



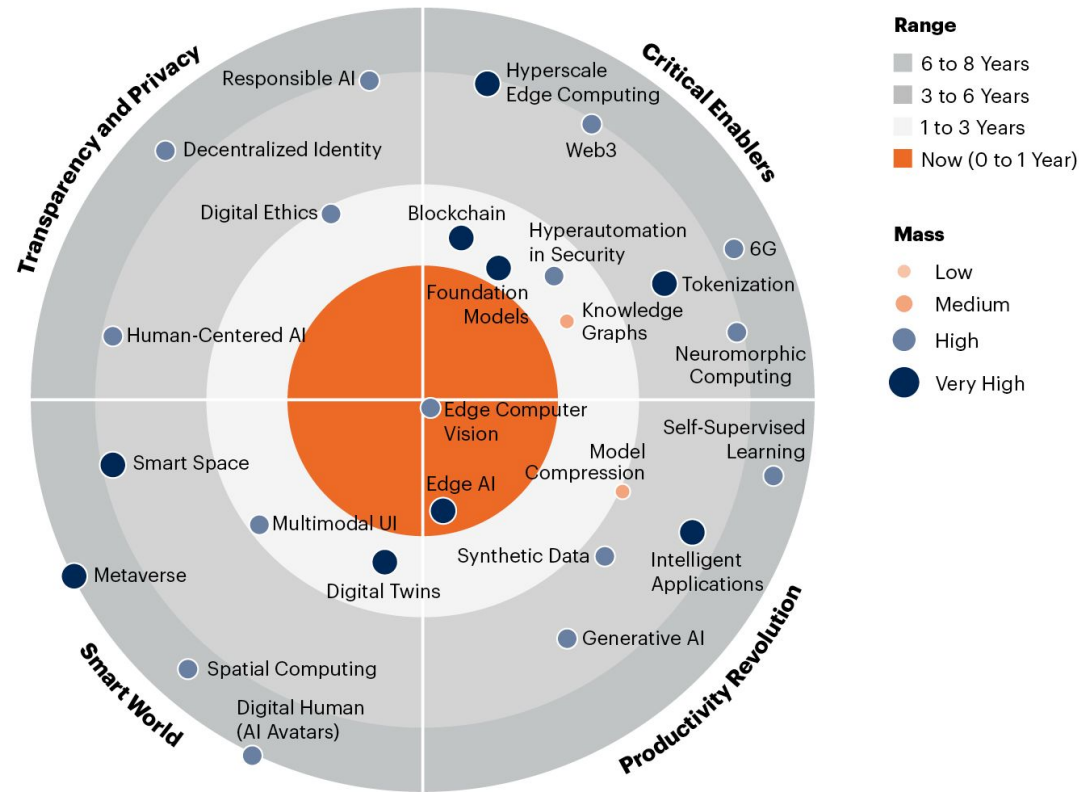
# Computer Vision (CV) at the Edge

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UNIFEI - Federal University of Itajuba, Brazil  
TinyML4D Academic Network Co-Chair



## 2023 Gartner Emerging Technologies and Trends Impact Radar



gartner.com

Note: Range measures number of years it will take the technology/trend to cross over from early adopter to early majority adoption. Mass indicates how substantial the impact of the technology or trend will be on existing products and markets.

Source: Gartner  
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Gartner

Edge Computer Vision has a high impact potential, and it is for now!

*"Visual recognition has undergone the largest changes and fastest development in the last decade, due in part to the availability of much larger labeled datasets as well as breakthroughs in deep learning."*

Computer Vision: Algorithms and Applications, 2nd ed.

# Computer Vision Recognition Tasks

## Image Classification (Multi-Class Classification)

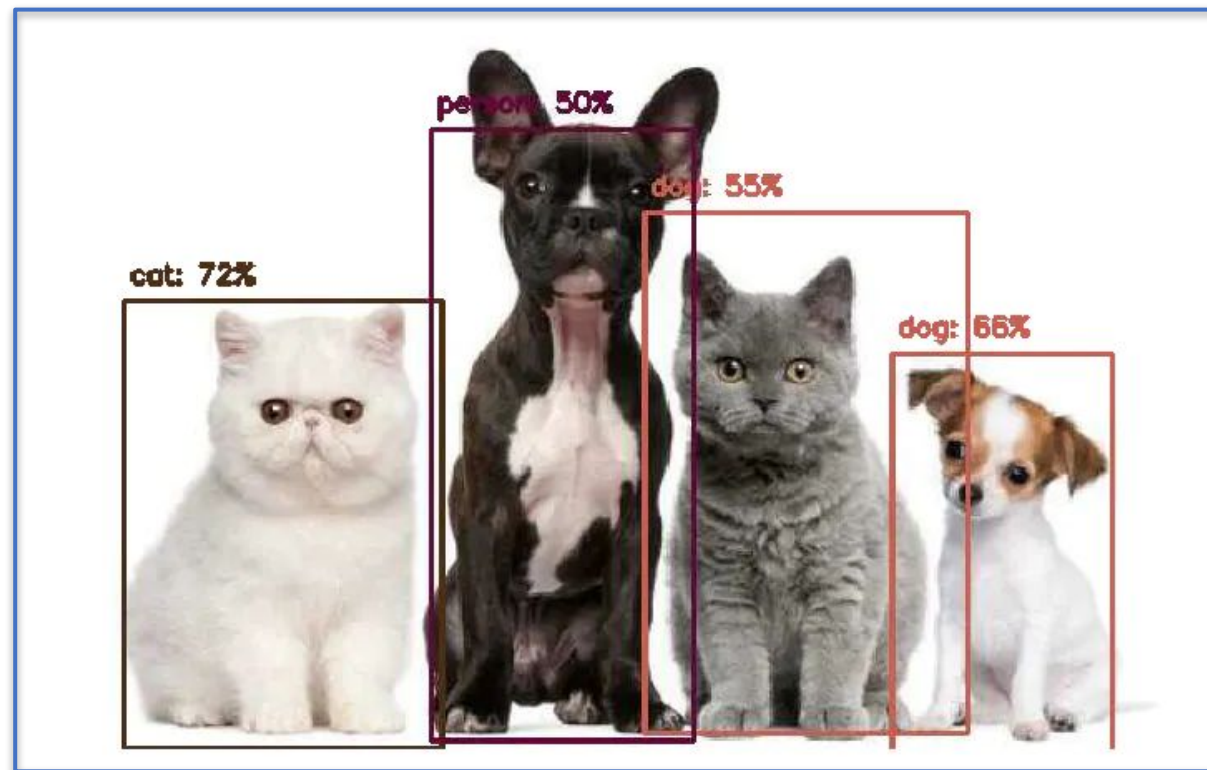


Cat: 70%



Dog: 80%

## Object Detection Multi-Label Classification + Object Localization



# Computer Vision Recognition Tasks

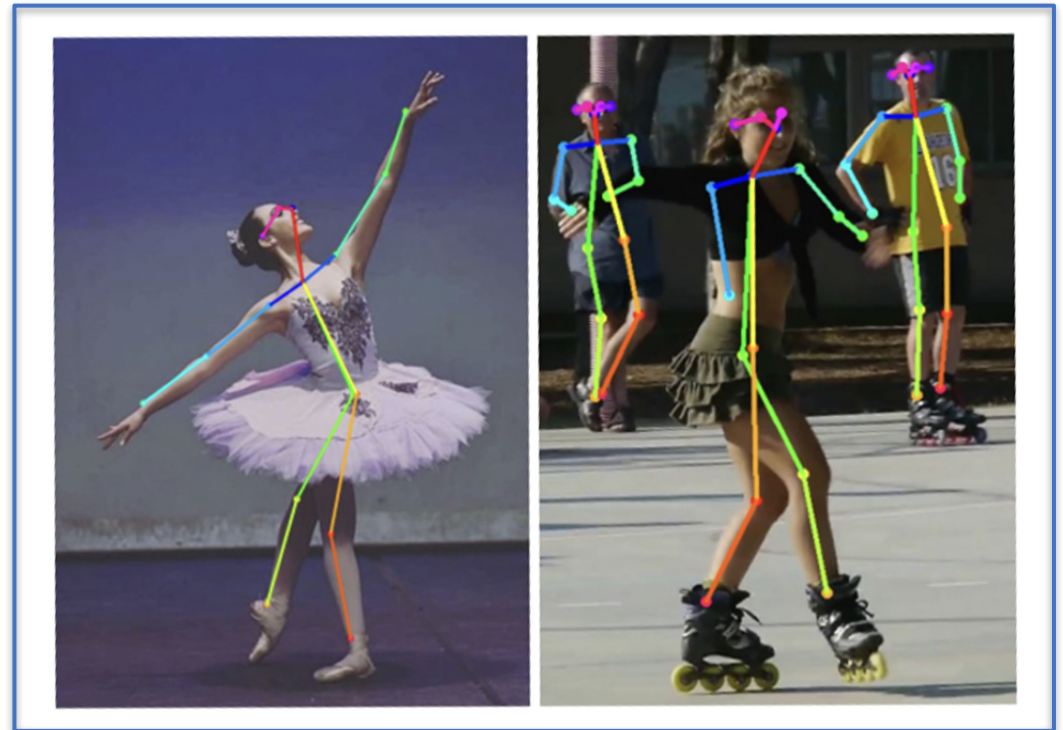
## Instance Segmentation

Each **pixel** in an image IS CLASSIFIED into a predefined category.



## Pose Estimation

**Key points (or landmarks)** on the object, such as joints on a human body are detected



# Computer Vision Recognition Tasks

## Image Classification (Multi-Class Classification)

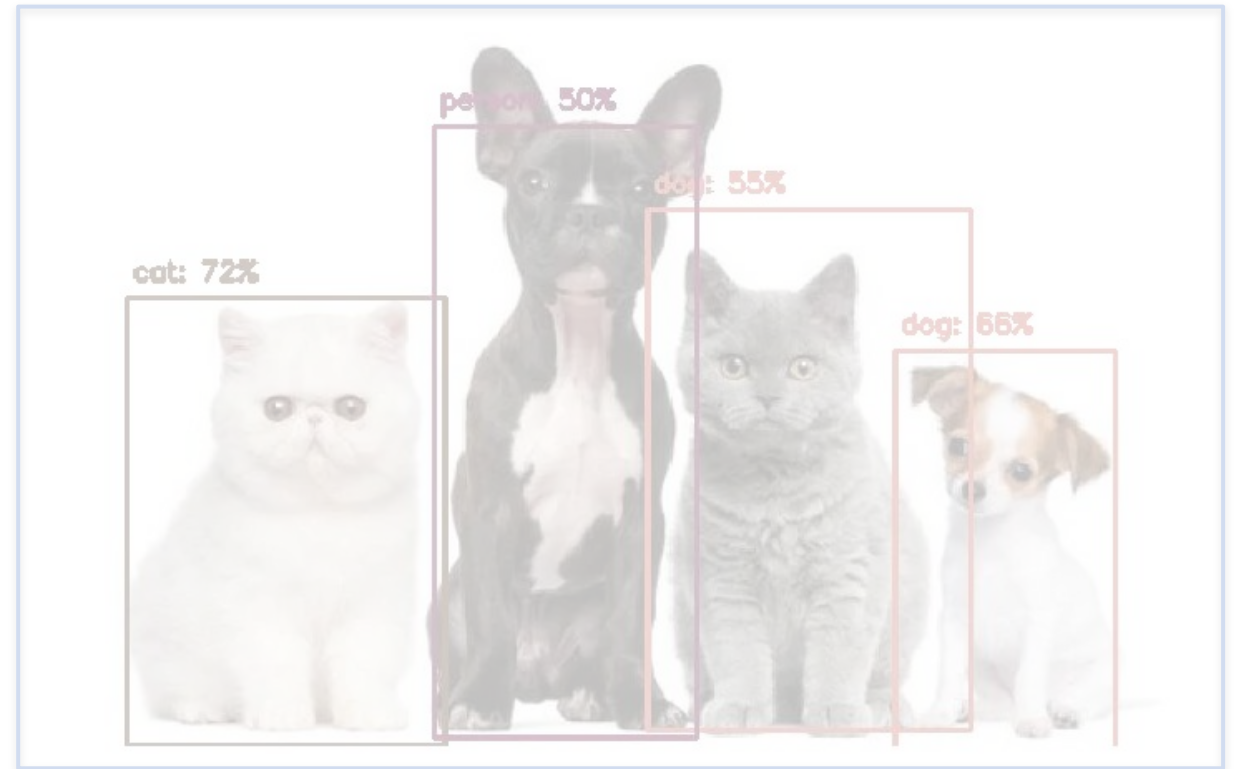


Cat: 70%



Dog: 80%

## Object Detection Multi-Label Classification + Object Localization

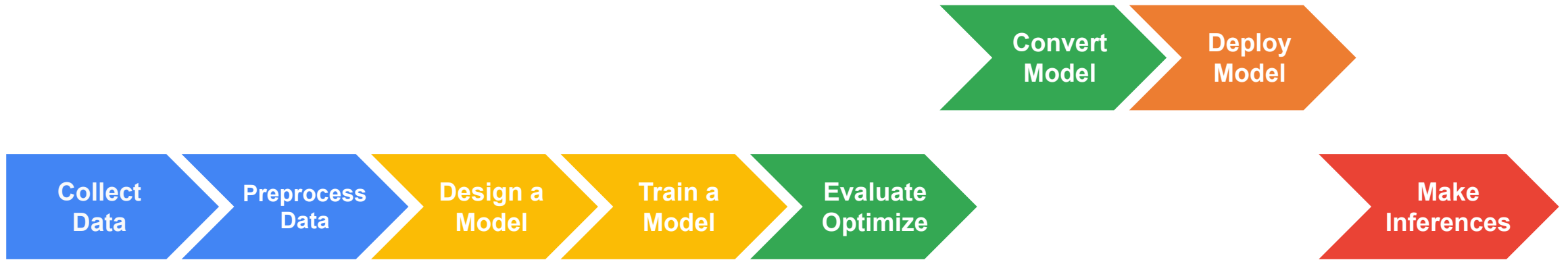


# Embedded Machine Learning (TinyML) Workflow Review

# Machine Learning Workflow

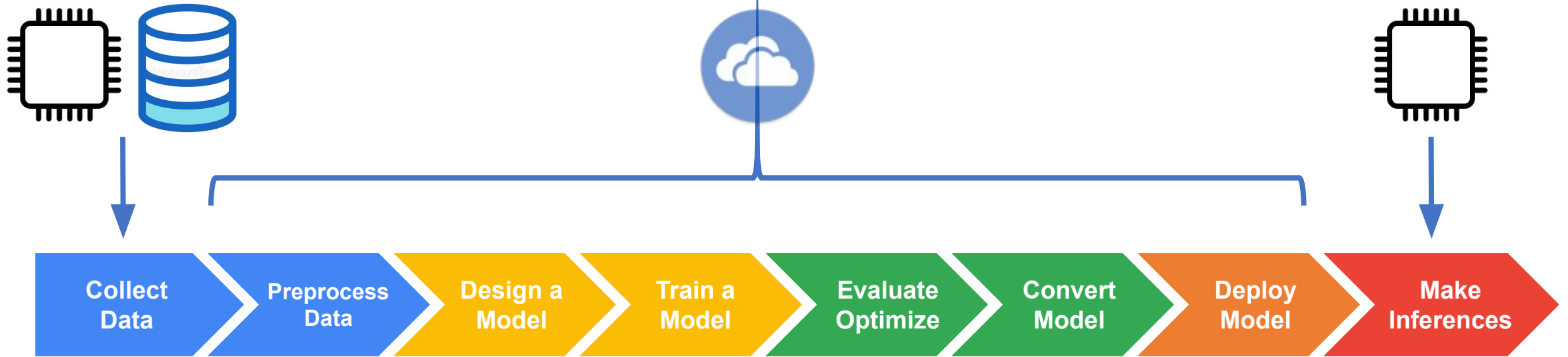


# Tiny Machine Learning Workflow (“What”)

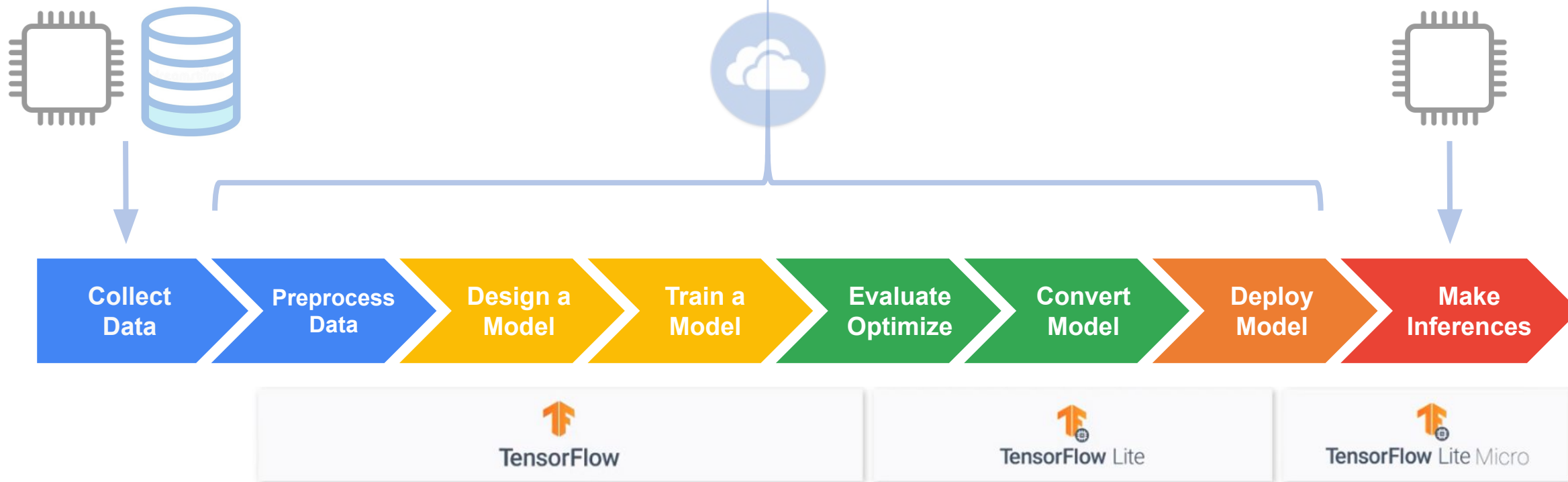




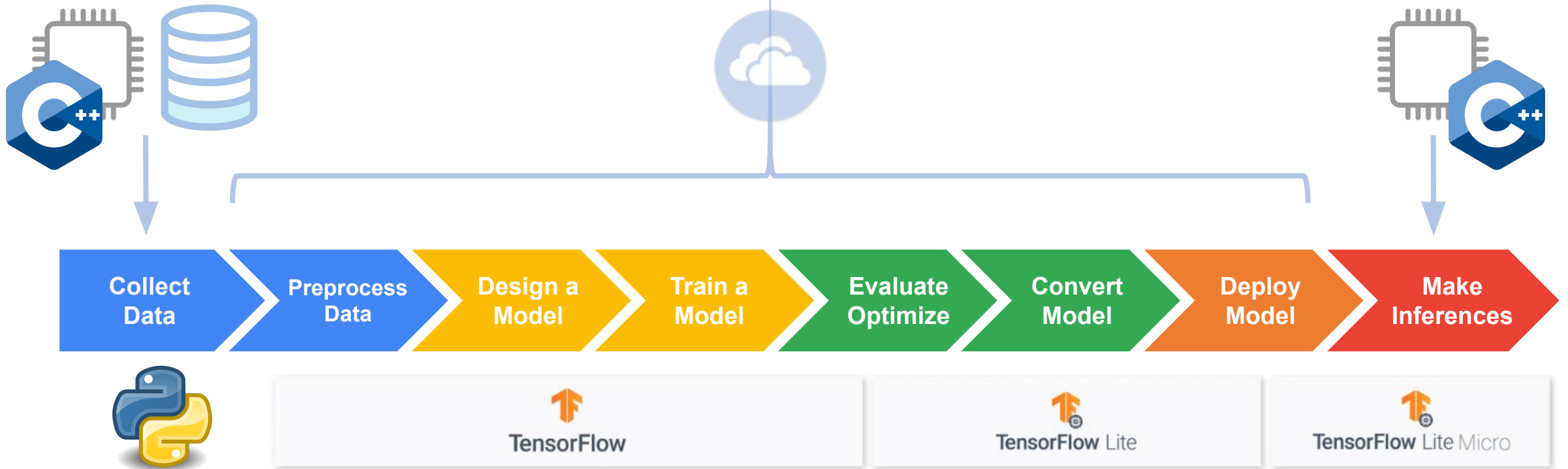
# Tiny Machine Learning Workflow (“Where”)



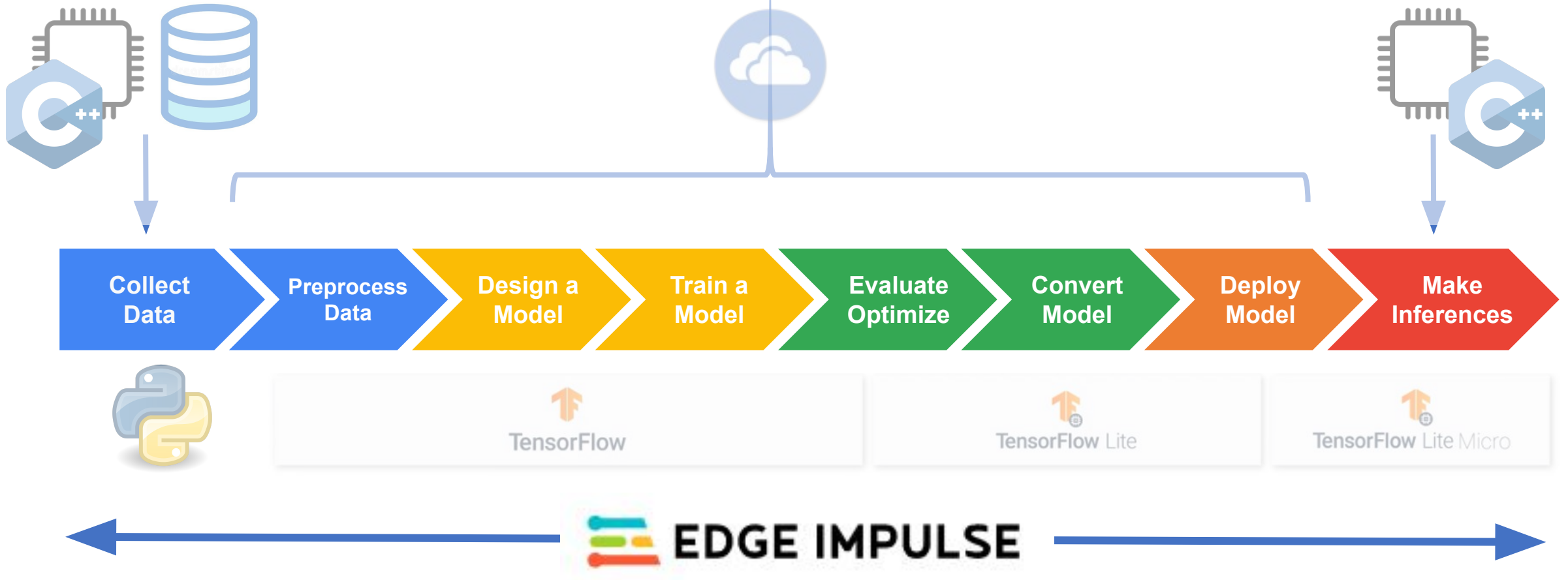
# Machine Learning Workflow (“How”)

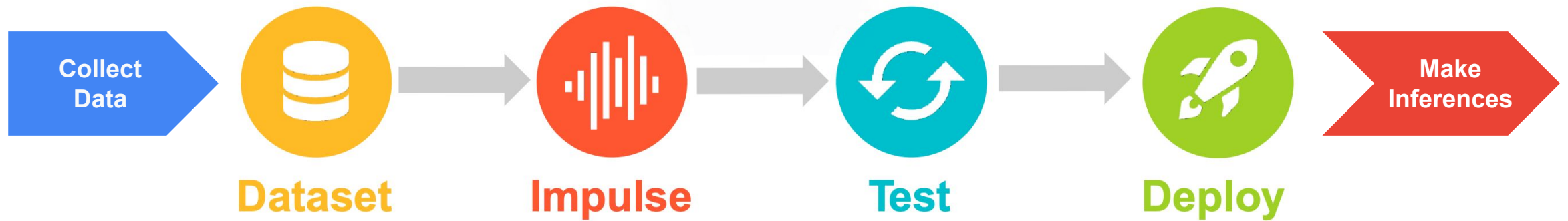


# Machine Learning Workflow (“How”)

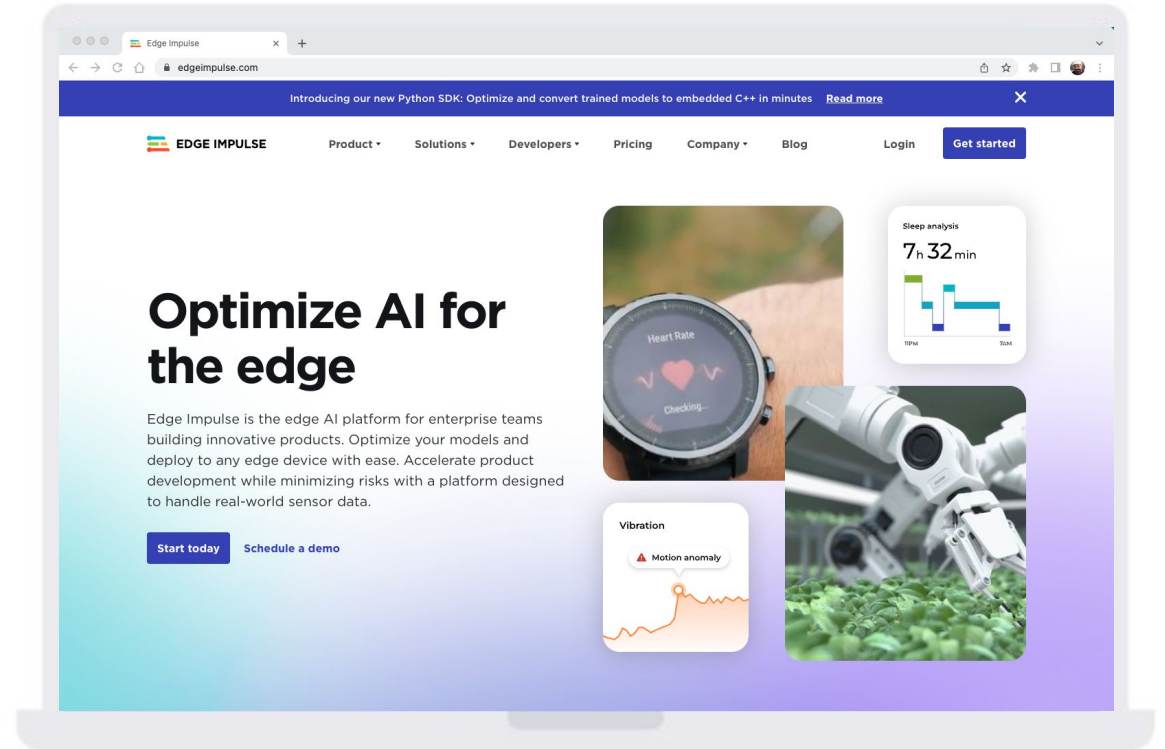
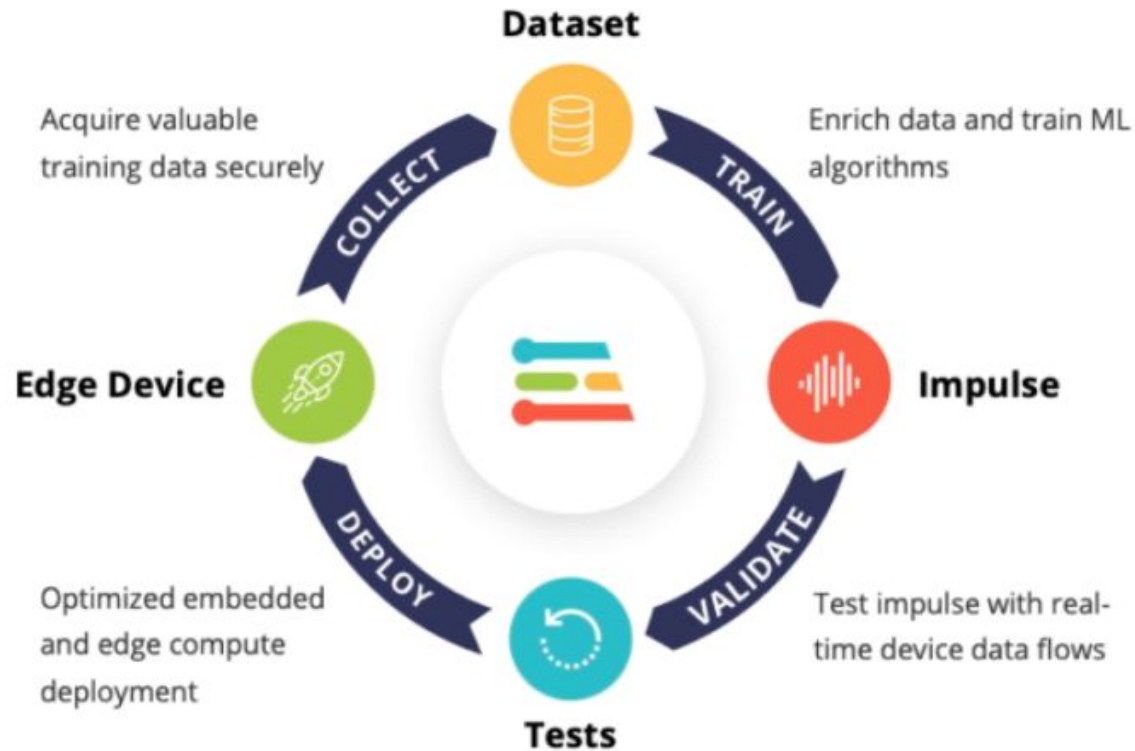


# Machine Learning Workflow (“How”)





# EI Studio - Embedded ML platform (“AutoML”)



Learn more at <http://edgeimpulse.com>



# Image Classification Project

## Edge Impulse Studio

<https://studio.edgeimpulse.com/public/353482/live>



The image shows a browser window displaying the Edge Impulse website. A yellow arrow labeled '1' points to the address bar containing 'edgeimpulse.com'. Another yellow arrow labeled '2' points to the 'Get started' button in the top navigation bar. The website features a blue header with a navigation menu and a main content area with a large heading and several data visualization cards.

Webinar November 9th: 'Fast Track AI to the Edge with NVIDIA and Edge Impulse' [Register here](#)

EDGE IMPULSE Product Solutions Developers Pricing Company Blog Login **Get started**

# Build. Train. Optimize. AI for the edge.

Build datasets, train models, and optimize libraries to run on any edge device, from extremely low-power MCUs to efficient Linux CPU targets and GPUs.

**Get Started** [Schedule a demo](#)

**Heart Rate**  
Checking...


**Sleep analysis**  
7h 32min

**Vibration**  
Motion anomaly



Sign up - Edge Impulse x +


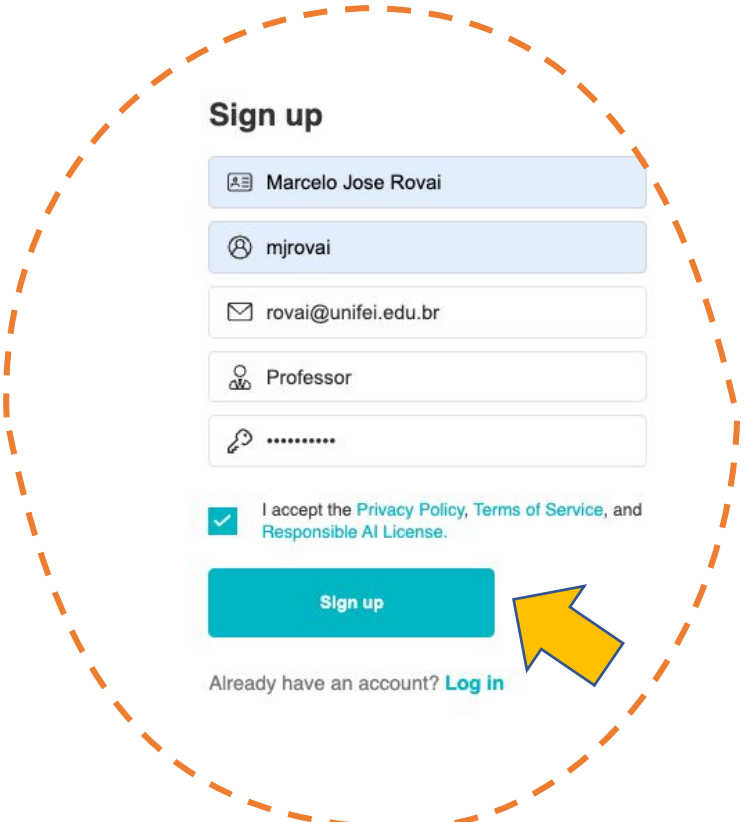
studio.edgeimpulse.com/signup


 **EDGE IMPULSE**

### Sign up

I accept the [Privacy Policy](#), [Terms of Service](#), and [Responsible AI License](#).

Already have an account? [Log in](#)



  
**Start building embedded machine learning models today.**

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Browser window showing the login page for Edge Impulse Studio. The URL is `studio.edgeimpulse.com/login`.

**EDGE IMPULSE**

### Log in

[Forgot your password?](#)

Don't have an account? [Sign up](#)



**Start building embedded machine learning models today.**

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Profile - Projects - Edge Impul

studio.edgeimpulse.com/studio/profile/projects

EDGE IMPULSE

Projects Custom ML blocks

+ Create new project

  
**MJRoBot**  
(Marcelo Rovai)

Organizations

EIE

**Create a new project**

Enter the name for your new project:

Cifar10\_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.

Create under organization: Edge Impulse Experts

Create new project

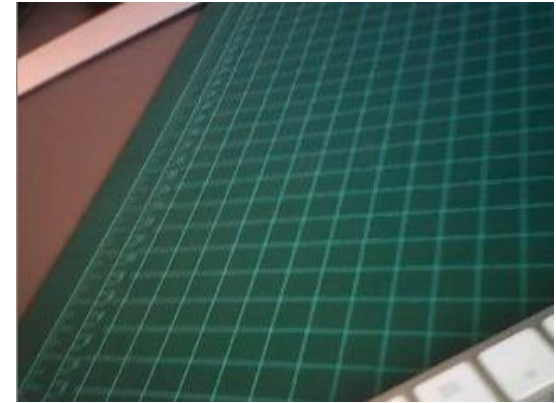
MJRoBot (Marcelo Rovai) / video\_tinyml\_raw

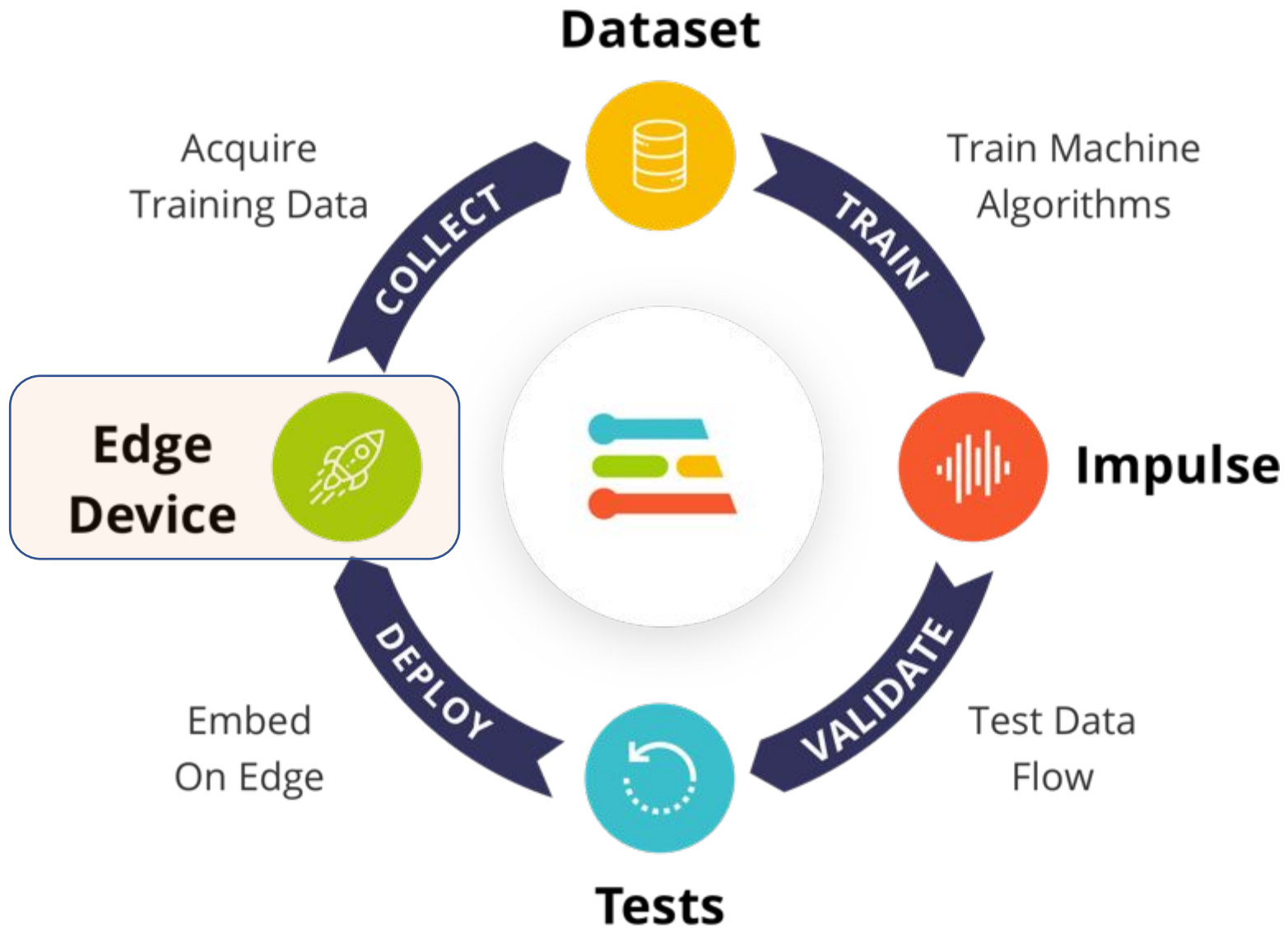
MJRoBot (Marcelo Rovai) / Pico\_Motion\_Detection PUBLIC

MJRoBot (Marcelo Rovai) / ci-rovai-1wv-moatun

Decide a Goal

- Classes:
  - background
  - periquito
  - robot



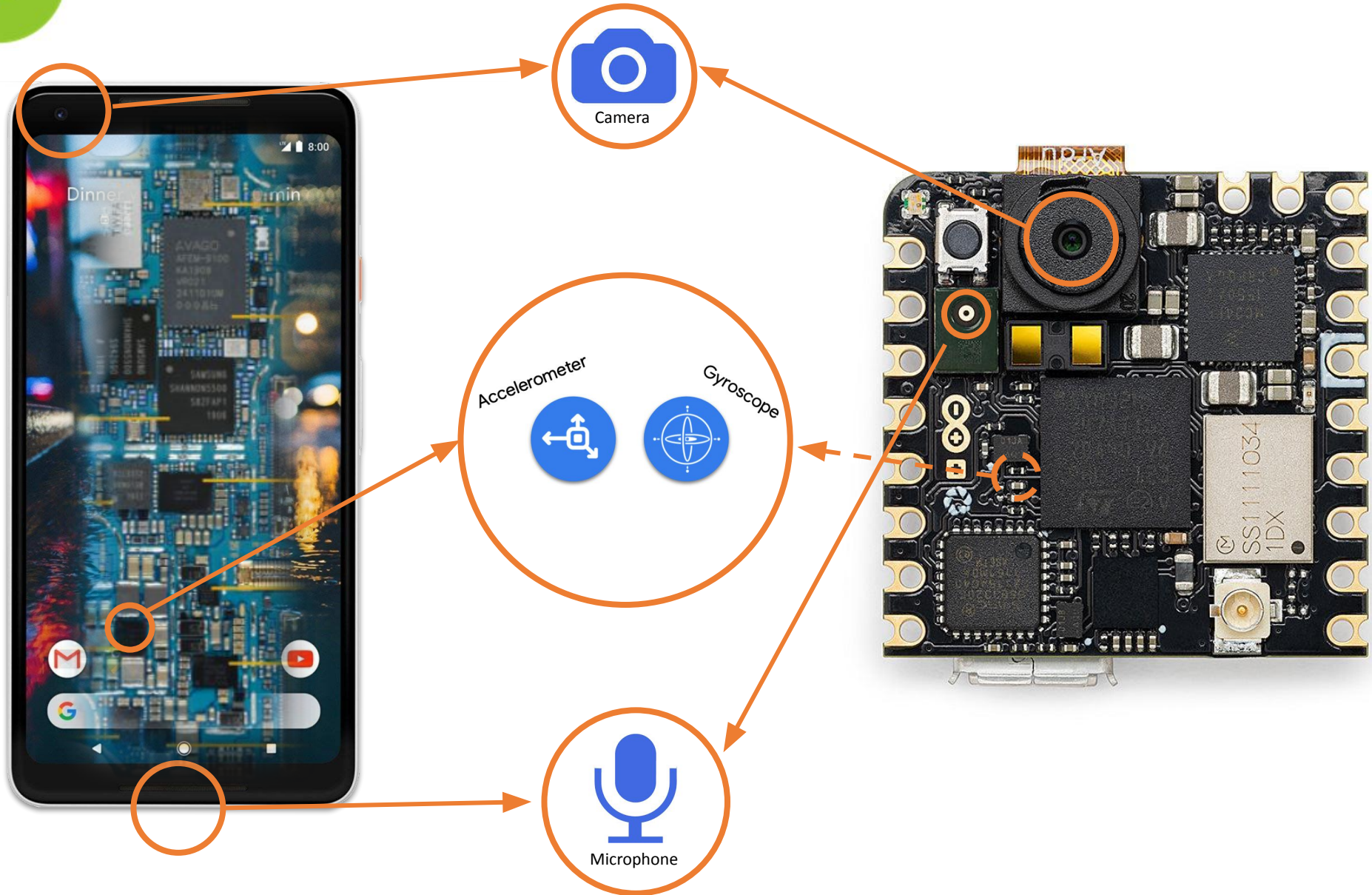


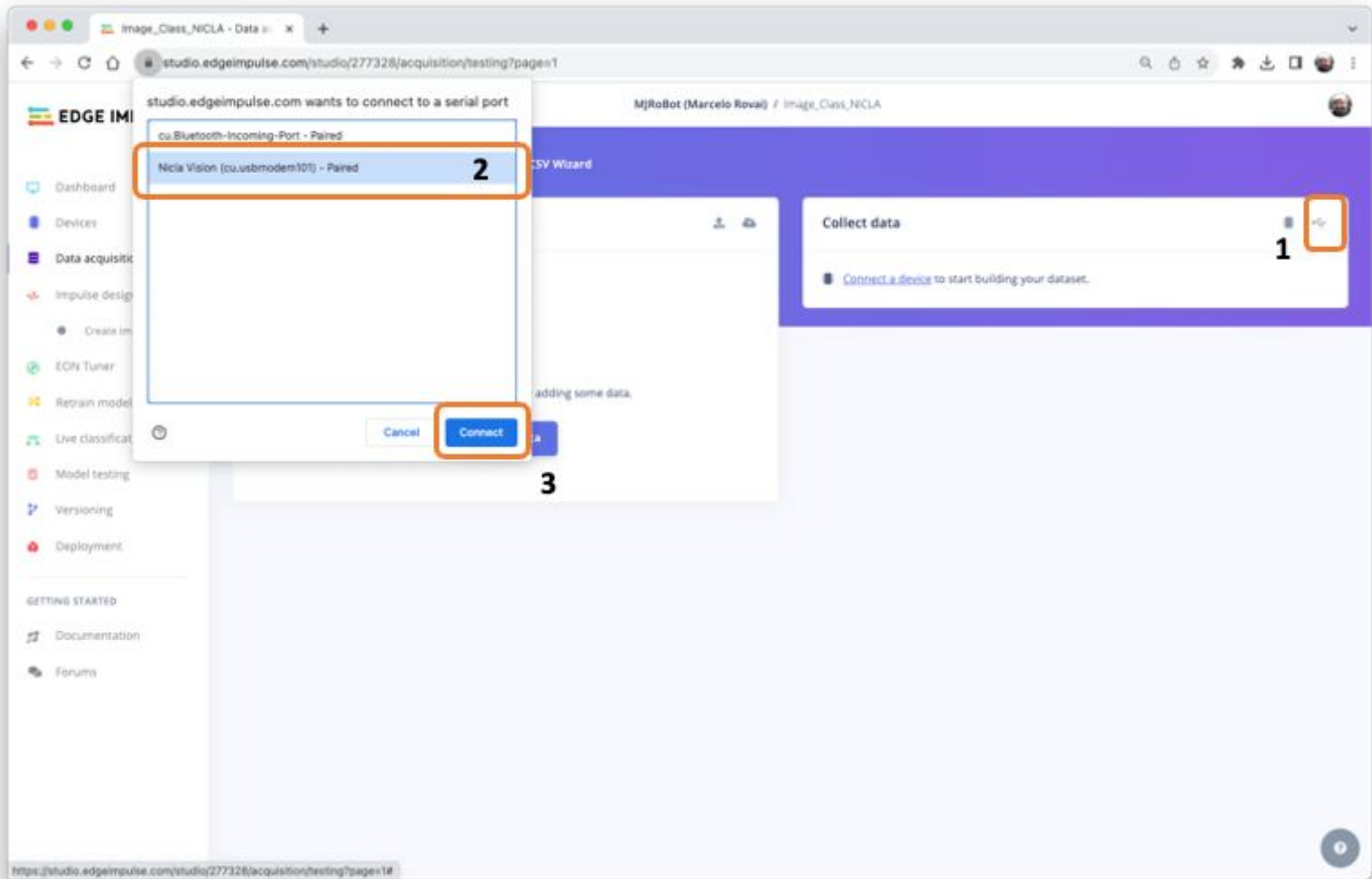
- Pre-Processing Data
- Design a Model
- Train a Model

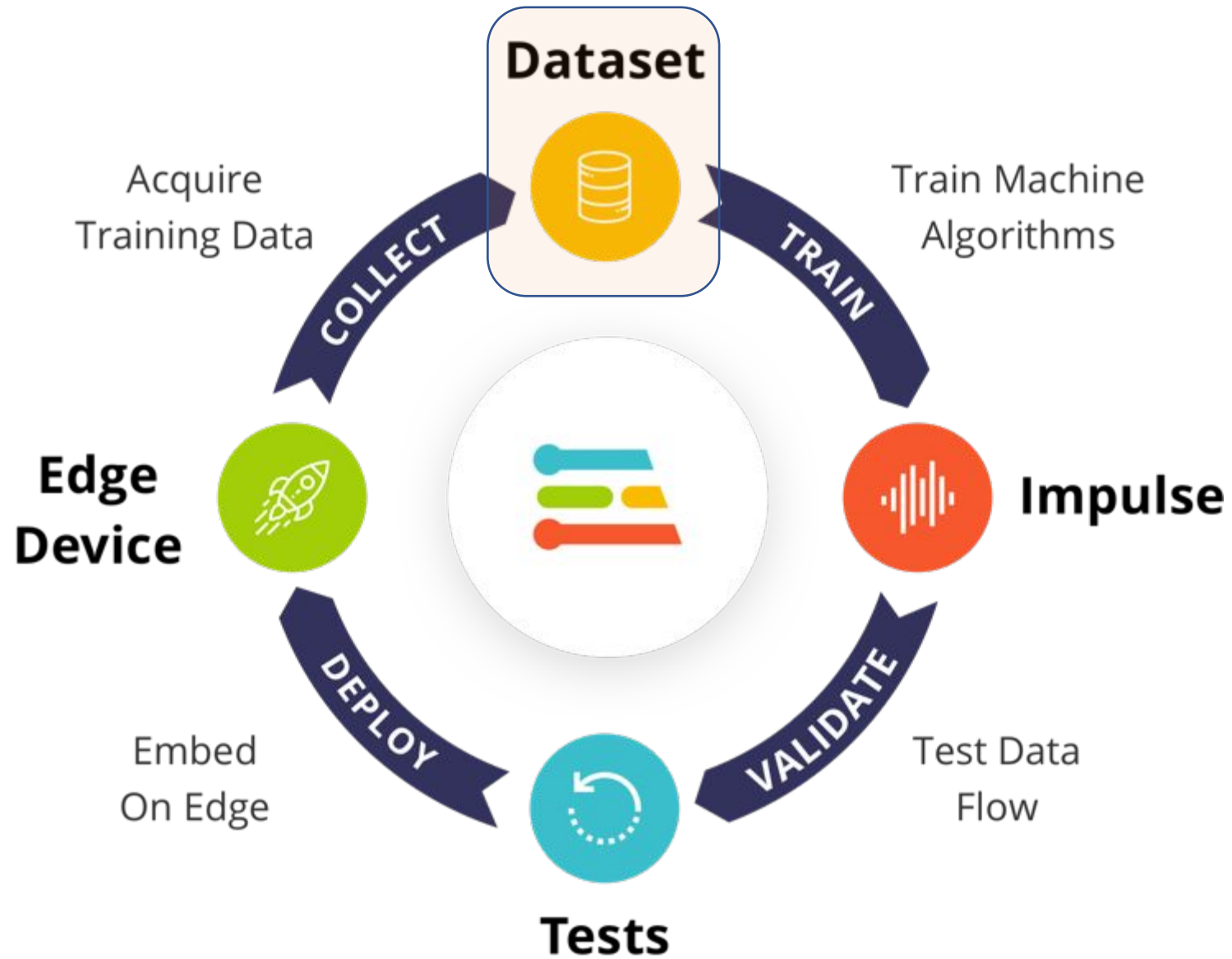
# Edge Device



## & Sensors







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



Image\_Class\_NICLA - Data x +

studio.edgeimpulse.com/studio/277328/acquisition/testing?page=1

MJRoBot (Marcelo Roval) / Image\_Class\_NICLA

### EDGE IMPULSE

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

GETTING STARTED

- Documentation
- Forums

**Dataset** | Data explorer | Data sources | CSV Wizard

DATA COLLECTED: 20s

TRAIN / TEST SPLIT: 0% / 100%

#### Dataset

Training (0) | Test (4)

SAMPLE NAME	LABEL	ADDED	
camera.4bobcgqn	camera	Today, 18:22:44	⋮
camera.4bobb4ak	camera	Today, 18:21:59	⋮
camera.4bob85un	IMU	Today, 18:20:22	⋮
camera.4bob1flv	camera	Today, 18:16:43	⋮

Collect data

Device: 51:0C:39:31:35:32

Label: camera

Sensor: Camera (320x240)

Camera feed

Start sampling

RAW DATA

camera.4bobcgqn

Metadata

Collect Data

dataset\_capture\_script.py - OpenMV IDE

http\_client\_1.py\* - dataset\_capture\_script.py\* - Line: 26, Col: 1

Record Zoom Disable

Dataset Editor dataset\_capture\_script.py


```

1 # Dataset Capture Script - By: marcelia.roval - Tue Aug 22 2023
2
3 # Use this script to control how your OpenMV Cam captures images for your dataset.
4 # You should apply the same image pre-processing steps you expect to run on images
5 # that you will feed to your model during run-time.
6
7 import sensor, image, time
8
9 sensor.reset()
10 sensor.set_pixformat(sensor.RGB565) # Modify as you like.
11 sensor.set_framesize(sensor.VGA) # Modify as you like.
12 sensor.skip_frames(time = 2000)
13
14 clock = time.clock()
15
16 while(True):
17     clock.tick()
18     img = sensor.snapshot()
19     # Apply lens correction if you need it.
20     # img.lens_corr()
21     # Apply rotation correction if you need it.
22     img.rotation_corr()
23     # Apply other filters...
24     # E.g. mean/median/mode/midpoint/etc.
25     print(clock.fps())
26

```

00000.jpg  
00001.jpg  
00002.jpg  
00003.jpg  
00004.jpg  
00005.jpg  
00006.jpg  
00007.jpg  
00008.jpg  
00009.jpg  
00010.jpg  
00011.jpg

Image Preview



Serial Terminal

```


13.8042
13.8043
13.8042
13.8043
13.8042
13.8043

```

Search Results Serial Terminal

Board: Arduino Nicla Vision Sensor: OC2145 Firmware Version: 4.4.2 - [latest] Serial Port: cu.usbmodem3170375234301 Drive: /Volumes/NO NAME FPS: 13.9

Frame Buffer



Histogram RGB Color Space

Res (w:320, h:240)

Mean	87	Median	58	Mode	41	StDev	66
Min	0	Max	255	LQ	41	UQ	123

Mean	98	Median	89	Mode	85	StDev	55
Min	0	Max	255	LQ	69	UQ	117

Mean	83	Median	74	Mode	74	StDev	50
Min	0	Max	255	LQ	49	UQ	99

Upload data - Cifar10\_Image\_C x +

studio.edgeimpulse.com/studio/51070/upload

**EDGE IMPULSE**

UPLOAD DATA (CIFAR10\_IMAGE\_CLASSIFICATION)

MJRoBot (Marcelo Rovai)

**Collect Data**

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

GETTING STARTED

- Documentation
- Forums

### Upload existing data

You can upload existing data to your project in the [Data Acquisition Format](#) (CBOR, JSON, CSV), or as WAV, JPG or PNG files.

Select files

No file chosen

Upload into category

Automatically split between training and testing

Training

Testing

Label

Infer from filename

Enter label:

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Periquito vs Robot - Img Clas x +

https://studio.edgeimpulse.com/studio/353482/acquisition/training?page=4

**EDGE IMPULSE**

Dataset | Data explorer | Data sources | CSV Wizard

DATA COLLECTED: 162 items










TRAIN / TEST SPLIT: 78% / 22%

Collect data

Connect a device to start building your dataset.


**Dataset**

Training (127) | Test (35)

00000  LABEL: periquito	00043  LABEL: periquito	00039  LABEL: periquito
00038  LABEL: periquito	00033  LABEL: periquito	00036  LABEL: periquito
00035  LABEL: periquito	00034  LABEL: periquito	00031  LABEL: periquito

RAW DATA

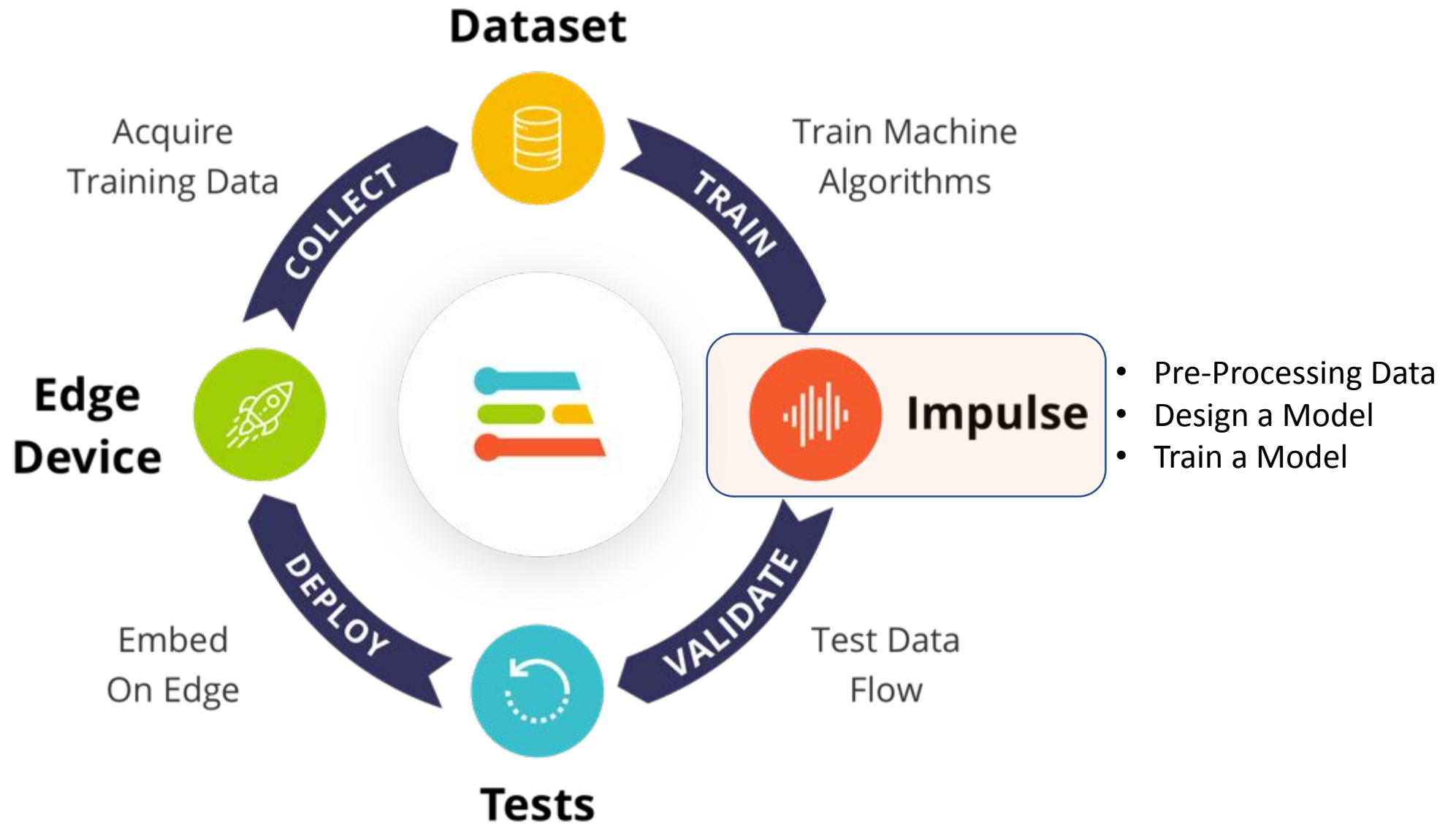
periquito.50nsp64i



Metadata

No metadata.

Collect Data



Periquito vs Robot - Img Clas x +

https://studio.edgeimpulse.com/studio/353482/create-impulse

**EDGE IMPULSE**

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
  - Image
  - Transfer learning
- EON Tuner
- Retrain model
- Live classification
- Model testing
- Versioning
- Deployment

**GETTING STARTED**

- Documentation
- Forums

**Image data** (Database icon)

Input axes

Image

Image width: 96    Image height: 96

Resize mode: Squash

**Image** (Lightning bolt icon)

Name: Image

Input axes (1):  image

**Transfer Learning (Images)** (Flask icon)

Name: Transfer learning

Input features:  Image

Output features: 3 (background, periquito, robot)

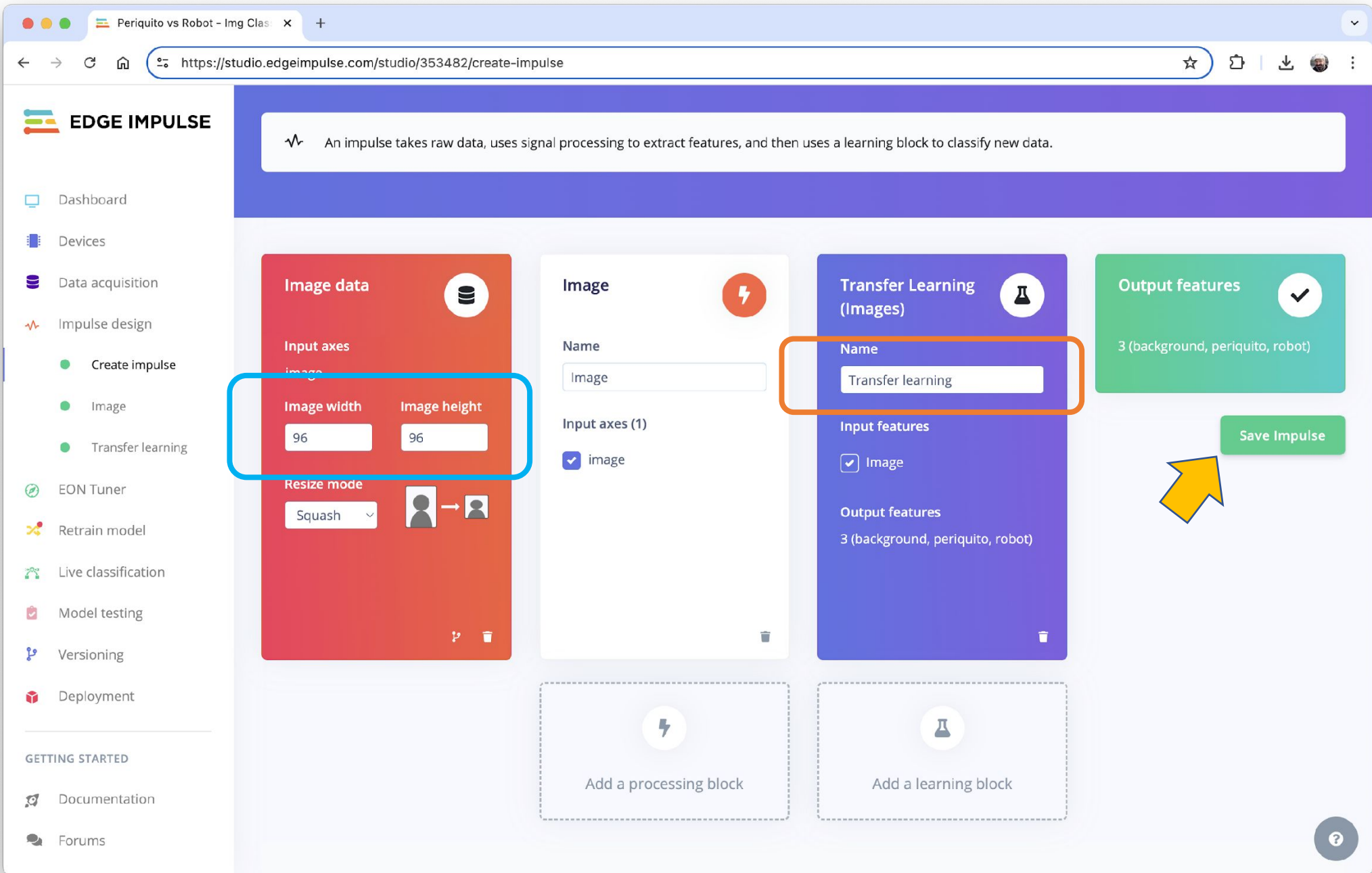
**Output features** (Checkmark icon)

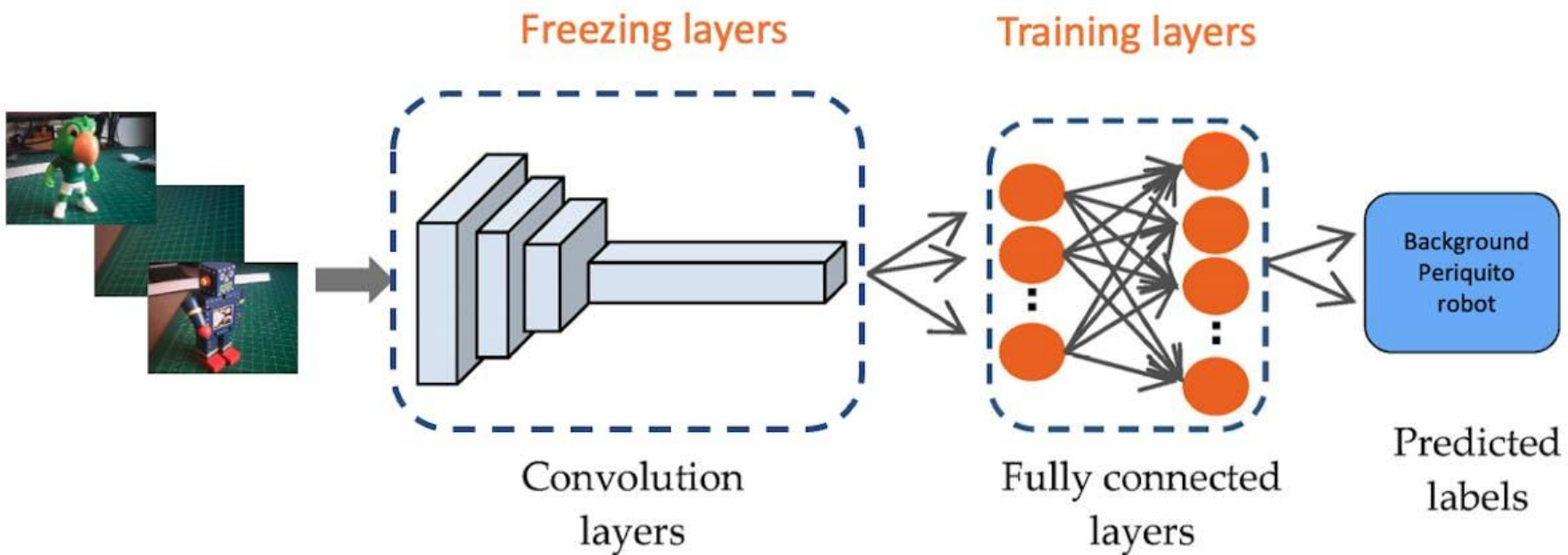
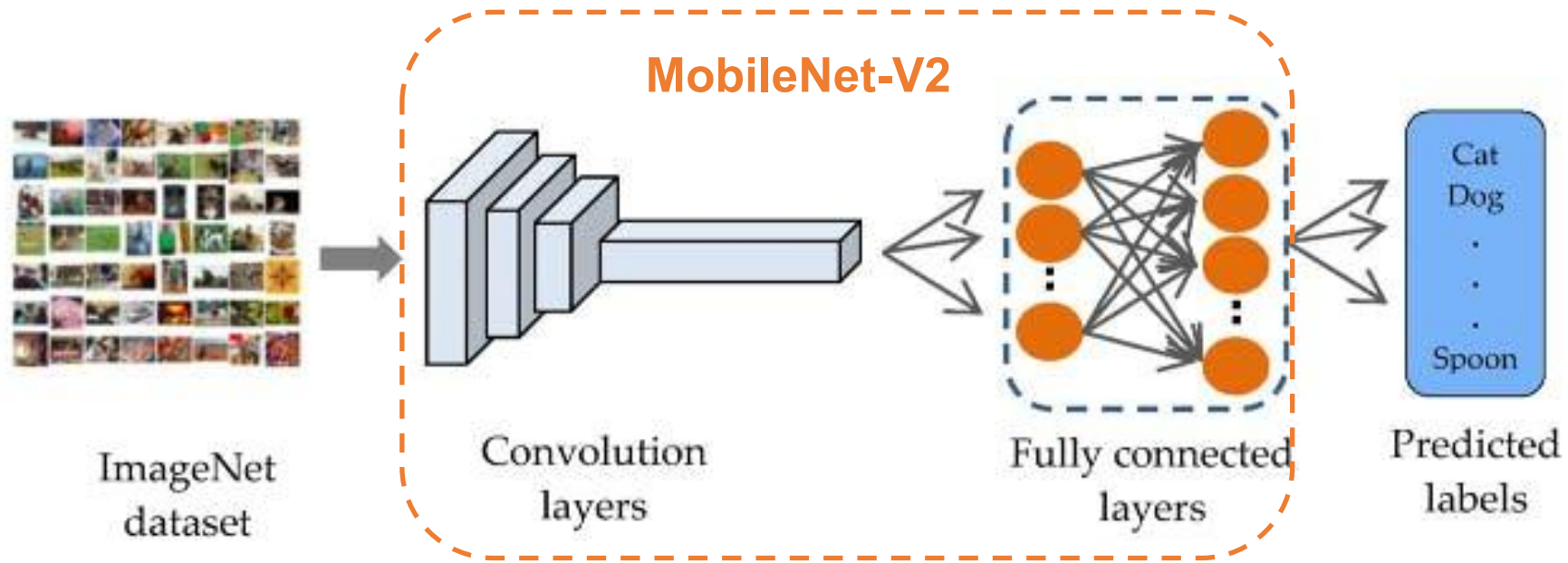
3 (background, periquito, robot)

Save Impulse

Add a processing block

Add a learning block






Periquito vs Robot - Img Clas x +

https://studio.edgeimpulse.com/studio/353482/dsp/image/3

**EDGE IMPULSE**

- Dashboard
- Devices
- Data acquisition
- Impulse design
  - Create impulse
  - Image
  - Transfer learning
- EON Tuner
- Retrain model
- Live classification
- Model testing
- Versioning
- Deployment

**Raw data** Show: All labels periquito.50nsp64i (periqu)



**Raw features**

0x2a241f, 0x2e2422, 0x302423, 0x312727, 0x30282a, 0x322a29, 0x3b2e28, 0...

**Parameters**


**Image**

Color depth ? RGB

**Save parameters**

**DSP result**

**Image**



$96 \times 96 \times 3 = 27,648$

**Processed features**

0.1647, 0.1412, 0.1216, 0.1804, 0.1412, 0.1333, 0.1882, 0.1412, 0.1373, ...

**On-device performance** ?

**PROCESSING TIME** 1 ms.

**PEAK RAM USAGE** 4 KB

Copy 27648 features to clipboard

Preprocess Data

https://studio.edgeimpulse.com/studio/353482/dsp/image/3#



Periquito vs Robot - Img Clas x +

https://studio.edgeimpulse.com/studio/353482/dsp/image/3/generate-features

# EDGE IMPULSE

#1 ▼ Click to set a description for this version

Parameters **Generate features**

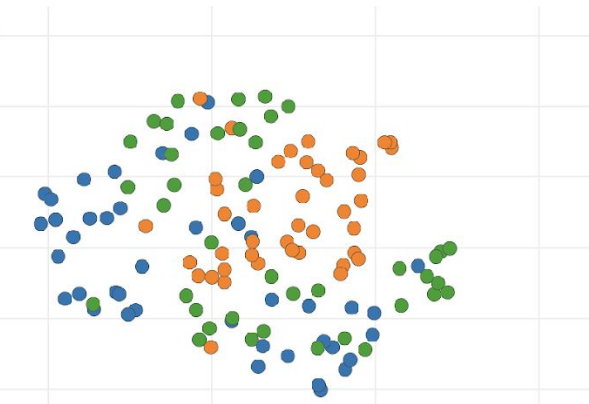
### Training set

Data in training set	127 items
Classes	3 (background, periquito, robot)

**Generate features**

### Feature explorer



- background
- periquito
- robot



### Feature generation output

**(0)**

### On-device performance ?

 PROCESSING TIME	 PEAK RAM USAGE
<b>1 ms.</b>	<b>4 KB</b>

Dashboard  
Devices  
Data acquisition  
Impulse design  
Create impulse  
Image  
Transfer learning  
EON Tuner  
Retrain model  
Live classification  
Model testing  
Versioning  
Deployment

GETTING STARTED  
Documentation  
Forums

Preprocess Data



Periquito vs Robot - Img Clas x +

https://studio.edgeimpulse.com/studio/353482/learning/keras-transfer-image/5

**EDGE IMPULSE**

- Dashboard
- Devices
- Data acquisition
- Impulse design
  - Create impulse
  - Image
  - Transfer learning
- EON Tuner
- Retrain model
- Live classification
- Model testing
- Versioning
- Deployment

GETTING STARTED

- Documentation
- Forums

**Training settings**

Number of training cycles 20

Use learned optimizer

Learning rate 0.0005

Training processor CPU

Data augmentation

**Advanced training settings**

Validation set size 20 %

Split train/validation set on metadata key

Batch size 32

Auto-weight classes

Profile int8 model

**Neural network architecture**

Input layer (27,648 features)

MobileNetV2 96x96 0.1 (final layer: 8 neurons, 0.1 dropout)

Choose a different model

Output layer (3 classes)

**Start training**

**Model** Model version: Quantized (int8)

**Last training performance (validation set)**

ACCURACY 92.0%

LOSS 0.19

**Confusion matrix (validation set)**

	BACKGROUND	PERIQUITO	ROBOT
BACKGROUND	77.8%	22.2%	0%
PERIQUITO	0%	100%	0%
ROBOT	0%	0%	100%
F1 SCORE	0.88	0.89	1.00

**Metrics (validation set)**

METRIC	VALUE
Area under ROC Curve	1.00
Weighted average Precision	0.94
Weighted average Recall	0.92
Weighted average F1 score	0.92

**Data explorer (full training set)**

- background - correct
- periquito - correct
- robot - correct
- background - incorrect
- robot - incorrect

Estimate for Arduino Nicla Vision (Cortex-M7 480MHz), compiled with Edge Impulse EON™ compiler

**On-device performance** Engine: EON™ Compiler

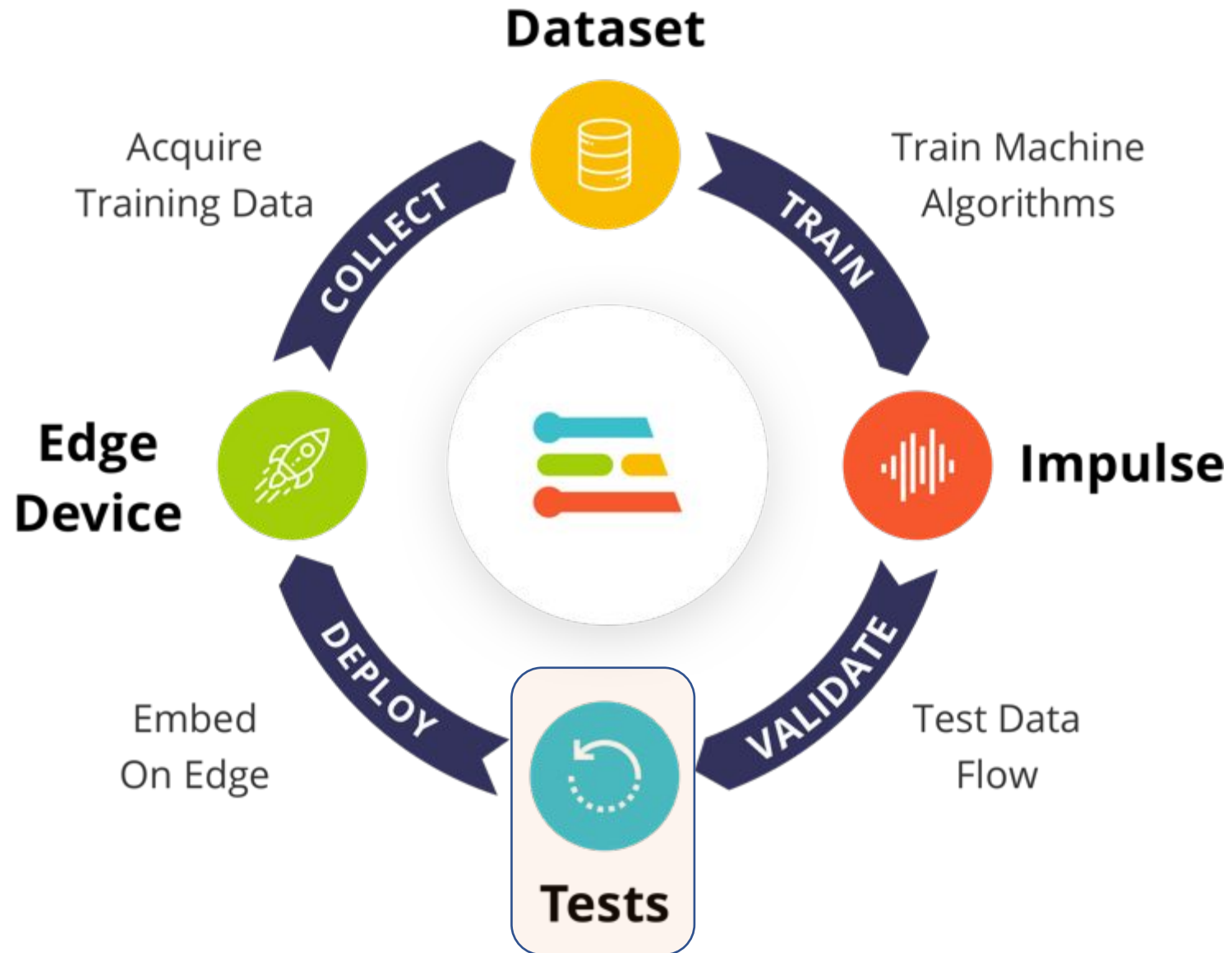
INFERRING TIME 76 ms.

PEAK RAM USAGE 280.9K

FLASH USAGE 212.0K

Design a Model

Train a Model



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

Periquito vs Robot - Img Clas x +

https://studio.edgeimpulse.com/studio/353482/validation

**EDGE IMPULSE**

Dashboard  
Devices  
Data acquisition  
Impulse design  
Create impulse  
Image  
Transfer learning  
EON Tuner  
Retrain model  
Live classification  
**Model testing**  
Versioning  
Deployment  
GETTING STARTED  
Documentation  
Forums

**Test data** Classify all

Set the 'expected outcome' for each sample to the desired class. The model will automatically score the impulse.

SAMPLE NAME	EXPECTED OUTCO...	LENGTH	ACCURACY	RESULT
testing.48m7...	periquito	0s	0%	1 uncertain
00000	background	0s	100%	1 background
00005	background	0s	100%	1 background
00009	background	0s	100%	1 background
00015	background	0s	100%	1 background
00017	background	0s	100%	1 background
00026	background	0s	100%	1 background
00028	background	0s	100%	1 background
00033	background	0s	100%	1 background
00044	background	0s	100%	1 background
00049	background	0s	100%	1 background

**Model testing output** (0)

**Results** Model version: Unoptimized (float32)

**ACCURACY**  
97.14%

**Metrics for Transfer learning**

METRIC	VALUE
Area under ROC Curve	1.00
Weighted average Precision	0.97
Weighted average Recall	0.97
Weighted average F1 score	0.97

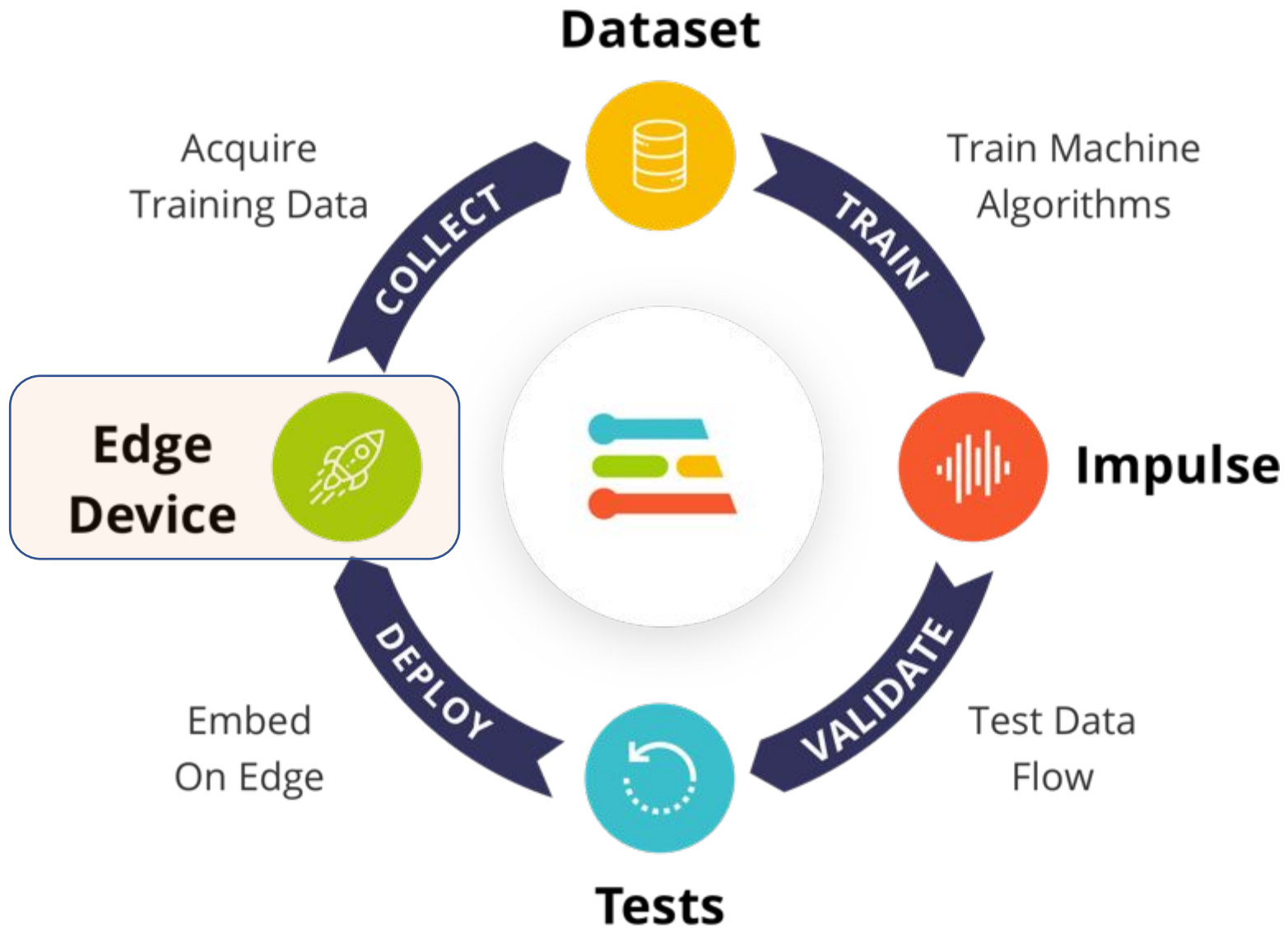
**Confusion matrix**

	BACKGROUND	PERIQUITO	ROBOT	UNCERTAIN
BACKGROUND	100%	0%	0%	0%
PERIQUITO	0%	91.7%	0%	8.3%
ROBOT	0%	0%	100%	0%
F1 SCORE	1.00	0.96	1.00	

**Feature explorer**

- background - correct
- periquito - correct
- robot - correct
- periquito - incorrect

Evaluate Optimize



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

Periquito vs Robot - Img Clas x +

https://studio.edgeimpulse.com/studio/353482/deployment

**EDGE IMPULSE**

- Dashboard
- Devices
- Data acquisition
- Impulse design
  - Create impulse
  - Image
  - Transfer learning
- EON Tuner
- Retrain model
- Live classification
- Model testing
- Versioning
- Deployment**
- GETTING STARTED
  - Documentation
  - Forums

### Configure your deployment

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.](#)

Arduino library x

**SELECTED DEPLOYMENT**

**Arduino library**  
An Arduino library with examples that runs on most Arm-based Arduino development boards.

**MODEL OPTIMIZATIONS**  
Model optimizations can increase on-device performance but may reduce accuracy.

**EON™ Compiler**  
Same accuracy, 17% less RAM, 26% less ROM.

**Quantized (int8)**  
**Selected**

	IMAGE	TRANSFER LEARNING	TOTAL
LATENCY	1 ms.	76 ms.	77 ms.
RAM	4.0K	280.9K	280.9K
FLASH	-	212.0K	-
ACCURACY			94.29%

**Unoptimized (float32)**  
**Select**

	IMAGE	TRANSFER LEARNING	TOTAL
LATENCY	1 ms.	159 ms.	160 ms.
RAM	4.0K	893.8K	893.8K
FLASH	-	401.1K	-
ACCURACY			97.14%

Estimate for Arduino Nida Vision (Cortex-M7 480MHz) [Change target](#)

**Build**

### Latest build

**ARDUINO** v28 (Arduino library)  
Today, 17:00:14 [View docs](#)

### Build output

```

Creating job... OK (ID: 22412220)

Scheduling job in cluster...
Container image pulled!
Job started
Writing templates...
Writing templates OK

Writing templates...
Scheduling job in cluster...
Container image pulled!
Job started
Copying Edge Impulse SDK...
Copying Edge Impulse SDK OK

Compiling EON model...
Compiling EON model OK

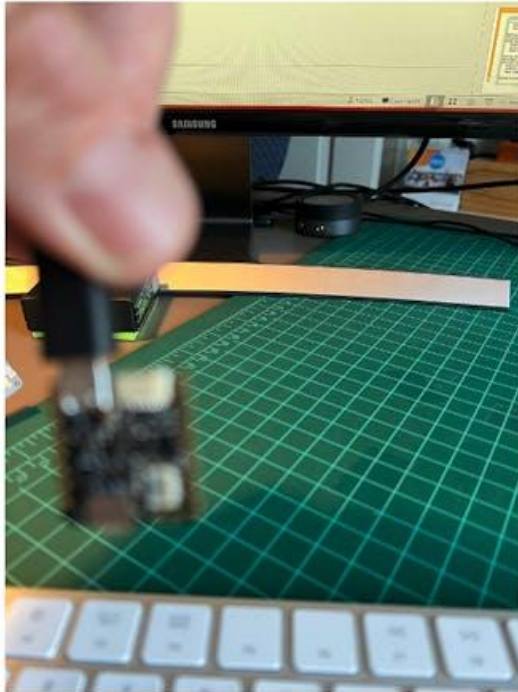
Removing clutter and updating headers...
Removing clutter and updating headers OK

Creating archive...
Creating archive OK

Job completed (success)
  
```

Deploy Model

Make Inferences



Predictions (DSP: 1 ms., Classification: 86 ms.)  
background: 0.992187  
periquito: 0.007813  
robot: 0.000000



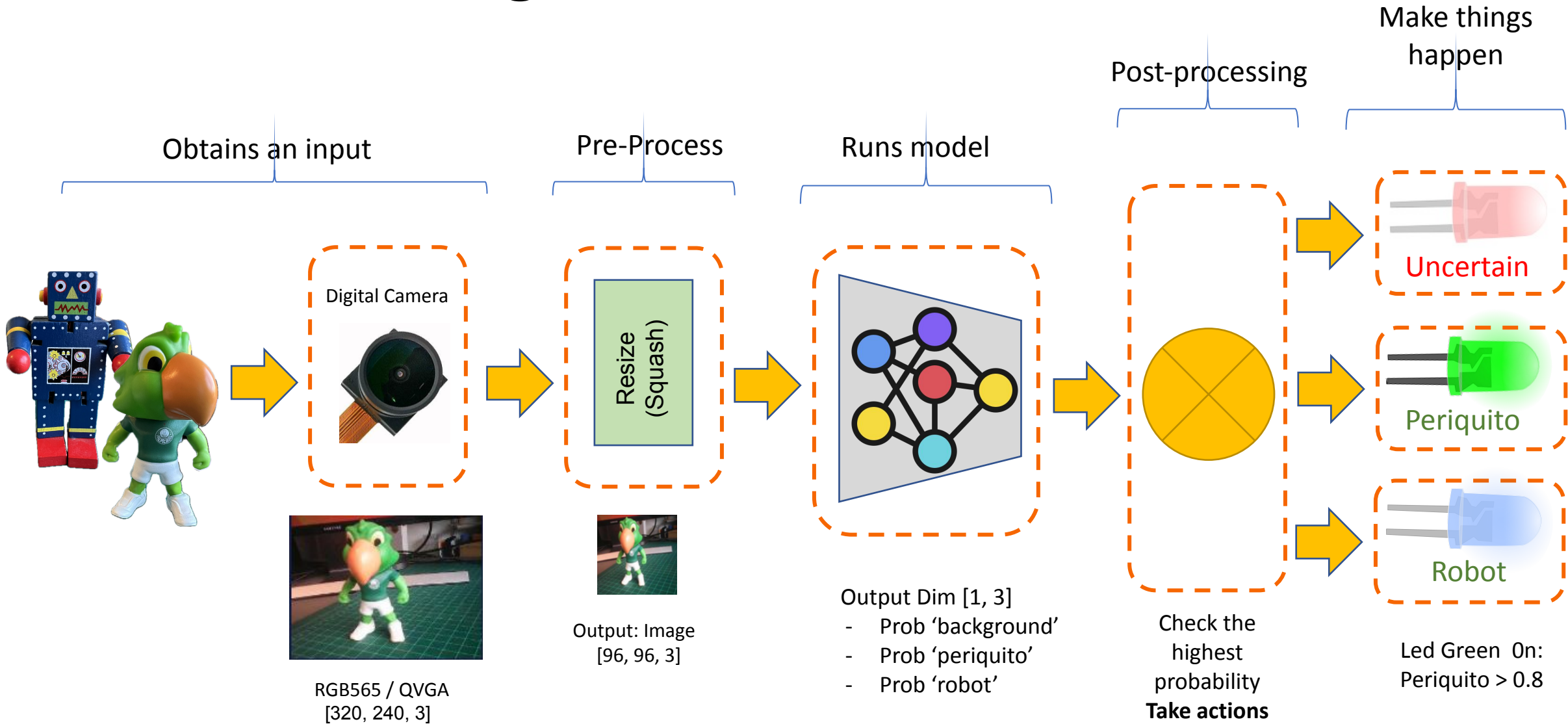
Predictions (DSP: 1 ms., Classification: 86 ms.)  
background: 0.015625  
periquito: 0.210937  
robot: 0.773437



Predictions (DSP: 1 ms., Classification: 86 ms.)  
background: 0.000000  
periquito: 0.992187  
robot: 0.007813





# Post-Processing with LEDs:











Serial Terminal    
\*\*\*\*\*  
Prediction:  
periquito with a prob of 0.99  
FPS: 7.37 fps ==> latency: 136 ms





Serial Terminal    
\*\*\*\*\*  
Prediction:  
robot with a prob of 0.96  
FPS: 7.34 fps ==> latency: 136 ms



Serial Terminal    
\*\*\*\*\*  
Prediction:  
background with a prob of 1.00  
FPS: 7.34 fps ==> latency: 136 ms



Serial Terminal    
\*\*\*\*\*  
Prediction:  
uncertain with a prob of 0.76  
FPS: 7.42 fps ==> latency: 135 ms



# Computer Vision Recognition Tasks

## Image Classification (Multi-Class Classification)

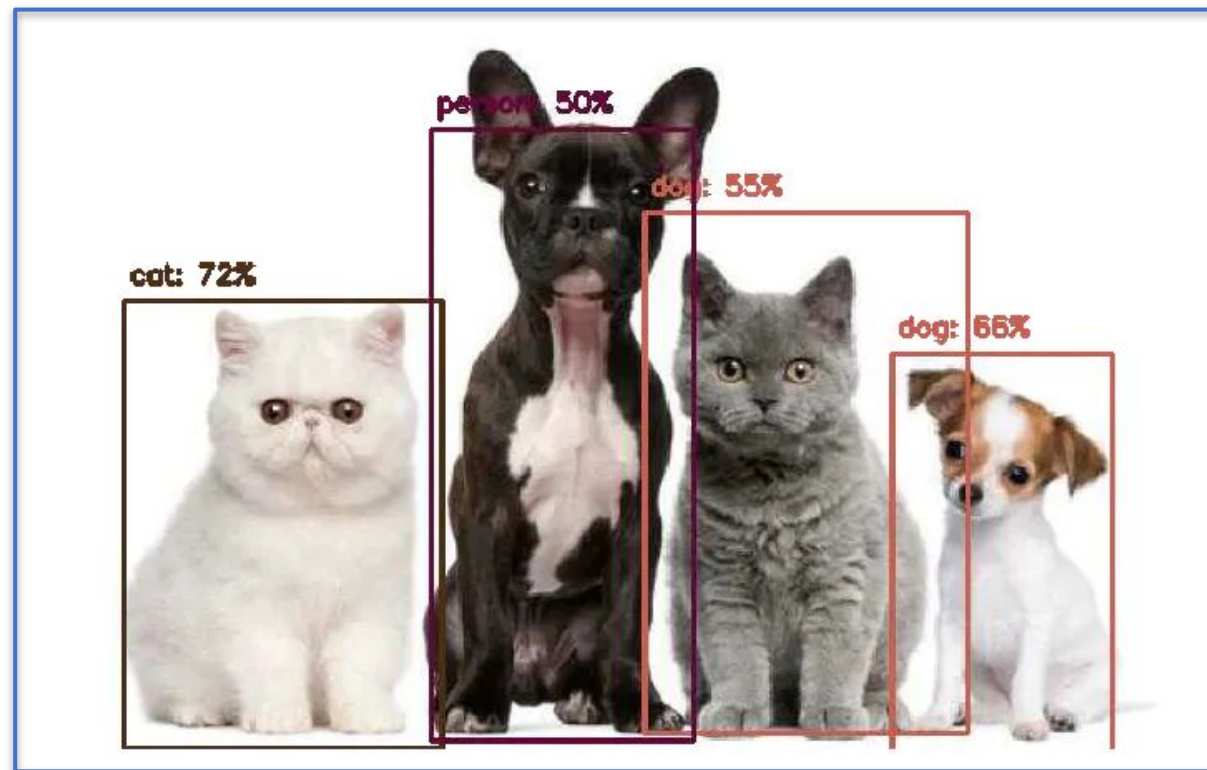


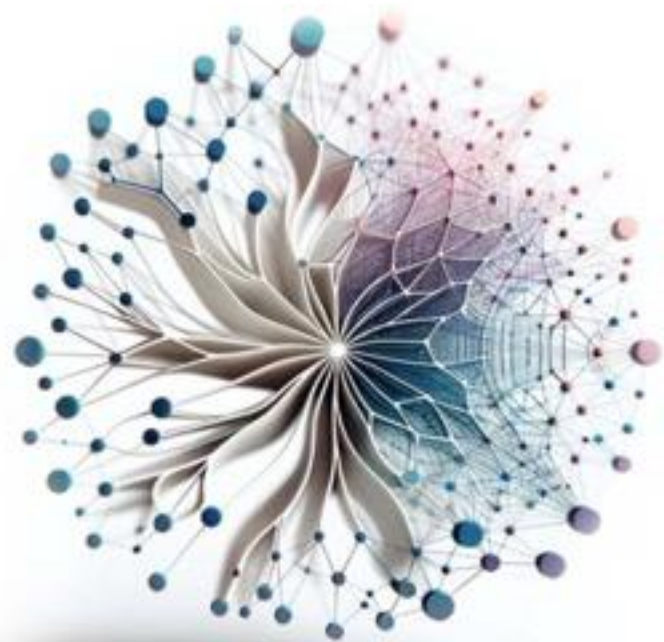
Cat: 70%



Dog: 80%

## Object Detection Multi-Label Classification + Object Localization





## Machine Learning Systems

with TinyML

Written, edited and curated by  
Prof. Vijay Janapa Reddi  
Harvard University

*With special thanks to the community for their contributions and support.*



Nicla Vision > Object Detection

### Object Detection

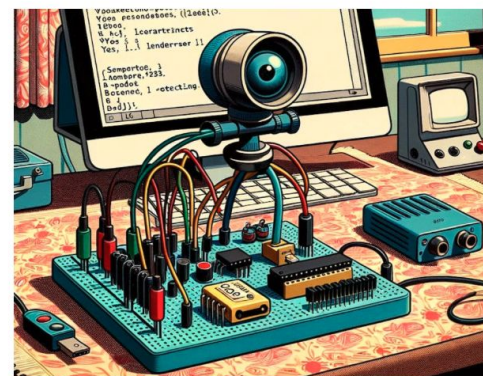


Nicla Vision



XIAO ESP32S3 > Object Detection

### Object Detection



XIAO ESP32S3

# FOMO

Object Detection model

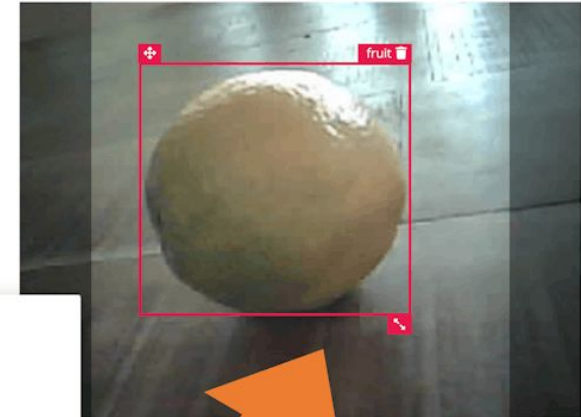
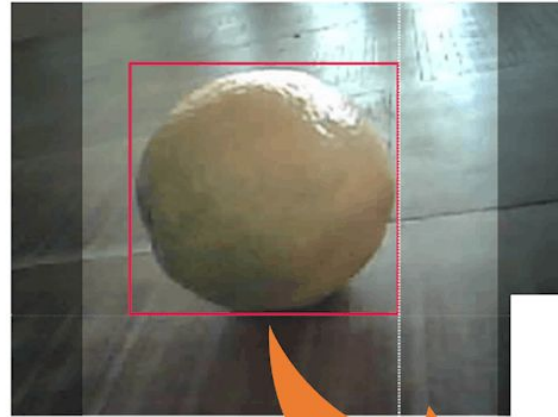
# Labeling

The screenshot shows the Edge Impulse Studio interface for a project named 'XIAO-ESP32S3-Sense-Object\_Detection'. The 'Labeling queue (47)' tab is selected and highlighted with an orange box and an arrow. The interface displays the following components:

- Dataset Summary:** 47 items collected, 0 items in the train/test split.
- Dataset Table:** A table with columns for Sample Name, Labels, Added, and Length. The first row is highlighted in blue.
- Raw Data Preview:** A preview of a raw data sample with ID 20231128151645, showing a video frame of two oranges on a table.
- Metadata:** A section indicating 'No metadata' for the selected sample.

SAMPLE NAME	LABELS	ADDED	LENGTH
20231128151645	-	Today, 15:27:09	-
20231128150613	-	Today, 15:27:09	-
20231128150604	-	Today, 15:27:09	-
20231128150833	-	Today, 15:27:09	-
20231128150600	-	Today, 15:27:09	-
20231128150855	-	Today, 15:27:09	-
20231128150458	-	Today, 15:27:09	-
20231128150713	-	Today, 15:27:09	-
20231128150908	-	Today, 15:27:09	-

# Labeling

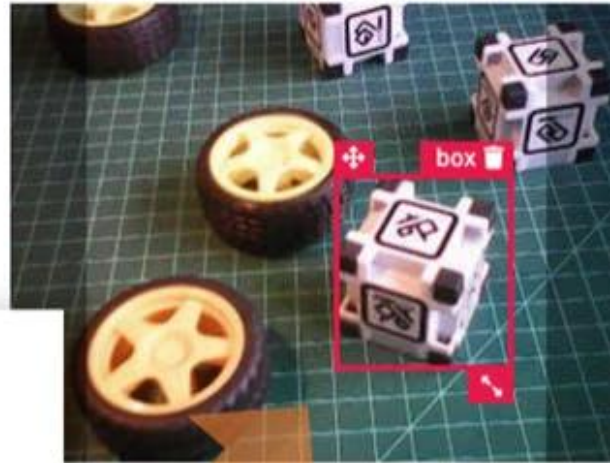
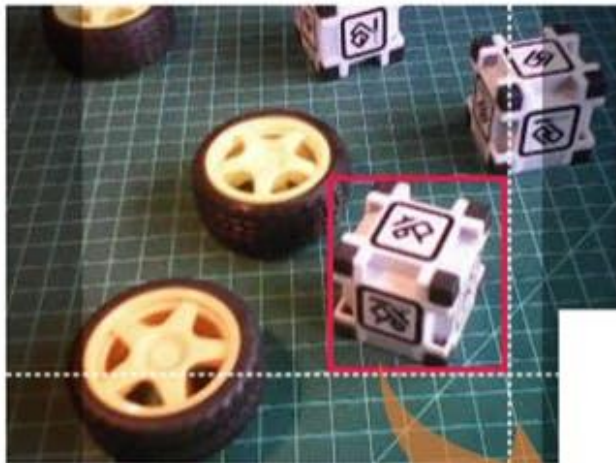


?

Enter label

Enter a label for this new section

Cancel Set label



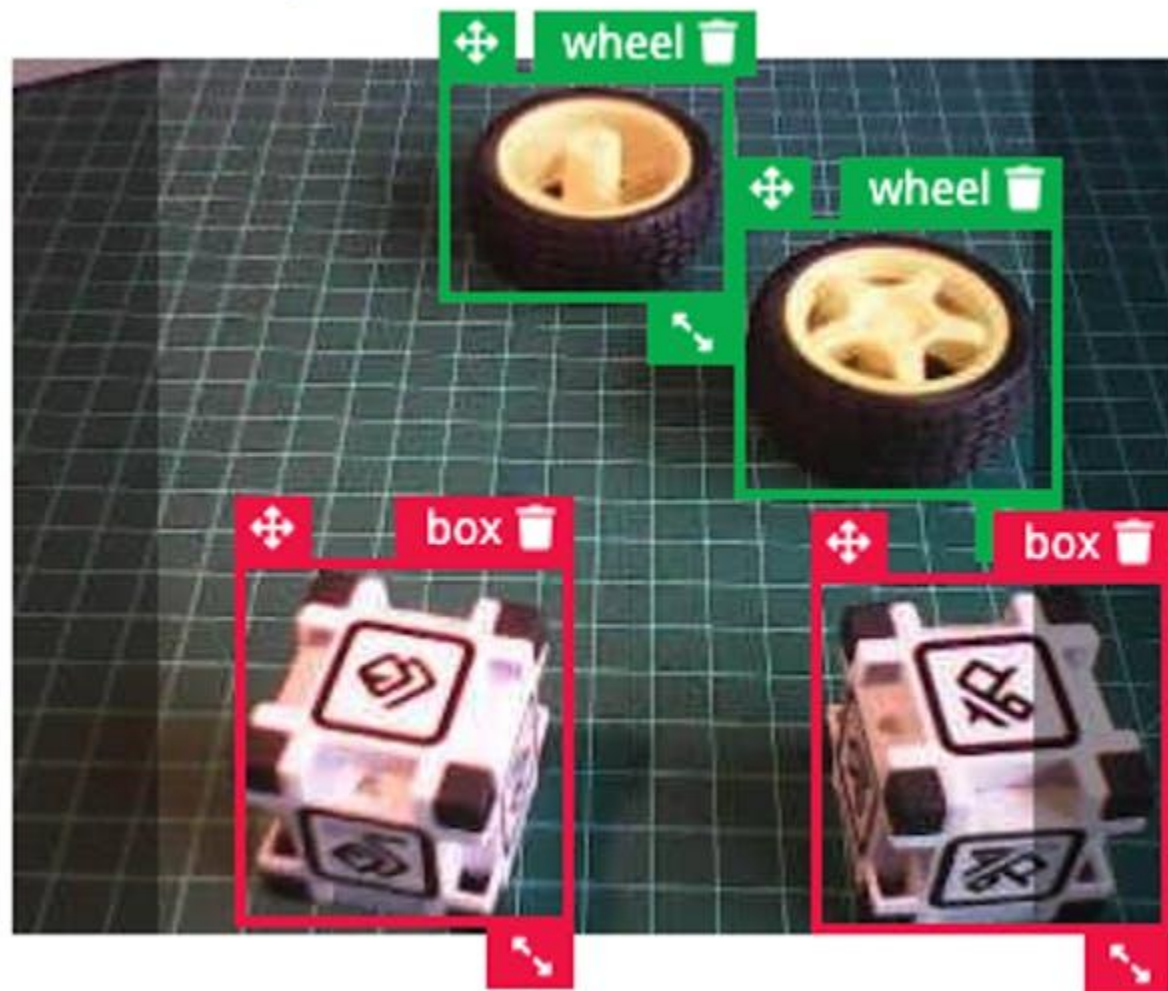
?

Enter label

Enter a label for this new section

Cancel Set label

# Labeling



XIAO-ESP32S3-Sense-Objec x +

studio.edgeimpulse.com/studio/315759/create-impulse

EDGE IMPULSE

MJRoBot (Marcelo Roval) / XIAO-ESP32S3-Sense-Object\_Detection

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 object detection use a square image size, e.g. 96x96, 160x160 or 320x320.

**Image**

Name: Image

Input axes (1)  
 image

**Object Detection (Images)**

Name: Object detection

Input features  
 Image

Output features  
2 (bug, fruit)

**Output features**

2 (bug, fruit)

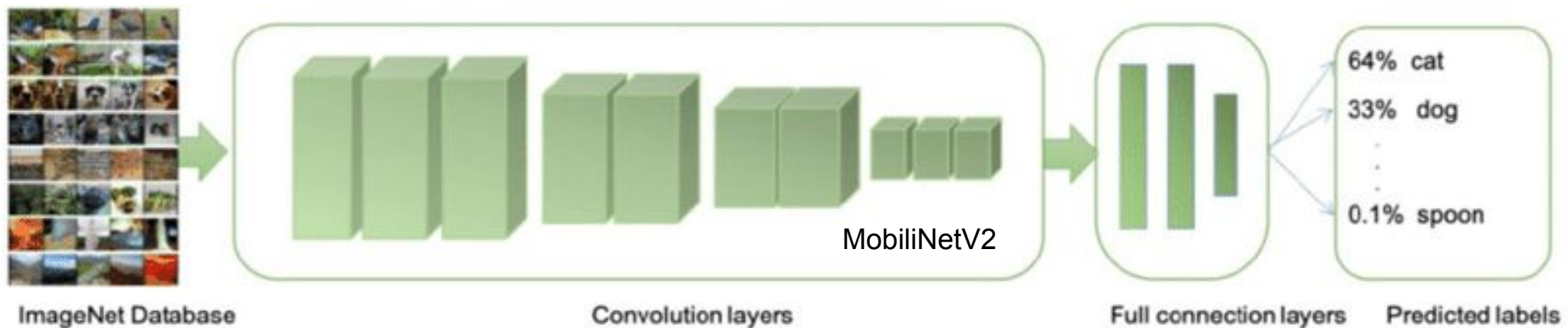
Save Impulse

Add a processing block    Add a learning block

Dashboard  
Devices  
Data acquisition  
Impulse design  
  Create impulse  
  Image  
  Object detection  
EON Tuner  
Retrain model  
Live classification  
Model testing  
Versioning  
Deployment

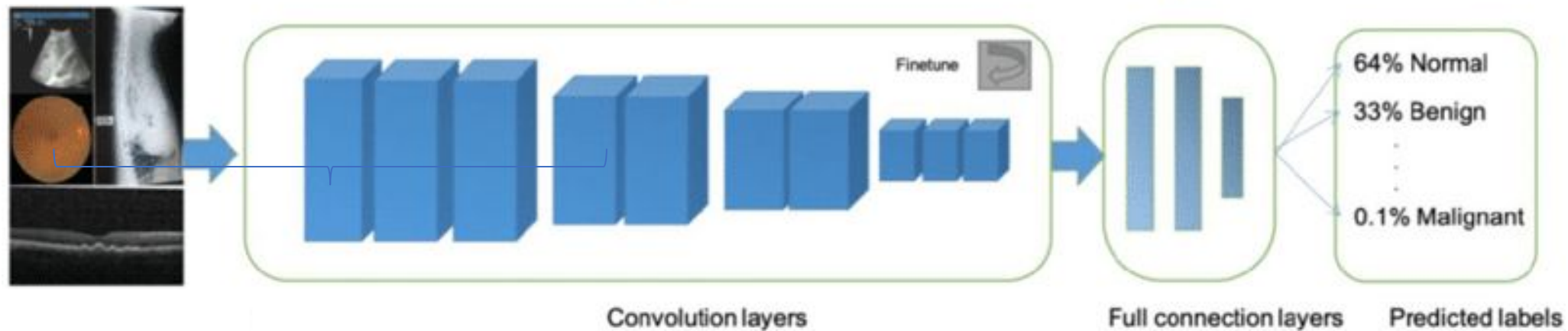
GETTING STARTED  
Documentation  
Forums



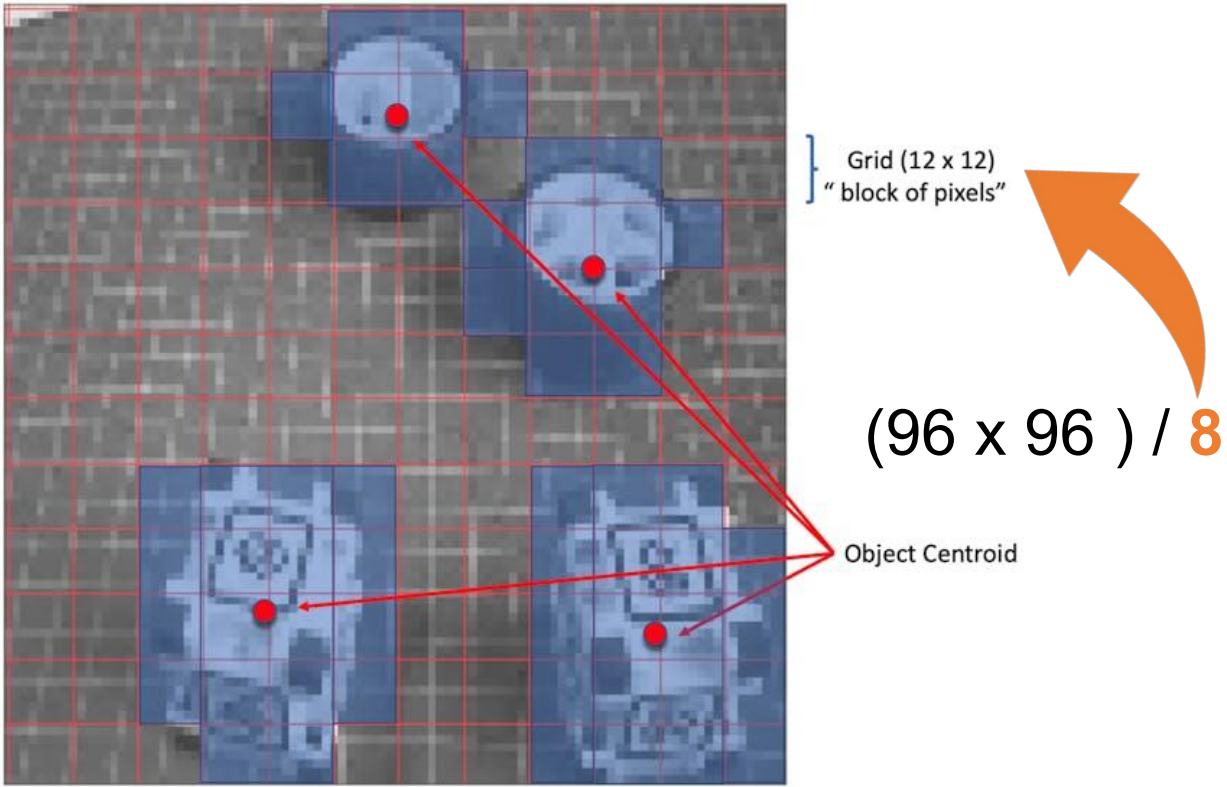
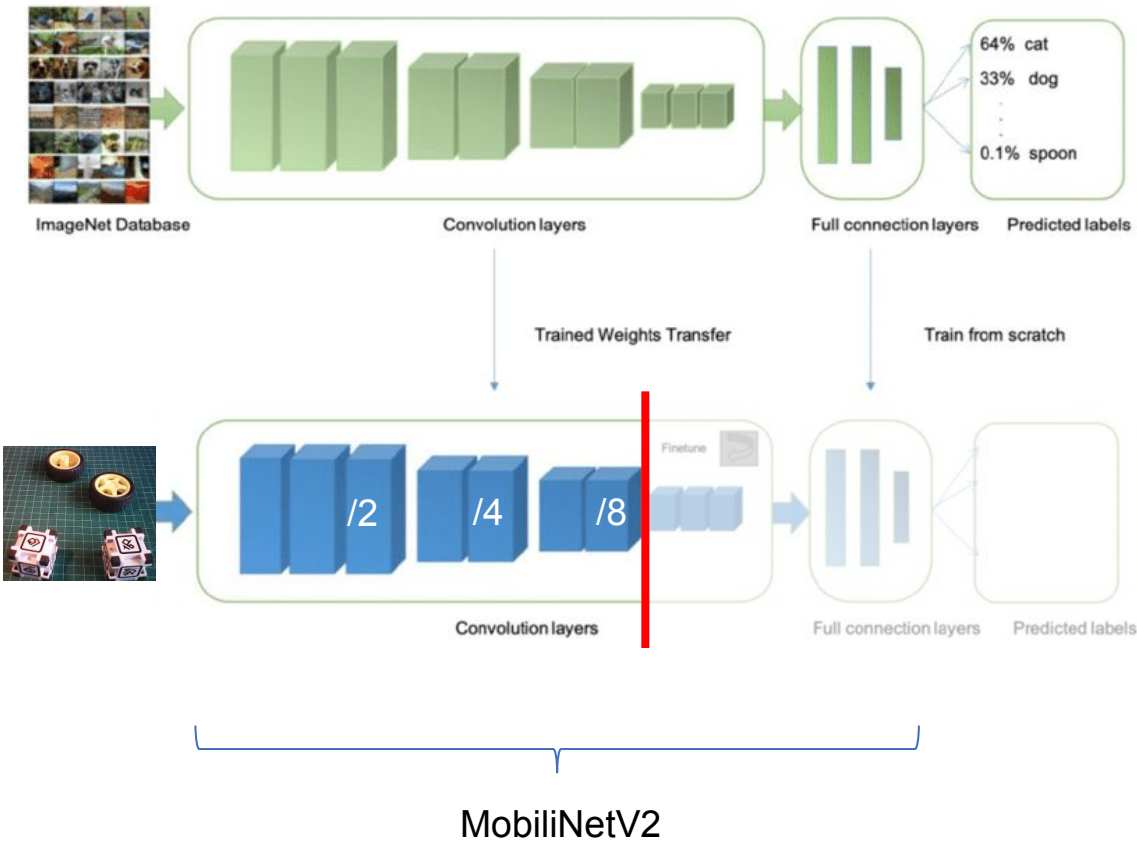


Trained Weights Transfer

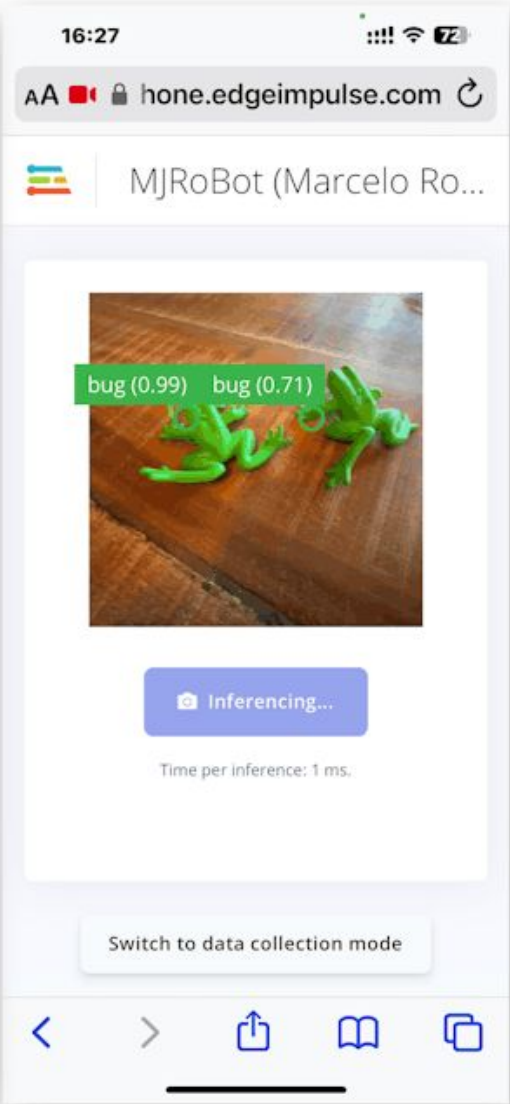
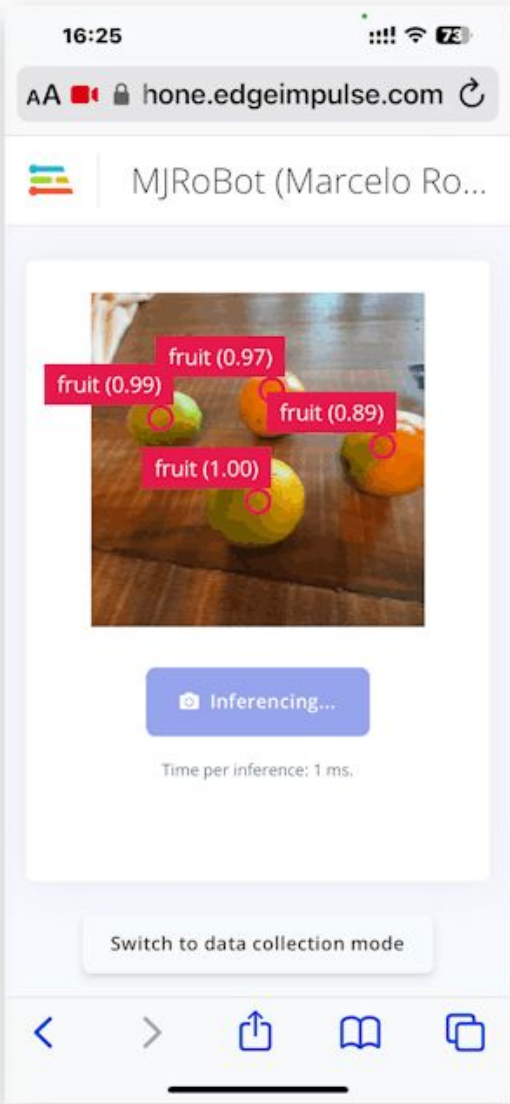
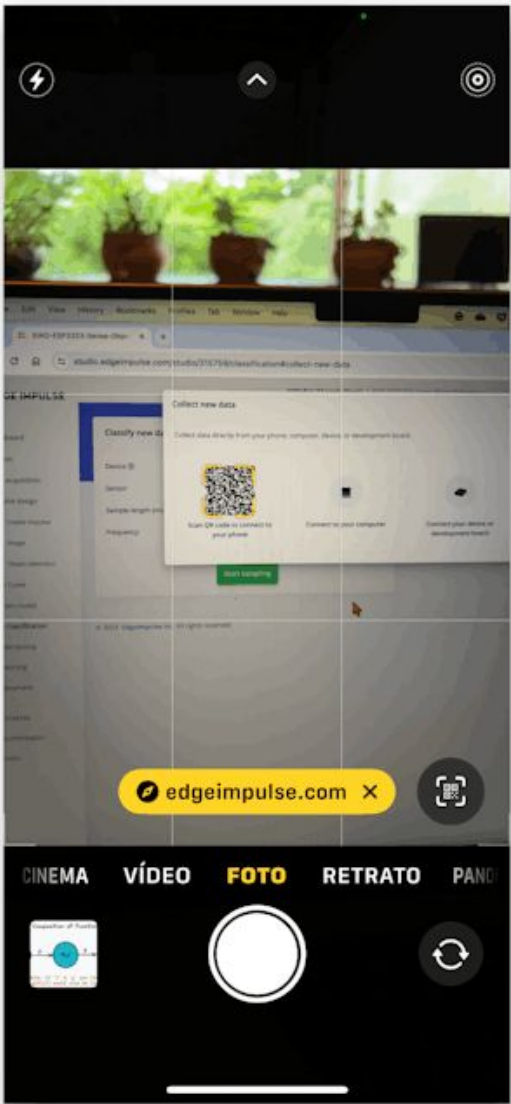
Train from scratch



# Model: FOMO



# Inference Test



# Deploy



## Serial Terminal

```
***** box *****
x 120  y 60
x 170  y 50
x 110  y 120
***** wheel *****
x 70   y 50
x 50   y 110
x 190  y 110
x 50   y 190
8.16685 fps
```

```
esp32_camera | Arduino IDE 2.2.1
XIAO_ESP32S3
esp32_camera.ino
18  * LIABILITY, WHETHER IN AN ACTION OF CONTRACT, TORT OR OTHERWISE, ARISING FROM,
19  * OUT OF OR IN CONNECTION WITH THE SOFTWARE OR THE USE OR OTHER DEALINGS IN THE
20  * SOFTWARE.
21  */
22
23  /* Includes ----- */
24  #include <XIAO-ESP32S3-Sense-Object_Detection_inferencing.h>
25  #include "edge-impulse-sdk/dsp/image/image.hpp"
26
27  #include "esp_camera.h"
28
29  // Select camera model - find more camera models in camera_pins.h file here
30  // https://github.com/espressif/arduino-esp32/blob/master/libraries/ESP32/examples/Camera/Camera
31
32  #define PWDN_GPIO_NUM    -1
33  #define RESET_GPIO_NUM  -1
34  #define XCLK_GPIO_NUM    10
35  #define SIOD_GPIO_NUM    40
36  #define STOC_GPIO_NUM    39

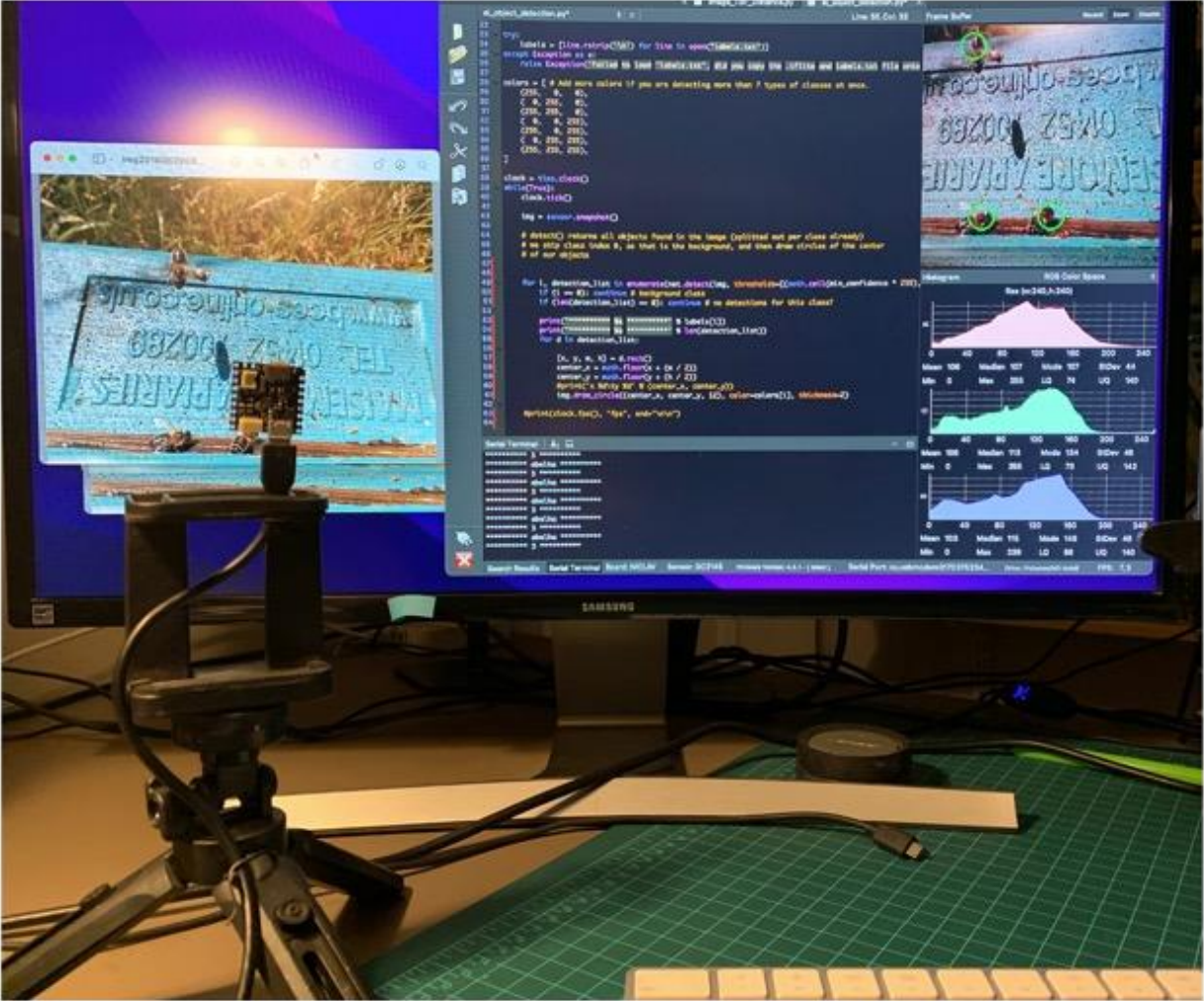
```

Serial Monitor x Output

```
Message (Enter to send message to 'XIAO_ESP32S3' on '/dev/cu.usbmodem2101')
fruit (0.566406) [ x: 56, y: 32, width: 8, height: 8 ]
Predictions (DSP: 4 ms., Classification: 143 ms., Anomaly: 0 ms.):
No objects found
Predictions (DSP: 4 ms., Classification: 143 ms., Anomaly: 0 ms.):
fruit (0.582031) [ x: 48, y: 32, width: 8, height: 8 ]
fruit (0.773438) [ x: 80, y: 32, width: 8, height: 8 ]
Predictions (DSP: 4 ms., Classification: 143 ms., Anomaly: 0 ms.):
fruit (0.550781) [ x: 64, y: 16, width: 8, height: 8 ]
Predictions (DSP: 4 ms., Classification: 143 ms., Anomaly: 0 ms.):
fruit (0.722656) [ x: 64, y: 16, width: 8, height: 8 ]
```



# Detecting Objects using TinyML (FOMO)



MicroPython



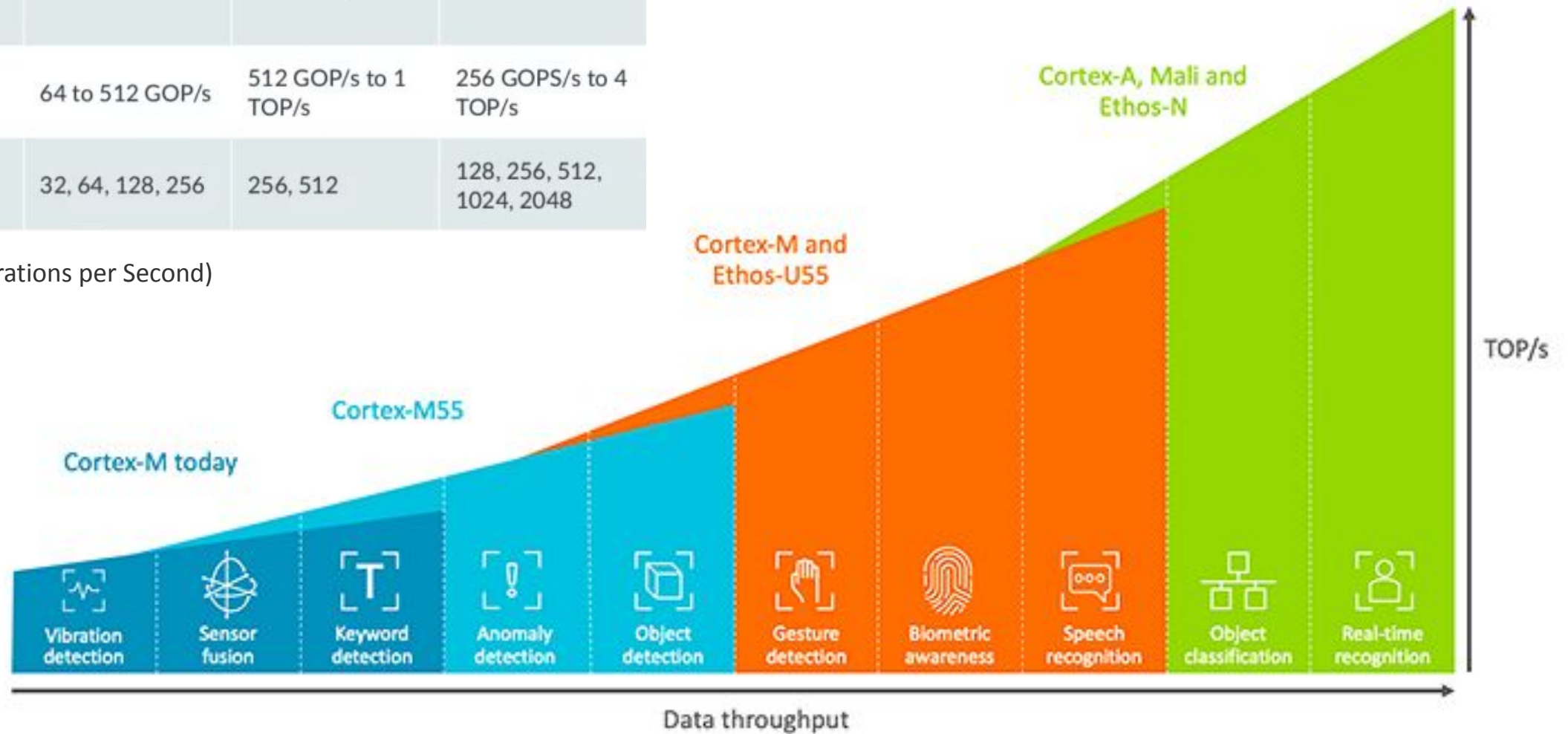
# microNPU

a neural network unit for TinyML

# ML- optimized Solutions

	Ethos-U55	Ethos-U65	Ethos-U85
Performance (At 1 GHz)	64 to 512 GOP/s	512 GOP/s to 1 TOP/s	256 GOPS/s to 4 TOP/s
MACs (8x8)	32, 64, 128, 256	256, 512	128, 256, 512, 1024, 2048

TOPS (Tera Operations per Second)



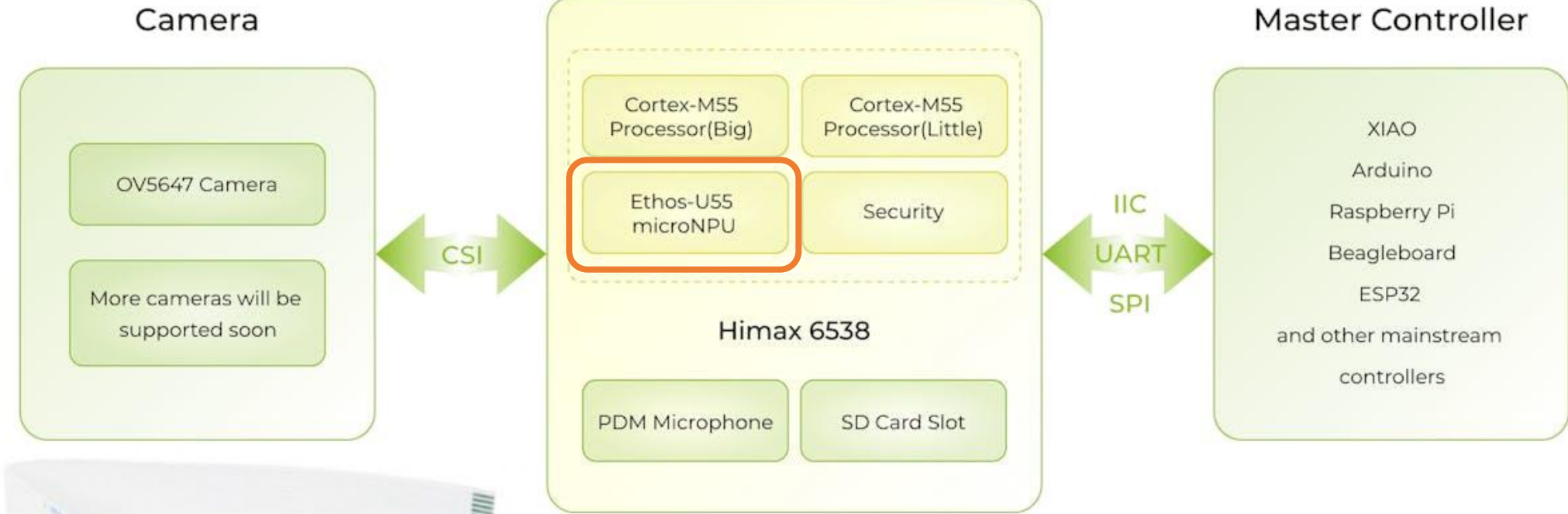


## Computer Vision at the Edge with Grove Vision AI Module V2

*Exploring Computer Vision applications such as Image Classification, Object Detection, and Pose estimation.*



## Grove Vision AI v2





Person Classification



Face Detection



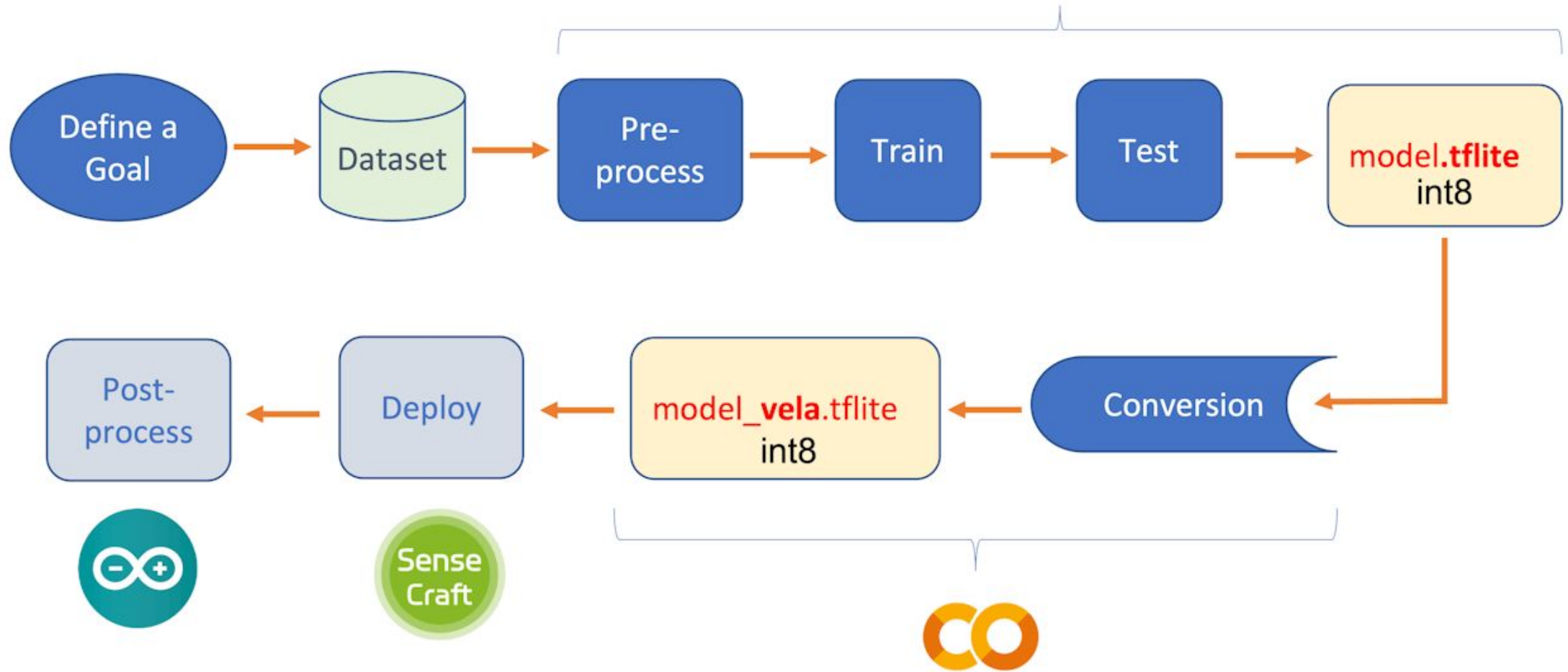
Person Detection

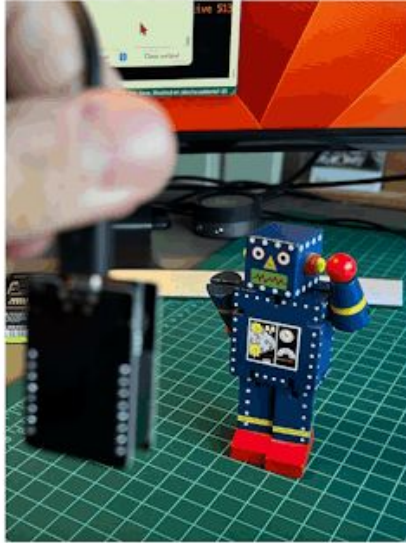


Human Pose Detection



# EDGE IMPULSE





Classification: 687 ms

1.5 FPS



**ESP - CAM**  
Xtensa LX6  
240 MHz



Classification: 142 ms

7.0 FPS



**XIAO ESP32S3**  
Xtensa LX7  
240 MHz

450mW



Classification: 86 ms

11.6 FPS



**Nicla-Vision**  
ARM M7  
480 MHz

590mW



Classification: 83 ms

12.0 FPS



**Portenta H7**  
ARM M7  
480 MHz



Classification: 6 ms

167 FPS



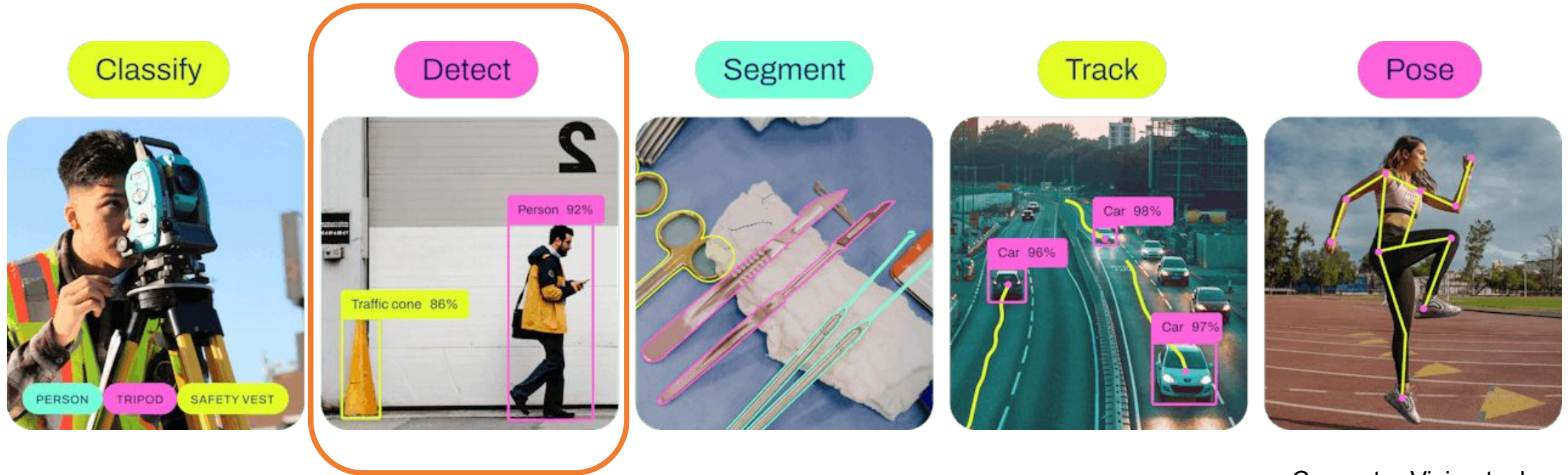
**Grove Vision AI V2**  
ARM Ethus-U55  
400 MHz

350mW

# YOLO

Object Detection Model for Bee Counting

# Ultralytics YOLO (You Only Look Once)



Computer Vision tasks

Real-time **object detection** systems that identify and classify many objects **very fast** in a single image pass.



## BuzzTech: Machine Learning at the Edge

*Deploying YOLOv8 on Raspberry Pi Zero 2W for Real-Time Bee Counting at the Hive Entrance.*

# Goal: Estimate the number of bees

Number of objects: 15 bees



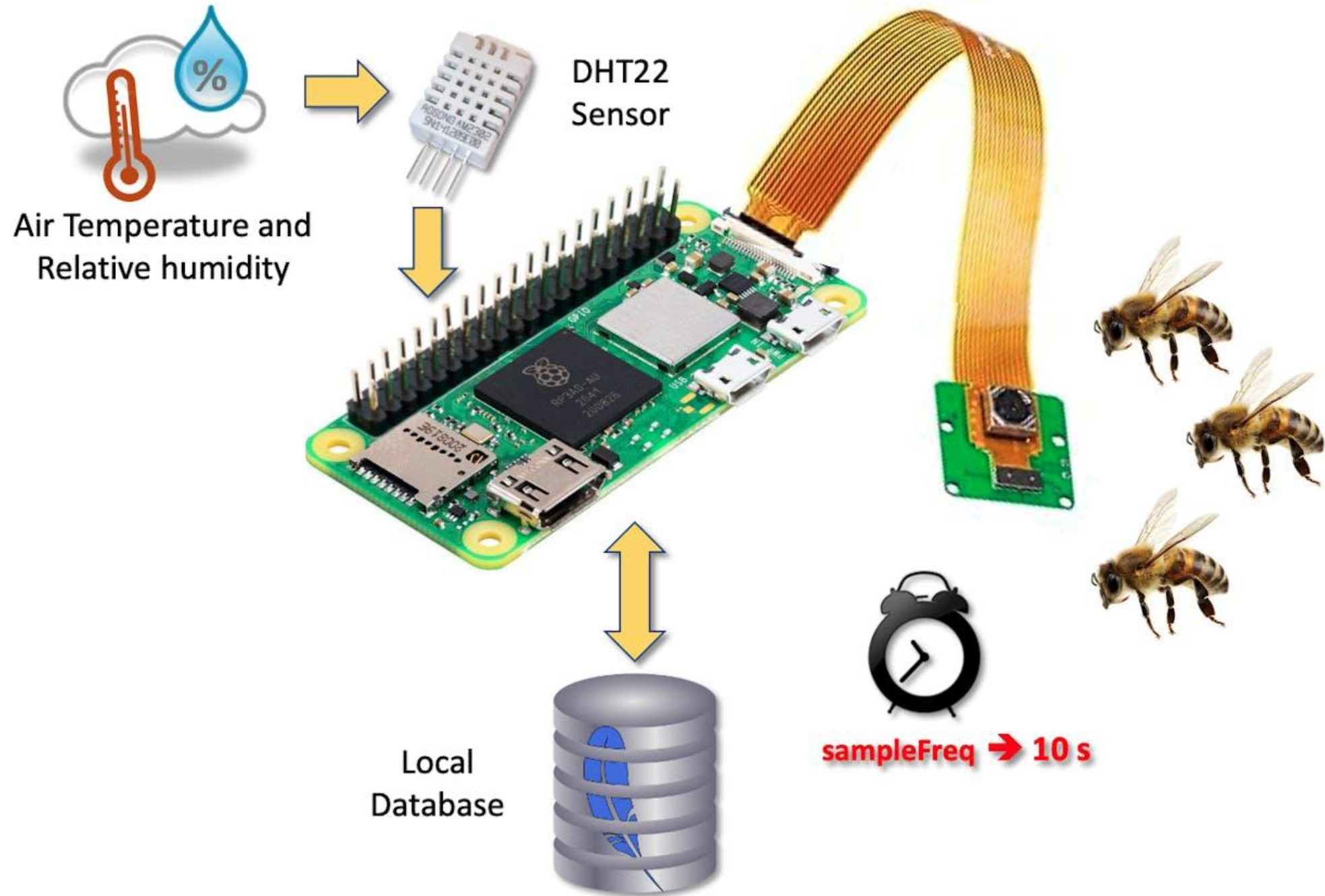
Number of objects: 36 bees



Number of objects: 28 bees







roboflow

# Let's create your project.

Marcelo Rovai > [New Public Project](#)


**Project Name** **License** [?](#)

Bees\_on\_Hive\_Landing\_boards CC BY 4.0

**Annotation Group** [?](#)

bees

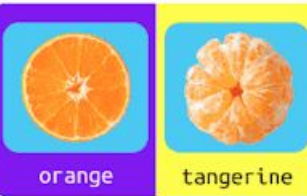
**Project Type**



**Object Detection**  
Identify objects and their positions with bounding boxes.

**Best For**

- # Counting
- Tracking




**Classification**  
Assign labels to the entire image.

Classification Type

Multi-Label  Single-Label

**Best For**


- Filtering
- Content Moderation



**Instance Segmentation**  
Detect multiple objects and their actual shape.

**Best For**

- Measurements
- Odd Shapes



**Keypoint Detection**  
Identify keypoints ("skeletons") to subjects.

**Best For**

- Pose Estimation

[Show More](#) ↓

[Cancel](#) [Create Public Project](#)

Bees\_on\_Hive\_landing\_boards

https://app.roboflow.com/marcelo-rovai-riila/bees\_on\_hive\_landing\_boards/images/34IC4TuHjkc5VtUNSKxC?queryText=&pageSize=50&startingIndex=0&browseQuer...

BEES\_ON\_HIVE\_LANDING\_BOARDS > ANNOTATE

20230711b6510.jpg 3 / 50 VALID

**Annotations**

Group: bees-4uet

CLASSES LAYERS

- bee 26

**Annotation Editor**

bee

Delete Save (Enter)

1 bee

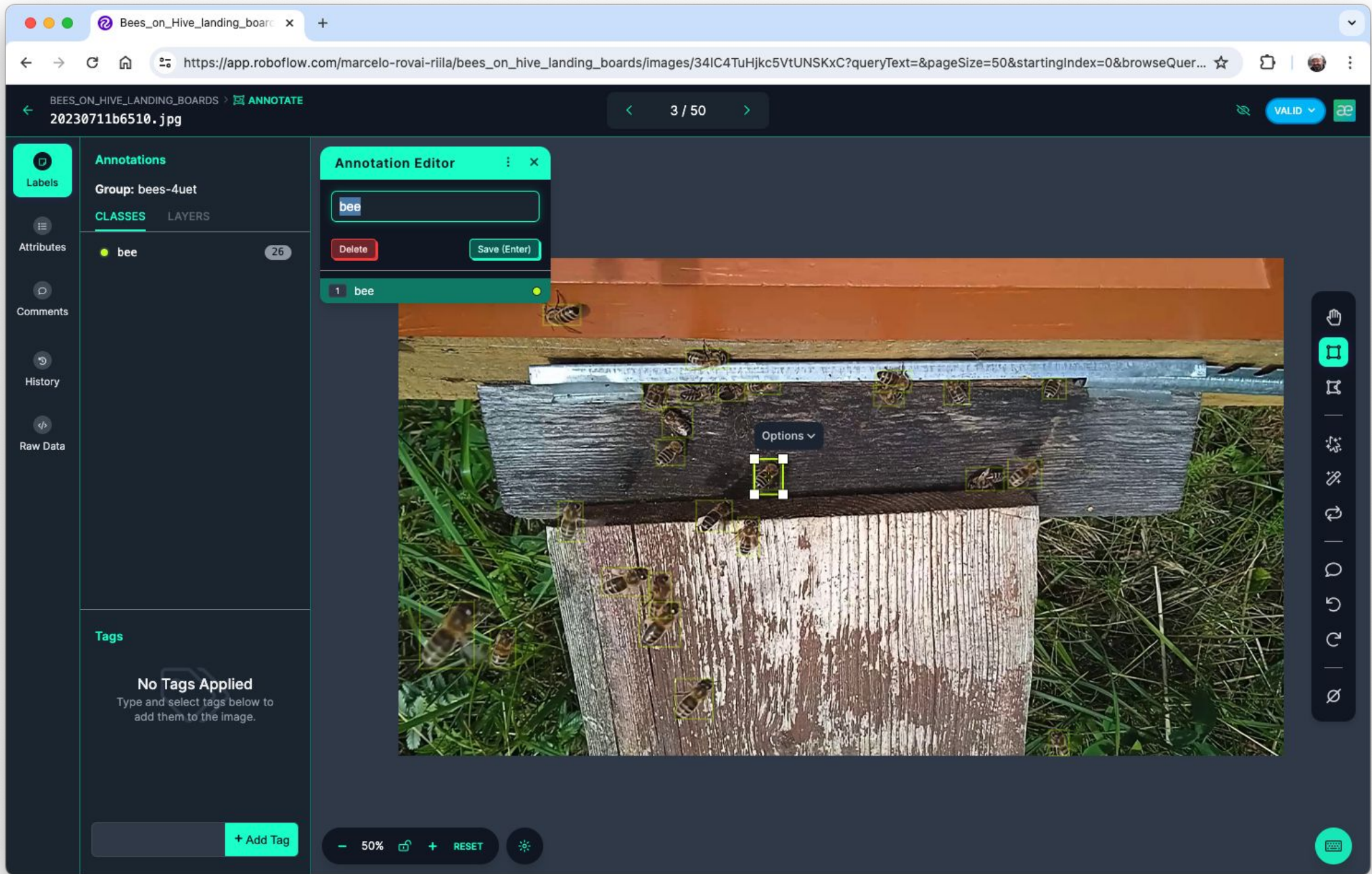
Options

No Tags Applied

Type and select tags below to add them to the image.

+ Add Tag

50% RESET

The image shows a web-based annotation interface for a photo of bees on a wooden landing board. The interface includes a top navigation bar with the project name and a URL. Below that, there's a breadcrumb trail and a file name. The main area is divided into several panels: a left sidebar with navigation options like 'Labels', 'Attributes', 'Comments', 'History', and 'Raw Data'; a central 'Annotations' panel showing a list of classes (currently 'bee') and a count of 26; an 'Annotation Editor' panel with a text input field containing 'bee', 'Delete' and 'Save (Enter)' buttons, and a list of 1 annotation; a large central image viewer showing the photo with yellow bounding boxes around the bees and a small 'Options' menu; and a bottom panel with a 'No Tags Applied' message, an 'Add Tag' button, and zoom controls (50%, RESET).

Bees\_on\_Hive\_landing\_board x +

https://app.roboflow.com/marcelo-rovai-riila/bees\_on\_hive\_landing\_boards/images/34IC4TuHjkc5VtUNSKxC?queryText=&pageSize=50&startingIndex=0&browseQuer... ☆

BEES\_ON\_HIVE\_LANDING\_BOARDS > ANNOTATE

20230711b6510.jpg 3 / 50 VALID

**Annotations**

Group: bees-4uet

CLASSES LAYERS

bee 25

Attributes

Comments

History

Raw Data

**Tags**

No Tags Applied

Type and select tags below to add them to the image.

+ Add Tag

50% + RESET

Colab interface showing a Jupyter Notebook titled "yolov8\_bees\_on\_hive\_landing\_board.ipynb".

**Files Panel:**

- content
  - datasets
    - Bees\_on\_Hive\_landing\_b...
      - test
        - images
        - labels
      - train
        - images
        - labels
      - valid
        - images
        - labels
      - README.dataset.txt
      - README.roboflow.txt
      - data.yaml
- datalab
- dev
- etc

Disk: 46.44 GB available

**Code Cell:**

```
[ ] 1 from ultralytics import YOLO
    2
    3 from IPython.display import display, Image
```

**Dataset Cell:**

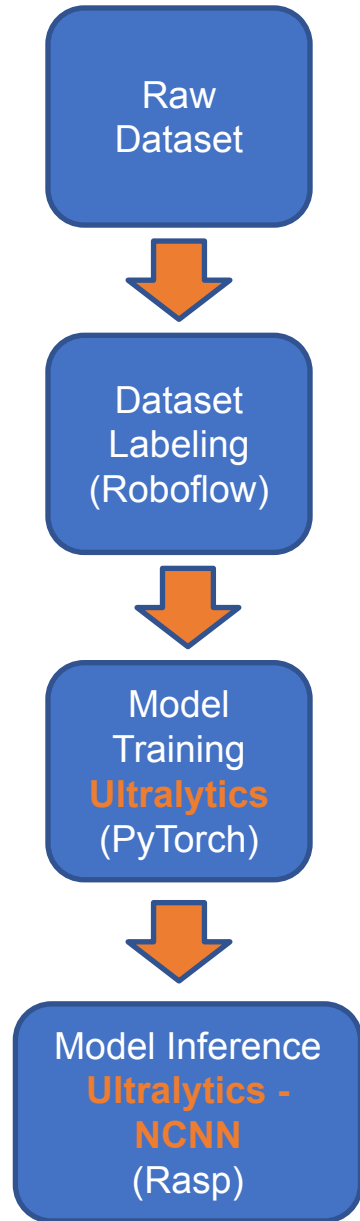
```
1 !mkdir {HOME}/datasets
2 %cd {HOME}/datasets
3
4 !pip install roboflow --quiet
5
6 from roboflow import Roboflow
7 rf = Roboflow(api_key="YOUR KEY HERE")
8 project = rf.workspace("marcelo-rovai-riila").project("bees_on_hive_landing_boards")
9 version = project.version(1)
10 dataset = version.download("yolov8")
11
```

**Output:**

```
/content/datasets
_____ 75.5/75.5 kB 3.6 MB/s eta 0:00:00
_____ 158.3/158.3 kB 7.7 MB/s eta 0:00:00
_____ 178.7/178.7 kB 8.3 MB/s eta 0:00:00
_____ 58.8/58.8 kB 6.9 MB/s eta 0:00:00
_____ 49.1/49.1 MB 16.7 MB/s eta 0:00:00
_____ 54.5/54.5 kB 7.1 MB/s eta 0:00:00

loading Roboflow workspace...
loading Roboflow project...
Dependency ultralytics==8.0.196 is required but found version=8.2.23, to fix: `pip install ultralytics==8.0.196`
Downloading Dataset Version Zip in Bees_on_Hive_landing_boards-1 to yolov8:: 100%|██████████| 1597328/1597328 [00
Extracting Dataset Version Zip to Bees_on_Hive_landing_boards-1 in yolov8:: 100%|██████████| 32468/32468 [00:09<0
```

50s completed at 8:46 AM



**Terminal 1: System Statistics**

```

marcelo_rovai — mjrovai@rpi-zero-2: ~ — ssh mjrovai@rpi-zero-2.local — 80x24
0[ 0.0%] Tasks: 30, 19 thr 110 kth; 2 running
1[ 1.3%] Load average: 0.02 0.02 0.09
2[ 0.0%] Uptime: 00:55:14
3[ 0.0%]
Mem[|||||] 22M/417M
Swp[|||||] 200M/1.95G
  
```

Main										
PID	USER	PRI	NI	VIRT	RES	SHR	S	CPU%-MEM%	TIME+	Command
688	mjrovai	20	0	7776	1536	896	R	2.0 0.4	0:48.64	htop
1	root	20	0	164M	2496	2292	S	0.0 0.6	0:04.29	/sbin/init
215	root	20	0	49888	1412	1284	S	0.0 0.3	0:00.84	/lib/systemd/
240	root	20	0	26056	836	836	S	0.0 0.2	0:00.94	/lib/systemd/
333	systemd-tl	20	0	90580	2176	1920	S	0.0 0.5	0:00.57	/lib/systemd/
394	systemd-tl	20	0	90580	2176	1920	S	0.0 0.5	0:00.01	/lib/systemd/
396	avahi	20	0	7620	1024	640	S	0.0 0.2	0:03.14	avahi-daemon:
397	root	20	0	6692	640	640	S	0.0 0.1	0:00.10	/usr/sbin/cro
398	messagebus	20	0	8708	1408	896	S	0.0 0.3	0:01.14	/usr/bin/dbus
401	polkitd	20	0	229M	512	512	S	0.0 0.1	0:00.18	/usr/lib/pol
413	root	20	0	25420	1664	1536	S	0.0 0.4	0:00.57	/lib/systemd/
414	avahi	20	0	7180	404	384	S	0.0 0.1	0:00.00	avahi-daemon:
417	nobody	20	0	5828	384	256	S	0.0 0.1	0:00.07	/usr/sbin/thd

**Terminal 2: YOLO Inference Results**

```

marcelo_rovai — mjrovai@rpi-zero-2: ~/Documents/YOLO — ssh mjrovai@rpi-zero-2.local — 142x7
mjrovai@rpi-zero-2:~/Documents/YOLO $ yolo predict task=detect model=bee_landing_640_best_ncnn_model imgs=640 source=test_images/15_bees.jpg
Ultralytics YOLOv8.2.15 Python-3.11.2 torch-2.1.2 CPU (Cortex-A53)
Loading bee_landing_640_best_ncnn_model for NCNN inference...

image 1/1 /home/mjrovai/Documents/YOLO/test_images/15_bees.jpg: 640x640 15 bees, 4639.9ms
Speed: 700.2ms preprocess, 4639.9ms inference, 31094.9ms postprocess per image at shape (1, 3, 640, 640)
Results saved to runs/detect/predict
  
```

# Thanks



**TINYML4D**