



# Topics in Applied Machine Learning: A Hands-on Approach – MS12 (Vision)

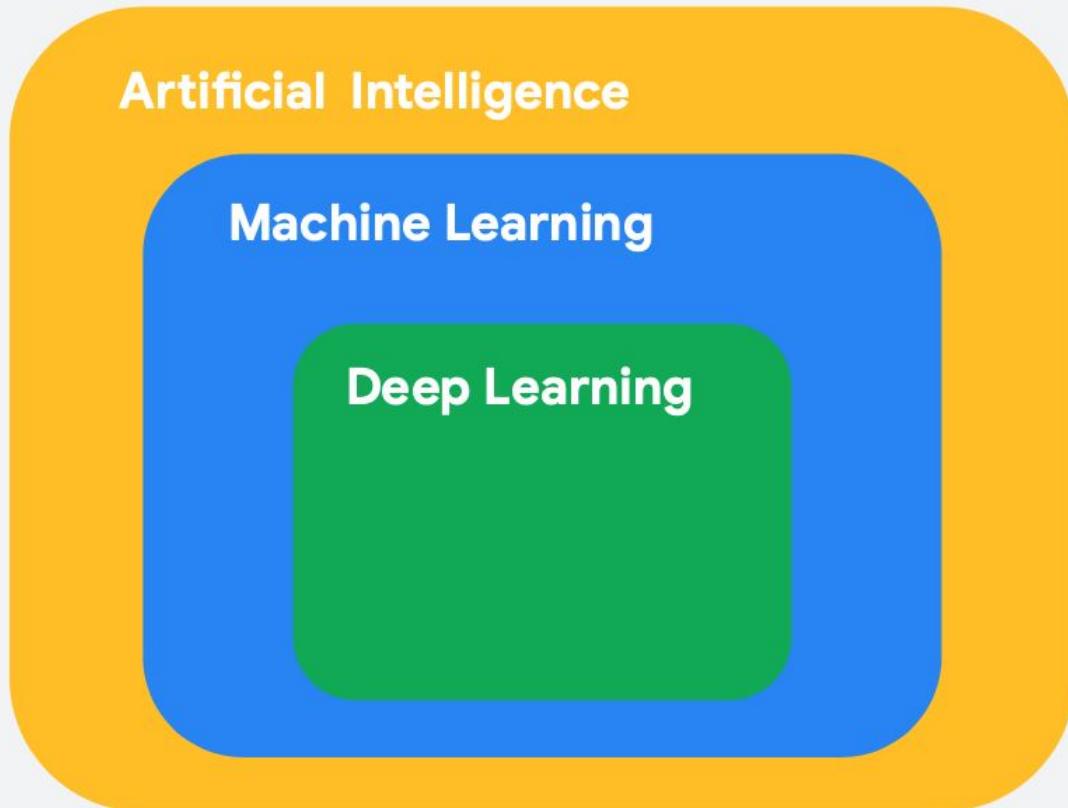
Marcelo José Rovai and José Alberto Ferreira Filho  
UNIFEI - Universidade Federal de Itajubá, Brazil

Flávio Calmon and Lucas Monteiro Paes  
Harvard University, USA



# Embedded ML (TinyML)

## Introduction



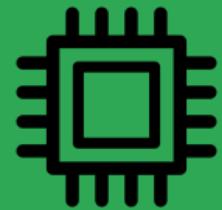
**AI:** Any technique that enables computers to mimic human behavior

**ML:** Ability to learn without explicitly being programmed

**DL:** Extract patterns from data using neural networks

**EdgeAI/ML**

**TinyML**



**Edge AI (or Edge ML)** is the processing of Artificial Intelligence algorithms on edge, that is, on users' devices. The concept derives from **Edge Computing**, which starts from the same premise: data is stored, processed, and managed directly at the Internet of Things (IoT) endpoints.

**TinyML** is a subset of **EdgeML**, where sensors are generating data with ultra-low power consumption (batteries), so that we can ultimately deploy machine learning continuously ("always on devices")

# What is Tiny Machine Learning (**TinyML**)?

**TinyML**



Fastest-growing field of **ML**



# What is Tiny Machine Learning (**TinyML**)?

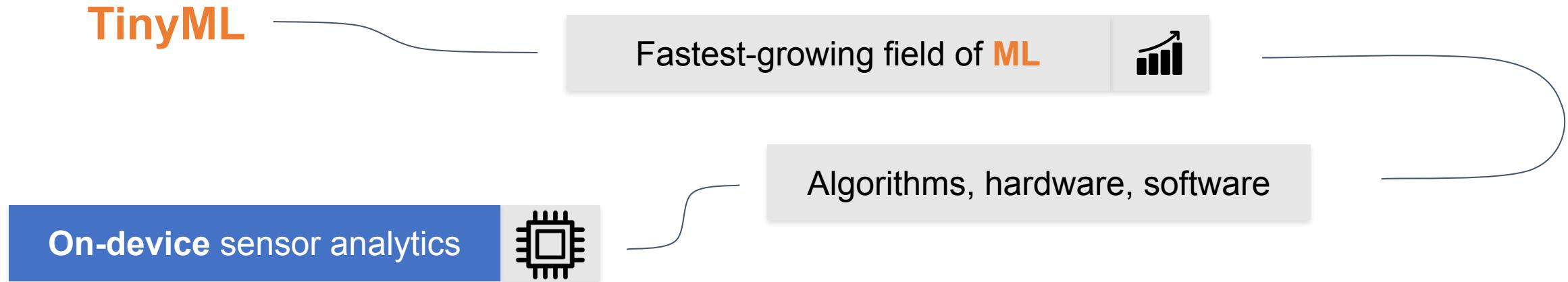
**TinyML**

Fastest-growing field of **ML**

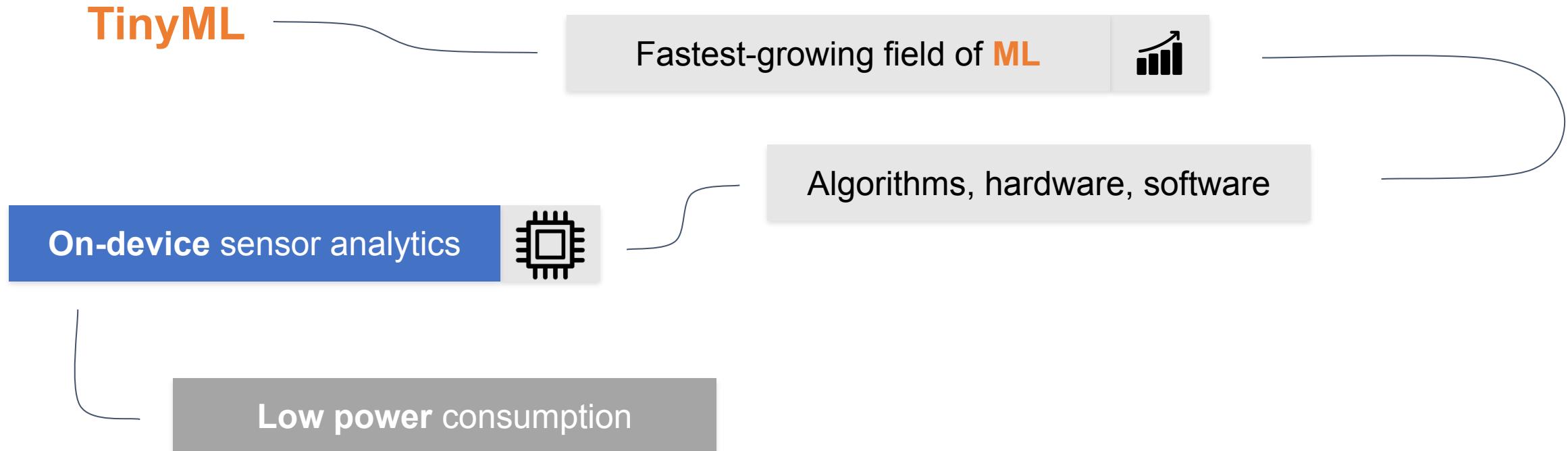


Algorithms, hardware, software

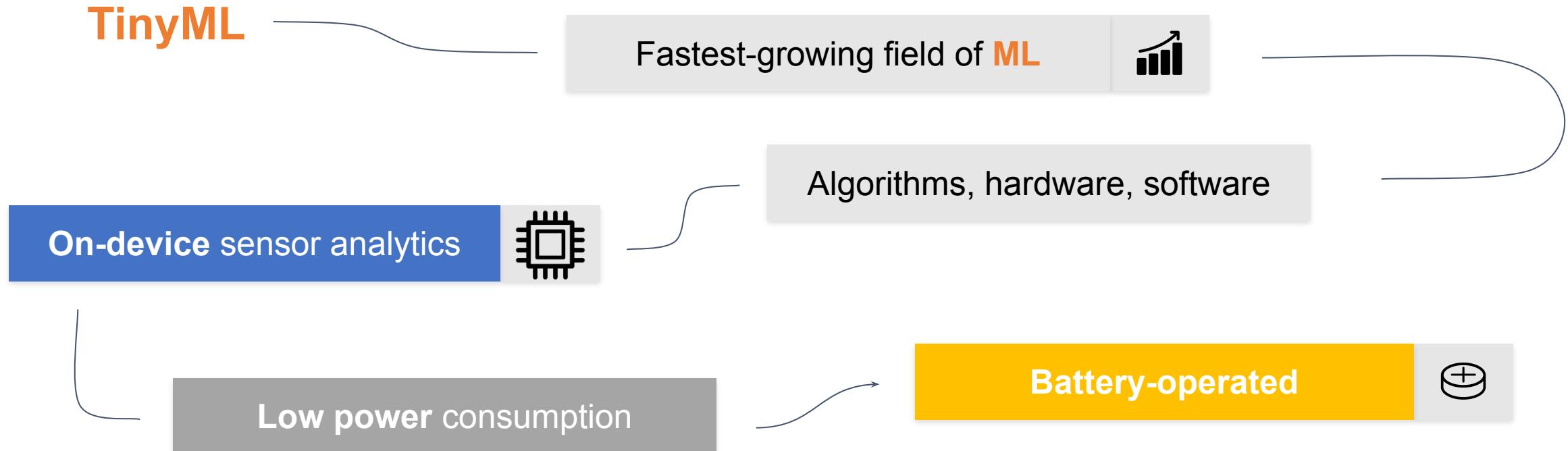
# What is Tiny Machine Learning (**TinyML**)?



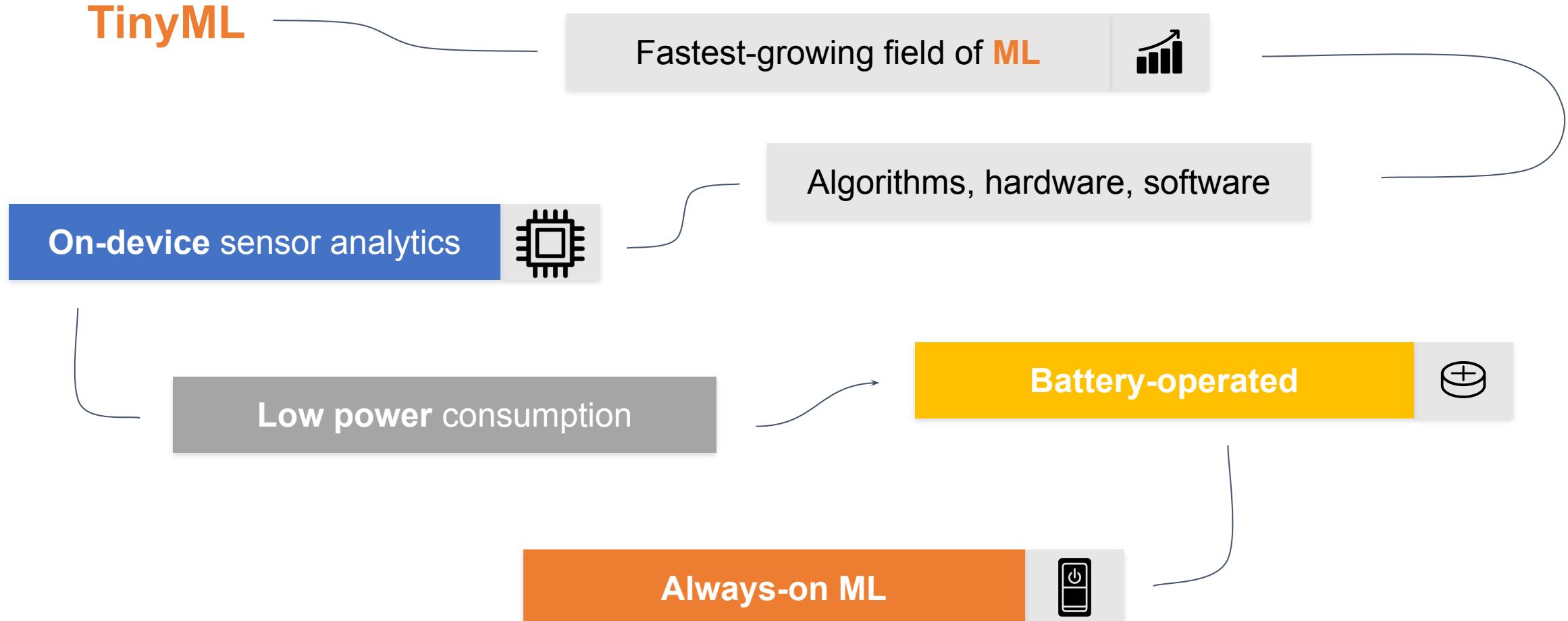
# What is Tiny Machine Learning (**TinyML**)?



# What is Tiny Machine Learning (**TinyML**)?



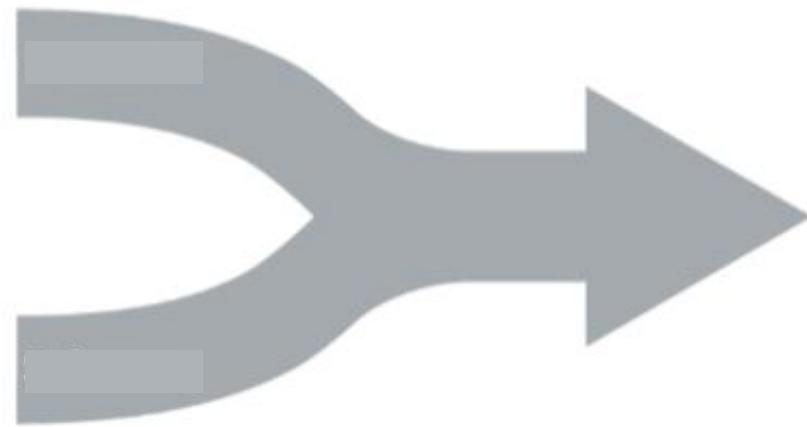
# What is Tiny Machine Learning (**TinyML**)?



# What Makes **TinyML** ?

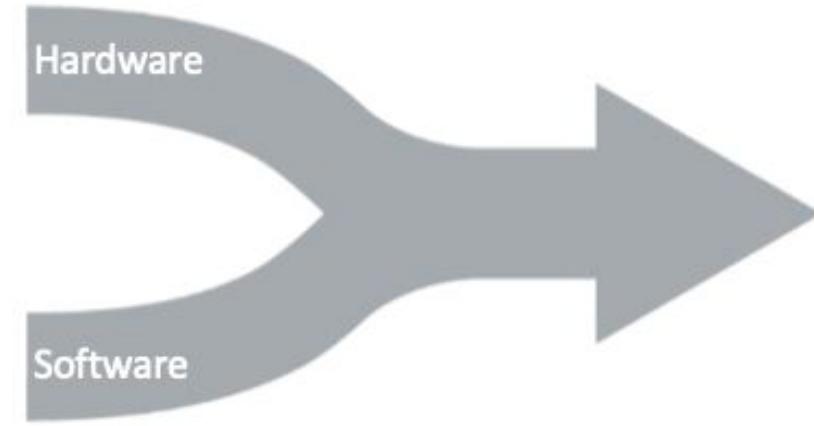
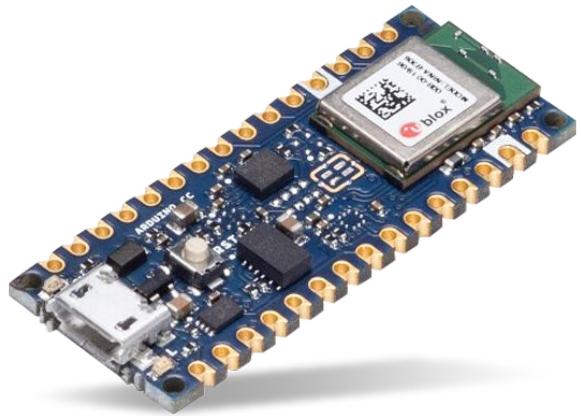
Embedded  
Systems

Machine  
Learning



**TinyML**

# What Makes **TinyML** ?



**TinyML**



**TensorFlow Lite**

# Application Complexity vs. HW

Power



# EdgeML

## TinyML



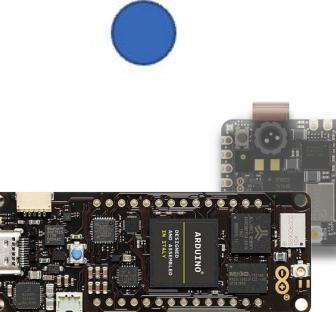
Anomaly Detection  
Sensor Classification  
20 KB



Rpi-Pico  
(Cortex-M0+)



KeyWord Spotting  
Audio Classification  
50 KB



Arduino Pro  
(Cortex-M7)

Image  
Classification  
250 KB+



## TinyML

Object Detection  
Complex Voice  
Processing  
1 MB+



Video  
Classification  
2 MB+



Video  
Classification  
2 MB+



RaspberryPi  
SmartPhone  
(Cortex-A)



Application Complexity ↑

CPU Power / Memory →

Rpi-Pico  
(Cortex-M0+)

Arduino Nano  
(Cortex-M4)

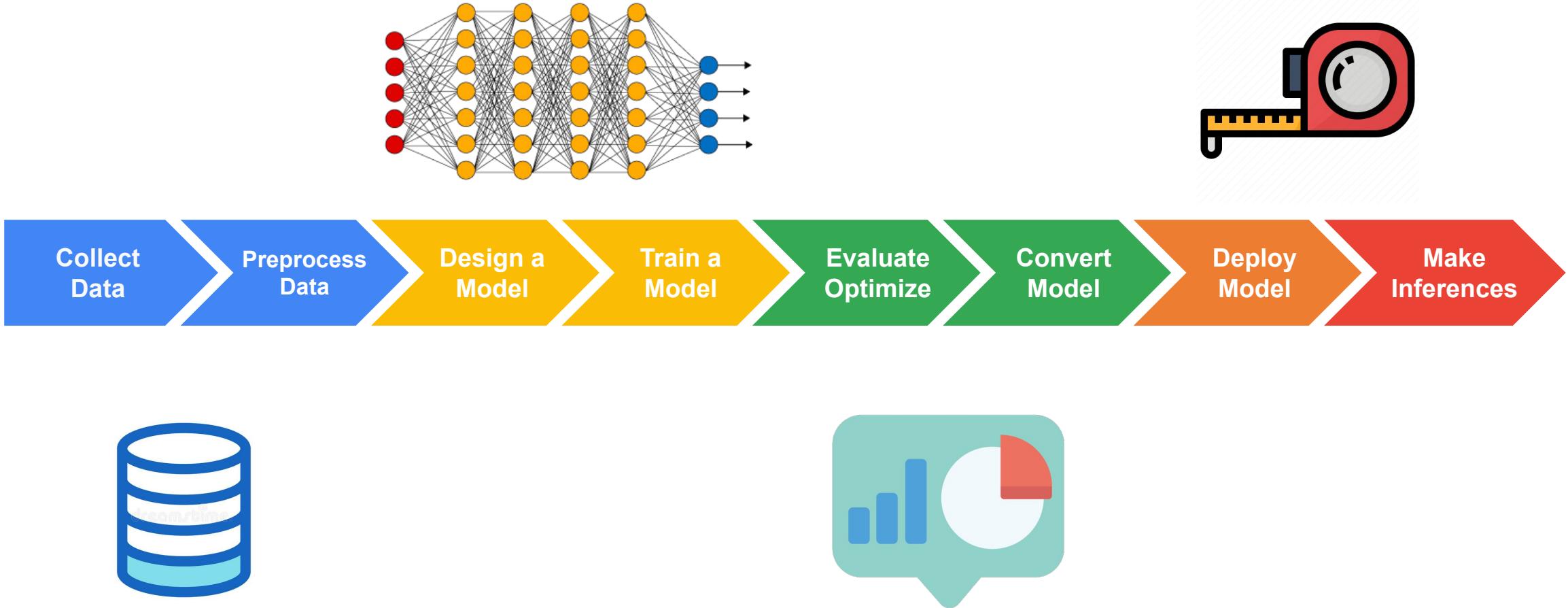
Arduino Pro  
(Cortex-M7)

RaspberryPi  
SmartPhone  
(Cortex-A)

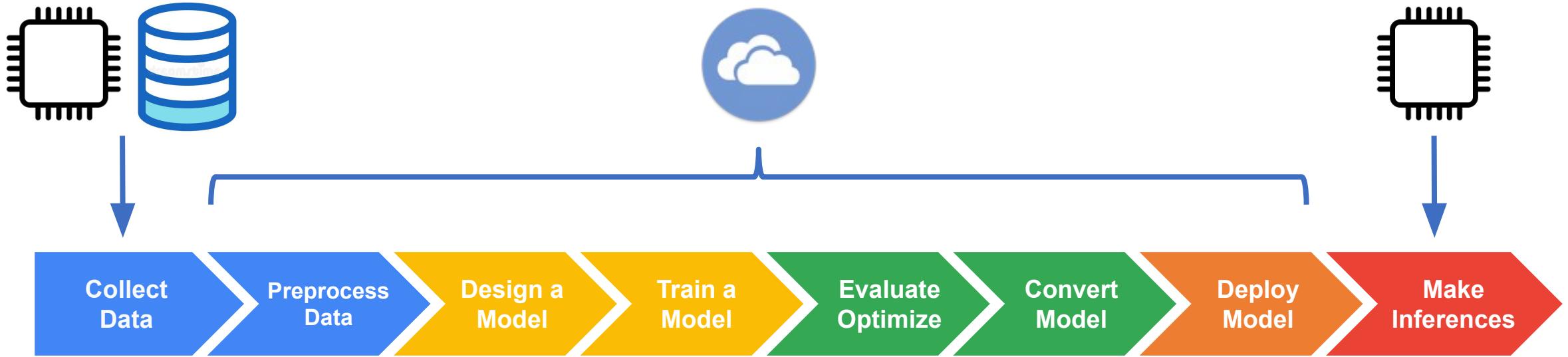
Jetson Nano  
(Cortex-A + GPU)

# How to Train a ML Model?

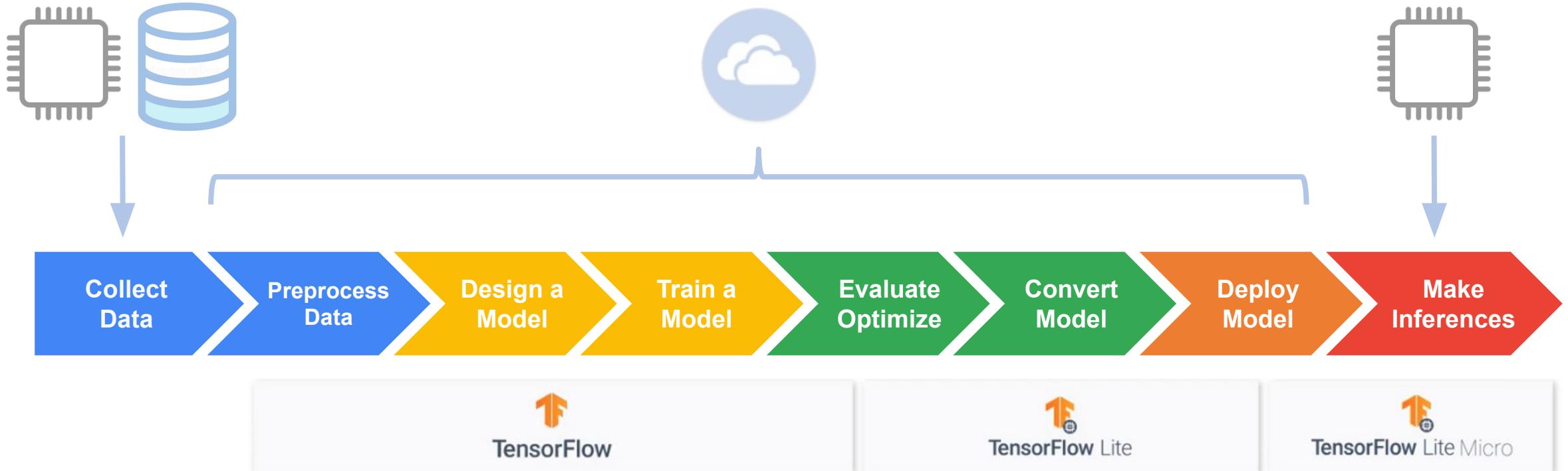
# Machine Learning Workflow (“What”)



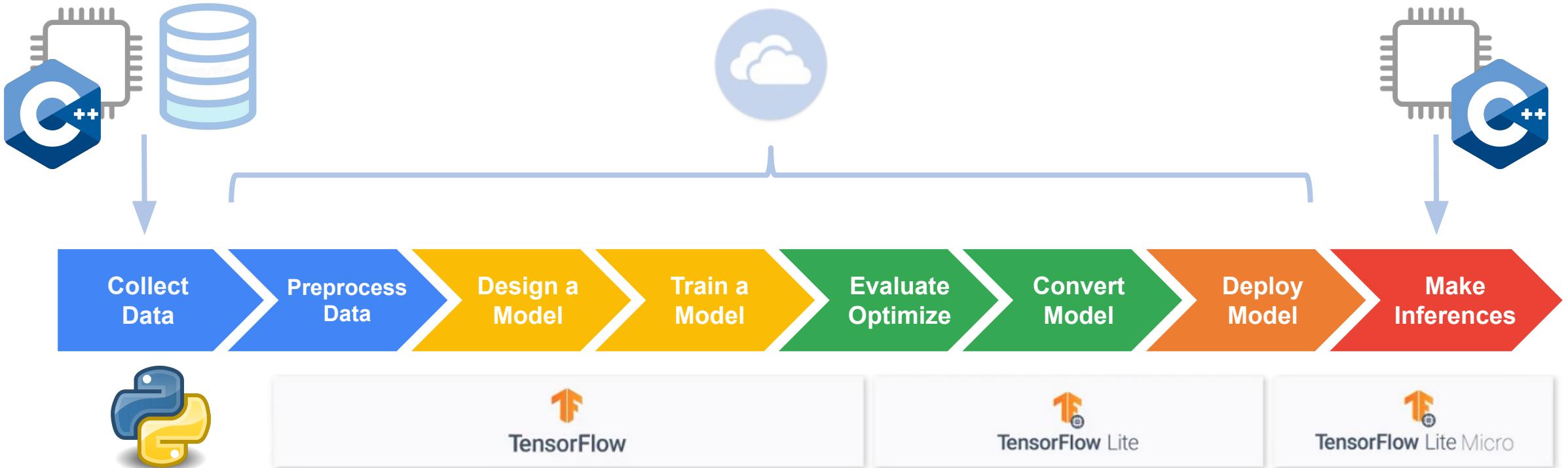
# Machine Learning Workflow (“Where”)



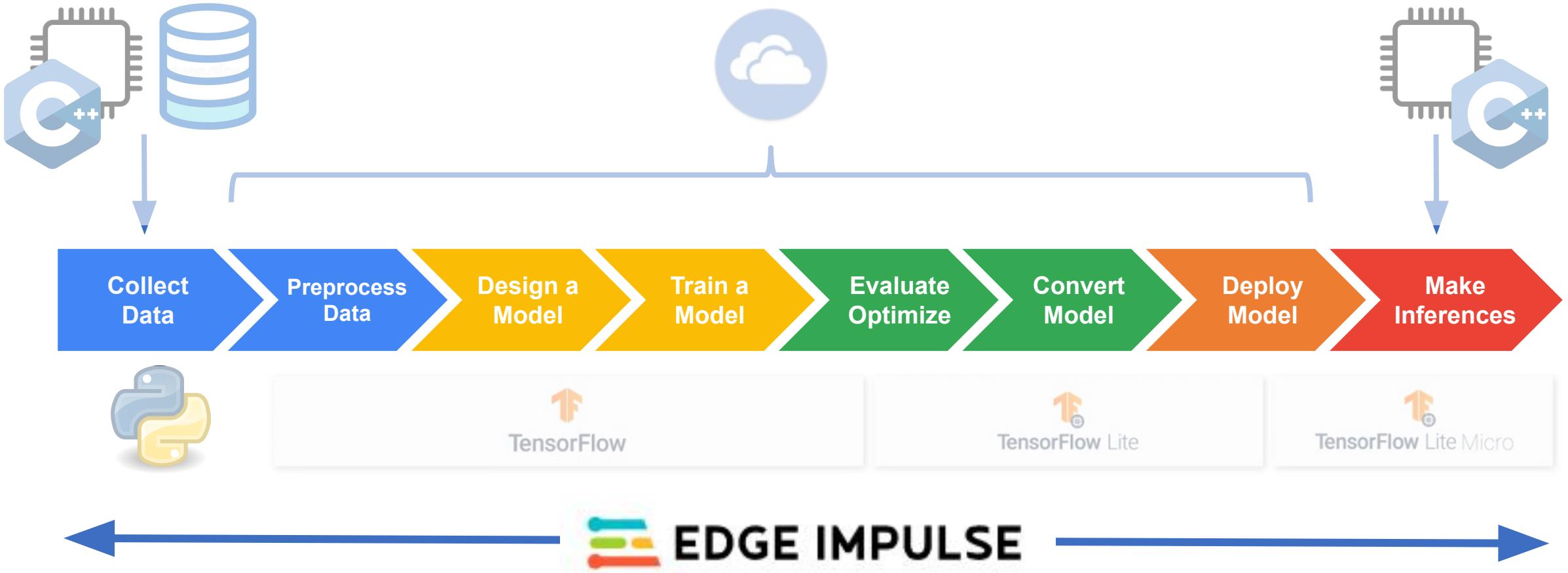
# Machine Learning Workflow (“How”)



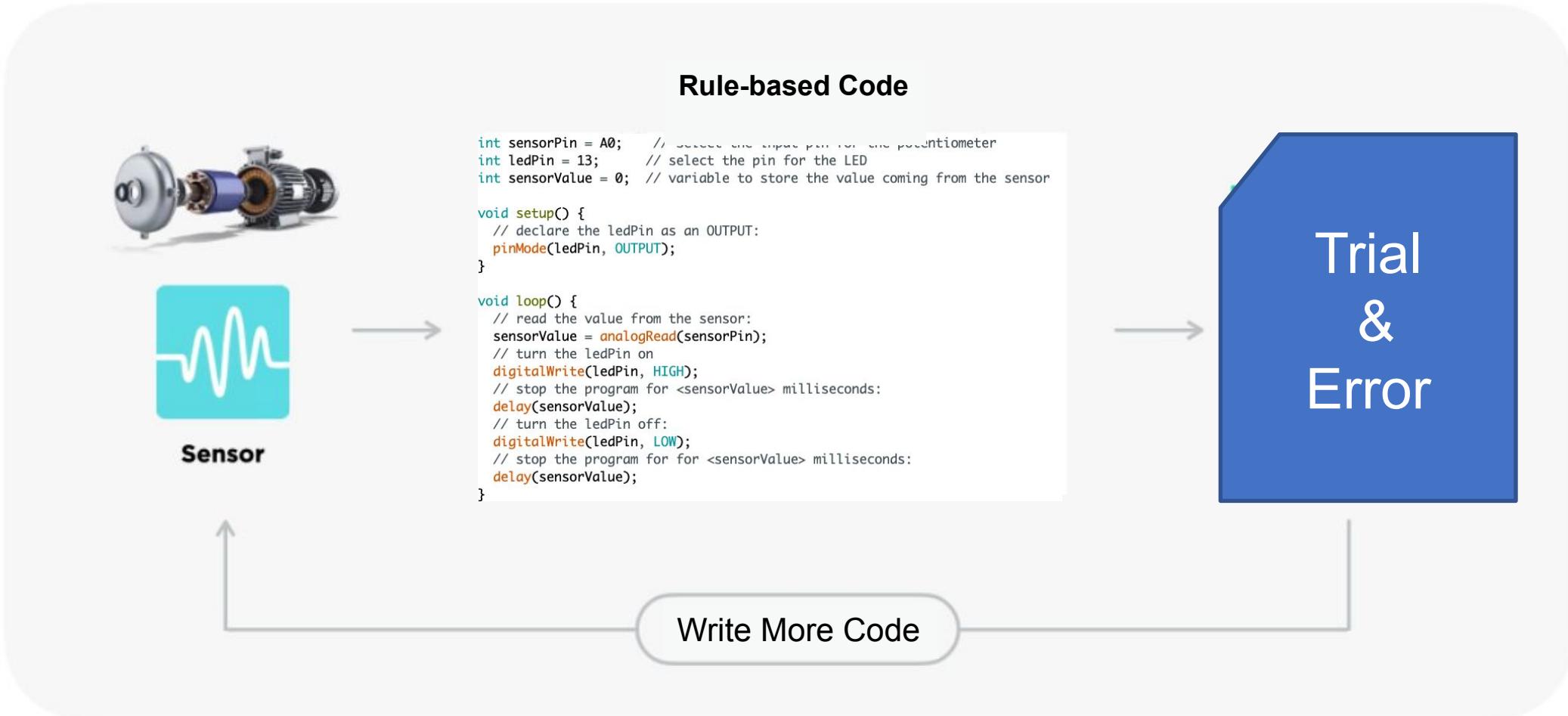
# Machine Learning Workflow (“How”)



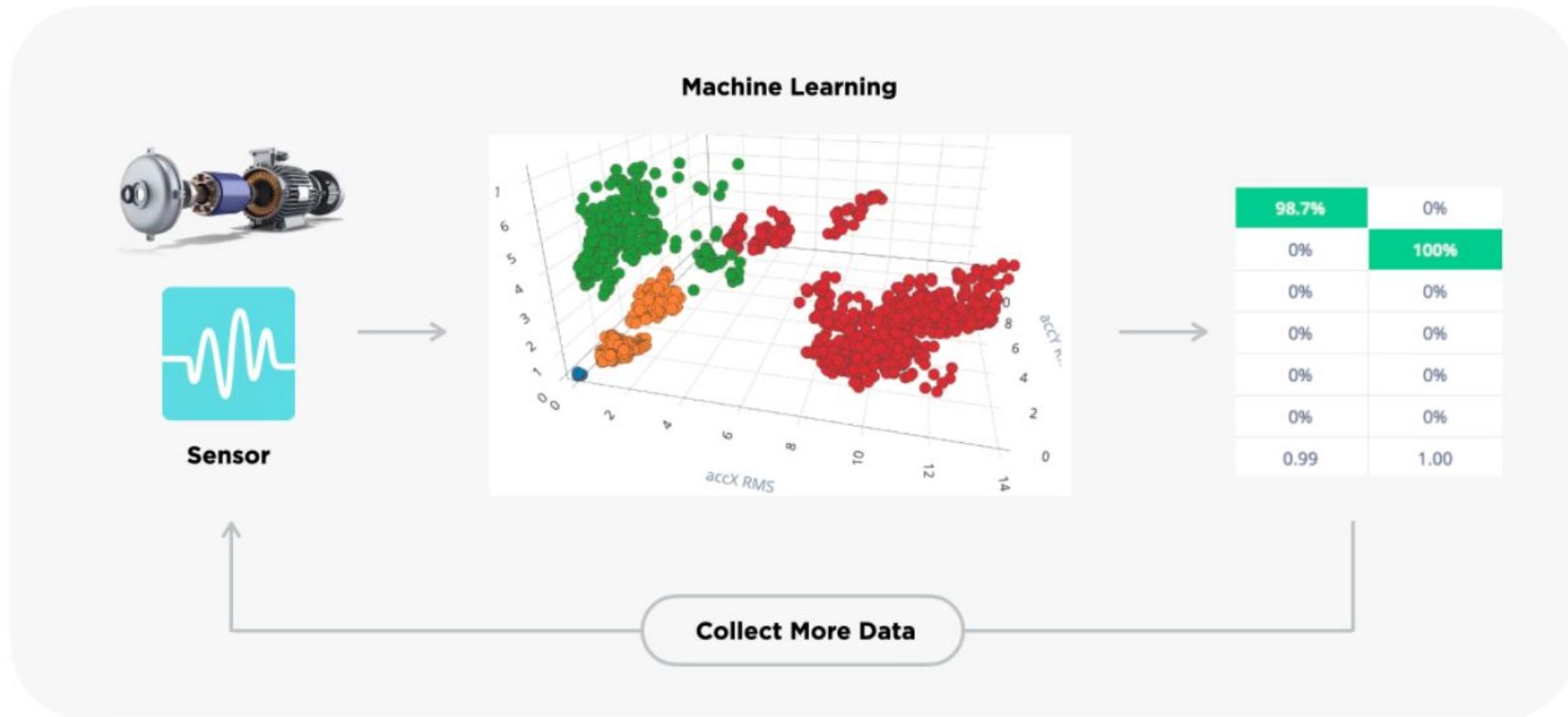
# Machine Learning Workflow (“How”)



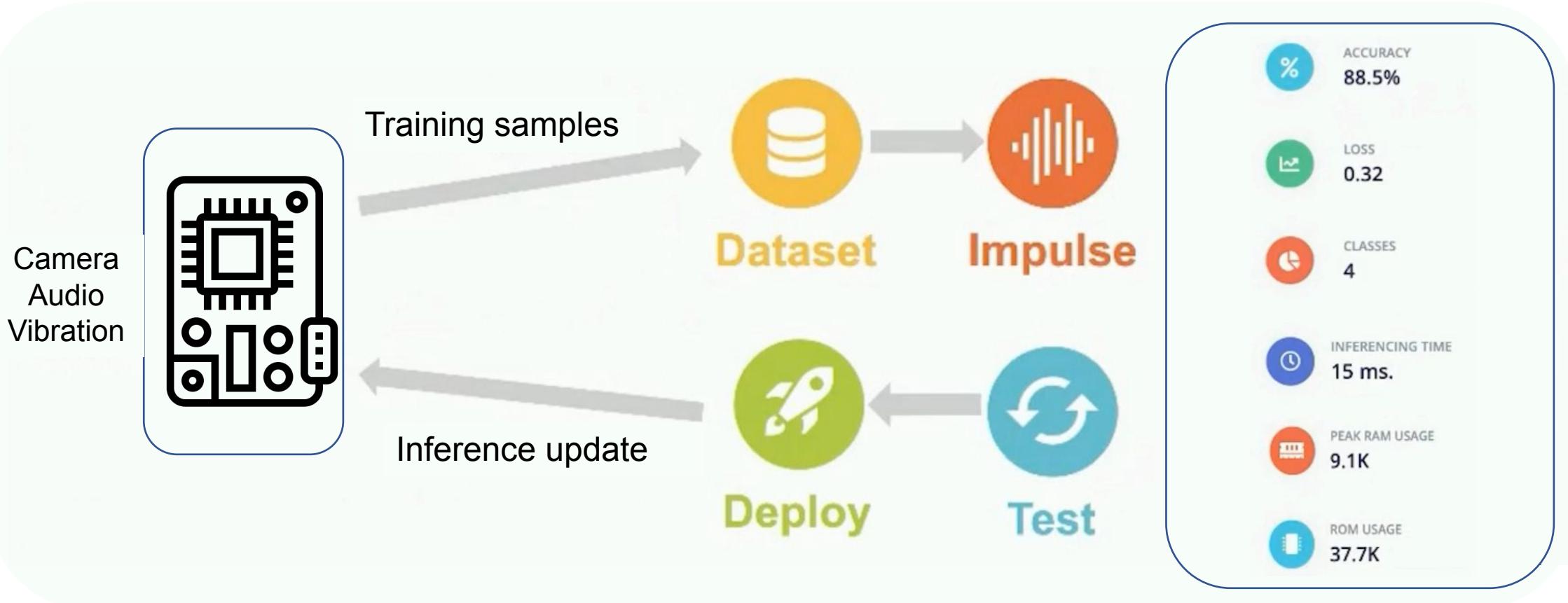
# From rule-based engineering to...

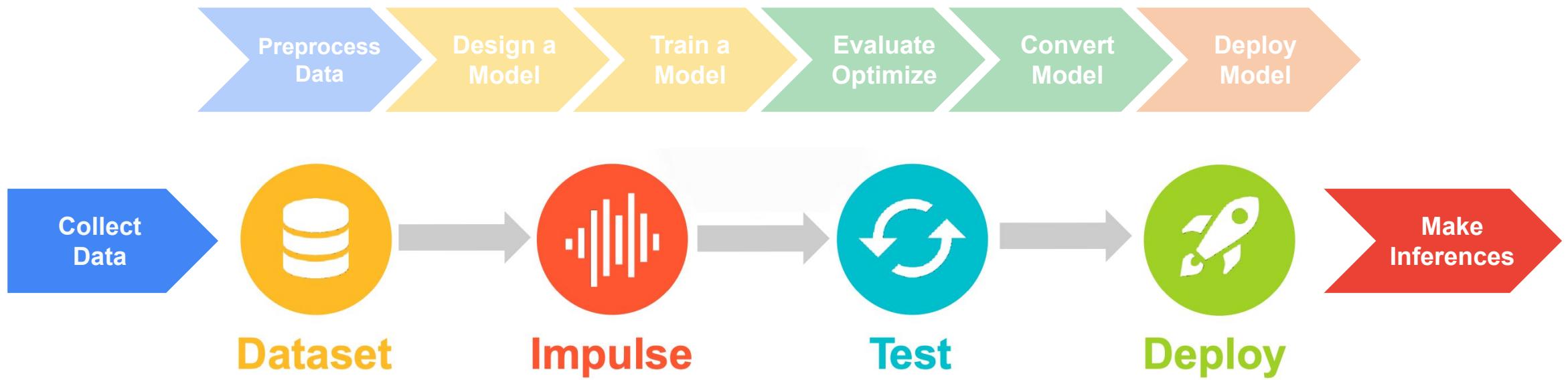


# Data-driven engineering

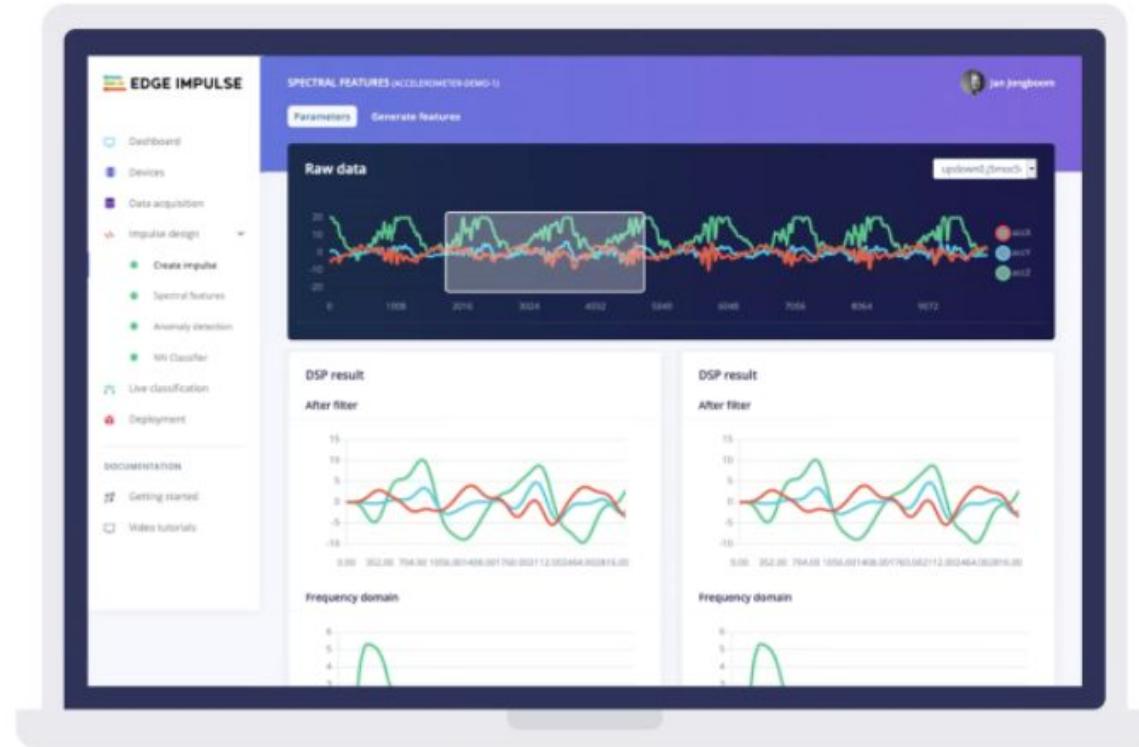
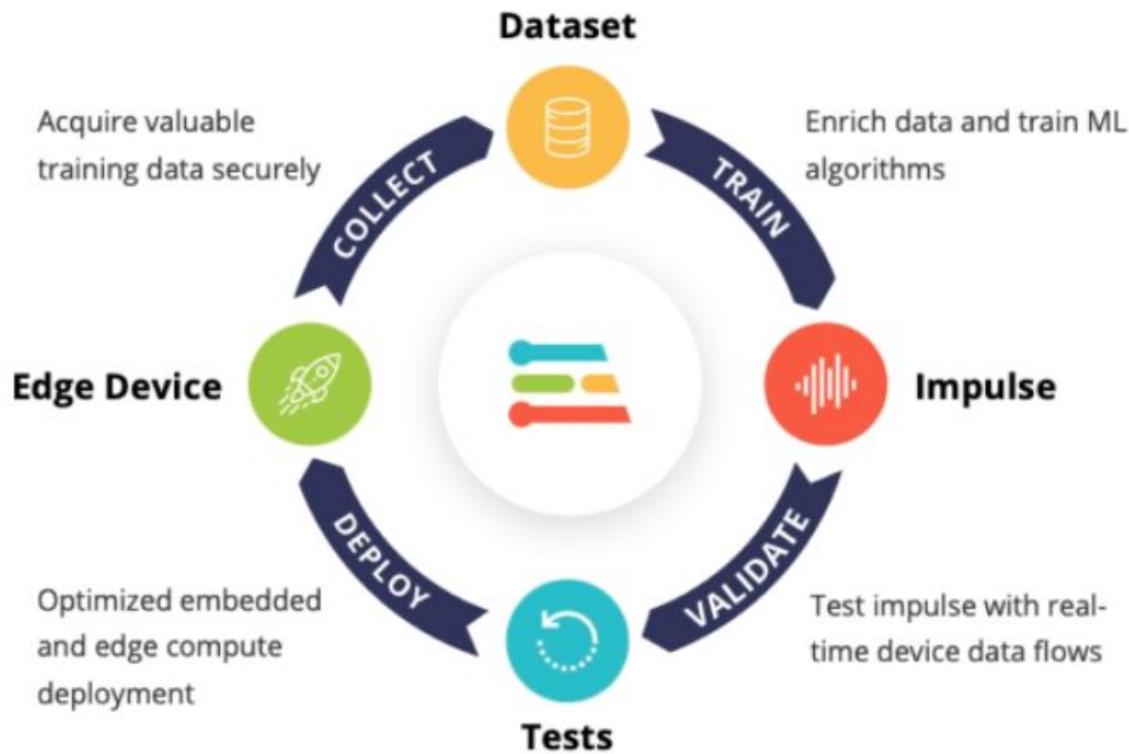


# Data-driven engineering





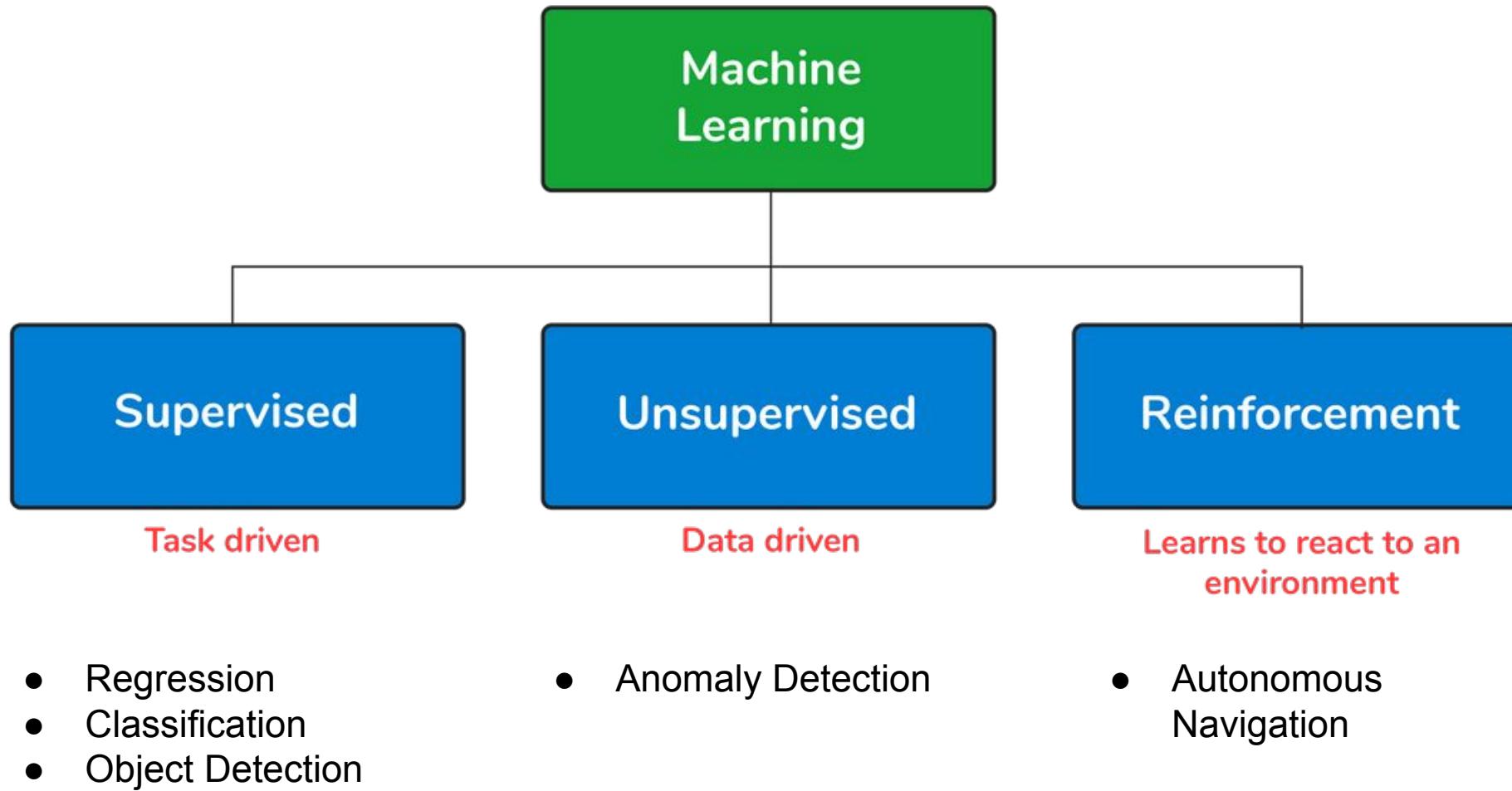
# EI Studio - Embedded ML platform (“AutoML”)



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



# TinyML Application Examples



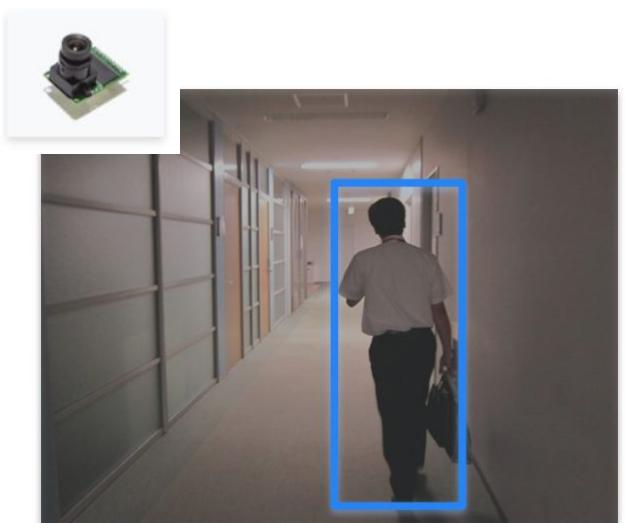
# Sound



# Vibration



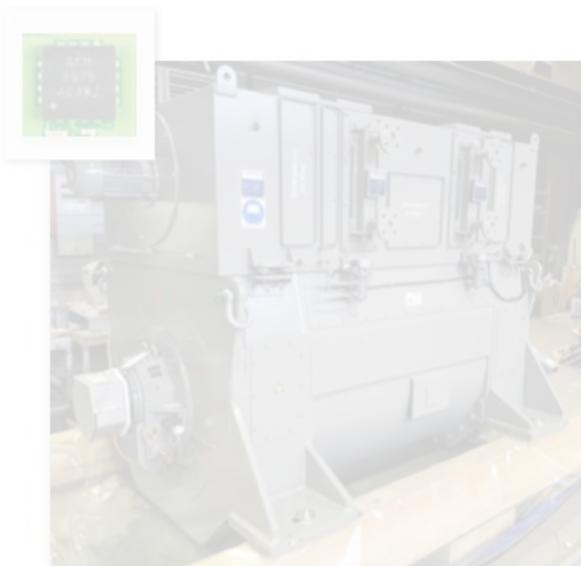
# Vision



# Sound



# Vibration



# Vision



# Image Classification Application: Design, Train, Test and Deploy



# Computer Vision Main Types

## Image Classification (Multi-Class Classification)

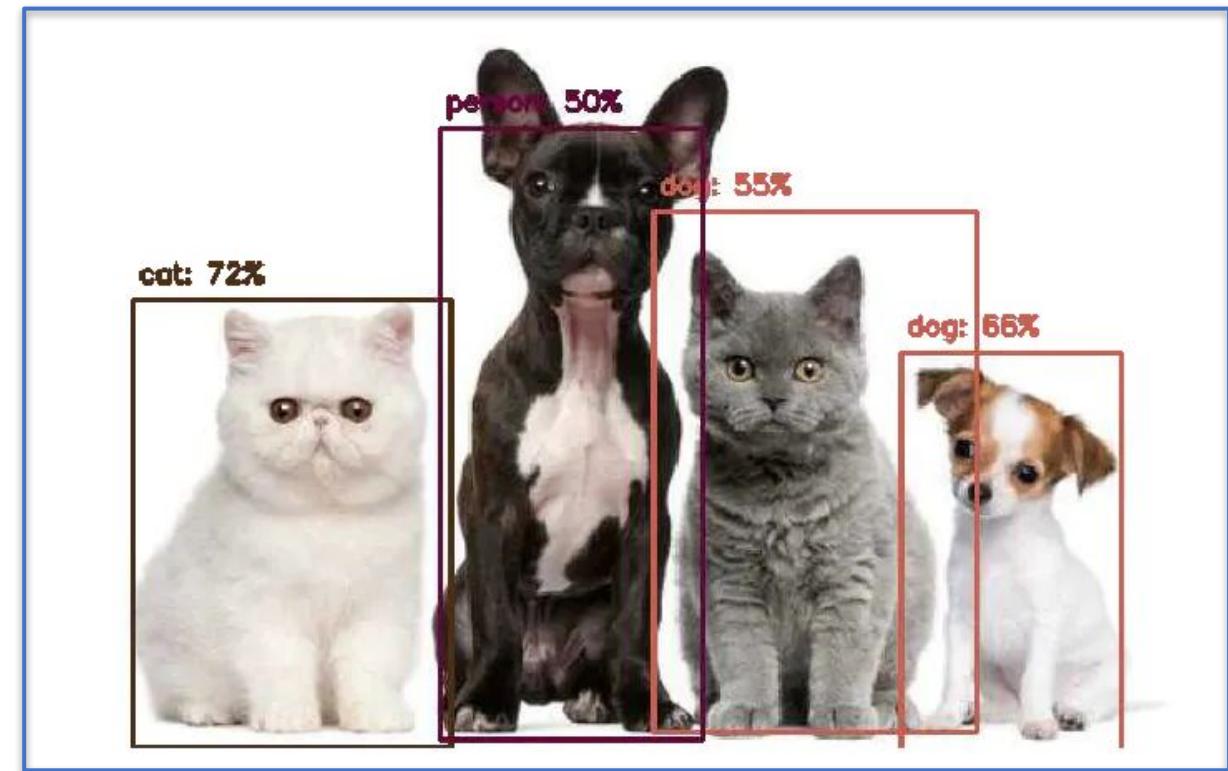


Cat: 70%



Dog: 80%

## Object Detection Multi-Label Classification + Object Localization



# Computer Vision Main Types

## Image Classification (Multi-Class Classification)

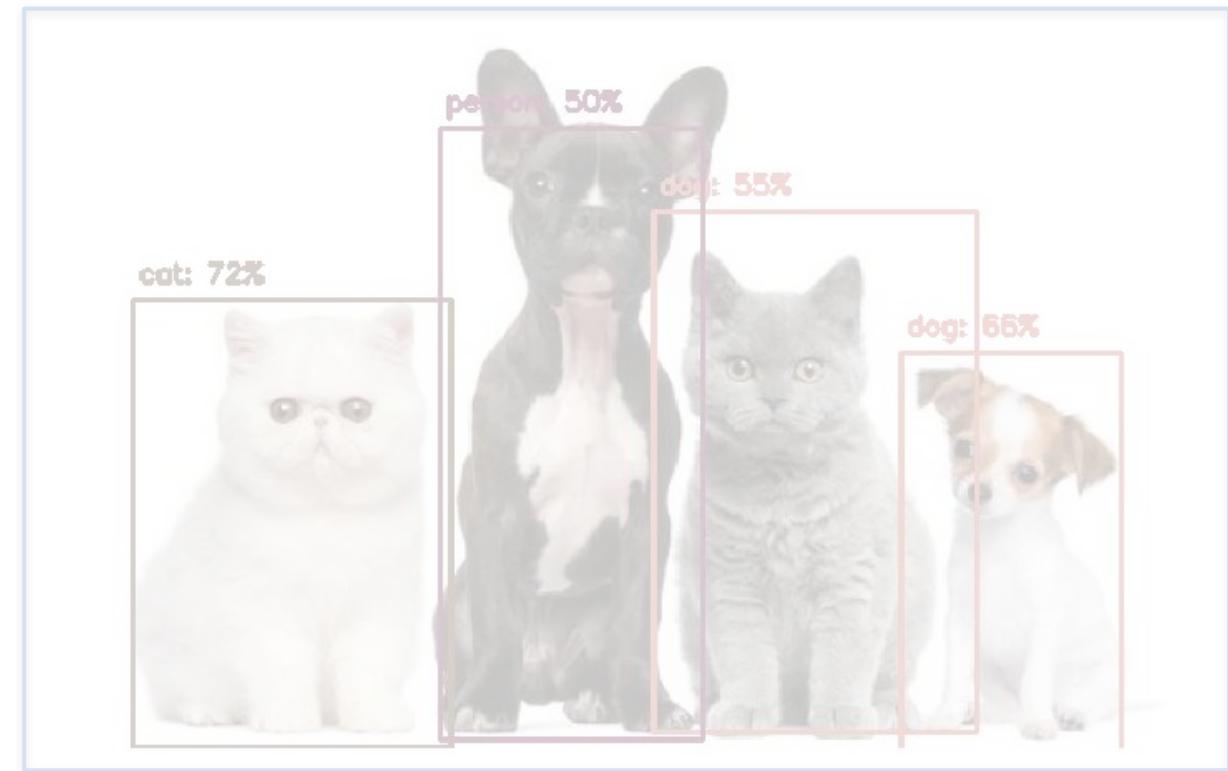


Cat: 70%



Dog: 80%

## Object Detection Multi-Label Classification + Object Localization



# Coffee Disease Classification



<https://www.hackster.io/Yukio/coffee-disease-classification-with-ml-b0a3fc>

**Introdução**

O Brasil é responsável por 50% do café exportado globalmente, sendo uma atividade importante para o país; geralmente a análise e classificação de doenças em plantas é feita manualmente, que não são acessíveis para pequenos produtores.

Com o aumento do poder de processamento das placas de microcontroladoras e processadores dedicados ao machine learning, a tarefa de embarcar todos meios tem-se tornado positiva em diversas áreas.



**João Vitor Yukio Bordin Yamashita**  
Graduando em Engenharia Eletrônica pela UNIFEI

# Package Inspection

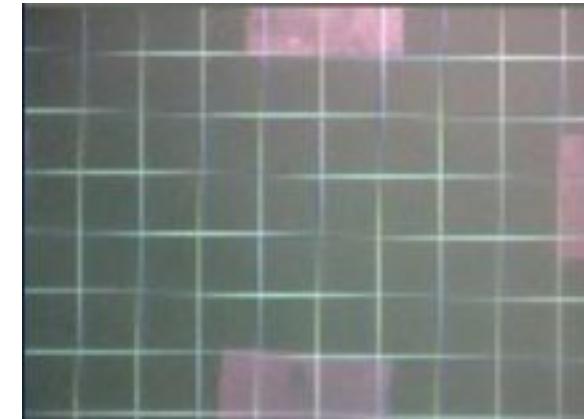


Deep Learning at the Edge Simplifies Package Inspection

# Image Classification Project 1

Decide a Goal

- Possible Images:
  - medicine
  - background



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

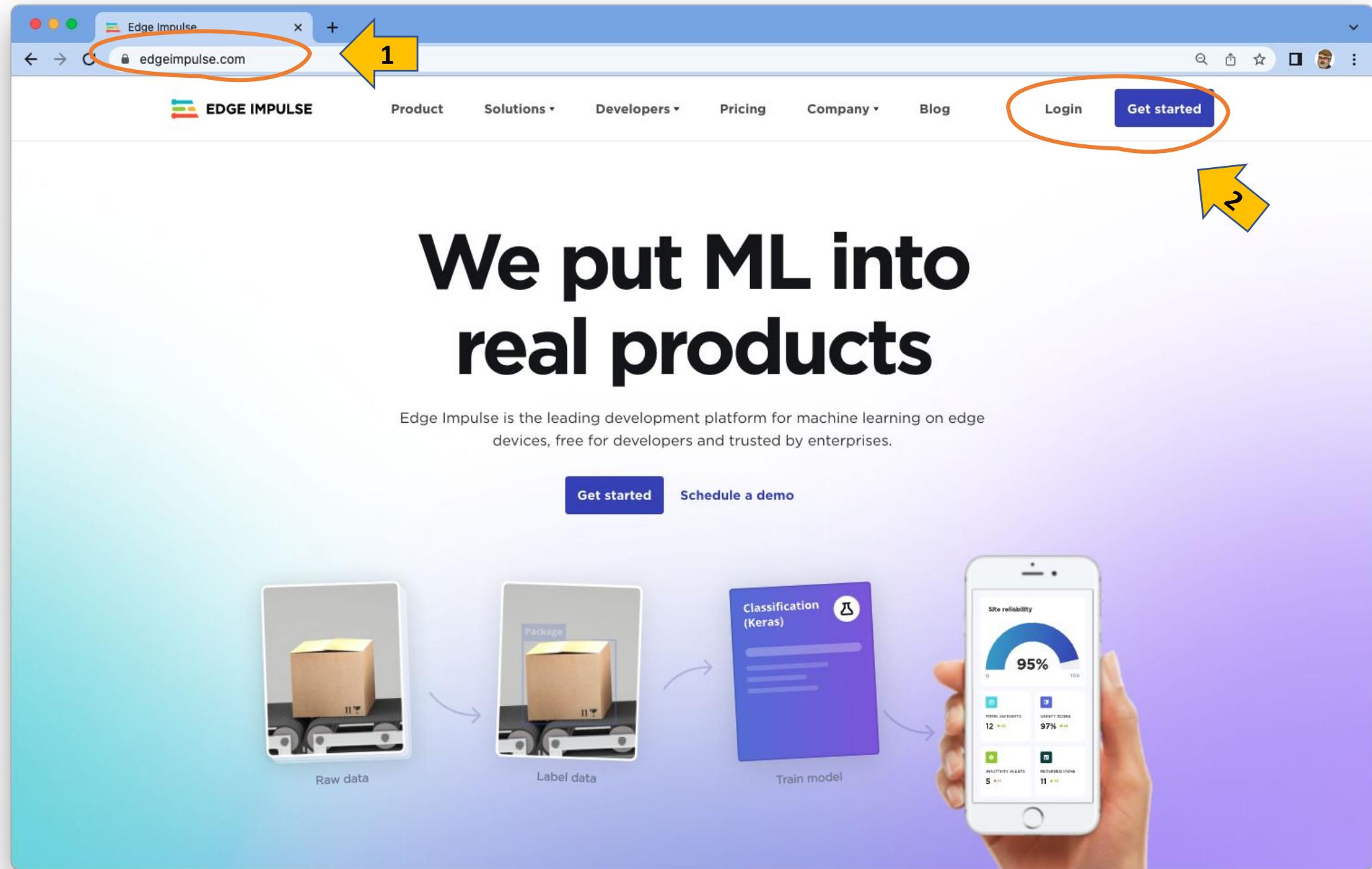
# Image Classification Project 2

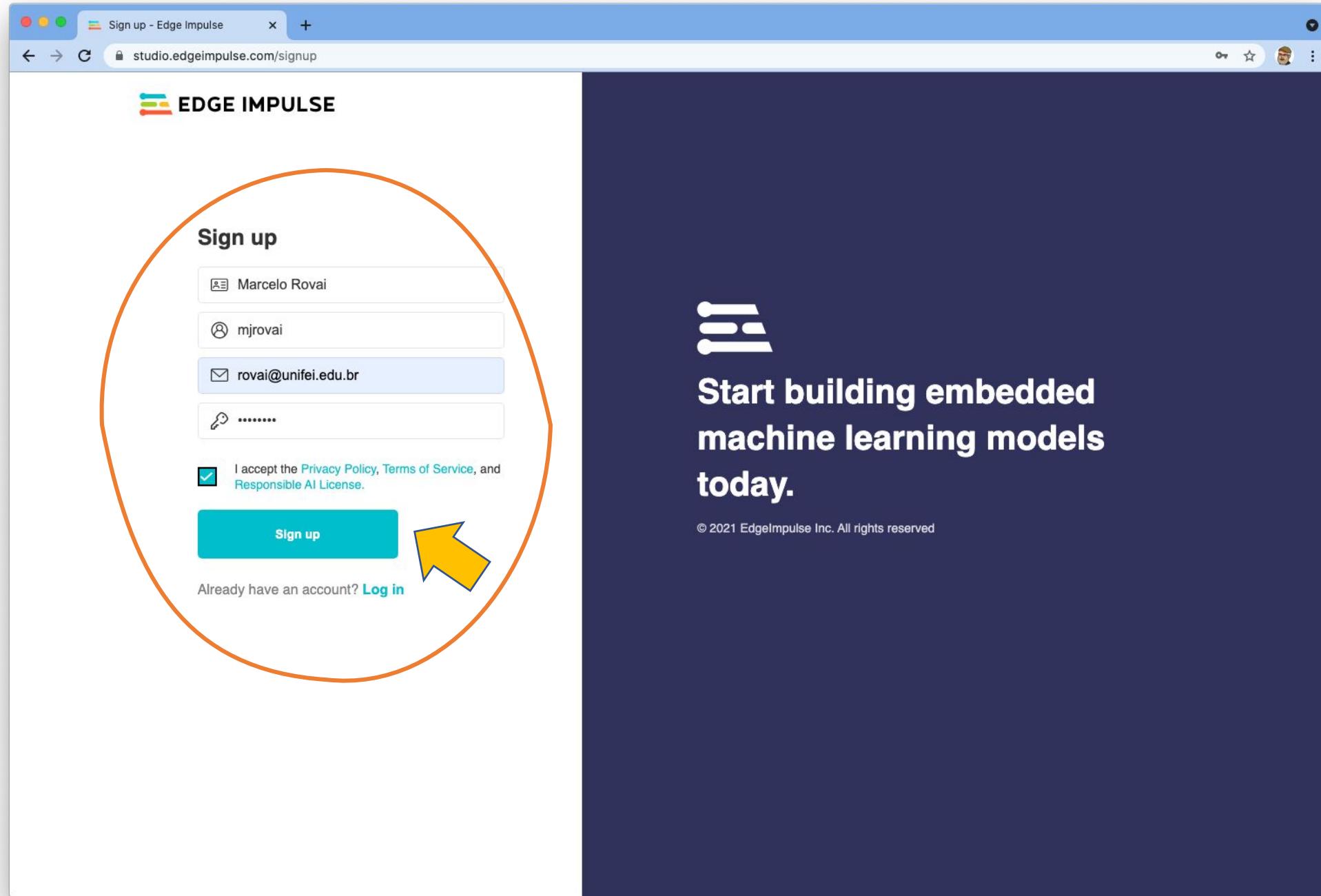
Decide a Goal

- Possible Images:
  - mug
  - background



<https://studio.edgeimpulse.com/public/139479/latest>





A screenshot of a web browser showing the Edge Impulse sign-up success page. The URL in the address bar is `studio.edgeimpulse.com/studio/signup-success`. The page features a white header with the Edge Impulse logo and a dark blue footer. The main content area on the left displays a success message and a button to build a model, while the right side has a large call-to-action for building machine learning models.

Sign up successful!

Thanks Marcelo Rovai!

You have successfully signed up for Edge Impulse.

Click here to build your first ML model!

Re-send activation email

Start building embedded machine learning models today.

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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

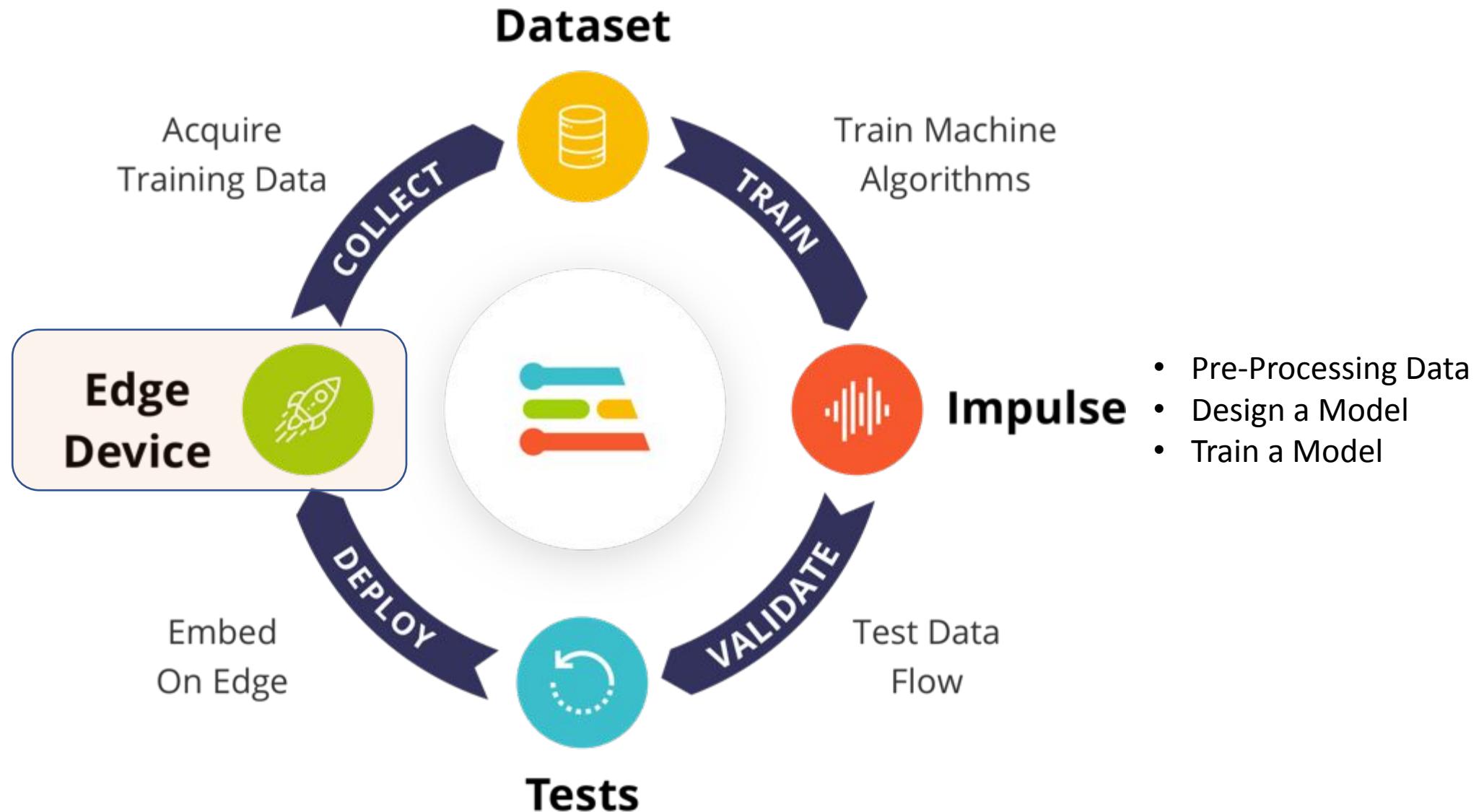
Marcelo Rovai / SciTinyML22-KWS

Marcelo Rovai / Cifar10\_Image\_Classification

Marcelo Rovai / IESTI01-Cifar10\_Classification

Marcelo Rovai / Bean Disease Classifier

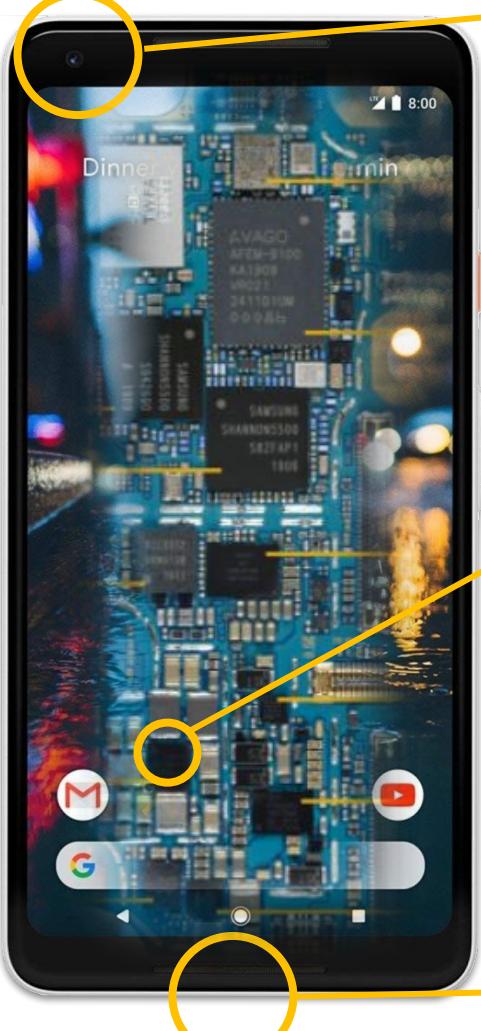
The screenshot shows the Edge Impulse Studio interface. A central modal window titled "Create a new project" is open, prompting the user to enter a project name ("IESTI01 - Image Classification") and choose a project type ("Developer" is selected). Below the modal, a list of existing projects is visible, each with a thumbnail and the author's name and project title. The background features a large orange and yellow geometric pattern.



# Edge Device



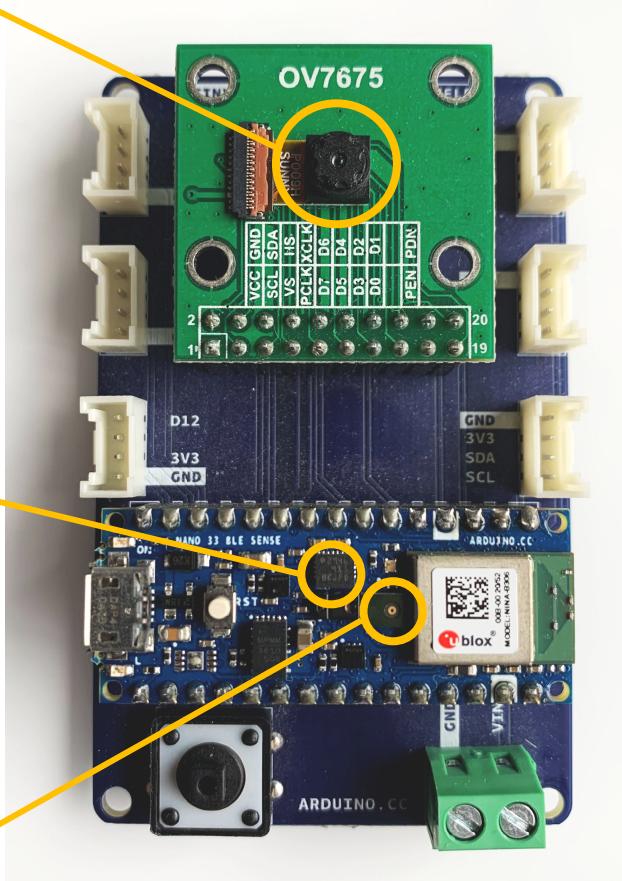
& Sensors



Camera



Microphone



**Devices - TinyML4D - Project**

DEVICES (TINYML4D - PROJECT SETUP)

Your devices

Collect data

These are the ways you can collect data:

- 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 mobile phone to capture movement, audio or images, and even run your trained model locally. No app required.  
[Show QR code](#)
- Use your computer**  
Capture audio or images from your webcam or microphone, or from an external audio device.  
[Collect data](#)
- Data from any device with the data forwarder**  
Capture data from any device or development board over a serial connection, in 10 lines of code.  
[Show docs](#)
- Upload data**  
Already have data? You can upload your existing datasets directly in WAV, JPG, PNG, CBOR, CSV or JSON format.  
[Go to the uploader](#)
- Integrate with your cloud**  
The enterprise version of Edge Impulse integrates directly with the data stored in your cloud platform.  
[Contact us](#)

CONNECT A NEW DEVICE

Dashboard

Devices

Data acquisition

Impulse design

Create impulse

Retrain model

Live classification

Model testing

Versioning

Deployment

GETTING STARTED

Documentation

Forums

Marcelo Rovai

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Devices - TinyML4D - Project

studio.edgeimpulse.com/studio/49268/devices

EDGE IMPULSE

DEVICES (TINYML4D - PROJECT SETUP)

Your devices

+ Connect a new device

Dashboard

Devices (highlighted with orange border)

Data acquisition

Impulse design

- Create impulse

Retrain model

Live classification

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Deployment

GETTING STARTED

Documentation

Forums

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

Collect data

You can collect data from any smartphone. From your smartphone go to [this URL](#), or scan the QR code below.



© 2021 Ed



Devices - TinyML4D - Project

studio.edgeimpulse.com/studio/49268/devices

EDGE IMPULSE

Dashboard

**Devices**

Data acquisition

Impulse design

- Create impulse
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- Deployment

GETTING STARTED

Documentation

Forums

DEVICES (TINYML4D - PROJECT SETUP)

Marcelo Rovai

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	REMO...	LAST SEEN
phone_kq6ray4k	phone_kq6ray4k	MOBILE CLIENT	Accelerometer, Microph...	...	Today, 12:06:04

Collect data

Device phone\_kq6ray4k is now connected

Get started!

smartphone.edgeimpulse.com 12:07 22% Camera WiFi

Data collection

Connected as phone\_kq6ray4k

You can collect data from this

© 2021 Ed

Devices - TinyML4D - Project

studio.edgeimpulse.com/studio/49268/devices

EDGE IMPULSE

Dashboard

**Devices**

Data acquisition

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GETTING STARTED

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DEVICES (TINYML4D - PROJECT SETUP)

Marcelo Rovai

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	REMO...	LAST SEEN
phone_kq6ray4k	phone_kq6ray4k	MOBILE_CLIENT	Accelerometer, Microph...	●	Today, 12:06:04

© 2021 EdgeImpulse Inc. All rights reserved

smartphone.edgeimpulse.com 12:07 22% Camera WiFi

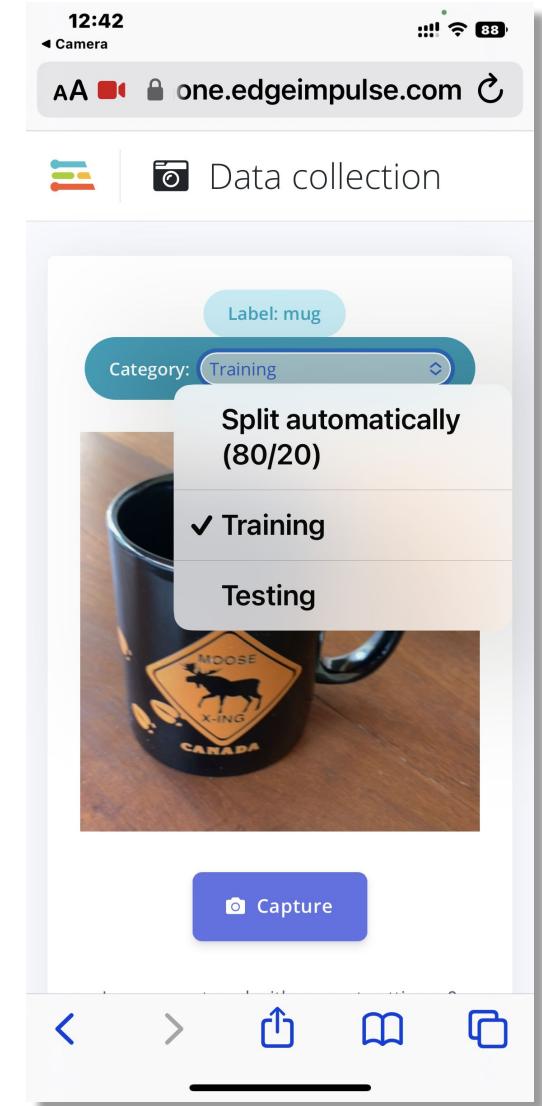
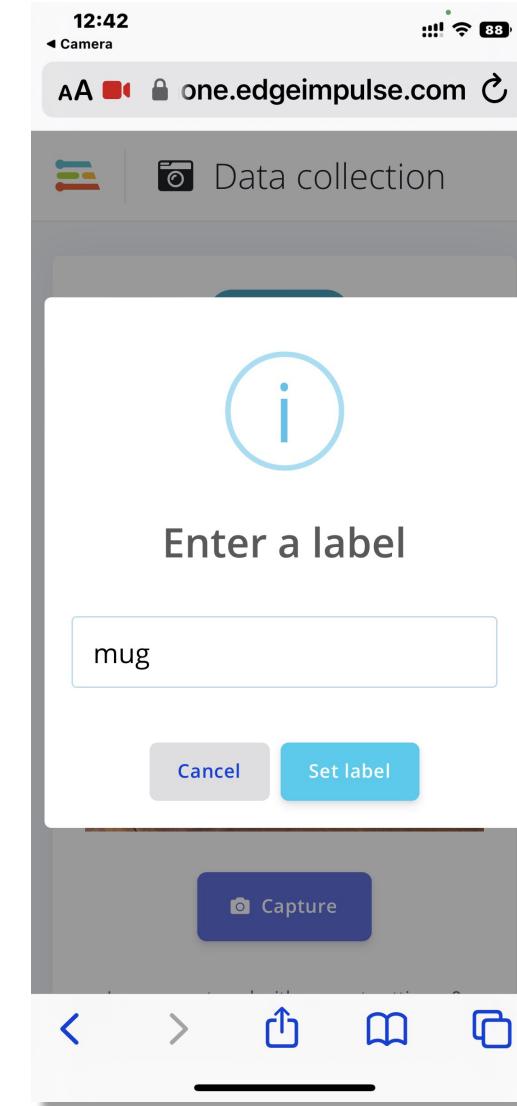
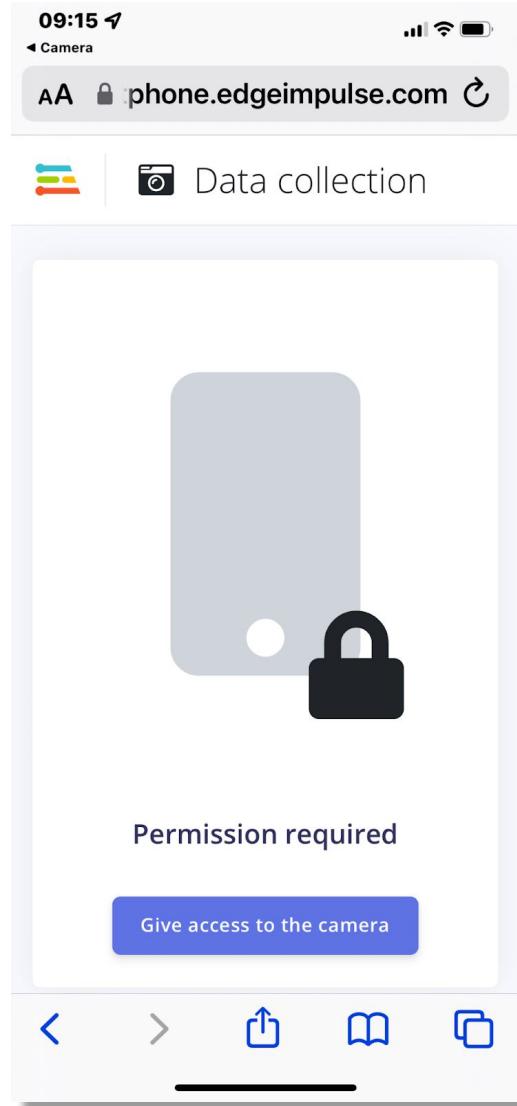
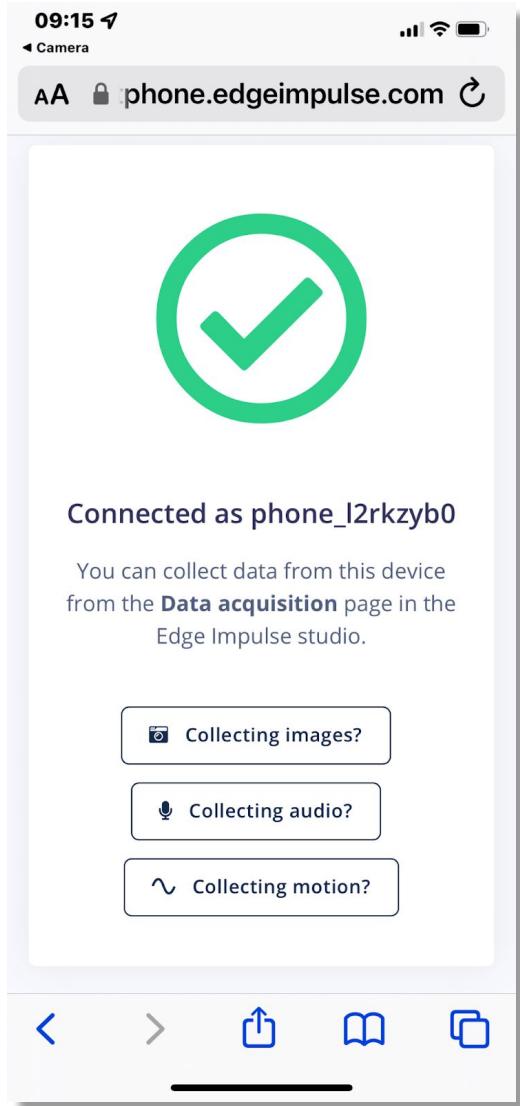
Data collection

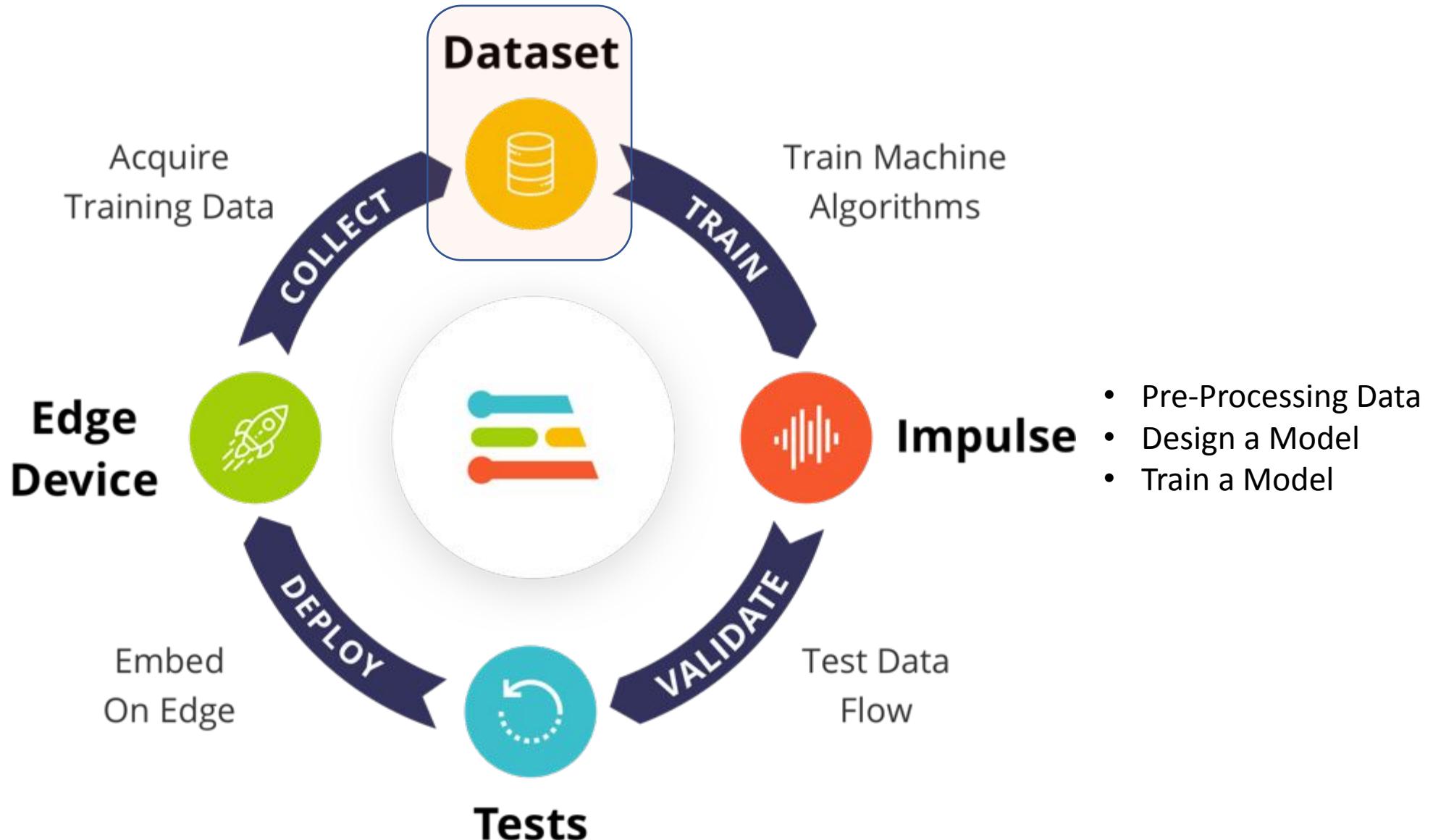
Connected as phone\_kq6ray4k

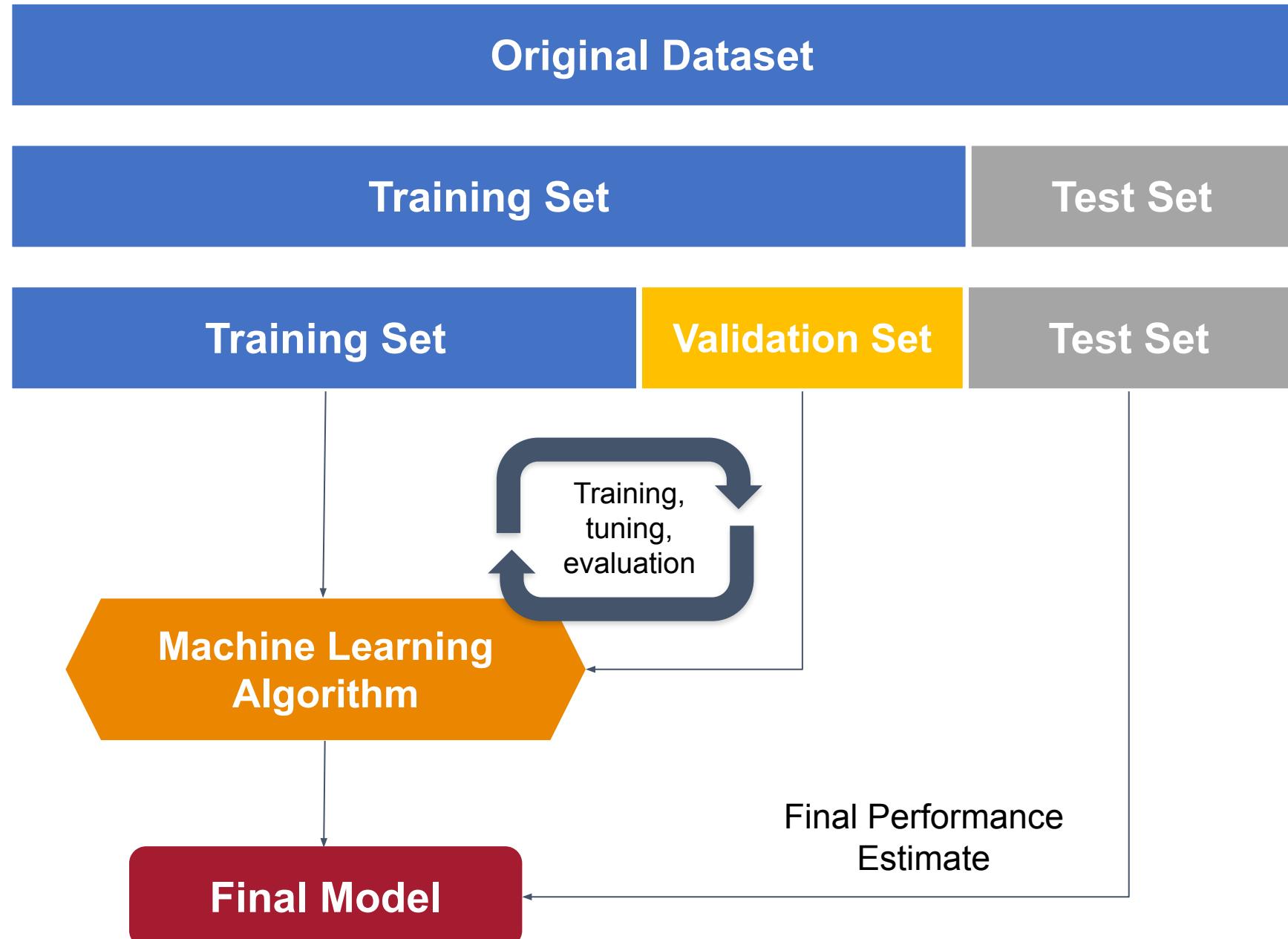
You can collect data from this

A yellow arrow points from the device name 'phone\_kq6ray4k' in the table to the green checkmark icon in the 'Data collection' window.

NAME	ID	TYPE	SENSORS	REMO...	LAST SEEN
phone_kq6ray4k	phone_kq6ray4k	MOBILE_CLIENT	Accelerometer, Microph...	●	Today, 12:06:04







CNMAC - Image Classification

studio.edgeimpulse.com/studio/139479/acquisition/training?page=1

Edge Impulse Imagine! Join us for the latest innovations in edge machine learning for the real world, Sept 28-30. [Learn more.](#)

Marcelo Rovai / CNMAC - Image Classification

EDGE IMPULSE

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](#)

DATA COLLECTED  
112 items

TRAIN / TEST SPLIT  
100% / 0% ▲

Collected data

SAMPLE NAME	LABEL	ADDED	⋮
background.3dd0bqga	background	Today, 12:47:34	⋮
background.3dd0bmck	background	Today, 12:47:29	⋮
background.3dd0b81r	background	Today, 12:47:15	⋮
background.3dd0b2vc	background	Today, 12:47:10	⋮
background.3dd0b1th	background	Today, 12:47:09	⋮
background.3dd0b1ls	background	Today, 12:47:08	⋮
mug.3dd09nrm	mug	Today, 12:46:25	⋮
mug.3dd09m8k	mug	Today, 12:46:24	⋮
mug.3dd09i9i	mug	Today, 12:46:23	⋮
<b>mug.3dd09hj2</b>	<b>mug</b>	Today, 12:46:19	⋮
mug.3dd09gj3	mug	Today, 12:46:18	⋮
mug.3dd09esl	mug	Today, 12:46:16	⋮

Record new data

No devices connected to the remote management API.

RAW DATA  
**mug.3dd09hj2**



CNMAC - Image Classification

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Enterprise performance

**EDGE IMPULSE**

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

GETTING STARTED

- Documentation
- Forums

Job limit in minutes: 20

Train job memory (MB): 8192

DSP file size limit (MB): 4096

**Administrative zone**

- Custom deploys
- Show Linux deploy options
- Performance calibration

**Danger zone**

Performing split...

Perform train / test split

Are you sure you want to rebalance your dataset? This splits all your data automatically between the training and testing set, and resets the categories for all data. This is irrevocable!

**?**

**Cancel** **Yes, perform the train / test split**

Launch getting started wizard

Delete this project

Delete all data in this project

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CNMAC - Image Classification

studio.edgeimpulse.com/studio/139479

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Enterprise performance

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Job limit in minutes: 20

Train job memory (MB): 8192

DSP file size limit (MB): 4096

Administrative zone

- Custom deploys
- Show Linux deploy options
- Performance calibration

Save experiments

?

Confirm

Enter "perform split" to continue

perform split

Cancel Perform train / test split

Danger zone

Performing split...

Launch getting started wizard

Delete this project

Delete all data in this project

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CNMAC - Image Classification

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Enterprise performance

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Job limit in minutes: 20

Train job memory (MB): 8192

DSP file size limit (MB): 4096

Administrative zone

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- Show Linux deploy options
- Performance calibration

Save experiments

Performed train / test split

Dataset was rebalanced!

OK

Danger zone

Performing split...

Launch getting started wizard

Delete this project

Delete all data in this project

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CNMAC - Image Classification

studio.edgeimpulse.com/studio/139479/acquisition/training?page=1

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Marcelo Rovai / CNMAC - Image Classification

EDGE IMPULSE

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](#)

DATA COLLECTED  
89 items

TRAIN / TEST SPLIT  
79% / 21%

Collected data

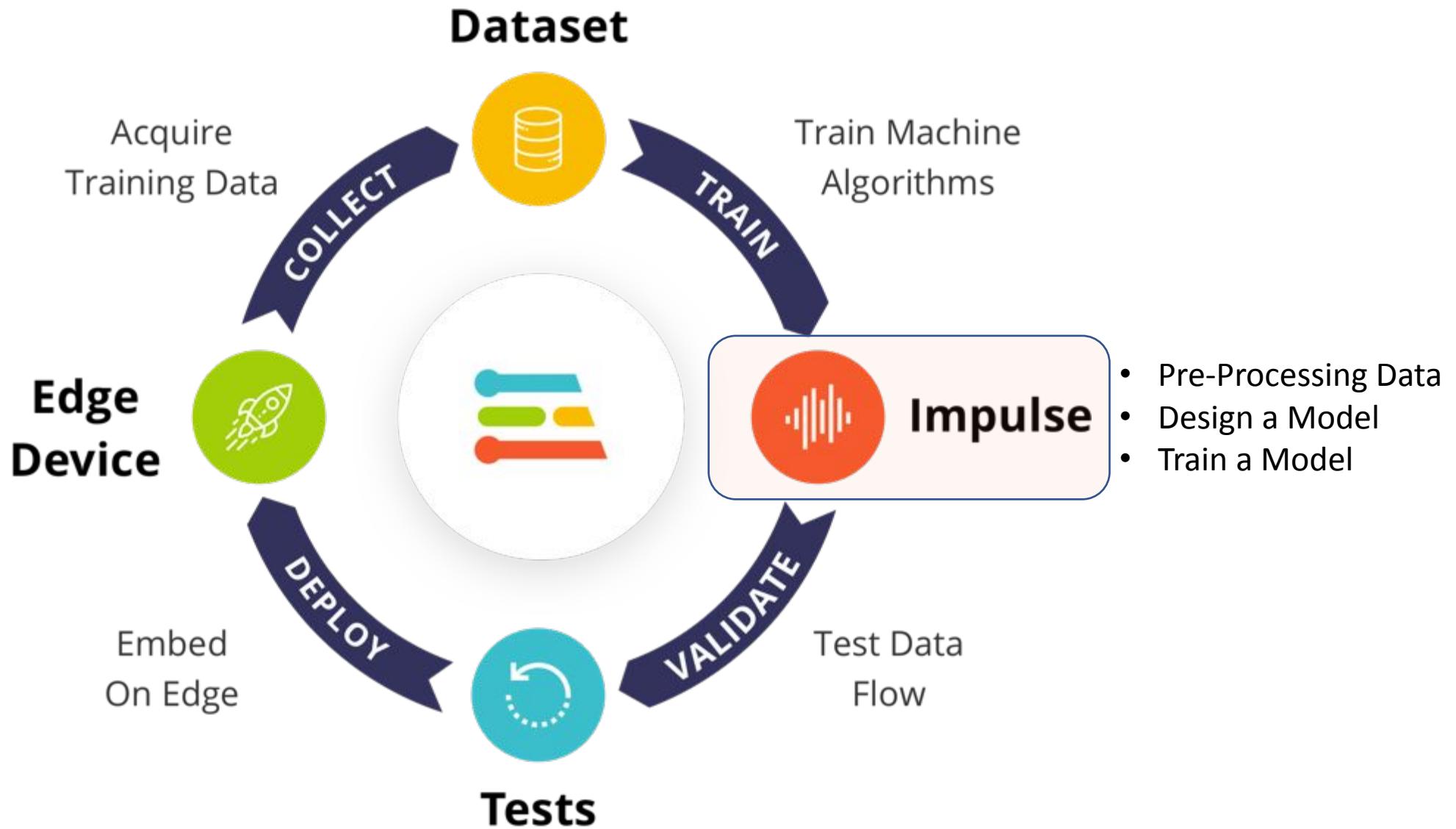
SAMPLE NAME	LABEL	ADDED	⋮
background.3dd0bqga	background	Today, 12:47:34	⋮
background.3dd0b81r	background	Today, 12:47:15	⋮
background.3dd0b2vc	background	Today, 12:47:10	⋮
background.3dd0b1th	background	Today, 12:47:09	⋮
<b>mug.3dd09nrm</b>	<b>mug</b>	Today, 12:46:25	⋮
mug.3dd09m8k	mug	Today, 12:46:24	⋮
mug.3dd09l9i	mug	Today, 12:46:23	⋮
mug.3dd09hj2	mug	Today, 12:46:19	⋮
mug.3dd09gj3	mug	Today, 12:46:18	⋮
mug.3dd09d81	mug	Today, 12:46:15	⋮
mug.3dd09c6f	mug	Today, 12:46:14	⋮
mug.3dd09atk	mug	Today, 12:46:12	⋮

Record new data

No devices connected to the remote management API.

RAW DATA  
**mug.3dd09nrm**





CNMAC - Image Classification

studio.edgeimpulse.com/studio/139479/create-impulse

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Marcelo Rovai / CNMAC - Image Classification

EDGE IMPULSE

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.

Add a processing block    Add a learning block

**Output features**

Save Impulse

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

GETTING STARTED

Documentation   Forums

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CNMAC - Image Classification

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**EDGE IMPULSE**

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- Create impulse
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- Model testing
- Versioning
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- Forums

An impulse takes raw data, uses it to make decisions, and outputs features.

**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.

**Add a processing block**

Did you know? You can bring your own DSP code.

DESCRIPTION	AUTHOR	RECOMMENDED
<b>Image</b> Preprocess and normalize image data, and optionally reduce the color depth.	EdgeImpulse Inc. ★	Add
<b>Raw Data</b> Use data without pre-processing. Useful if you want to use deep learning to learn features.	EdgeImpulse Inc.	Add

Some processing blocks have been hidden based on the data in your project. Show all blocks anyway

Add custom block Cancel

**Output features**

Save Impulse

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An impulse takes raw data, uses it to make decisions, and outputs features.

**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.

**Add a learning block**

Did you know? You can bring your own model in PyTorch, Keras or scikit-learn.

DESCRIPTION	AUTHOR	RECOMMENDED
<b>Transfer Learning (Images)</b> Fine tune a pre-trained image classification model on your data. Good performance even with relatively small image datasets.	EdgeImpulse Inc.	<b>Add</b>
<b>Classification (Keras)</b> Learns patterns from data, and can apply these to new data. Great for categorizing movement or recognizing audio.	EdgeImpulse Inc.	<b>Add</b>
<b>Regression (Keras)</b> Learns patterns from data, and can apply these to new data. Great for predicting numeric continuous values.	EdgeImpulse Inc.	<b>Add</b>

Some learning blocks have been hidden based on the data in your project. [Show all blocks anyway](#)

**Output features**

**Save Impulse**

**Add a processing block**

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CNMAC - Image Classification

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EDGE IMPULSE

Successfully stored impulse. Configure the signal processing and learning blocks in the navigation bar.

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Impulse design

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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, mug)

Output features

2 (background, mug)

Save Impulse

Add a processing block

Add a learning block

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The screenshot shows the Edge Impulse studio interface for creating a new impulse named 'CNMAC - Image Classification'. The main workspace displays four configuration panels: 'Image data' (red background), 'Image' (white background), 'Transfer Learning (Images)' (purple background), and 'Output features' (green background). A success message at the top indicates the impulse was stored successfully. Below the panels, there are two dashed boxes labeled 'Add a processing block' and 'Add a learning block'. The left sidebar contains a navigation menu with various options like Dashboard, Devices, and Data acquisition, along with a 'GETTING STARTED' section for documentation and forums. The top right corner shows the user's profile picture and name, Marcelo Rovai.

CNMAC - Image Classification

studio.edgeimpulse.com/studio/139479/dsp/image/3

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Marcelo Rovai / CNMAC - Image Classification

#1 ▾ Click to set a description for this version

Parameters Generate features

Raw data

Show: All labels background.3dd0bqga (background)

Raw features

0xf4dcd7, 0xf9dfd7, 0xf2d5d0, 0xe2c8c4, 0xebcc6, 0xedcdc4, 0xe5c4ba, 0xe9c4b6, 0xdebbaf, 0xd5b3ab,...

Parameters

Image

Color depth: RGB

Save parameters

DSP result

Image

Processed features

0.9569, 0.8627, 0.8431, 0.9765, 0.8745, 0.8431, 0.9490, 0.8353, 0.8157, 0.8863, 0.7843, 0.7686, 0.9...

On-device performance

PROCESSING TIME: 1 ms.

PEAK RAM USAGE: 4 KB

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CNMAC - Image Classification

studio.edgeimpulse.com/studio/139479/dsp/image/3/generate-features

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Marcelo Rovai / CNMAC - Image Classification

#1 ▾ Click to set a description for this version

Parameters Generate features

Training set

Data in training set 89 items

Classes 2 (background, mug)

Generate features

Feature explorer

background mug

Feature generation output

Still running... completed 0 / 500 epochs completed 50 / 500 epochs completed 100 / 500 epochs completed 150 / 500 epochs completed 200 / 500 epochs completed 250 / 500 epochs completed 300 / 500 epochs completed 350 / 500 epochs completed 400 / 500 epochs completed 450 / 500 epochs

Wed Sep 21 17:11:23 2022 Finished embedding Reducing dimensions for visualizations OK

Job completed

On-device performance

PROCESSING TIME 1 ms.

PEAK RAM USAGE 4 KB

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# Model Design

## 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

### MobileNetV2 96x96 0.35

Uses around 296.8K RAM and 575.2K ROM with default settings and optimizations. Works best with 96x96 input size. Supports both RGB and grayscale.

## Image Size

### MobileNetV2 96x96 0.1

Uses around 270.2K RAM and 212.3K ROM with default settings and optimizations. Works best with 96x96 input size. Supports both RGB and grayscale.

### MobileNetV2 96x96 0.05 Alpha

Uses around 265.3K RAM and 162.4K ROM with default settings and optimizations. Works best with 96x96 input size. Supports both RGB and grayscale.

CNMAC - Image Classification

studio.edgeimpulse.com/studio/139479/learning/keras-transfer-image/5

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CLICK TO SET A DESCRIPTION

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**Neural Network settings**

**Training settings**

Number of training cycles ②

Learning rate ②

Validation set size ②

Auto-balance dataset ②

**Data augmentation ②**

**Neural network architecture**

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.

Add

MobileNetV1 96x96 0.2

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.

Add

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.

Add

MobileNetV2 96x96 0.35

Uses around 296.8K RAM and 575.2K ROM with default settings and optimizations. Works best with 96x96 input size. Supports both RGB and grayscale.

Add

MobileNetV2 96x96 0.1

Uses around 270.2K RAM and 212.3K ROM with default settings and optimizations. Works best with 96x96 input size. Supports both RGB and grayscale.

Add

MobileNetV2 96x96 0.05

Uses around 265.3K RAM and 162.4K ROM with default settings and optimizations. Works best with 96x96 input size. Supports both RGB and grayscale.

Add

MobileNetV2 160x160 1.0

Uses around 1.3M RAM and 2.6M ROM with default settings and optimizations. Works best with 160x160 input size. Supports RGB only.

Add

MobileNetV2 160x160 0.75

Uses around 1.3M RAM and 1.7M ROM with default settings and optimizations. Works best with 160x160 input size. Supports RGB only.

Add

MobileNetV2 160x160 0.5

Uses around 700.7K RAM and 982.4K ROM with default settings and optimizations. Works best with 160x160 input size. Supports RGB only.

Add

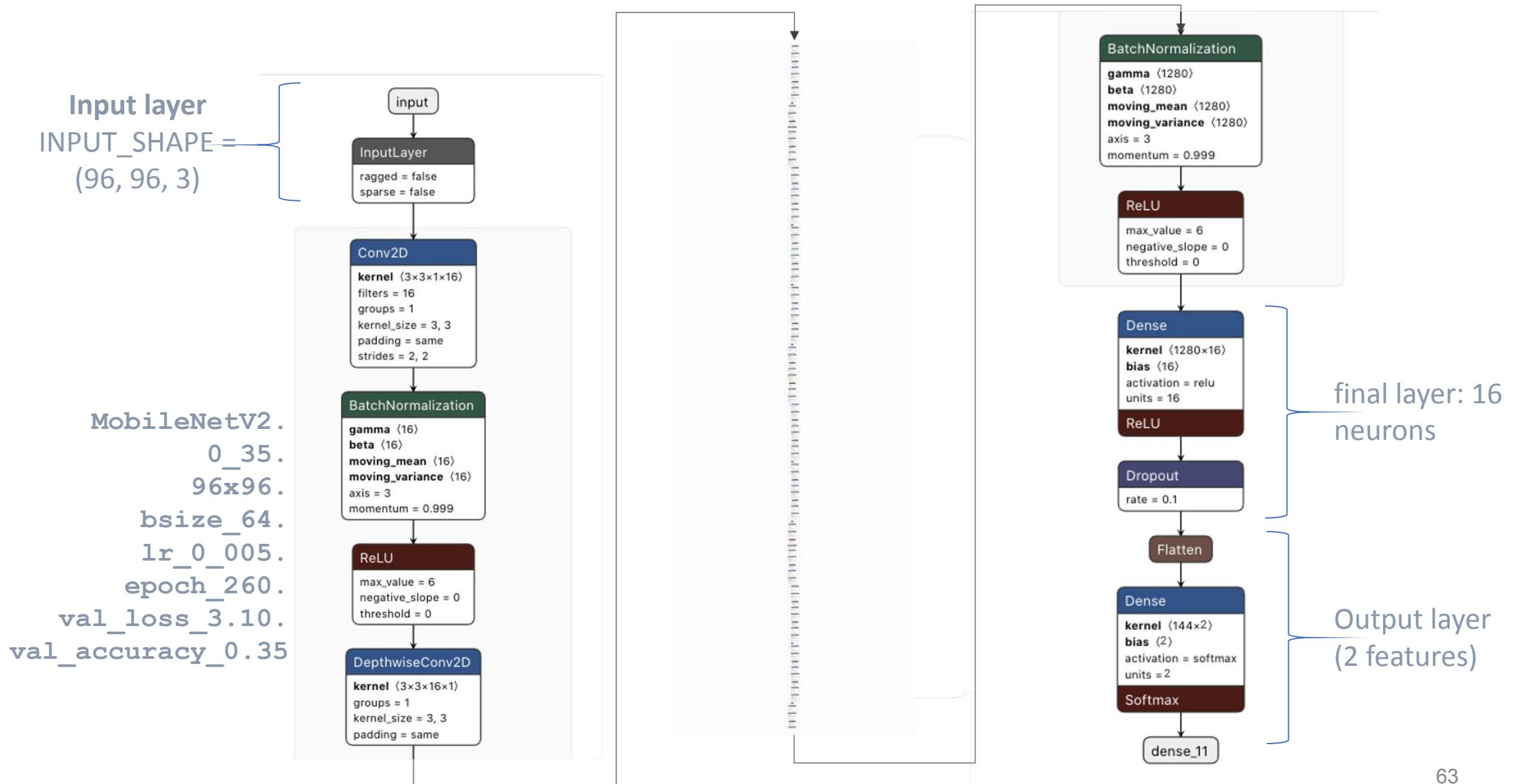
MobileNetV2 160x160 0.35

Uses around 683.3K RAM and 658.4K ROM with default settings and optimizations. Works best with 160x160 input size. Supports RGB only.

Add

Cancel

# MobileNetV2 96x96 0.35



**Neural Network settings**

**Training settings**

Number of training cycles ②  
20

Learning rate ②  
0.0005

Validation set size ②  
20 %

Auto-balance dataset ②

Data augmentation ②

**Neural network architecture**

Input layer (27,648 features)



MobileNetV2 96x96 0.35 (final layer: 16 neurons, 0.1 dropout)

Choose a different model

Output layer (2 classes)

**Start training**

**Neural Network settings**

**Training settings**

Validation set size ② 20 %

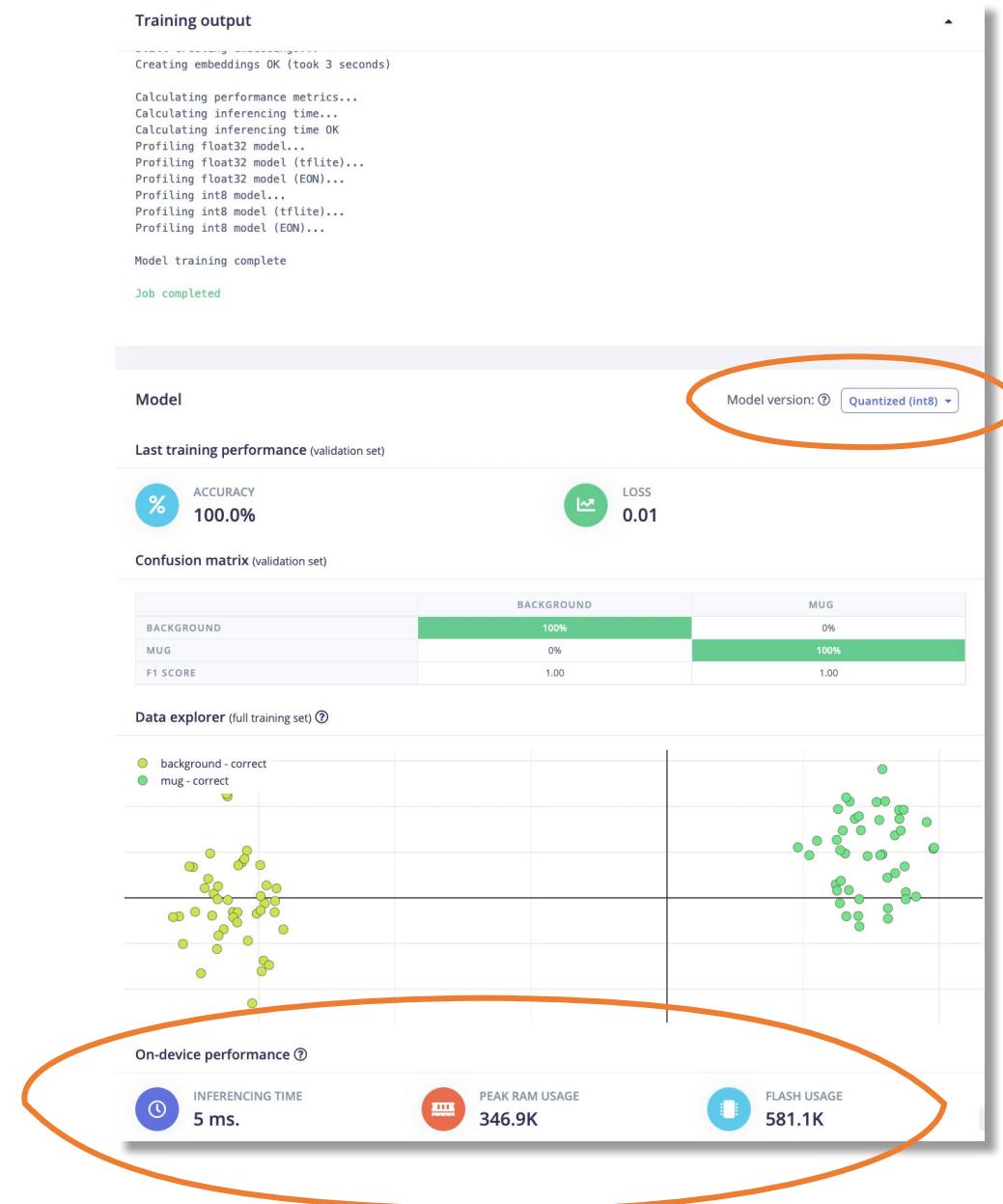
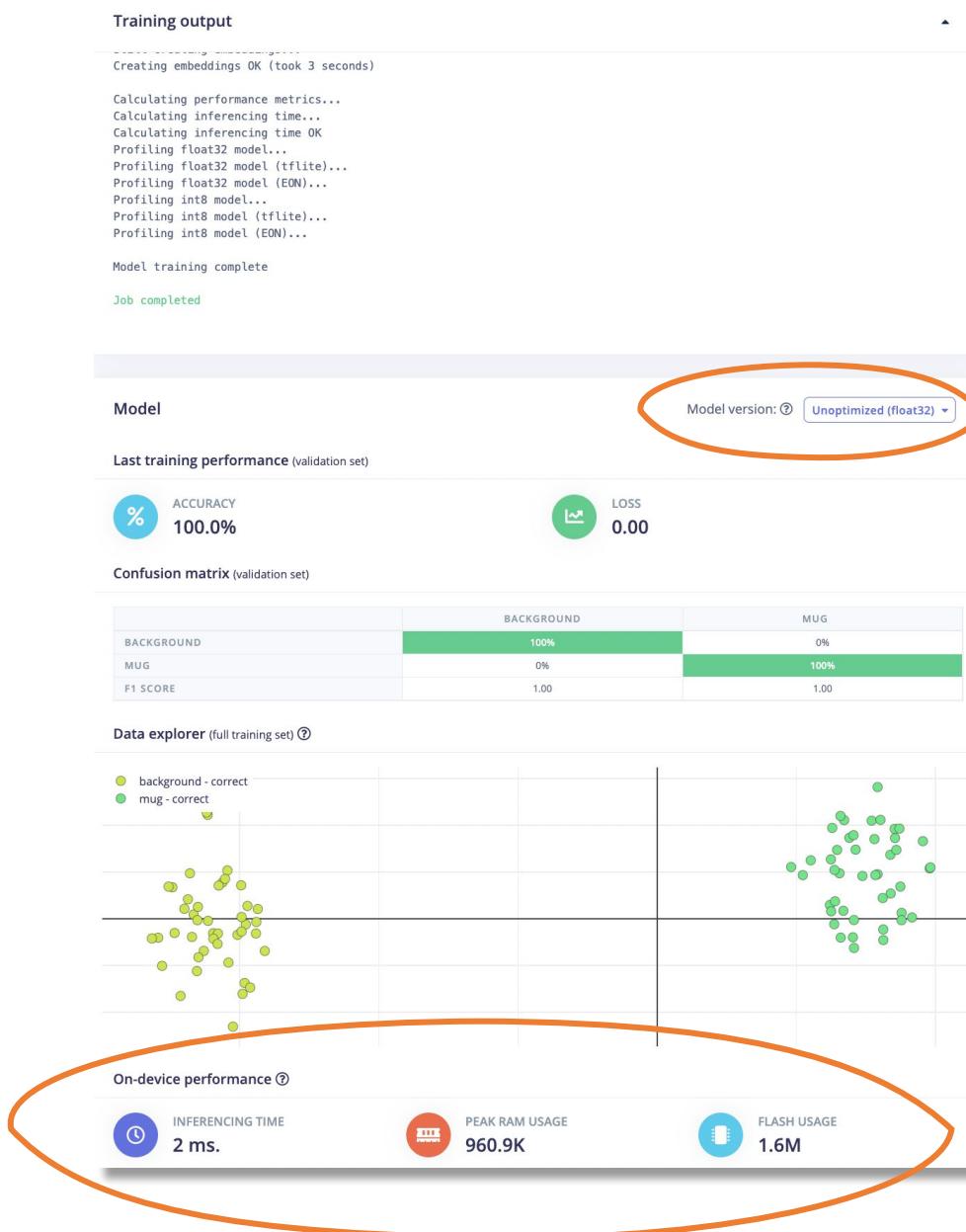
**Neural network architecture**

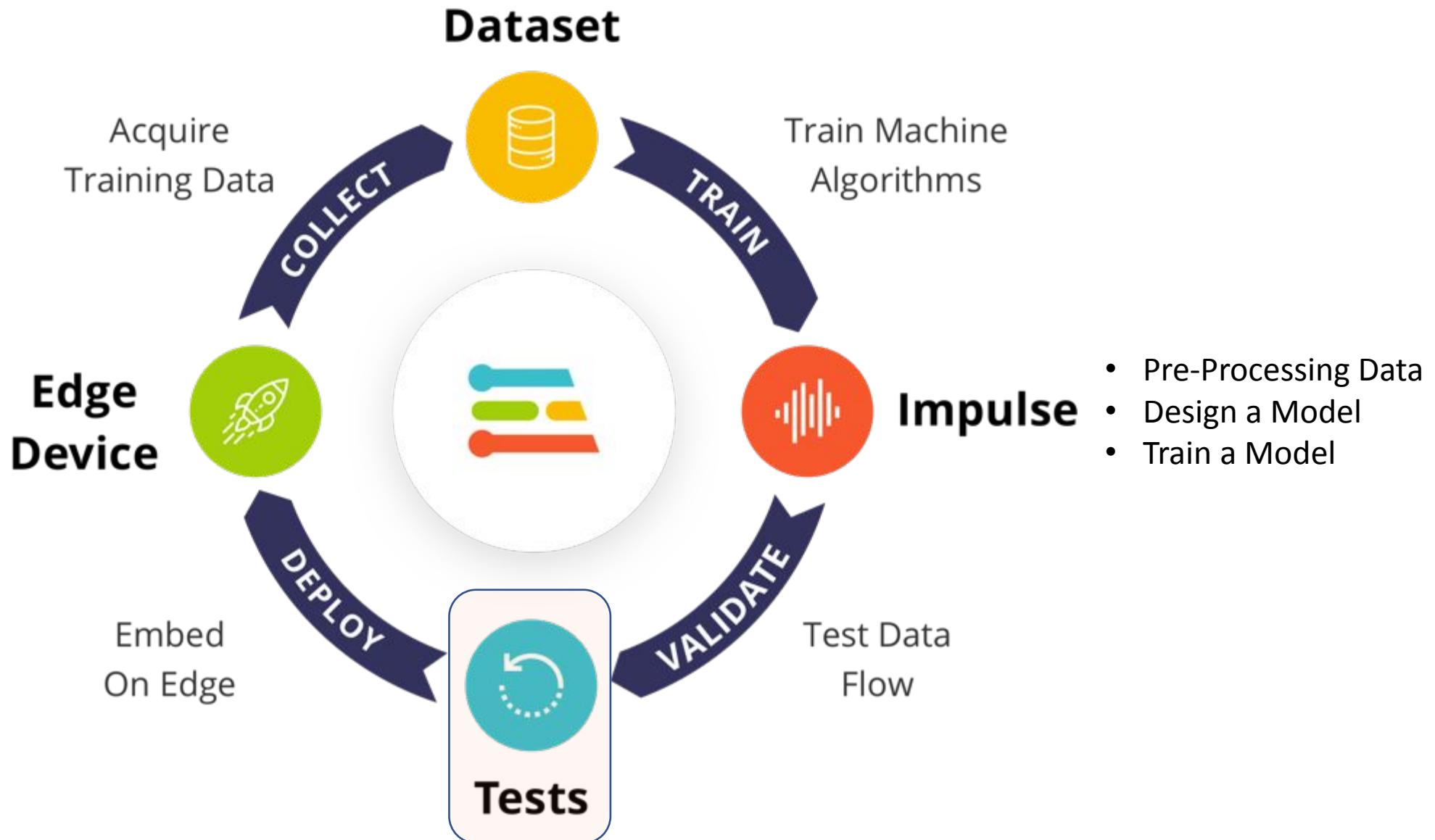
```

49
50
51 # Implements the data augmentation policy
52 - def augment_image(image, label):
53     # Flips the image randomly
54     image = tf.image.random_flip_left_right(image)
55
56     # Increase the image size, then randomly crop it down to
57     # the original dimensions
58     resize_factor = random.uniform(1, 1.2)
59     new_height = math.floor(resize_factor * INPUT_SHAPE[0])
60     new_width = math.floor(resize_factor * INPUT_SHAPE[1])
61     image = tf.image.resize_with_crop_or_pad(image, new_height, new_width)
62     image = tf.image.random_crop(image, size=INPUT_SHAPE)
63
64     # Vary the brightness of the image
65     image = tf.image.random_brightness(image, max_delta=0.2)
66
67     return image, label
68
69 train_dataset = train_dataset.map(augment_image, num_parallel_calls=tf.data.AUTOTUNE)
70
71 BATCH_SIZE = 32
72 EPOCHS = args.epochs or 20
73 LEARNING_RATE = args.learning_rate or 0.0005
74 train_dataset = train_dataset.batch(BATCH_SIZE, drop_remainder=False)
75 validation_dataset = validation_dataset.batch(BATCH_SIZE, drop_remainder=False)
76 callbacks.append(BatchLoggerCallback(BATCH_SIZE, train_sample_count, epochs=EPOCHS))

```

**Start training**





CNMAC - Image Classification

studio.edgeimpulse.com/studio/139479/validation

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### Test data

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

SAMPLE NAME	EXPECTED OUTCOME	LENGTH	ACCURACY	RESULT	⋮
background.3dd0...	background	-	100%	1 background	⋮
background.3dd0...	background	-	100%	1 background	⋮
mug.3dd09esl	mug	-	100%	1 mug	⋮
mug.3dd0990a	mug	-	100%	1 mug	⋮
mug.3dd09302	mug	-	100%	1 mug	⋮
mug.3dd08us0	mug	-	100%	1 mug	⋮
mug.3dd08qm7	mug	-	100%	1 mug	⋮
mug.3dd08lfc	mug	-	100%	1 mug	⋮
mug.3dd08bro	mug	-	100%	1 mug	⋮
mug.3dd086lr	mug	-	100%	1 mug	⋮
mug.3dd082l7	mug	-	100%	1 mug	⋮
			100%	1 mug	⋮
			100%	1 mug	⋮
			100%	1 background	⋮
			100%	1 background	⋮

**Model testing output**

```

Completed 200 / 500 epochs
Completed 350 / 500 epochs
Completed 400 / 500 epochs
Completed 450 / 500 epochs
Wed Sep 21 17:53:02 2022 Finished embedding
Reducing dimensions for visualizations OK
Classifying data for Transfer learning...
Classifying data for float32 model...
Classifying data for float32 model...
Scheduling job in cluster...
Job started
Job completed
  
```

**Model testing results**

**ACCURACY** **100.00%**

	BACKGROUND	MUG	UNCERTAIN
BACKGROUND	100%	0%	0%
MUG	0%	100%	0%
F1 SCORE	1.00	1.00	

**Feature explorer**

The Feature explorer displays a scatter plot comparing background and mug samples. Green dots represent 'background - correct' samples, and yellow dots represent 'mug - correct' samples. The plot shows that the algorithm has correctly identified all background samples and all mug samples.

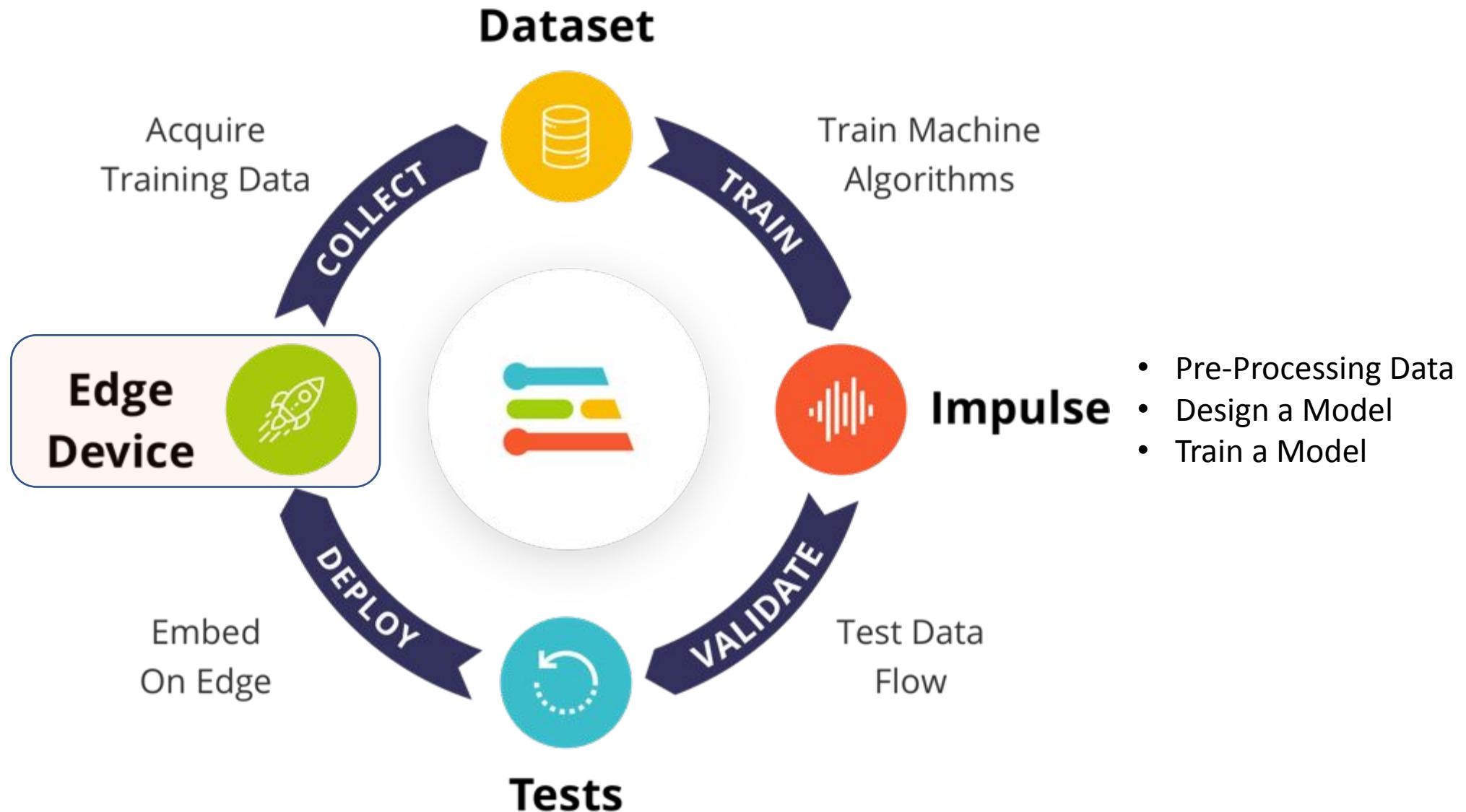
**Training Set** | **Validation Set** | **Test Set**

Machine Learning Algorithm

Final Model

Final Performance Estimate

Training, tuning, evaluation



CNMAC - Image Classification

studio.edgeimpulse.com/studio/139479/deployment

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Arduino Portenta H7    SiLabs xG24 Dev Kit    Himax WE-I Plus

**openMV**

OpenMV Firmware    Sony's Spresense    Synaptics KA10000

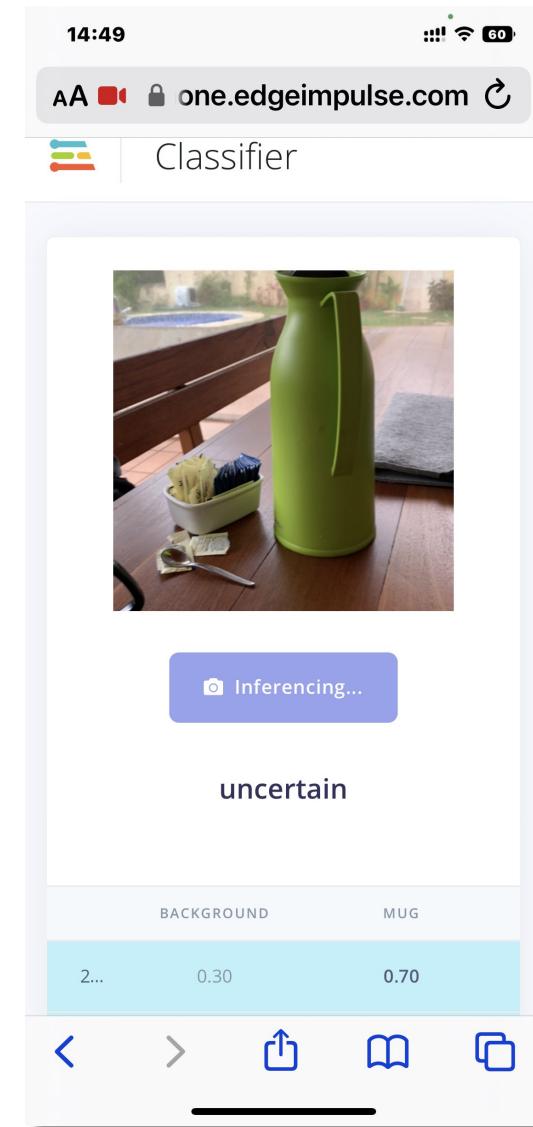
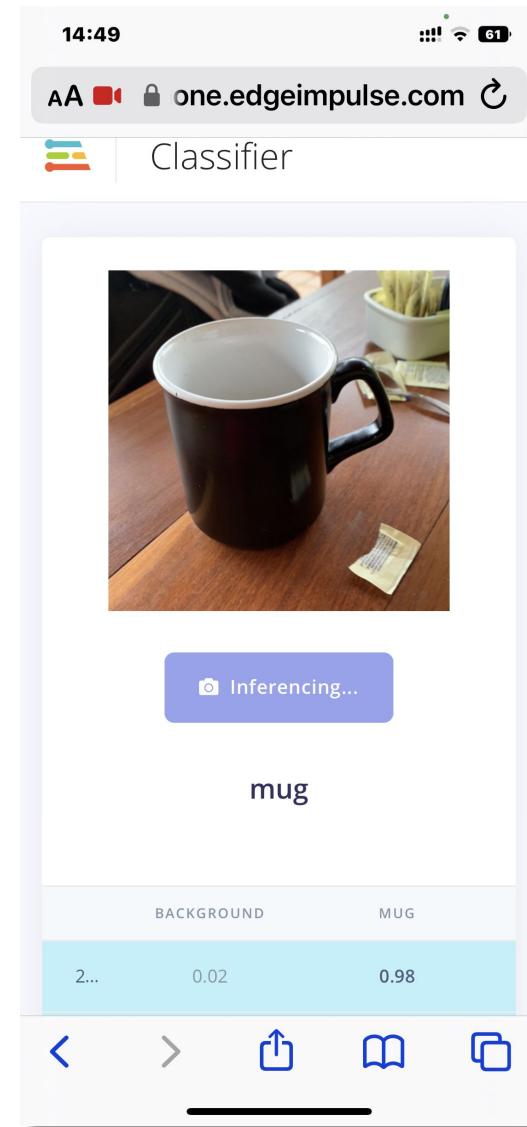
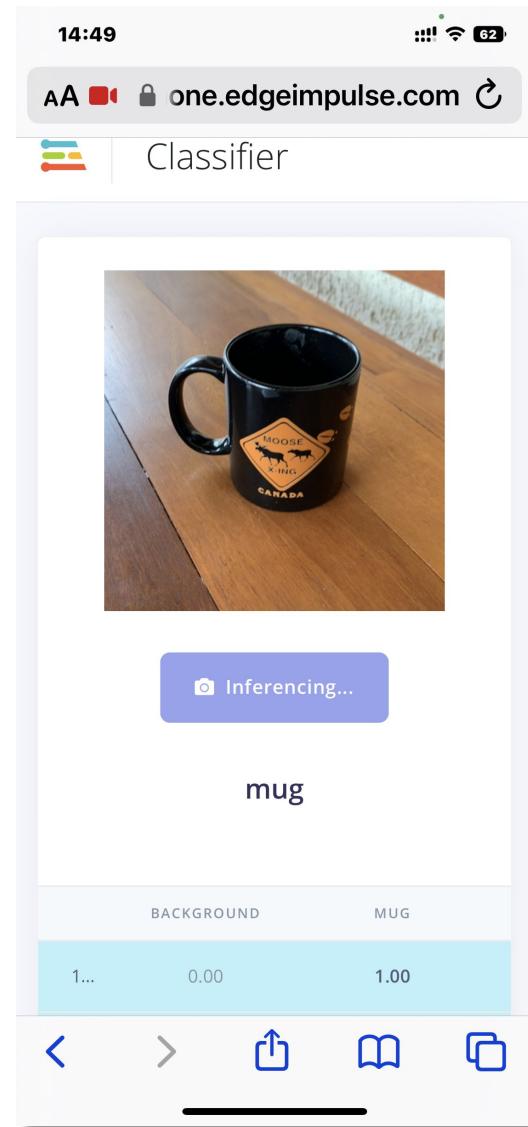
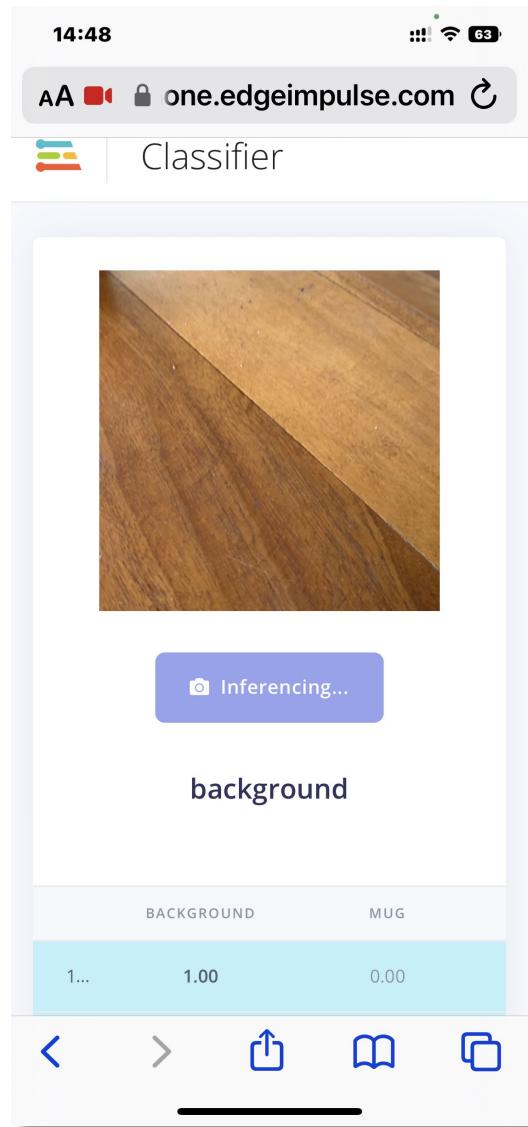
Alif Ensemble E7    Linux boards    Custom firmware

Run your impulse directly  
Run this impulse directly on your mobile phone, no app required

Computer    Mobile phone

Build

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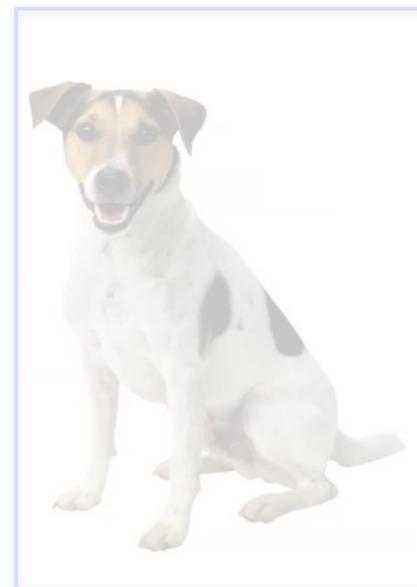


# Computer Vision Main Types

**Image Classification**  
(Multi-Class Classification)

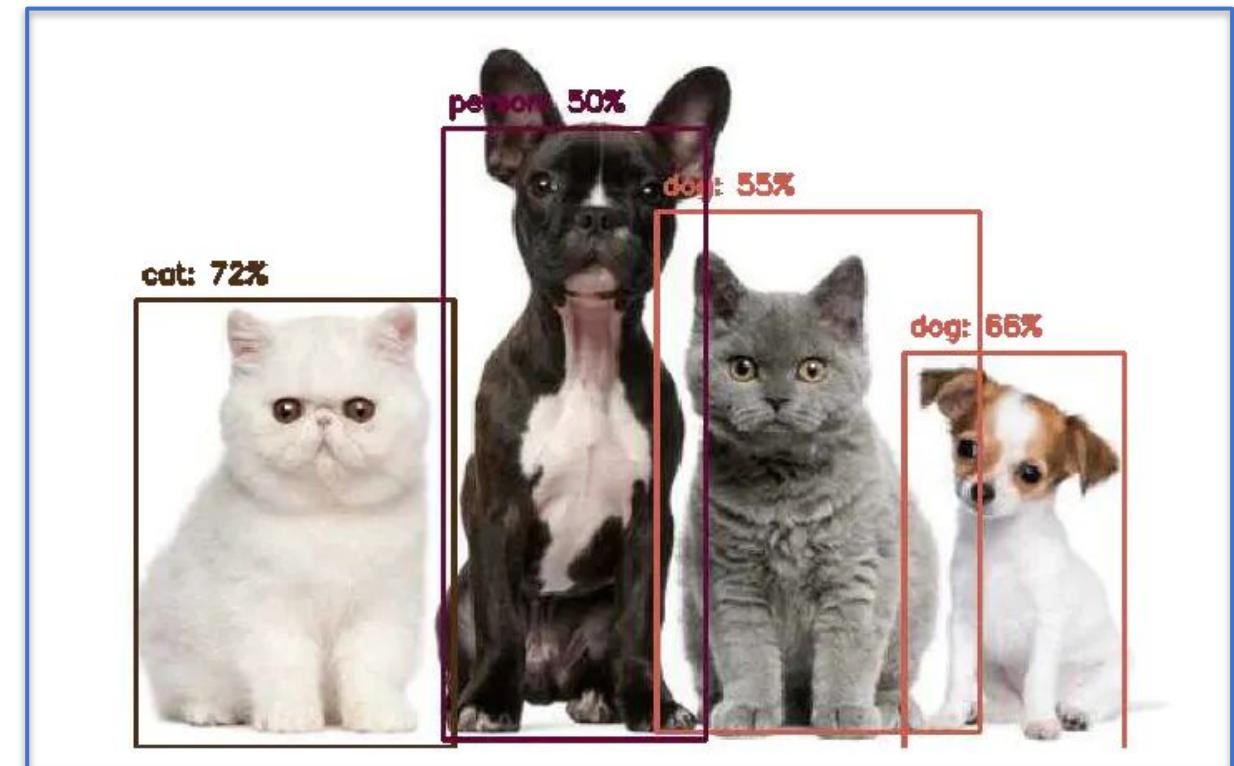


Cat: 70%

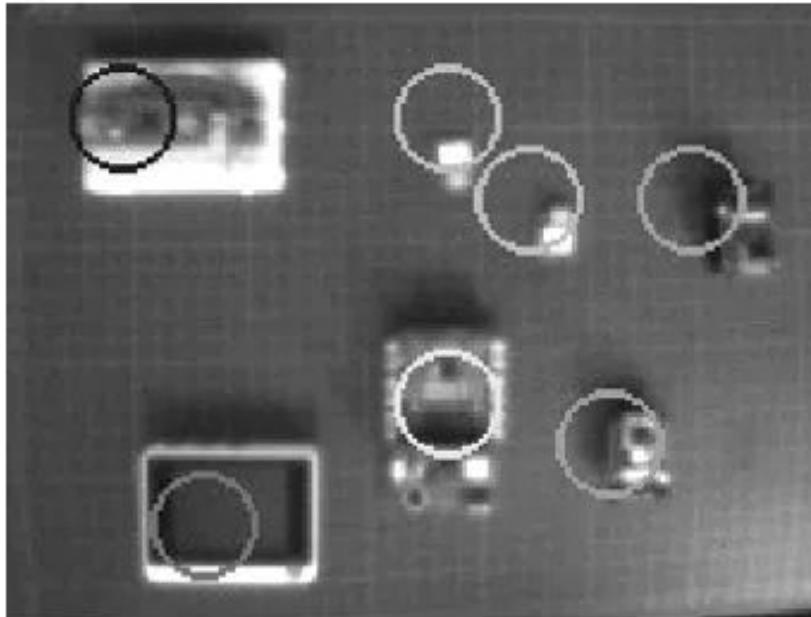


Dog: 80%

**Object Detection**  
**Multi-Label Classification + Object Localization**



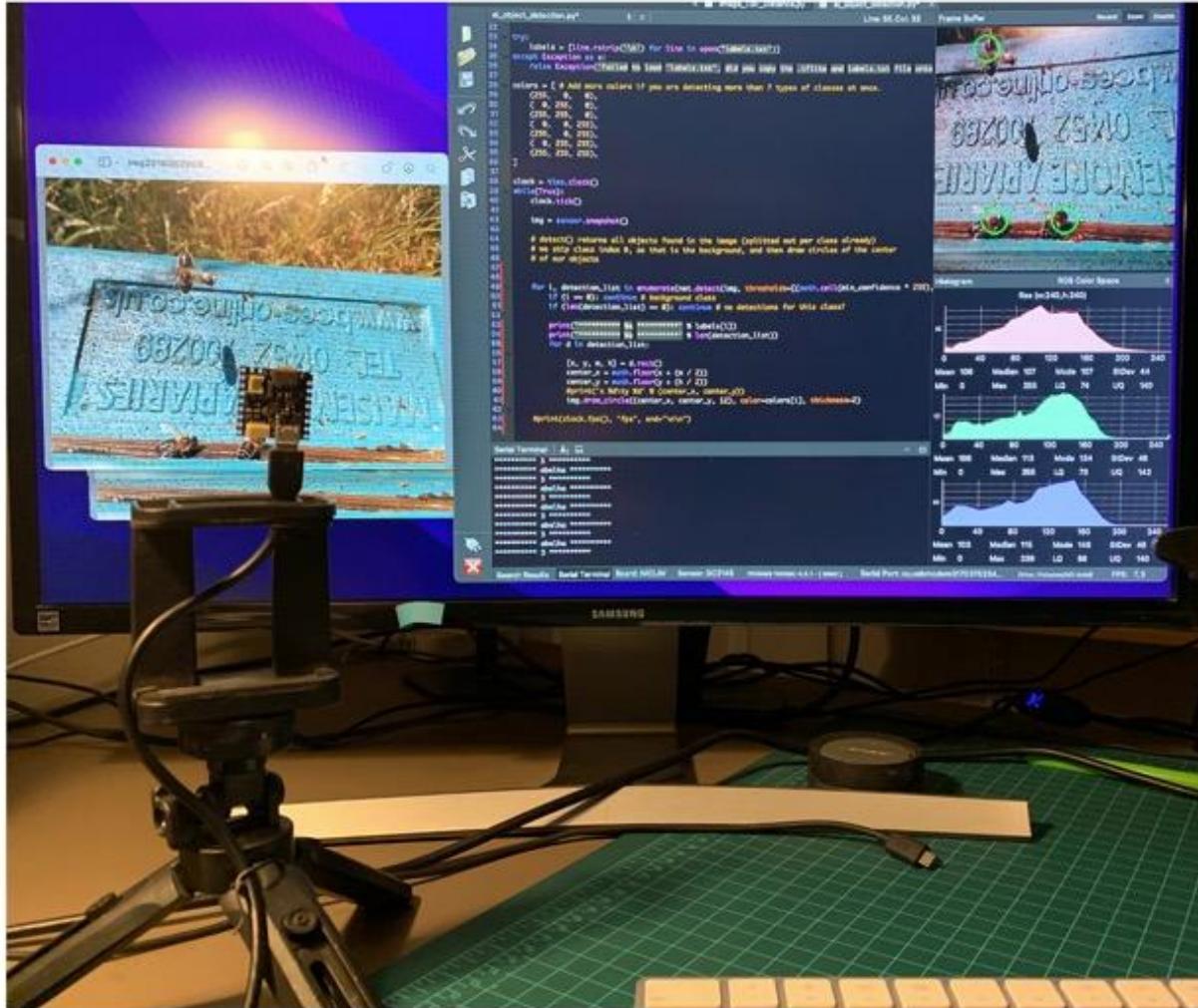
# Detecting Objects using TinyML (FOMO)



```
***** espcam *****
x 70  y 150
x 130  y 170
*****
***** nano *****
x 70  y 110
*****
***** pico *****
x 150  y 30
*****
***** wio *****
x 50  y 50
*****
***** xiao *****
x 150  y 110
x 130  y 130
6.97512 fps
```

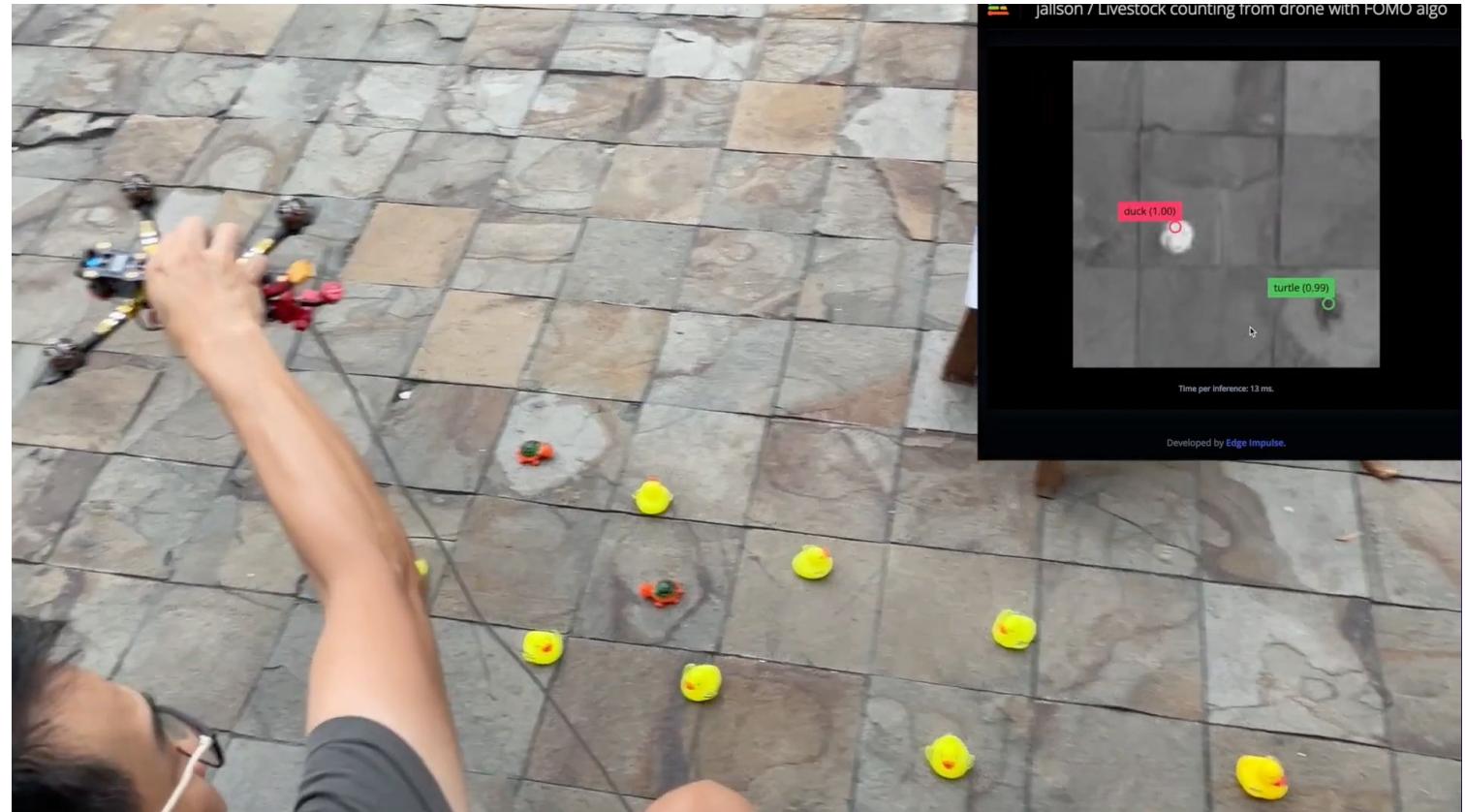
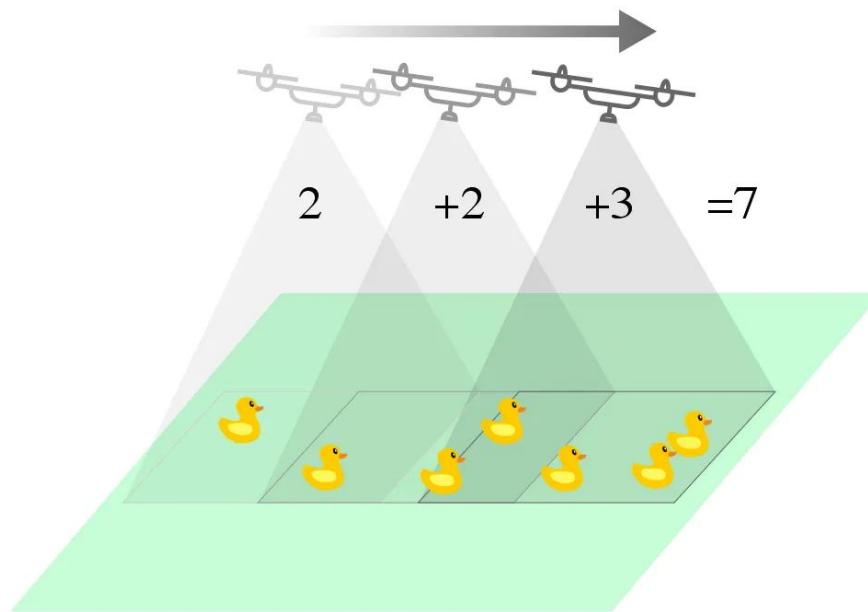
[EdgeAI made simple - Exploring Image Processing \(Object Detection\) on microcontrollers with Arduino Portenta, Edge Impulse FOMO, and OpenMV](#)

# Detecting Objects using TinyML (FOMO)



<https://youtu.be/MYuc3QISquw>

# Livestock / Wildlife Counting from Drone with FOMO



<https://www.hackster.io/jallsonsuryo/livestock-wildlife-counting-from-drone-with-fomo-algorithm-a2f734>

# To learn more about Edge AI

- 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
- "TinyML Cookbook" by Gian Marco Iodice
- "AI at the Edge" book by Daniel Situnayake, Jenny Plunkett

# Thanks

