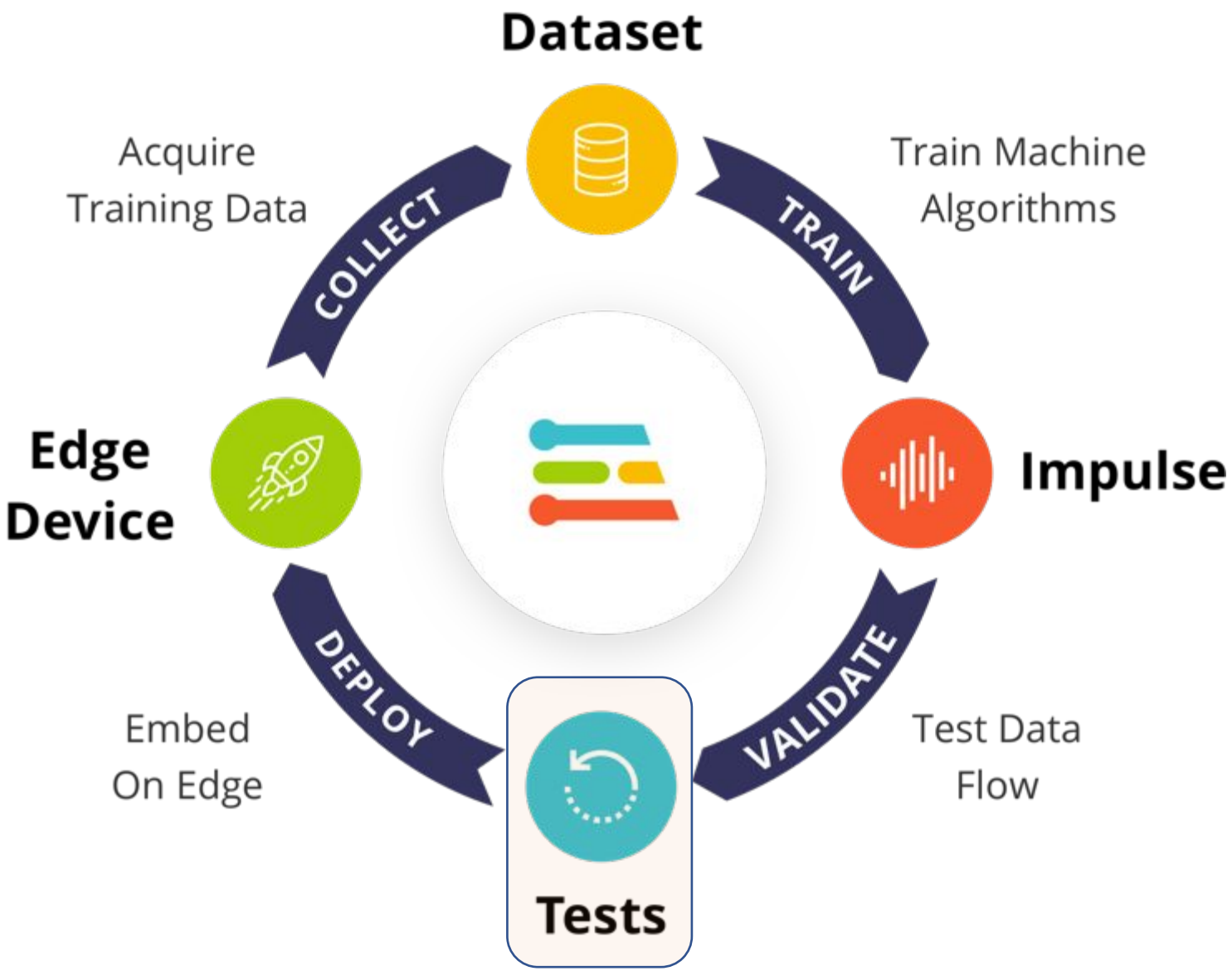
MobileNetV1.0_2
.96x96
.grayscale
.bsize_96
.lr_0_05
.epoch_204
.val_loss_3.87
.val_accuracy_0.23



Output layer
(2 classes)

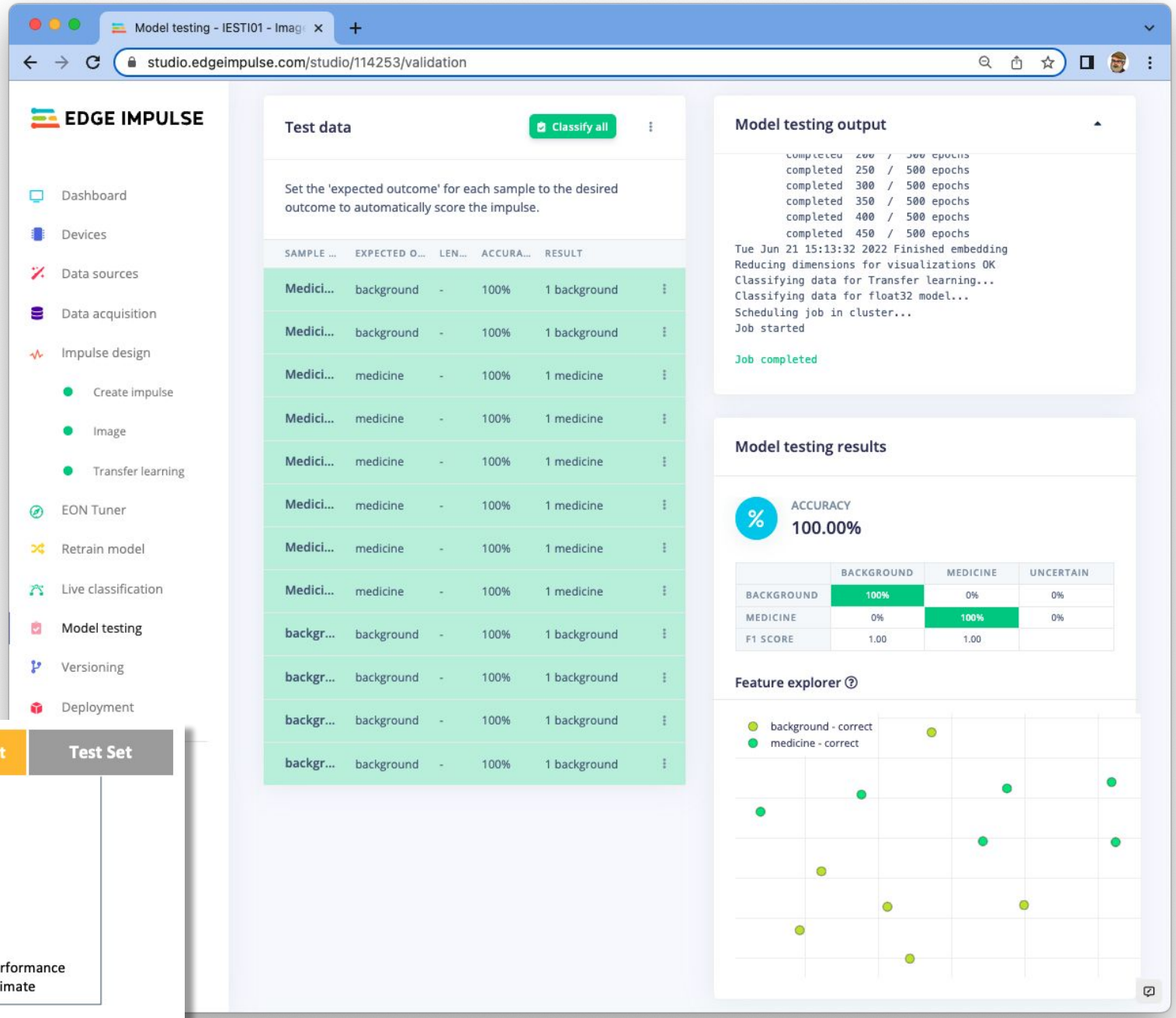
Train

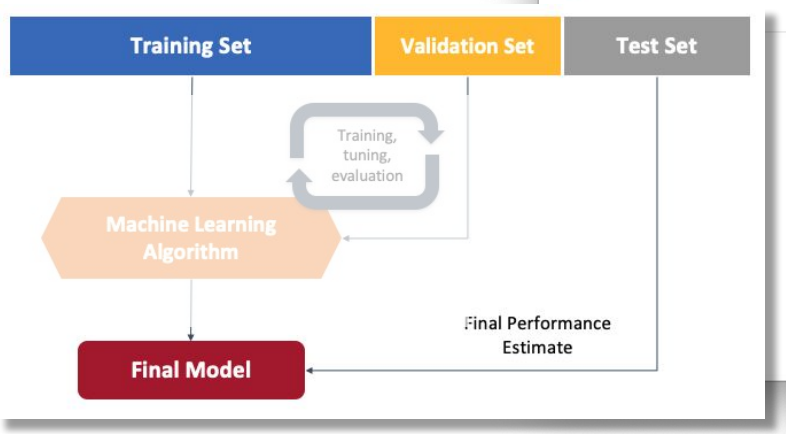

Transfer learning - IESTI01 - Im
studio.edgeimpulse.com/studio/114253/learning/keras-transfer-image/5
EDGE IMPULSE
TRANSFER LEARNING (IESTI01 - IMAGE CLASSIFICATION)
Marcelo Rovai
#1 Click to set a description for this version
Dashboard
Devices
Data sources
Data acquisition
Impulse design
Create impulse
Image
Transfer learning
EON Tuner
Retrain model
Live classification
Model testing
Versioning
Deployment
GETTING STARTED
Documentation
Forums
Neural Network settings
Training settings
Number of training cycles 50
Learning rate 0.0005
Validation set size 20 %
Auto-balance dataset
Data augmentation
Neural network architecture
Input layer (9,216 features)
MobileNetV1 96x96 0.2 (no final dense layer, 0.1 dropout)
Choose a different model
Output layer (2 classes)
Start training
High Latency
Training output
Very Good Accuracy
Model
Model version: Quantized (int8)
Last training performance (validation set)
ACCURACY 100.0%
LOSS 0.28
Confusion matrix (validation set)
BACKGROUND MEDICINE
BACKGROUND 100% 0%
MEDICINE 0% 100%
F1 SCORE 1.00 1.00
Data explorer (full training set)
background - correct
medicine - correct
medicine - incorrect
Memory OK
On-device performance
INFERENCIN... 3,592 ms.
PEAK RAM US... 106.2K
FLASH USAGE 225.3K



- Pre-Processing Data
- Design a Model
- Train a Model

Test


Model testing - IESTI01 - Imag
studio.edgeimpulse.com/studio/114253/validation
EDGE IMPULSE
Dashboard
Devices
Data sources
Data acquisition
Impulse design
Create impulse
Image
Transfer learning
EON Tuner
Retrain model
Live classification
Model testing
Versioning
Deployment
Test data
Classify all
Set the 'expected outcome' for each sample to the desired outcome to automatically score the impulse.
SAMPLE ... EXPECTED O... LEN... ACCURA... RESULT
Medici... background - 100% 1 background
Medici... background - 100% 1 background
Medici... medicine - 100% 1 medicine
Medici... medicine - 100% 1 medicine
Medici... medicine - 100% 1 medicine
Medici... medicine - 100% 1 medicine
Medici... medicine - 100% 1 medicine
Medici... medicine - 100% 1 medicine
backgr... background - 100% 1 background
backgr... background - 100% 1 background
backgr... background - 100% 1 background
backgr... background - 100% 1 background
Model testing output
completed 250 / 500 epochs
completed 300 / 500 epochs
completed 350 / 500 epochs
completed 400 / 500 epochs
completed 450 / 500 epochs
Tue Jun 21 15:13:32 2022 Finished embedding
Reducing dimensions for visualizations OK
Classifying data for Transfer learning...
Classifying data for float32 model...
Scheduling job in cluster...
Job started
Job completed
Model testing results
ACCURACY
100.00%
BACKGROUND MEDICINE UNCERTAIN
BACKGROUND 100% 0% 0%
MEDICINE 0% 100% 0%
F1 SCORE 1.00 1.00
Feature explorer
background - correct
medicine - correct


Training Set
Validation Set
Test Set
Training, tuning, evaluation
Machine Learning Algorithm
Final Performance Estimate
Final Model

Live classification - IESTI0

studio.edgeimpulse.com/studio/114253/classification#load-sample-10929...

Classification result

Summary

Name: testing.3601u5mo

Expected outcome: testing

CATEGORY	COUNT
background	1
medicine	0
uncertain	0

Detailed result — Show only unknowns

BACKGROUND	MEDICINE
0.91	0.09

RAW DATA

testing.3601u5mo

Raw features

0x92917f, 0x92917f, 0x93907f, 0x969080, 0x969080, 0x979080, 0x958e7e, 0x948e80, 0x948f83, 0x949085, 0x939085, 0x8…

Live classification - IESTI0

studio.edgeimpulse.com/studio/114253/classification#load-sample-10929...

Classification result

Summary

Name: testing.36020g3v

Expected outcome: testing

CATEGORY	COUNT
background	0
medicine	1
uncertain	0

Detailed result — Show only unknowns

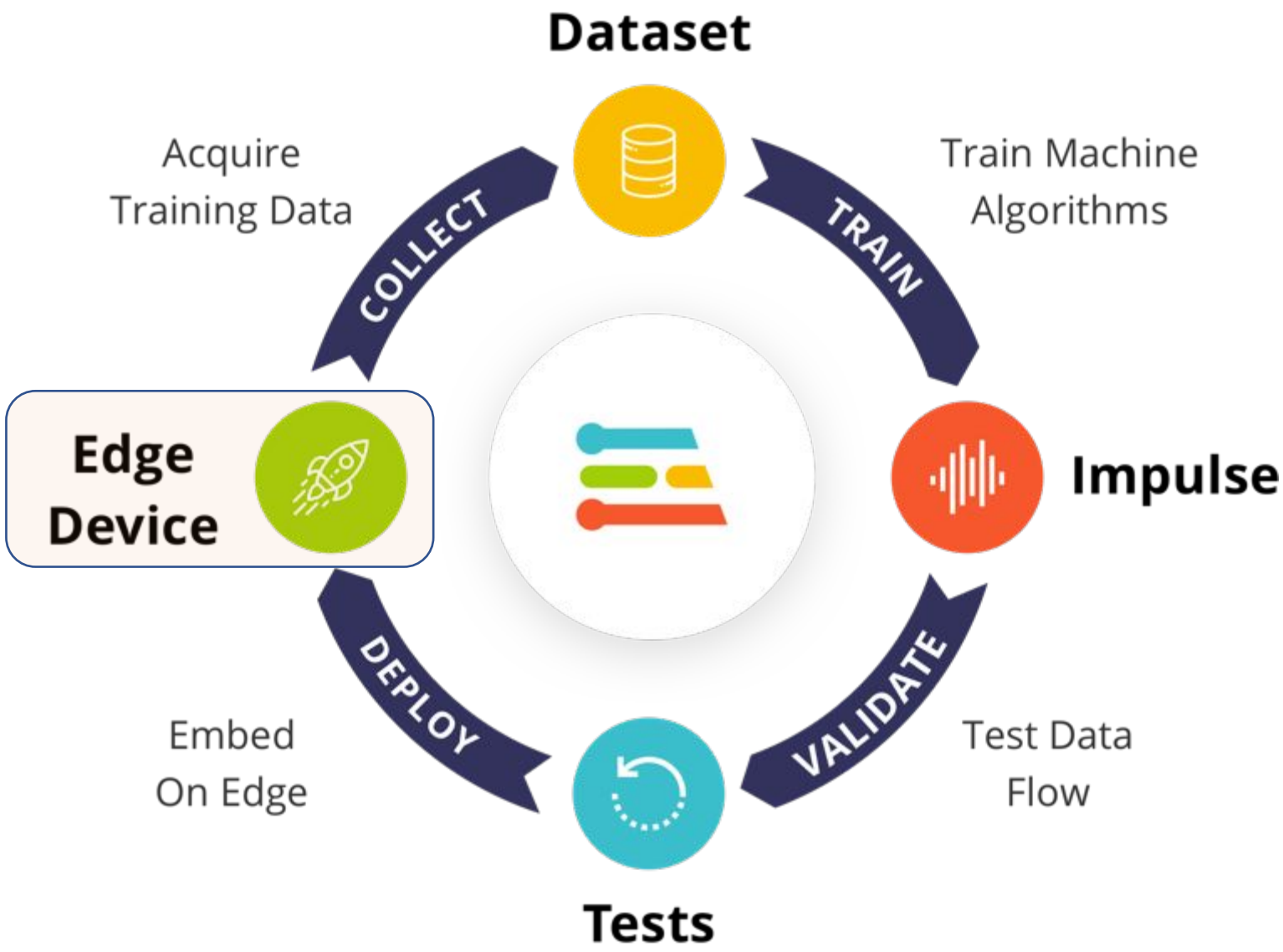
BACKGROUND	MEDICINE
0.03	0.97

RAW DATA

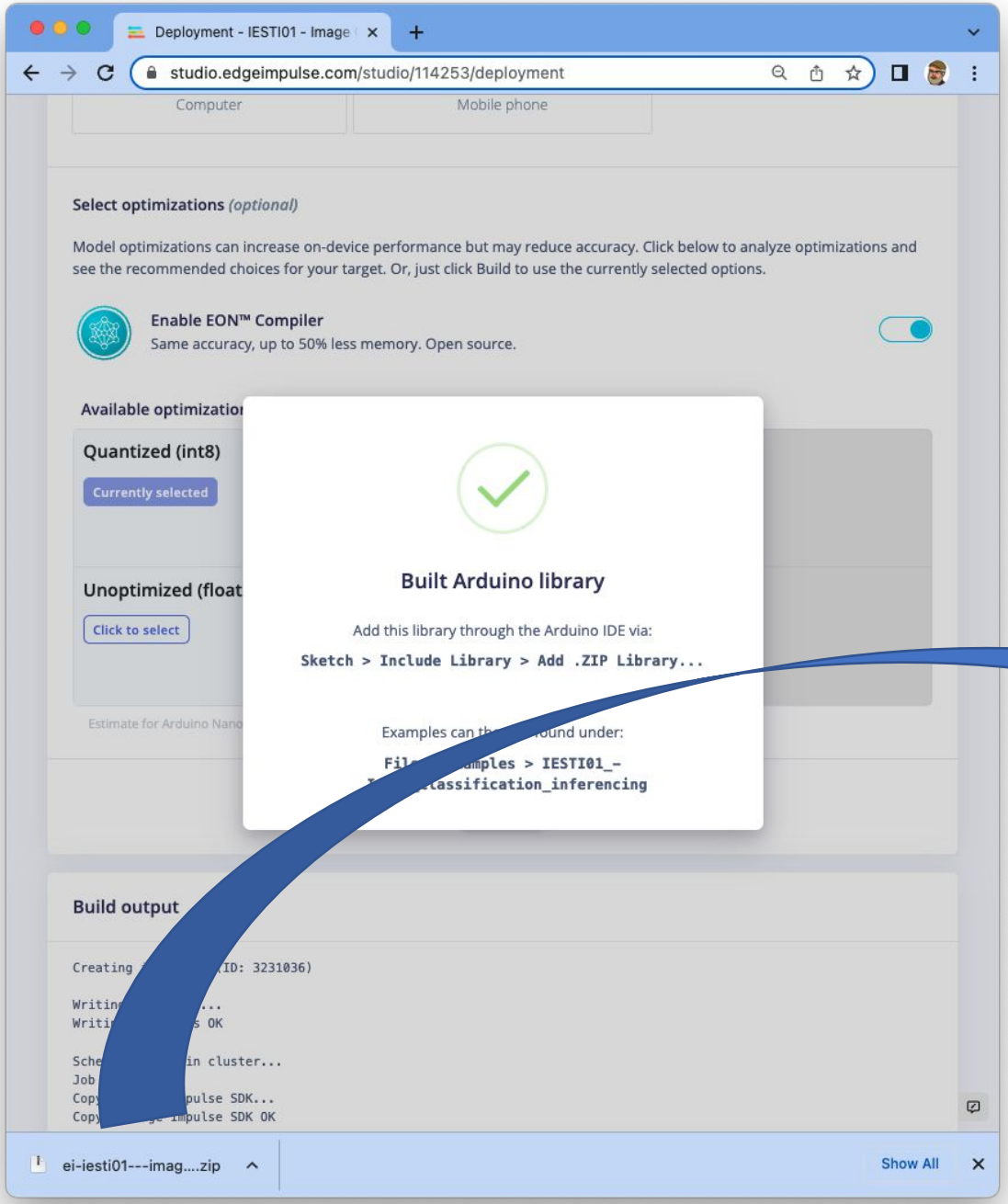
testing.36020g3v

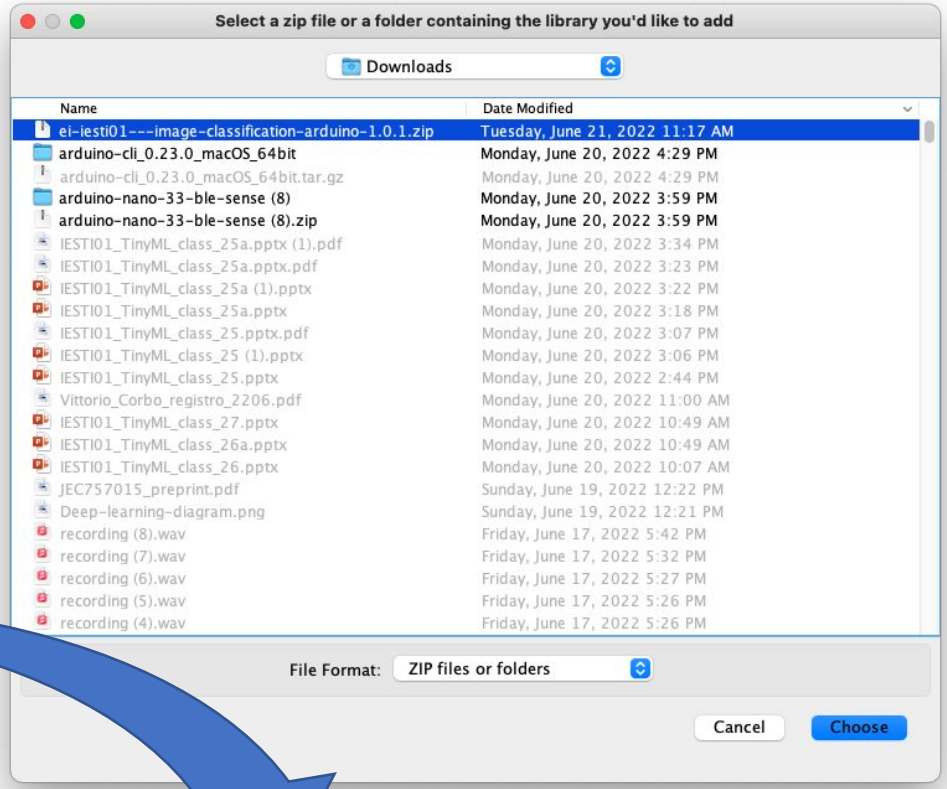
Raw features

0x1d2a23, 0x1d2a23, 0x1c2922, 0x1d2824, 0x1e2825, 0x1e2925, 0x1f2a26, 0x1d2926, 0x1e2a28, 0x1c2b28, 0x1b2a28, 0x1…

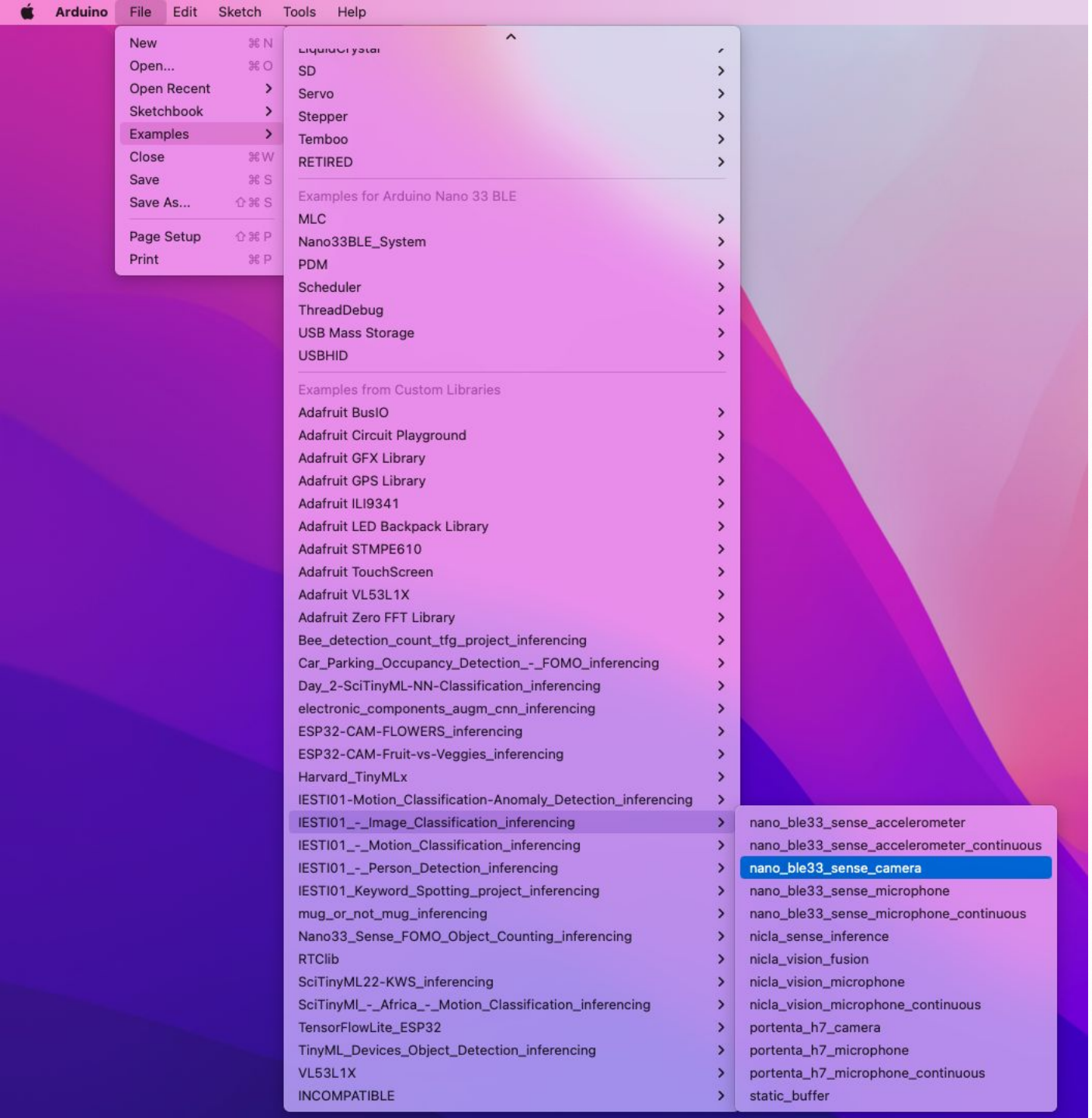


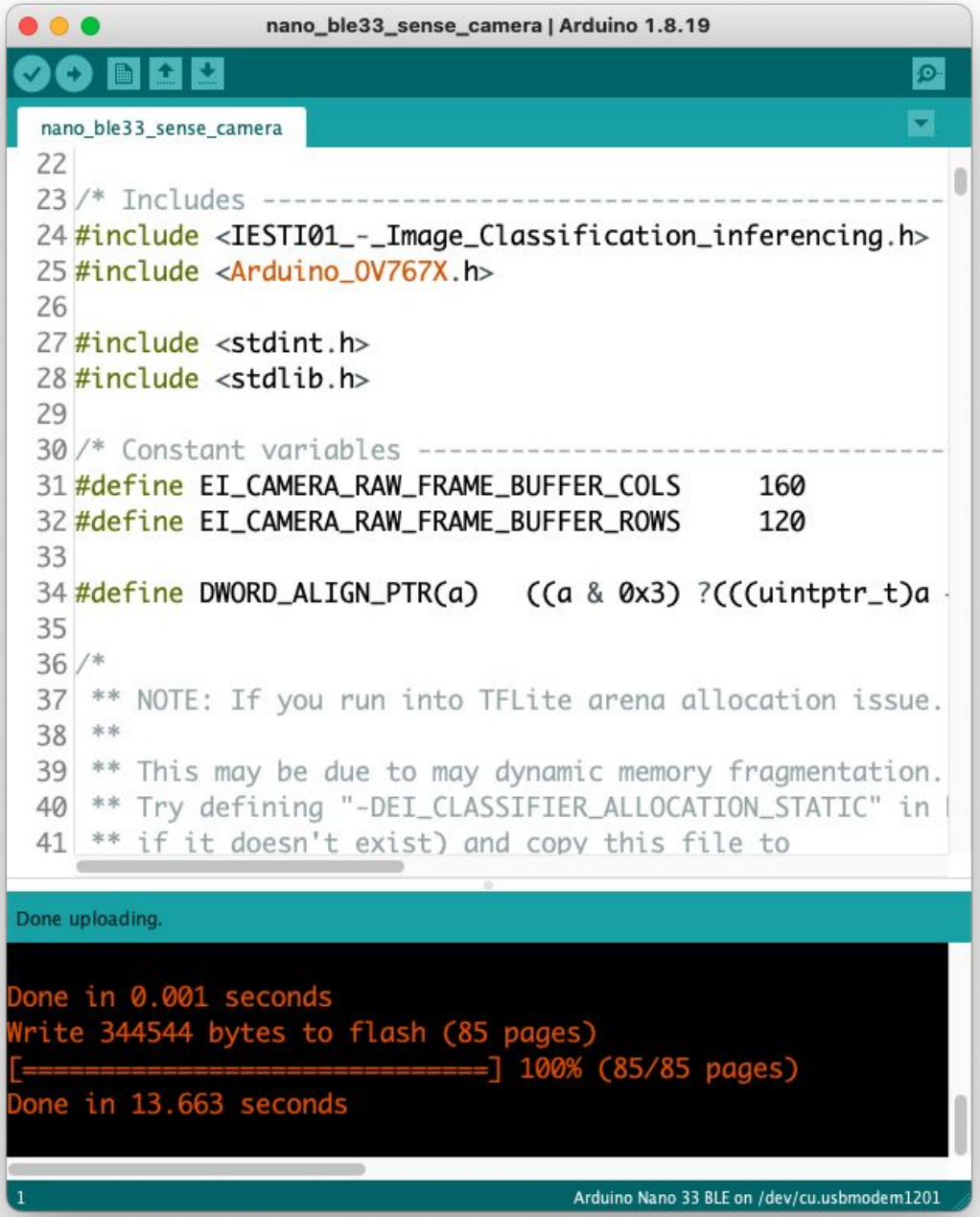
- Pre-Processing Data
- Design a Model
- Train a Model


Deployment - IESTI01 - Image
studio.edgeimpulse.com/studio/114253/deployment
Computer
Mobile phone
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.
Quantized (int8)
Currently selected
Unoptimized (float
Click to select
Built Arduino library
Add this library through the Arduino IDE via:
Sketch > Include Library > Add .ZIP Library...
Build output
ei-iesti01---imag....zip
Show All

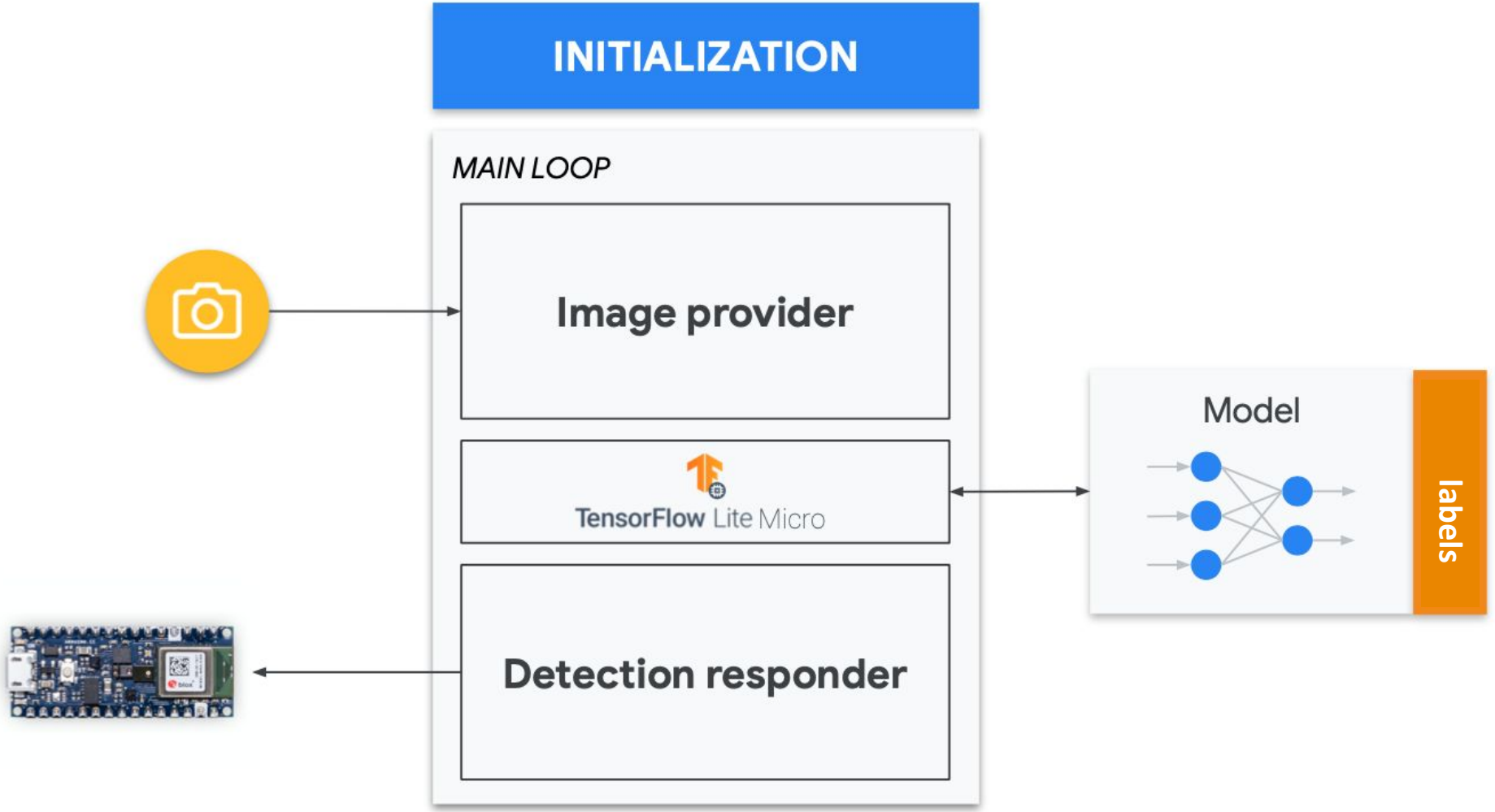

Select a zip file or a folder containing the library you'd like to add
Downloads
Name
Date Modified
ei-iesti01---image-classification-arduino-1.0.1.zip
Tuesday, June 21, 2022 11:17 AM
arduino-cli_0.23.0_macOS_64bit
Monday, June 20, 2022 4:29 PM
arduino-nano-33-ble-sense (8)
Monday, June 20, 2022 3:59 PM
arduino-nano-33-ble-sense (8).zip
Monday, June 20, 2022 3:59 PM
File Format:
ZIP files or folders
Cancel
Choose

Model Inference

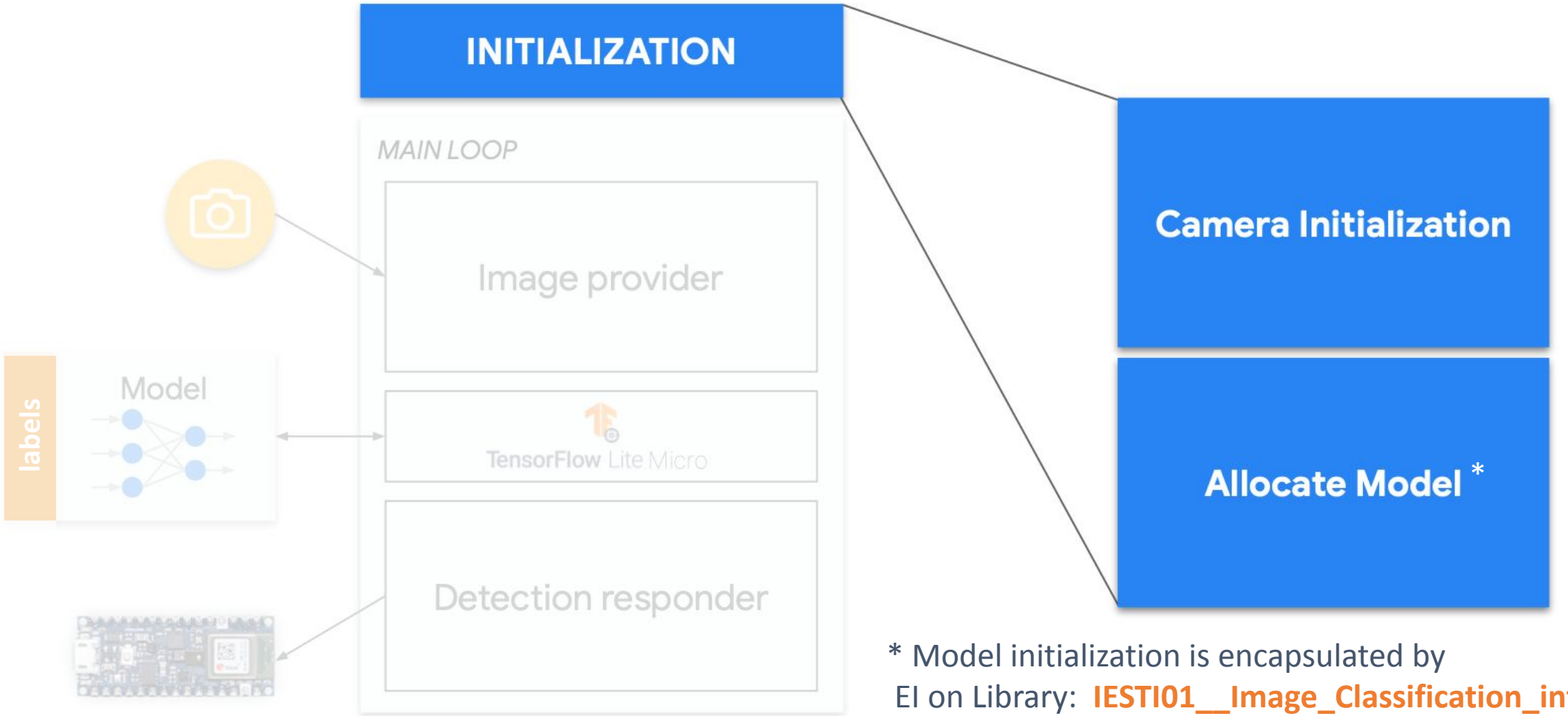

Arduino
File
Edit
Sketch
Tools
Help
New ⌘N
Open... ⌘O
Open Recent
Sketchbook
Examples
Close ⌘W
Save ⌘S
Save As... ⇧⌘S
Page Setup ⇧⌘P
Print ⌘P
SD
Servo
Stepper
Temboo
RETIRED
Examples for Arduino Nano 33 BLE
MLC
Nano33BLE_System
PDM
Scheduler
ThreadDebug
USB Mass Storage
USBHID
Examples from Custom Libraries
Adafruit BusIO
Adafruit Circuit Playground
Adafruit GFX Library
Adafruit GPS Library
Adafruit ILI9341
Adafruit LED Backpack Library
Adafruit STMPE610
Adafruit TouchScreen
Adafruit VL53L1X
Adafruit Zero FFT Library
Bee_detection_count_tfg_project_inferencing
Car_Parking_Occupancy_Detection_-_FOMO_inferencing
Day_2-SciTinyML-NN-Classification_inferencing
electronic_components_augm_cnn_inferencing
ESP32-CAM-FLOWERS_inferencing
ESP32-CAM-Fruit-vs-Veggies_inferencing
Harvard_TinyMLx
IESTI01-Motion_Classification-Anomaly_Detection_inferencing
IESTI01_-_Image_Classification_inferencing
IESTI01_-_Motion_Classification_inferencing
IESTI01_-_Person_Detection_inferencing
IESTI01_Keyword_Spotting_project_inferencing
mug_or_not_mug_inferencing
Nano33_Sense_FOMO_Object_Counting_inferencing
RTClib
SciTinyML22-KWS_inferencing
SciTinyML_-_Africa_-_Motion_Classification_inferencing
TensorFlowLite_ESP32
TinyML_Devices_Object_Detection_inferencing
VL53L1X
INCOMPATIBLE
nano_ble33_sense_accelerometer
nano_ble33_sense_accelerometer_continuous
nano_ble33_sense_camera
nano_ble33_sense_microphone
nano_ble33_sense_microphone_continuous
nicla_sense_inference
nicla_vision_fusion
nicla_vision_microphone
nicla_vision_microphone_continuous
portenta_h7_camera
portenta_h7_microphone
portenta_h7_microphone_continuous
static_buffer


nano_ble33_sense_camera | Arduino 1.8.19
nano_ble33_sense_camera
22
23 /* Includes ----------
24 #include <IESTI01_-_Image_Classification_inferencing.h>
25 #include <Arduino_OV767X.h>
26
27 #include <stdint.h>
28 #include <stdlib.h>
29
30 /* Constant variables ----------
31 #define EI_CAMERA_RAW_FRAME_BUFFER_COLS 160
32 #define EI_CAMERA_RAW_FRAME_BUFFER_ROWS 120
33
34 #define DWORD_ALIGN_PTR(a) ((a & 0x3) ?(((uintptr_t)a
35
36 /*
37 ** NOTE: If you run into TFLite arena allocation issue.
38 **
39 ** This may be due to may dynamic memory fragmentation.
40 ** Try defining "-DEI_CLASSIFIER_ALLOCATION_STATIC" in
41 ** if it doesn't exist) and copy this file to
Done uploading.
Done in 0.001 seconds
Write 344544 bytes to flash (85 pages)
[==============================] 100% (85/85 pages)
Done in 13.663 seconds
1
Arduino Nano 33 BLE on /dev/cu.usbmodem1201

Img. Classification **Components** (nano_ble33_sense_camera.ino)



Initialization

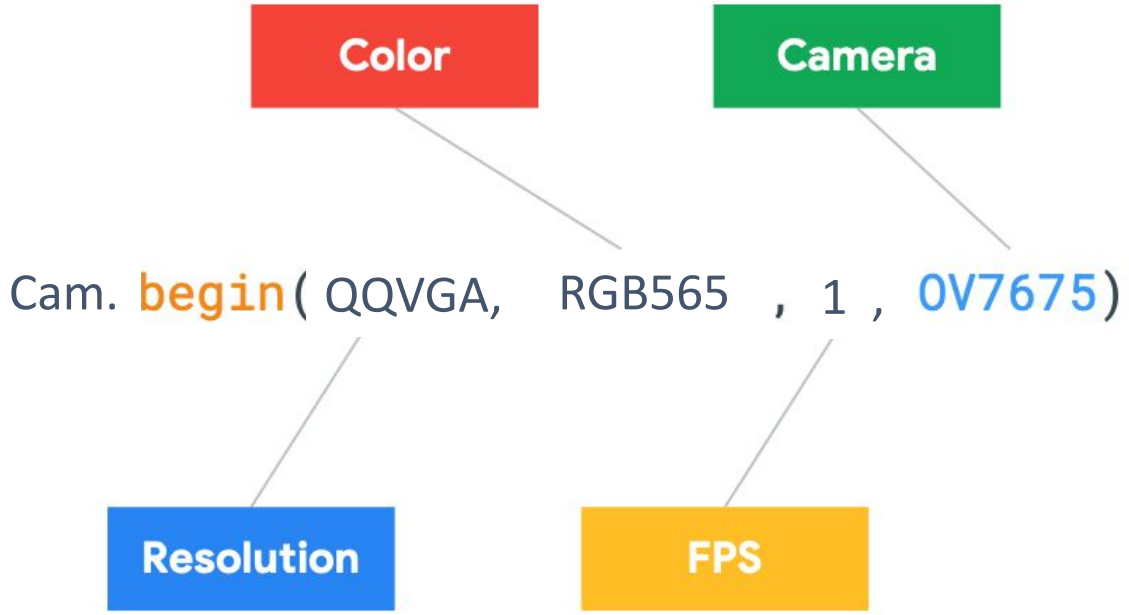


* Model initialization is encapsulated by
EI on Library: **IESTI01__Image_Classification_inferencing.h**

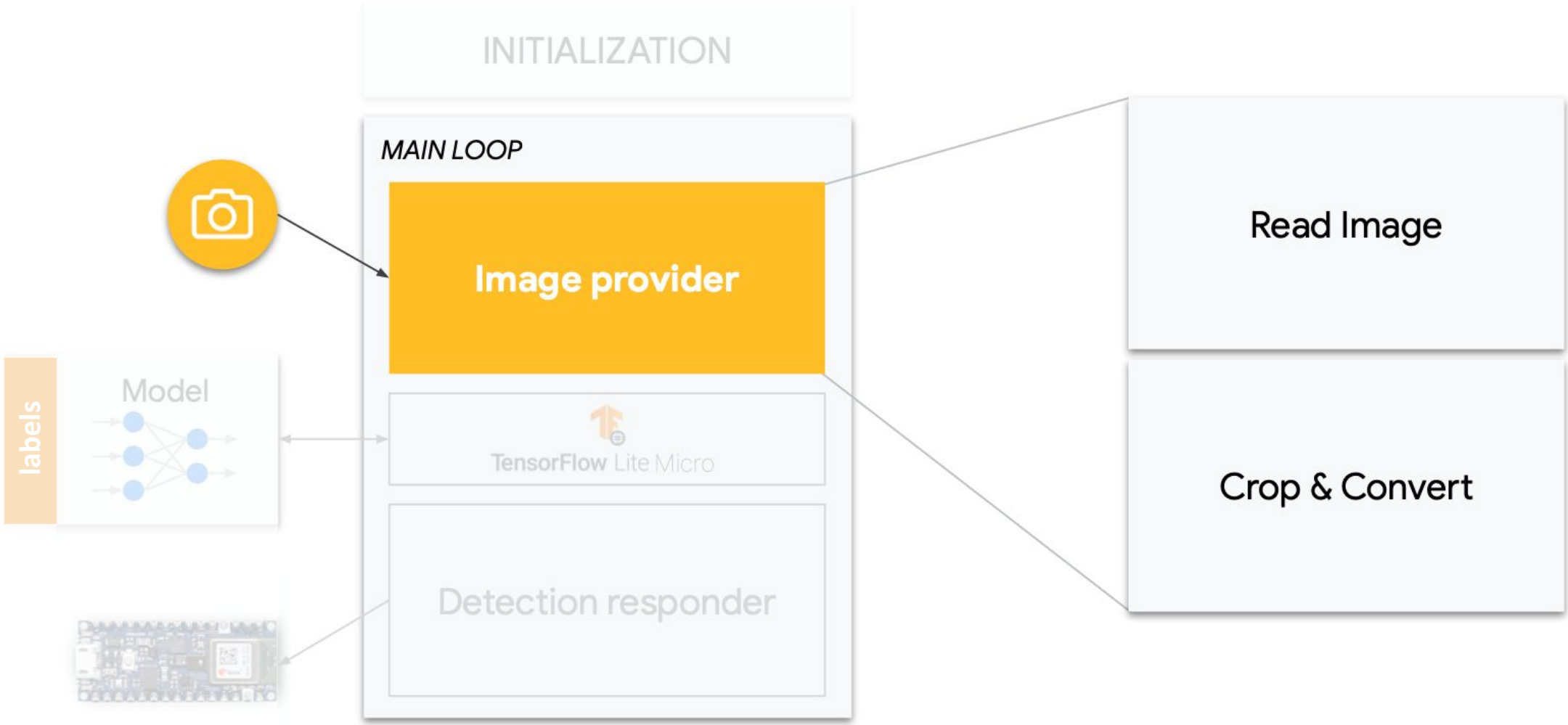
Initialization

Camera Initialization

Allocate Model



Pre-processing



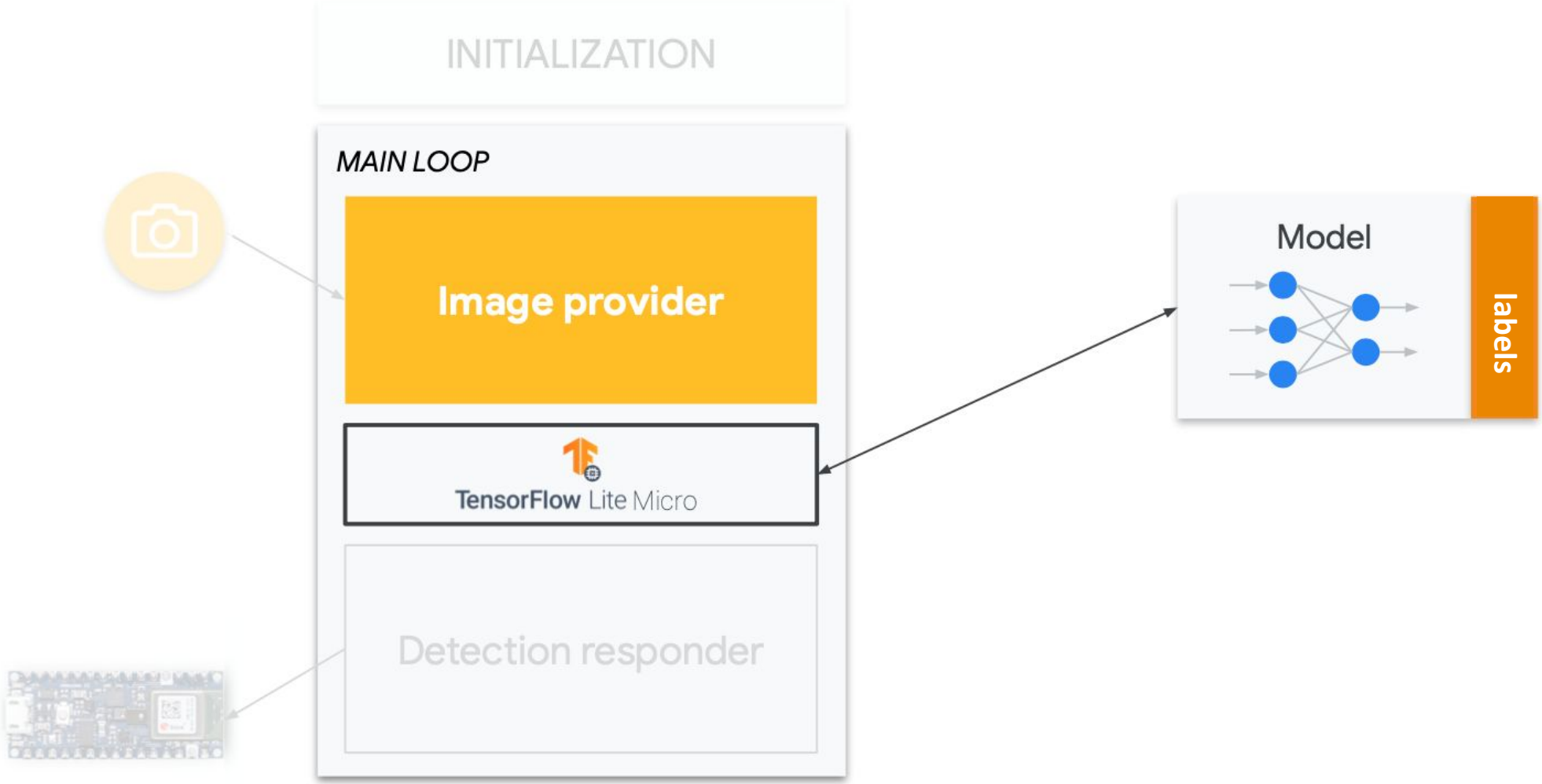
Pre-processing

Read Image

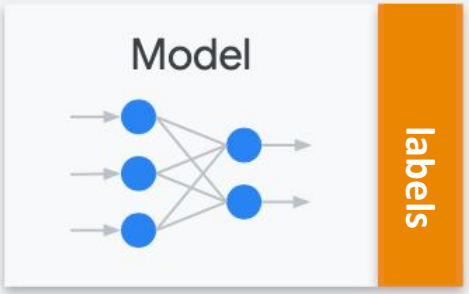
Crop & Convert

```
void *snapshot_mem = NULL;
uint8_t *snapshot_buf = NULL;
snapshot_mem = ei_malloc(resize_col_sz*resize_row_sz*2);
if(snapshot_mem == NULL) {
    ei_printf("failed to create snapshot_mem\r\n");
    break;
}
snapshot_buf = (uint8_t *)DWORD_ALIGN_PTR((uintptr_t)snapshot_mem);

if (ei_camera_capture(EI_CLASSIFIER_INPUT_WIDTH,
    EI_CLASSIFIER_INPUT_HEIGHT, snapshot_buf) == false) {
    ei_printf("Failed to capture image\r\n");
    if (snapshot_mem) ei_free(snapshot_mem);
    break;
}

ei::signal_t signal;
signal.total_length = EI_CLASSIFIER_INPUT_WIDTH * EI_CLASSIFIER_INPUT_HEIGHT;
signal.get_data = &ei_camera_cutout_get_data;
```

Interpreter + Model

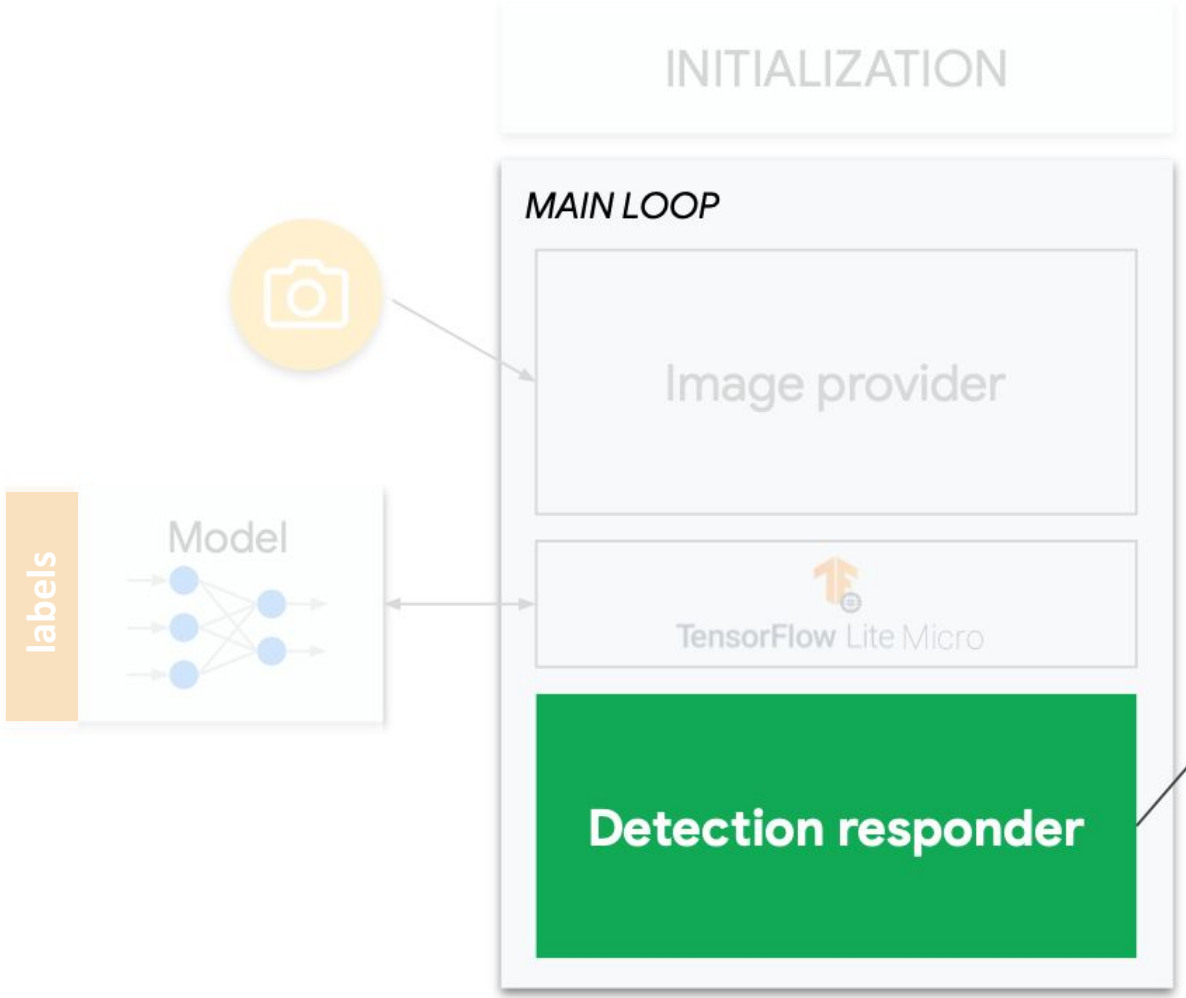


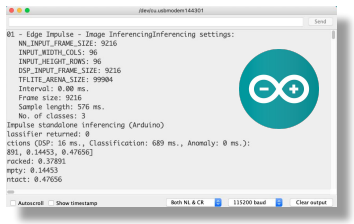
Interpreter + Model




```
// run the impulse: DSP, neural network and the Anomaly algorithm
ei_impulse_result_t result = { 0 };

EI_IMPULSE_ERROR ei_error = run_classifier(&signal, &result, debug_nn);
if (ei_error != EI_IMPULSE_OK) {
    ei_printf("Failed to run impulse (%d)\n", ei_error);
    ei_free(snapshot_mem);
    break;
}
```

Post-processing





Detection responder

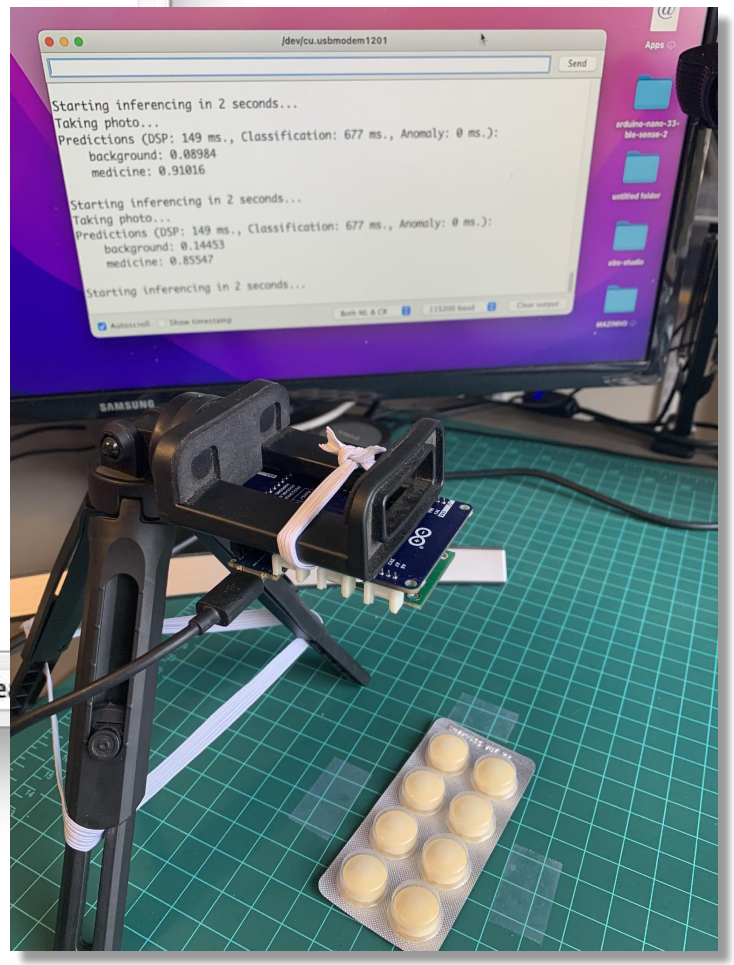
```
        // print the predictions
        ei_printf("Predictions (DSP: %d ms., Classification: %d ms., Anomaly: %d ms.): \n",
                  result.timing.dsp, result.timing.classification, result.timing.anomaly);
#if EI_CLASSIFIER_OBJECT_DETECTION == 1
        bool bb_found = result.bounding_boxes[0].value > 0;
        for (size_t ix = 0; ix < EI_CLASSIFIER_OBJECT_DETECTION_COUNT; ix++) {
            auto bb = result.bounding_boxes[ix];
            if (bb.value == 0) {
                continue;
            }

            ei_printf("    %s (%f) [ x: %u, y: %u, width: %u, height: %u ]\n",
            bb.label, bb.value, bb.x, bb.y, bb.width, bb.height);
        }

        if (!bb_found) {
            ei_printf("    No objects found\n");
        }
#else
        for (size_t ix = 0; ix < EI_CLASSIFIER_LABEL_COUNT; ix++) {
            ei_printf("    %s: %.5f\n", result.classification[ix].label,
                                        result.classification[ix].value);
        }
```

/dev/cu.usbmodem1201

Send

```
Starting inferencing in 2 seconds...
Taking photo...
Predictions (DSP: 149 ms., Classification: 677 ms., Anomaly: 0 ms.):
    background: 0.10938
    medicine: 0.89062

Starting inferencing in 2 seconds...
Taking photo...
Predictions (DSP: 149 ms., Classification: 677 ms., Anomaly: 0 ms.):
    background: 0.10547
    medicine: 0.89453

Starting inferencing in 2 seconds...
Taking photo...
```

Autoscroll Show timestamp Both NL & CR 115200 baud Cle

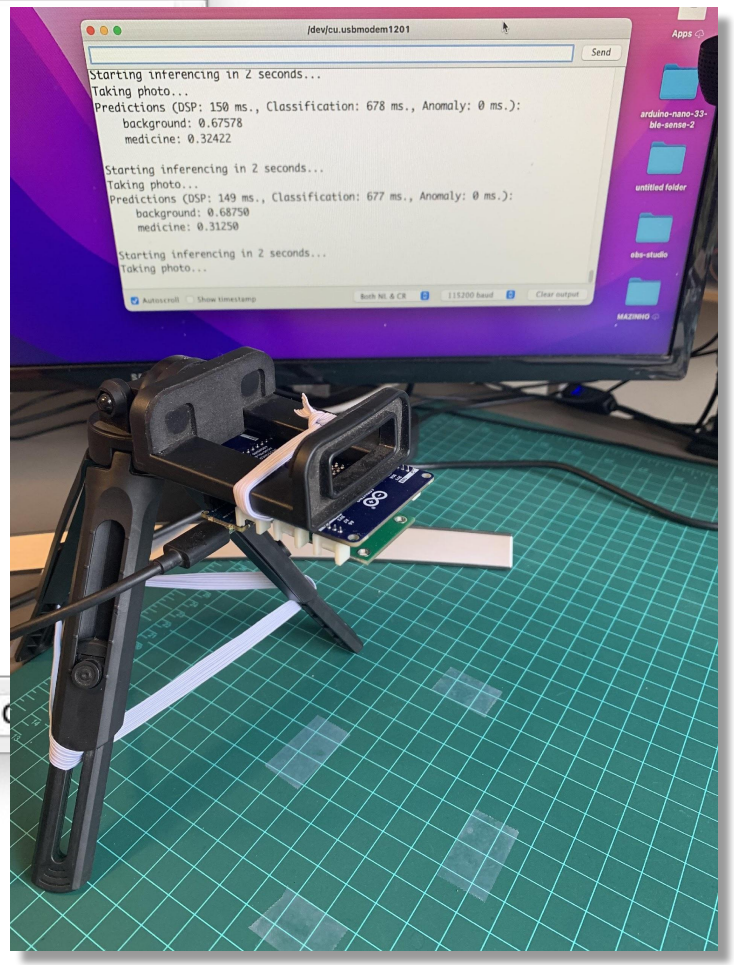


/dev/cu.usbmodem1201

Send

```
Starting inferencing in 2 seconds...
Taking photo...
Predictions (DSP: 149 ms., Classification: 678 ms., Anomaly: 0 ms.):
    background: 0.69922
    medicine: 0.30078

Starting inferencing in 2 seconds...
Taking photo...
Predictions (DSP: 149 ms., Classification: 678 ms., Anomaly: 0 ms.):
    background: 0.71484
    medicine: 0.28516

Starting inferencing in 2 seconds...
```

Autoscroll Show timestamp Both NL & CR 115200 baud



Main References:

- UNIFEI - IESTI01 TinyML - Machine Learning for Embedding Devices
- 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
- "Deep Learning with Python" book by François Chollet
- "TinyML" book by Pete Warden, Daniel Situnayake

I want to thank Shawn Hymel and Edge Impulse, Pete Warden and Laurence Moroney from Google, Professor Vijay Janapa Reddi and Brian Plancher from Harvard, and the rest of the TinyMLedu team for preparing the excellent material on TinyML that is the basis of this Workshop.

The SciTinyML workshops are part of the **TinyML4D**, an initiative to make TinyML education available to everyone globally.

Thanks

UNIFEI