

# SciTinyML - ICTP workshop

## Scientific Use of Machine Learning on Low Power Devices

### Setting up the software tools

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*Prof. Marcelo José Rovai*

*UNIFEI - Universidade Federal de Itajubá, Brazil*

*Web: <https://github.com/Mjrovai>*



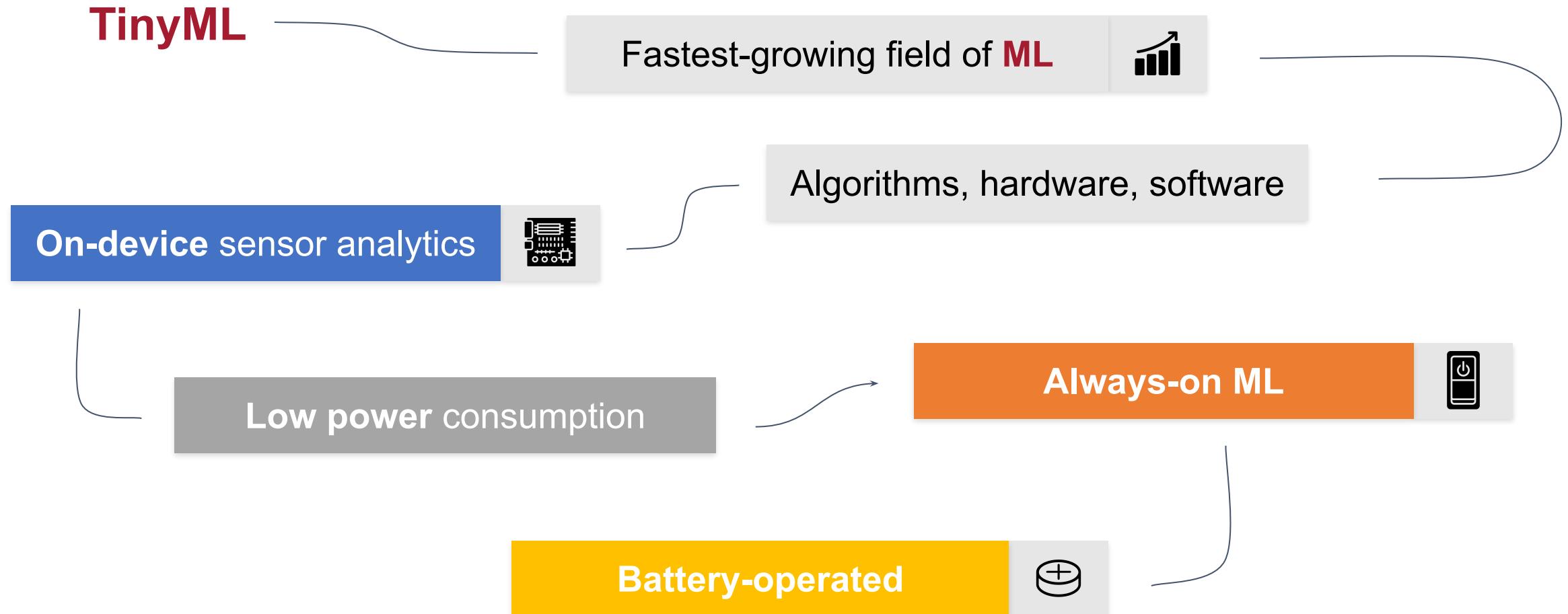
# Who I am

- Brazilian from São Paulo, **Data Science Master's degree by UDD, Chile**, and MBA by IBMEC (INSPER), Brazil.
- Graduated in 1982 as an **Engineer from UNIFEI** with Specialization from Poli/USP, both in Brazil.
- Worked as a **teacher, engineer, and executive** in several technology companies such as CDT/ETEP, AVIBRAS Aeroespacial, SID Informática, ATT-GIS, NCR, DELL, COMPAQ (HP), and more recently at IGT, where I continue as a Senior Advisor for Latin America.
- **Write about electronics**, publishing my works in sites as MJRoBot.org (Editor/Writer), Hackster.io (#1 Contributor), Instructables.com, and Medium.com (TDS – Towards Data Science).
- **Volunteer Professor** at UNIFEI Engineering Institute: “Machine Learning applied to Embedded Devices” course (IESTI01).
- Active member of the **TinyML4D group**, an initiative to bring TinyML education to developing countries.

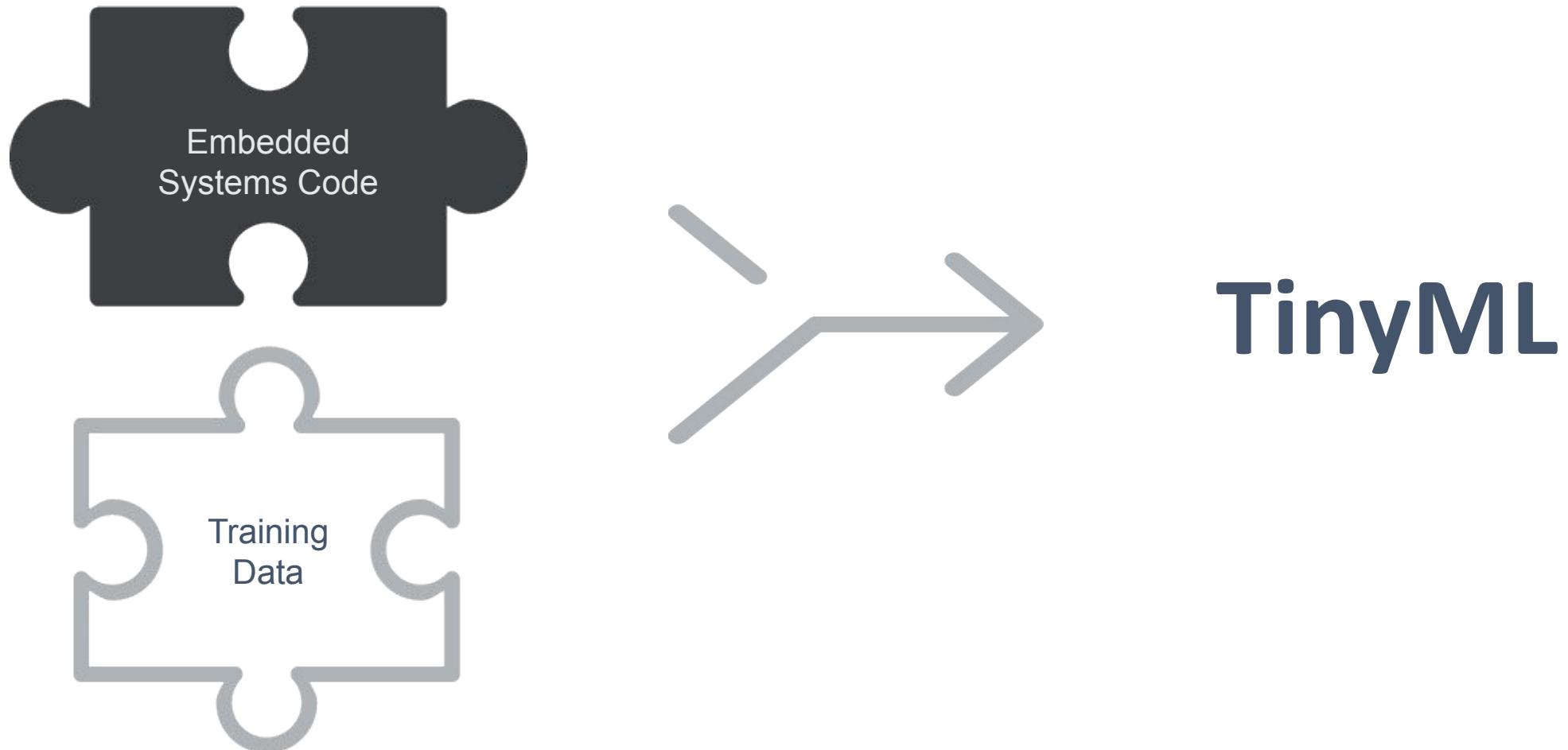


**Marcelo Rovai**

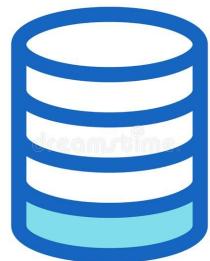
# What is Tiny Machine Learning (**TinyML**)?



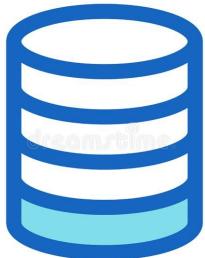
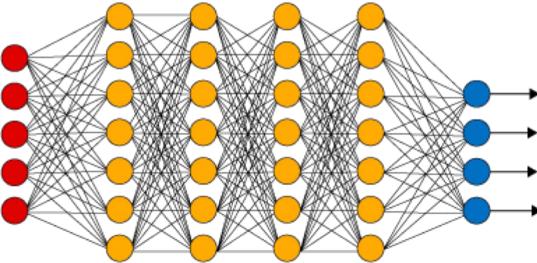
# What Makes **TinyML**?



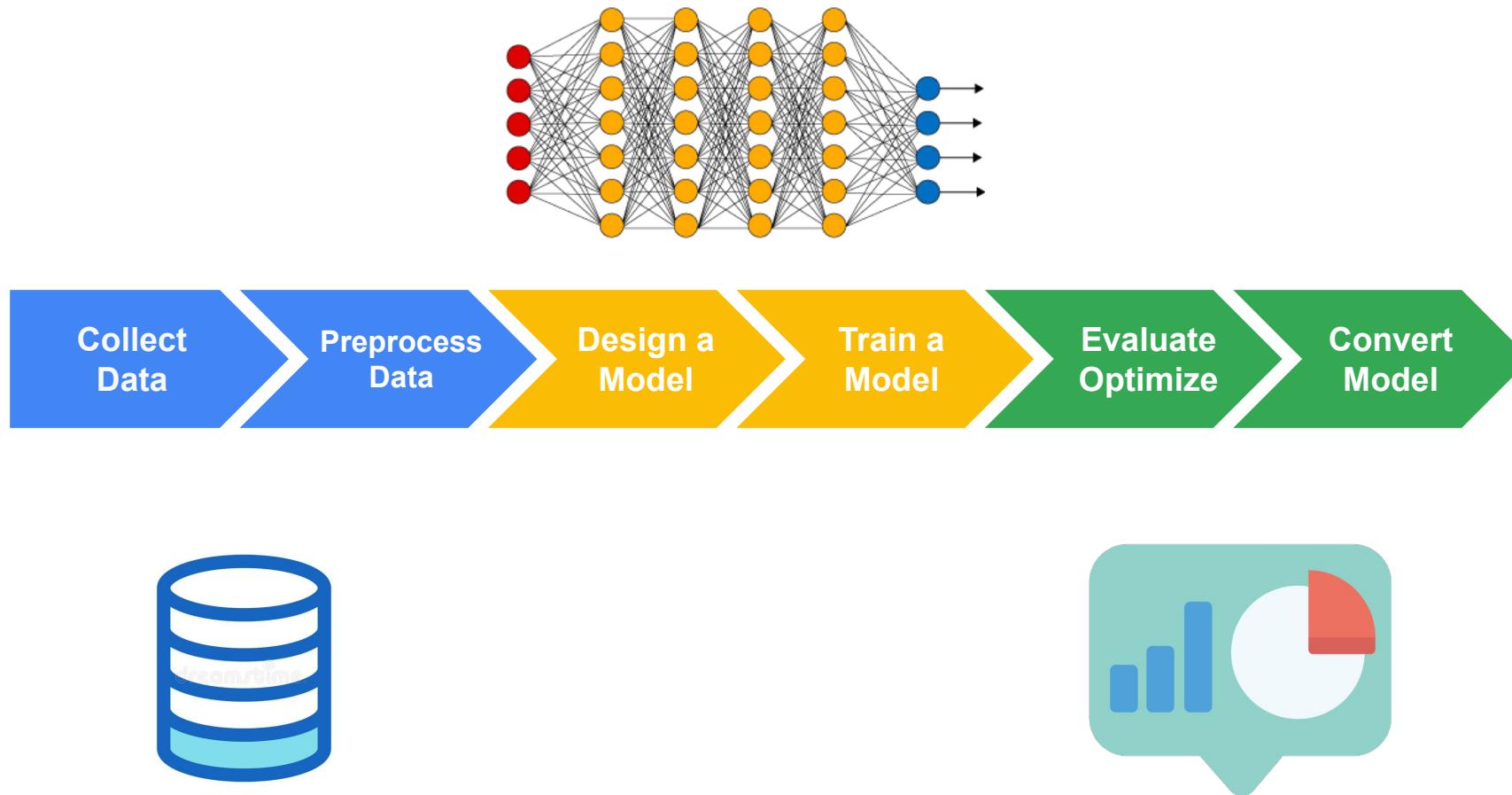
# Machine Learning Workflow



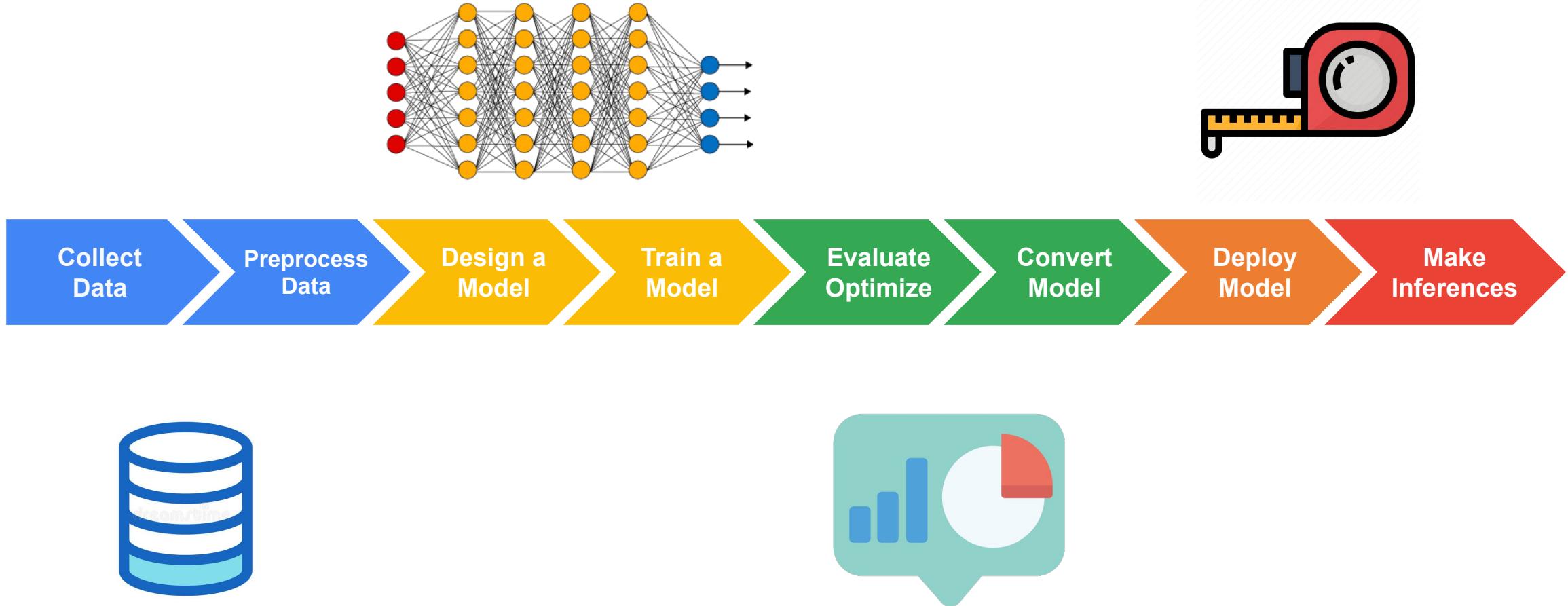
# Machine Learning Workflow



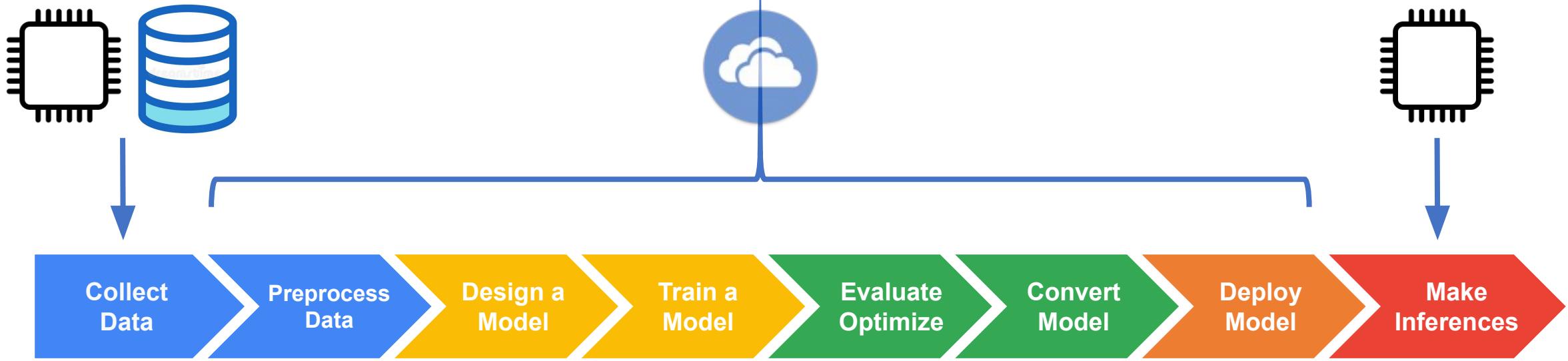
# Machine Learning Workflow



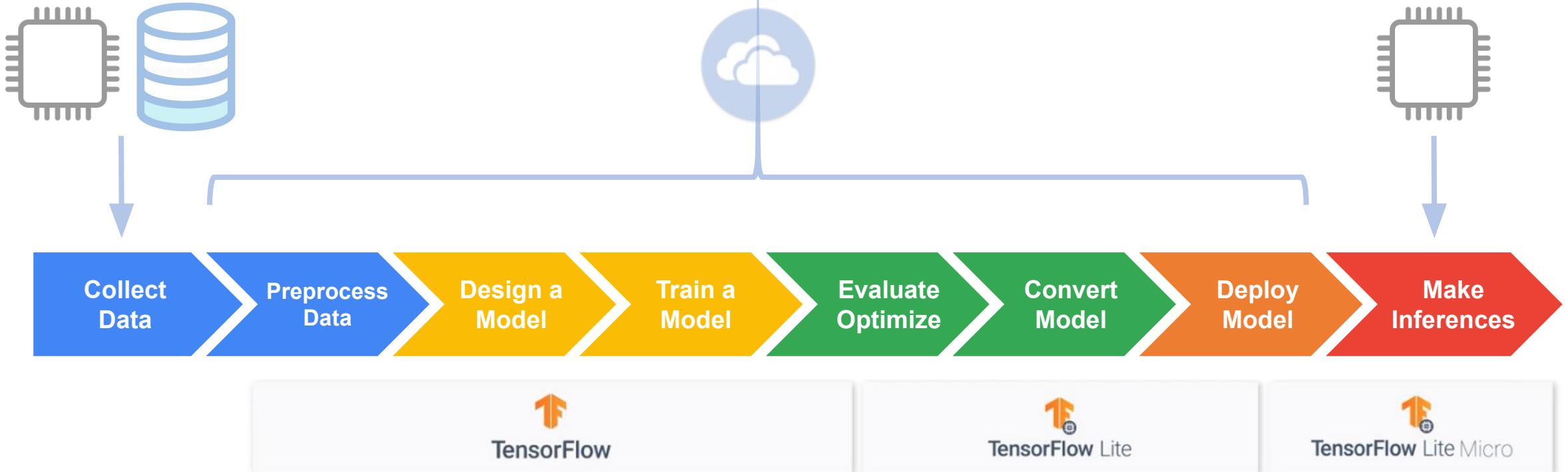
# Machine Learning Workflow (“What”)



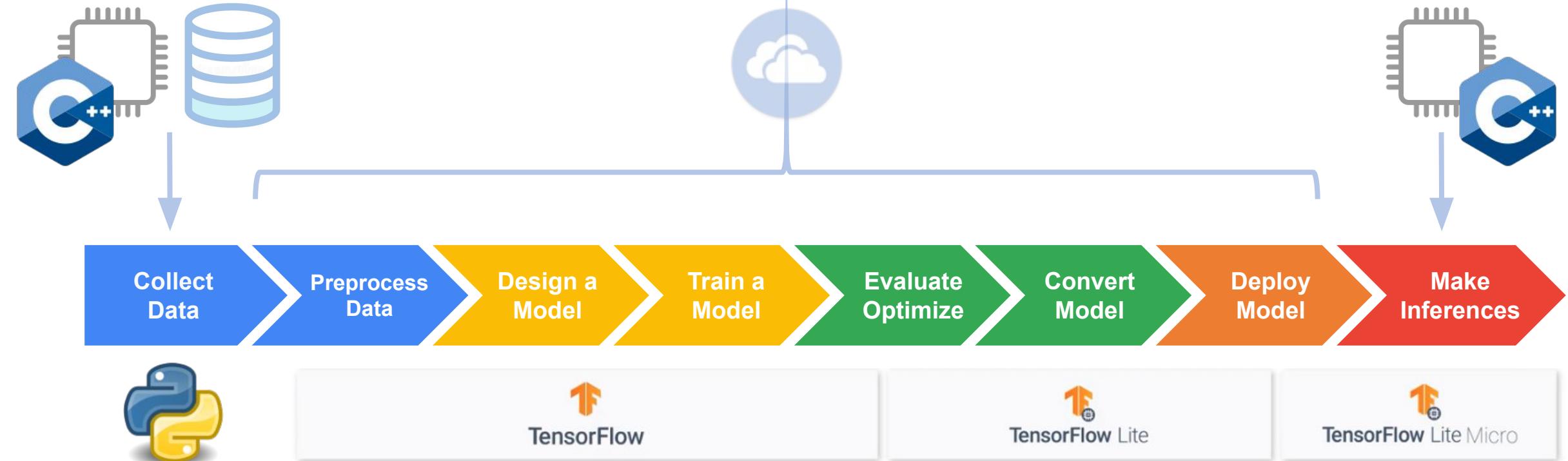
# Machine Learning Workflow (“Where”)



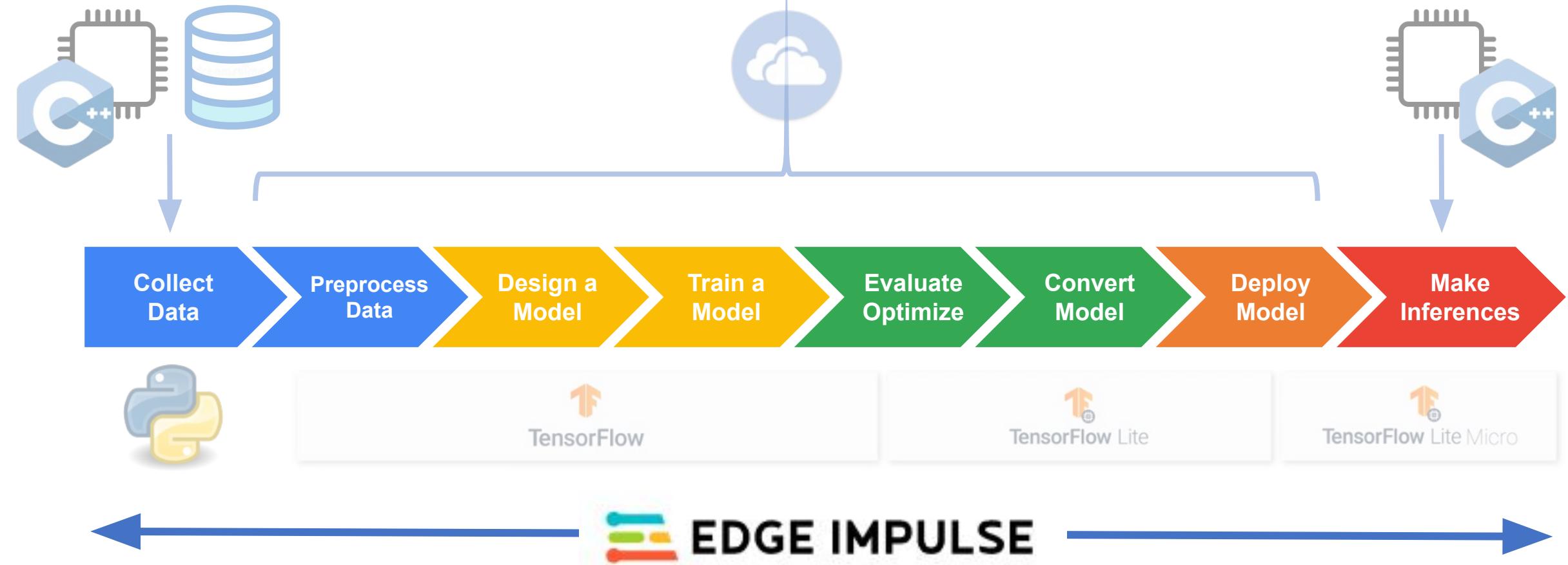
# Machine Learning Workflow (“How”)



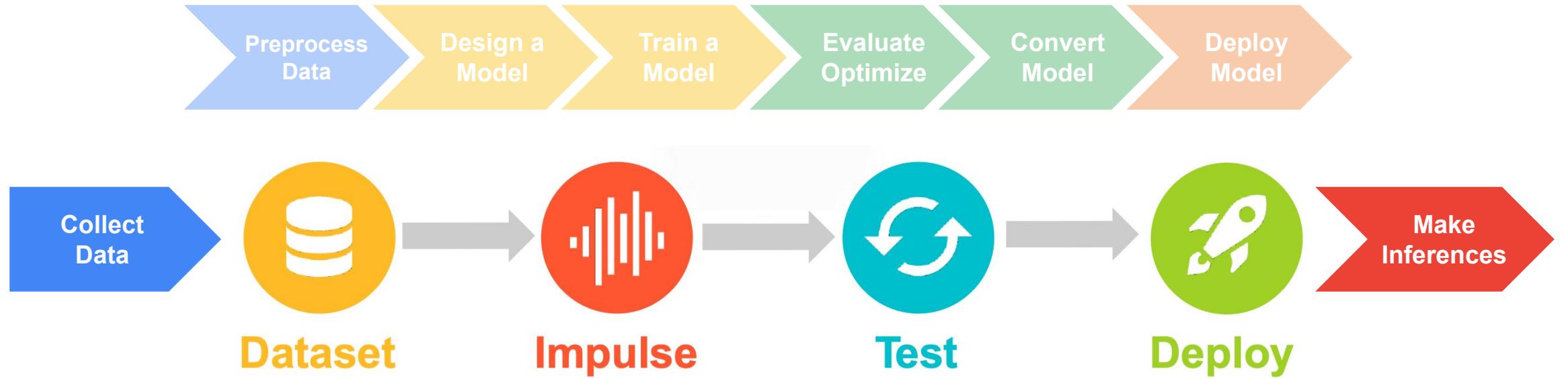
# Machine Learning Workflow (“How”)

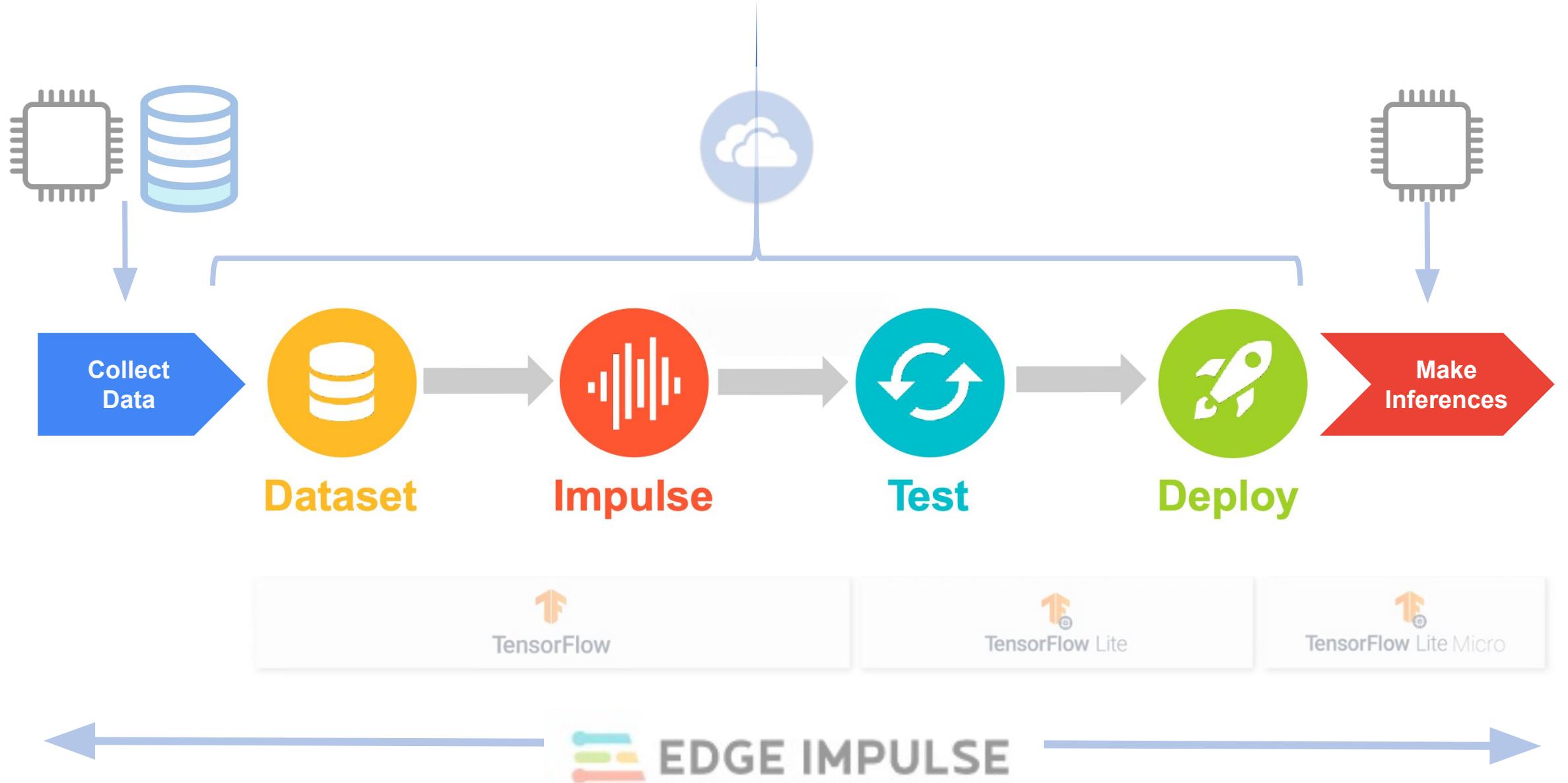


# Machine Learning Workflow (“How”)

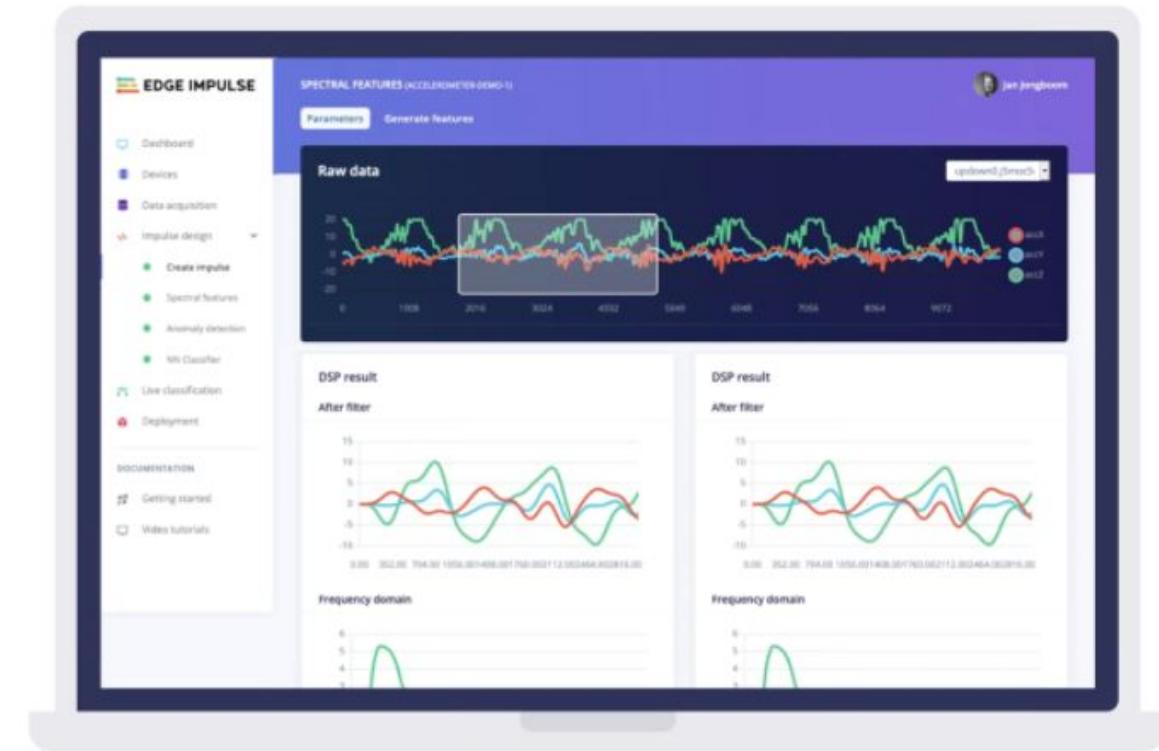
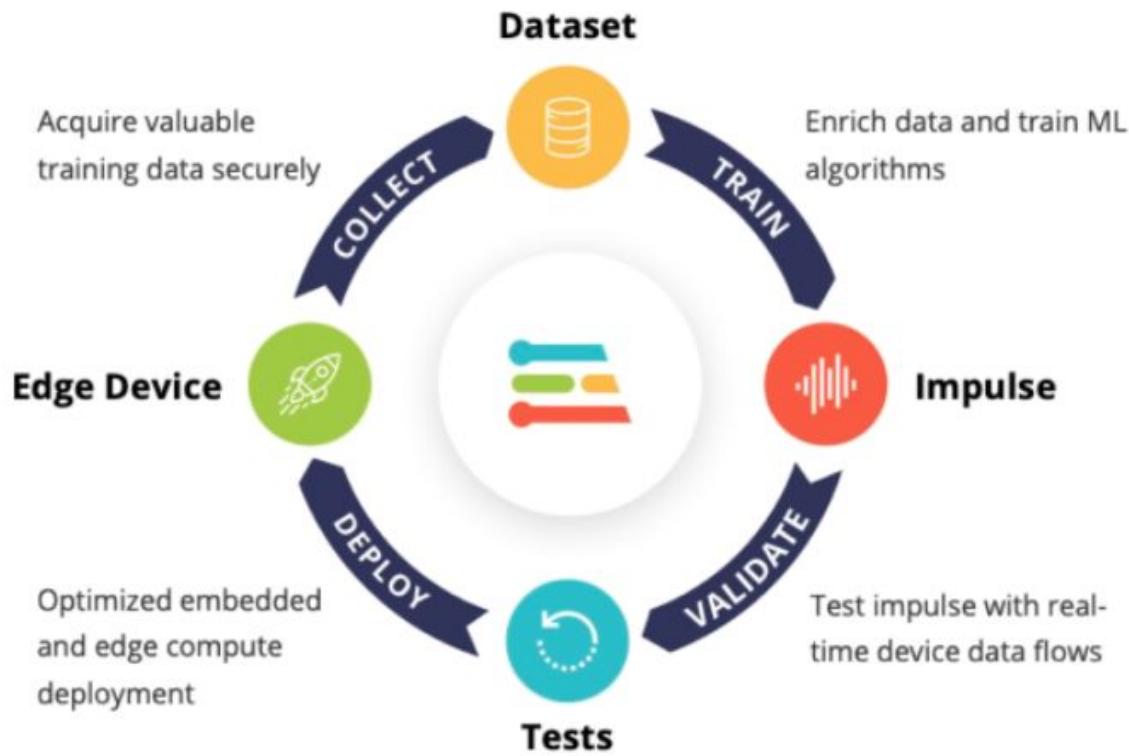








# EI Studio - Embedded ML platform



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Join the biggest embedded ML event of the year, Imagine 2021. Register now for free! >

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# Making things smarter

Edge Impulse is the leading development platform for machine learning on edge devices, free for developers and trusted by enterprises.

Name

Email

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CONSERVATION  
Elephant Activity

ELEPHANT  
**Human Proximity Confirmed**

Trusted by thousands of embedded developers running critical machine learning projects across millions of data samples.

**ML PROJECTS**  
▲ 39,151

Jan 2020 Today

**DATA SAMPLES**  
▲ 45.53 M

Jan 2020 Today

**CLOUD JOBS**  
▲ 1.12 M

Jan 2020 Today

**EDGE IMPULSE**

**Sign up**

Marcelo Rovai

mjrovai

rovai@unifei.edu.br

.....

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

**Sign up**

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

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

Sign up succeeded - Edge Impulse

studio.edgeimpulse.com/studio/signup-success

 EDGE IMPULSE

**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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Dashboard - rovai-project-1 - E X +

studio.edgeimpulse.com/studio/49268

EDGE IMPULSE

Project info Keys Export

Marcelo Rovai

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

This is your first project! You can add multiple models.

Welcome to your new Edge Impulse project!

You're ready to add real intelligence to your edge devices. Let's set up your project. What type of data are you dealing with?

Accelerometer data

Analyze movement of your device in real-time to predict machine failure, detect human gestures, or monitor rotating machines.

Audio

Listen to what's happening around you to create voice interfaces, listen to keywords, detect audible events, or to hear what's happening around your device.

Images

Add sight to your sensors with image classification or object detection - to detect humans and animals, monitor production lines or track objects.

Something else

Different sensor? No problem! You can collect and import data from any sensor, from environmental sensors to radars - and deploy your trained model back to virtually any device.

I know what I'm doing, hide this wizard!

Deploy

Package the complete impulse up, from signal processing code to trained model, and deploy it on your device. This ensures that the impulse runs with low latency and without requiring a network connection.

Your project is private.

Make this project public

Summary

DEVICES CONNECTED 0

DATA COLLECTED -

Collaborators

Marcelo Rovai OWNER



Dashboard - rovai-project-1 - E X +

studio.edgeimpulse.com/studio/49268

EDGE IMPULSE

Project info Keys Export

Marcelo Rovai

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

This is your first project! You can use it to train models.

Welcome to your new Edge Impulse project!

Great! Here's how you get started with accelerometer data:

**Connect a development board**

Get started with real hardware from Nordic, Arduino, OpenMV, ST, Eta Compute, Himax and SiLabs, or connect any development board with the Data Forwarder.

**Connect your development board**

**Tutorial: continuous motion recognition**

Follow our end-to-end tutorial to collect accelerometer data, train a model, and deploy it back to your device to analyze movement in realtime.

**Read the tutorial**

I know what I'm doing, hide this wizard!

**Let's get started!**

Deploy

Package the complete impulse up, from signal processing code to trained model, and deploy it on your device. This ensures that the impulse runs with low latency and without requiring a network connection.

DEVICES CONNECTED 0

DATA COLLECTED -

Collaborators

Marcelo Rovai OWNER



Dashboard - rovai-project-1 - E X +

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EDGE IMPULSE

Project info Keys Export

Marcelo Rovai

# Marcelo Rovai / rovai-project-1

This is your Edge Impulse project. From here you acquire new training data, design impulses and train models.

Creating your first impulse (0% complete)

Acquire data

Every Machine Learning project starts with data. You can capture data from a development board or your phone, or import data you already collected.

LET'S COLLECT SOME DATA

Design an impulse

Teach the model to interpret previously unseen data, based on historical data. Use this to categorize new data, or to find anomalies in sensor readings.

GETTING STARTED: CONTINUOUS MOTION RECOGNITION

GETTING STARTED: RESPONDING TO YOUR VOICE

GETTING STARTED: ADDING SIGHT TO YOUR SENSORS

Deploy

Package the complete impulse up, from signal processing code to trained model, and deploy it on your device. This ensures that the impulse runs with low latency and without requiring a network connection.

Sharing

Your project is private.

Make this project public

Summary

DEVICES CONNECTED 0

DATA COLLECTED -

Collaborators

Marcelo Rovai OWNER



<https://studio.edgeimpulse.com/studio/49268#>

Dashboard - rovai-project-1 - E X +

studio.edgeimpulse.com/studio/49268

EDGE IMPULSE

Project info Keys Export

Marcelo Rovai

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

Creating your first impulse

Acquire data Every Machine Learning model needs training data. Use this to collect data from a development board or mobile device.

LET'S COLLECT SOME DATA

Design an impulse Teach the model to identify different types of motion based on sensor readings. Use this to categorize continuous motion recognition.

GETTING STARTED: CONTINUOUS MOTION RECOGNITION

GETTING STARTED: RESPONDING TO YOUR VOICE

GETTING STARTED: ADDING SIGHT TO YOUR SENSORS

Deploy Package the complete impulse up, from signal processing code to trained model, and deploy it on your device. This ensures that the impulse runs with low latency and without requiring a network connection.

New project name

Enter new name for project "rovai-project-1"

TinyML4D - Project Setup

Cancel Change project name

Sharing

Your project is private.

Make this project public

Summary

DEVICES CONNECTED 0

DATA COLLECTED -

Collaborators

Marcelo Rovai OWNER

A yellow arrow points to the 'Change project name' button in the modal dialog.

The screenshot shows the Edge Impulse Studio interface for a project titled "Marcelo Rovai / TinyML4D - Project Setup".

**Left Sidebar:**

- Dashboard:** Indicated by a yellow arrow pointing to it.
- Devices
- Data acquisition
- Impulse design
  - Create impulse
- Retrain model
- Live classification
- Model testing
- Versioning
- Deployment

**GETTING STARTED**

- Documentation
- Forums

**Central Area:**

## Creating your first impulse (0% complete)

**Acquire data**  
Every Machine Learning project starts with data. You can capture data from a development board or your phone, or import data you already collected.  
[LET'S COLLECT SOME DATA](#)

**Design an impulse**  
Teach the model to interpret previously unseen data, based on historical data. Use this to categorize new data, or to find anomalies in sensor readings.  
[GETTING STARTED: CONTINUOUS MOTION RECOGNITION](#)  
[GETTING STARTED: RESPONDING TO YOUR VOICE](#)  
[GETTING STARTED: ADDING SIGHT TO YOUR SENSORS](#)

**Deploy**  
Package the complete impulse up, from signal processing code to trained model, and deploy it on your device. This ensures that the impulse runs with low latency and without requiring a network connection.

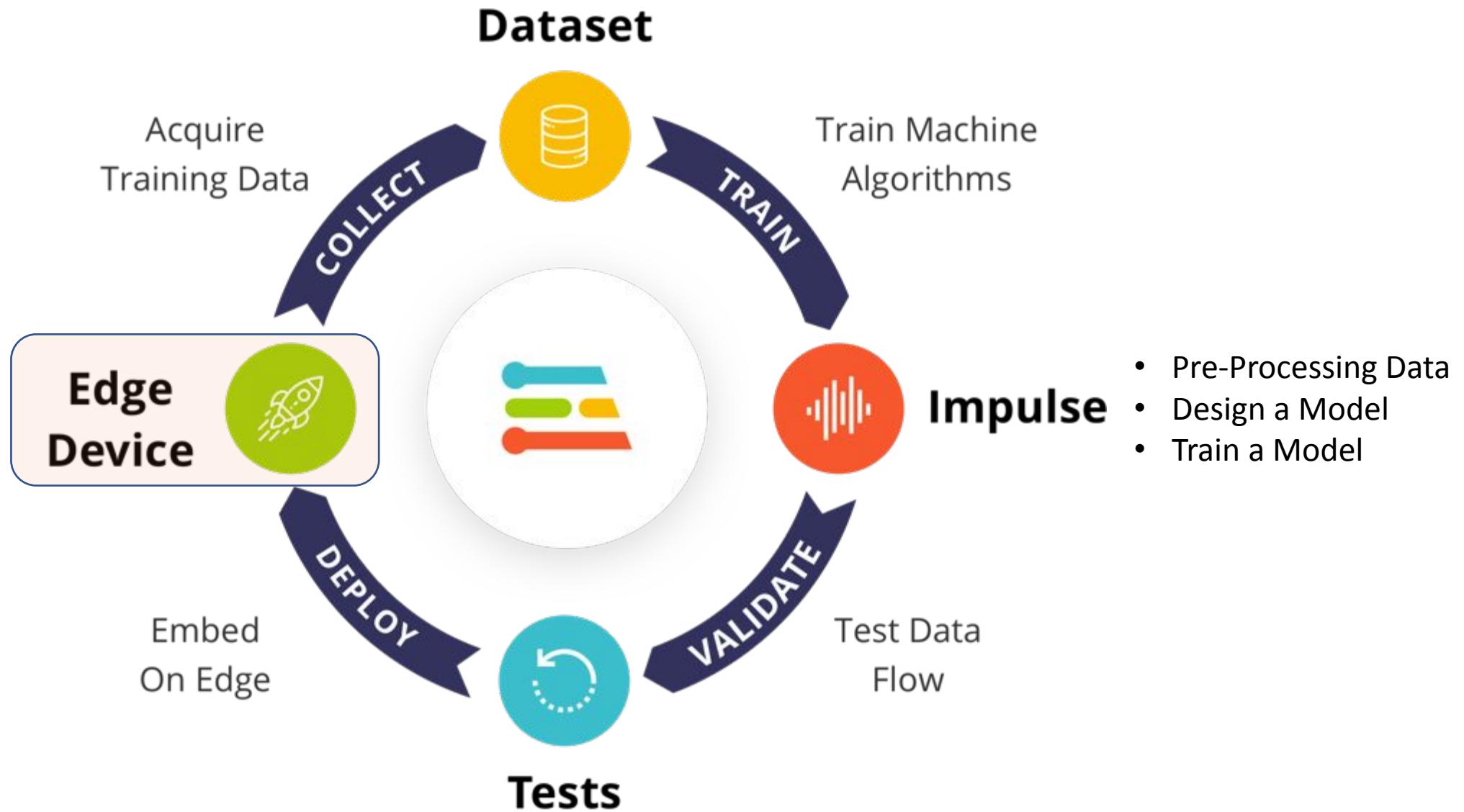
**Sharing**  
Your project is private.  
[Make this project public](#)

**Summary**

- DEVICES CONNECTED: 0
- DATA COLLECTED: -

**Collaborators**

Marcelo Rovai OWNER

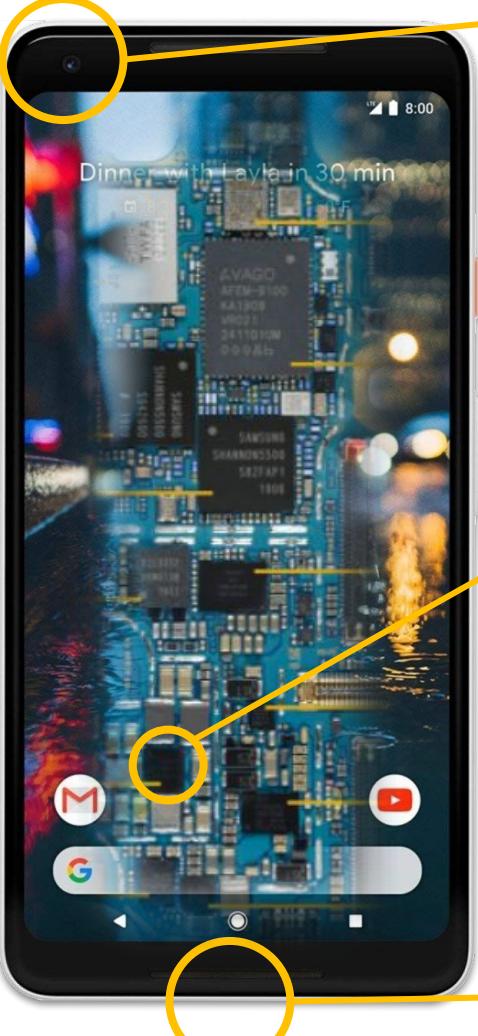


The screenshot shows the Edge Impulse studio interface, specifically the 'Devices' page for a project titled 'TinyML4D - Project'. The left sidebar contains navigation links for Dashboard, Devices (which is currently selected and highlighted with a dashed orange border), Data acquisition, Impulse design, Create impulse, Retrain model, Live classification, Model testing, Versioning, Deployment, Documentation, and Forums. The main content area is titled 'DEVICES (TINYML4D - PROJECT SETUP)' and features a section titled 'Your devices' with the sub-instruction: 'These are devices that are connected to the Edge Impulse remote management API, or have posted data to the ingestion SDK.' Below this, it states 'No devices connected yet.' A green button labeled 'Learn how to connect a new device' with a gear icon is present. In the top right corner, there is a user profile for 'Marcelo Roval' and a yellow arrow points to a blue button labeled '+ Connect a new device' located in a red dashed box. At the bottom left, a copyright notice reads '© 2021 EdgeImpulse Inc. All rights reserved.'

# Edge Device



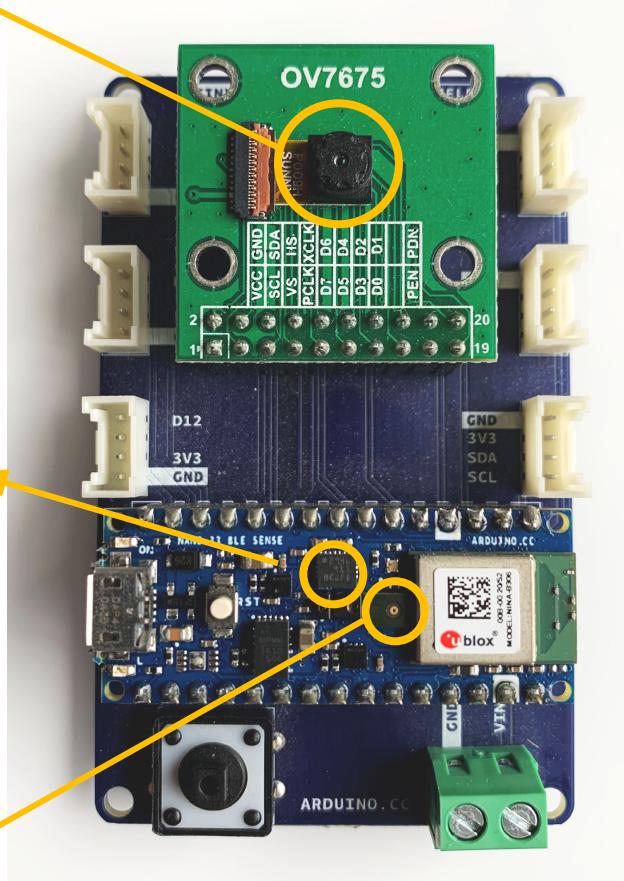
& Sensors

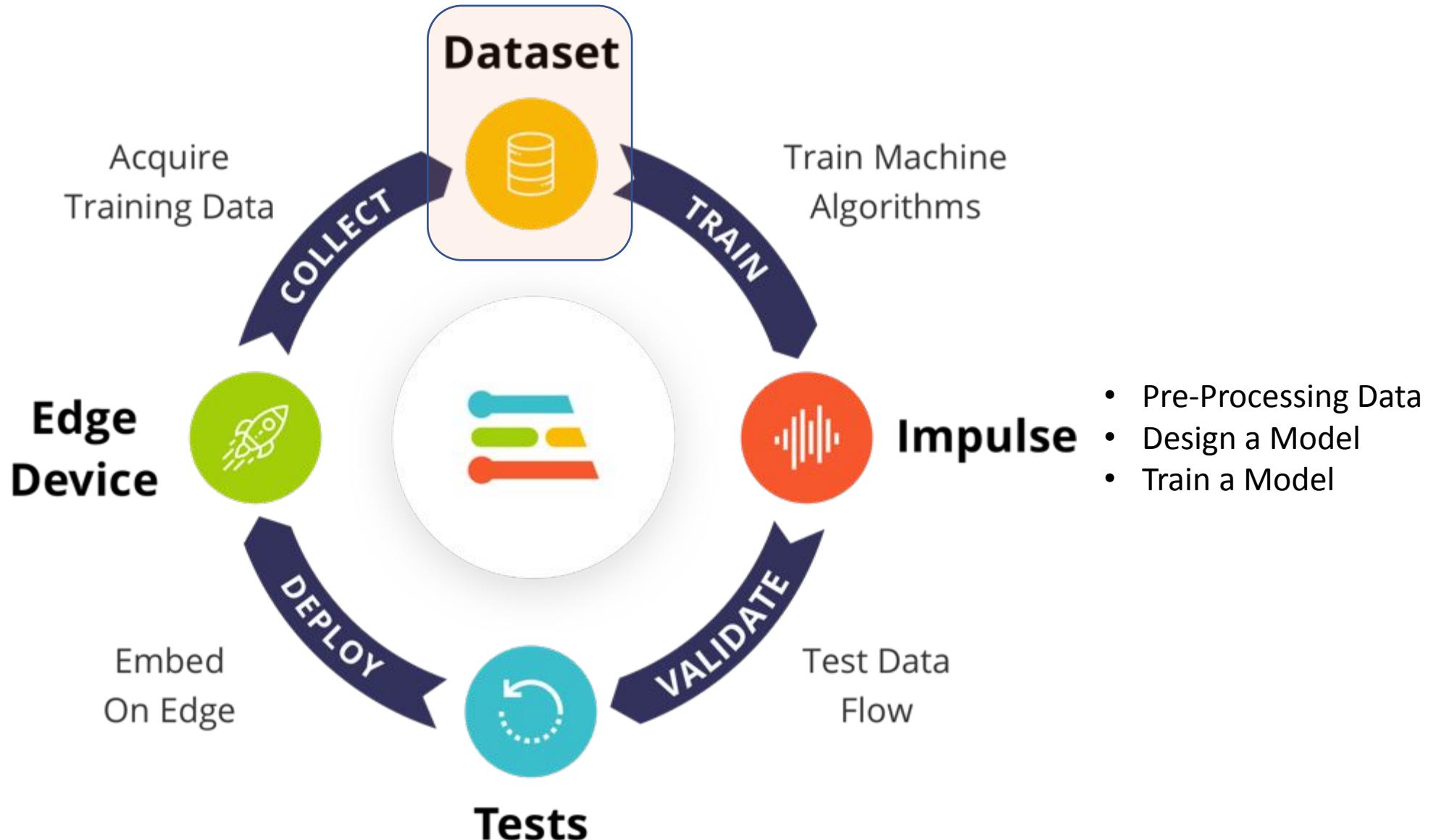


Camera



Microphone





# Gesture Classification

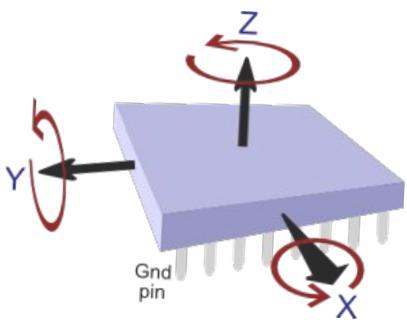
- Manual gestures (“labels”):
  - up-down
  - left-right
  - circle
  - idle



# Gesture Classification

- Manual gestures (“labels”):

- up-down
- left-right
- circle
- idle



- Data: collect & test using accelerometer as sensor



Devices - TinyML4D - Project

studio.edgeimpulse.com/studio/49268/devices

EDGE IMPULSE

Dashboard

Devices

Data acquisition

Impulse design

Create impulse

Retrain model

Live classification

Model testing

Versioning

Deployment

GETTING STARTED

Documentation

Forums

DEVICES (TINYML4D - PROJECT SETUP)

Your projects

Collect data

These are the ways you can collect data:

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

**Connect a fully supported development board**

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

**Show QR code**

**Use your mobile phone**

Use your mobile phone to capture movement, audio or images, and even run your trained model locally. No app required.

**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

Marcelo Rovai

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A yellow arrow points to the 'Show QR code' button in the 'Use your mobile phone' section of the 'Collect data' modal.

Devices - TinyML4D - Project

studio.edgeimpulse.com/studio/49268/devices

EDGE IMPULSE

DEVICES (TINYML4D - PROJECT SETUP)

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.

Collect data

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



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Devices

Dashboard

Data acquisition

Impulse design

Create impulse

Retrain model

Live classification

Model testing

Versioning

Deployment

GETTING STARTED

Documentation

Forums

Marcelo Rovai

WEBSITE QR CODE  
Open "edgeimpulse.com" in Safari



Devices - TinyML4D - Project

studio.edgeimpulse.com/studio/49268/devices

EDGE IMPULSE

Devices

Your devices

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, Microphone	...	Today, 12:06:04

+ Connect a new device

Collect data

Device phone\_kq6ray4k is now connected

Get started!

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Camera 12:07 22% smartphone.edgeimpulse.com

Data collection

Connected as phone\_kq6ray4k

You can collect data from this

A large yellow arrow points upwards towards the 'Get started!' button in the 'Collect data' modal.

Devices - TinyML4D - Project

studio.edgeimpulse.com/studio/49268/devices

EDGE IMPULSE

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

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Dashboard

Devices (highlighted with orange dashed box)

Data acquisition

Impulse design

- Create impulse

Retrain model

Live classification

Model testing

Versioning

Deployment

GETTING STARTED

Documentation

Forums

Camera 12:07 22%

smartphone.edgeimpulse.com

Data collection

Connected as phone\_kq6ray4k

You can collect data from this



DATA ACQUISITION (TINYML4D - PROJECT SETUP)

Training data Test data

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

DATA COLLECTED -

LABELS 0

Record new data

Device ⓘ No devices connected

Label up\_down

Sensor

RAW DATA Click on a sample to load...

Connect using WebUSB

12:20 44% smartphone.edgeimpulse.com

Data collection

Not connected

Refresh this page to reconnect to Edge Impulse

The screenshot shows the Edge Impulse Data Acquisition interface for the TinyML4D project. On the left sidebar, 'Data acquisition' is selected. The main area displays a message about capturing data from devices or uploading datasets. Below this, a 'Collected data' section shows 'No data collected yet' and a 'Let's collect some data' button. To the right, a 'Record new data' form is open, showing a 'Device' dropdown set to 'No devices connected'. The 'Label' field contains 'up\_down' and the 'Sensor' dropdown is empty. At the bottom, a dark blue bar says 'Click on a sample to load...'. A large orange 'X' icon and the text 'Not connected' are prominently displayed on the right side. The top right corner shows a user profile for Marcelo Rovai and a system status bar with time (12:20), battery (44%), and a connection to smartphone.edgeimpulse.com.

**Collect Data**

EDGE IMPULSE

DATA ACQUISITION (TINYML4D - PROJECT SETUP)

Training data Test data

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

DATA COLLECTED -

LABELS 0

Collected data

No data collected yet

Let's collect some data

Record new data

Device ? phone\_kq6ray4k

Label up\_down

Sample length (ms.) 10000

Sensor Accelerometer

Frequency 62.5Hz

Start sampling

RAW DATA

Click on a sample to load...

Marcelo Rovai

Dashboard

Devices

Data acquisition

Impulse design

Create impulse

Retrain model

Live classification

Model testing

Versioning

Deployment

GETTING STARTED

Documentation

Forums

**Collect Data**

The screenshot shows the Edge Impulse Data Acquisition interface. On the left, a sidebar menu includes options like Dashboard, Devices, Data acquisition (highlighted with a blue arrow), and Create impulse. The main area is titled "DATA ACQUISITION (TINYML4D - PROJECT SETUP)" and shows tabs for "Training data" and "Test data". A "Did you know?" message suggests capturing data from any device or development board. The "DATA COLLECTED" section shows a red "Record" button and a "LABELS 0" count. Below this is a large image of a hand holding a smartphone connected to a laptop via USB. The laptop screen displays the Edge Impulse software interface. To the right, the "Record new data" section allows setting a device (set to "phone\_kq6ray4k"), label ("up\_down"), sample length (10000 ms), sensor (Accelerometer at 62.5Hz), and frequency (62.5Hz). A "Sampling... (6s left)" button is active. At the bottom, a "RAW DATA" section says "Click on a sample to load..." and features a circular progress bar with segments labeled 4s, 4s, and 4s.

EDGE IMPULSE

DATA ACQUISITION (TINYML4D - PROJECT SETUP)

Training data Test data

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

DATA COLLECTED

LABELS 0

Record new data

Device ?

phone\_kq6ray4k

Label

up\_down

Sample length (ms.)

10000

Sensor

Accelerometer

Frequency

62.5Hz

Sampling... (6s left)

RAW DATA

Click on a sample to load...

4s

4s

4s

Recording data

**Collect Data**

Data acquisition - TinyML4D - [+](#)

studio.edgeimpulse.com/studio/49268/acquisition/training?page=1

**EDGE IMPULSE**

[Training data](#) [Test data](#)

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

**DATA COLLECTED**  
10s

**LABELS**  
1

**Collected data**

SAMPLE NAME	LABEL	ADDED	LENGTH
up_down.2gbe7ljv	up_down	Today, 12:36:16	10s

**Record new data** [Connect using WebUSB](#)

**Device** [?](#)  
phone\_kq6ray4k

**Label** up\_down **Sample length (ms.)** 10000

**Sensor** Accelerometer **Frequency** 62.5Hz

**Start sampling**

**RAW DATA**  
**up\_down.2gbe7ljv**

The graph displays three data series: accX (red), accY (green), and accZ (blue). The x-axis represents time points from 0 to 9165. The y-axis ranges from -20 to 20. The accY series shows the most significant fluctuations, while accX and accZ are relatively stable around zero.

accX accY accZ

**Collect Data**

The screenshot shows the Edge Impulse web studio interface for data acquisition. On the left, a blue sidebar menu titled "Collect Data" lists various project management and documentation options. The main content area displays a summary of collected data: "DATA COLLECTED 6m 23s" and "LABELS 4". Below this is a table titled "Collected data" listing 15 samples, each with a name, label, added date, length, and a three-dot menu icon. A yellow arrow points from the "Test data" button at the top to the "Did you know?" message. Another yellow arrow points from the "Did you know?" message to the "Record new data" section.

Data acquisition - TinyML4D - X Data acquisition - TinyML4D - X +

studio.edgeimpulse.com/studio/49283/acquisition/training?page=1

**EDGE IMPULSE**

Training data Test data

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

DATA COLLECTED  
6m 23s

LABELS  
4

Collected data

SAMPLE NAME	LABEL	ADDED	LENGTH
idle.2gbr2djm	idle	Today, 16:20:35	10s
idle.287udis0	idle	Jun 16 2021, 16:56...	10s
circle.287uco09	circle	Jun 16 2021, 16:56...	10s
up_down.287ubs0k	up_down	Jun 16 2021, 16:55...	10s
up_down.287ub4l7	up_down	Jun 16 2021, 16:55...	0s
left_right.287u9k1o	left_right	Jun 16 2021, 16:54...	10s
left_right.287u7iqd	left_right	Jun 16 2021, 16:53...	10s
idle.285d4180	idle	Jun 15 2021, 17:15...	10s
idle.285d3fb6	idle	Jun 15 2021, 17:15...	10s
idle.285d2sbr	idle	Jun 15 2021, 17:15...	10s
idle.285d28r0	idle	Jun 15 2021, 17:14...	10s
idle.285d1mbb	idle	Jun 15 2021, 17:14...	10s

Record new data

Connect using WebUSB

No devices connected to the remote management API.

RAW DATA

Click on a sample to load...

**EDGE IMPULSE**

DATA ACQUISITION - TESTING (TINYML4D - PROJECT SETUP - GESTURE CLASSIFICATION)

Training data Test data

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

DATA COLLECTED 1m 40s

LABELS 4

Collected data

SAMPLE NAME	LABEL	ADDED	LENGTH
testing.28800fpm	up_down	Jun 16 2021, 17:24:23	9s
testing.287vv6g7	left_right	Jun 16 2021, 17:23:40	10s
testing.287vss3q	left_right	Jun 16 2021, 17:22:24	10s
testing.287vqgd1	up_down	Jun 16 2021, 17:21:07	10s
up_down.287h3nkm	up_down	Jun 16 2021, 13:04:00	10s
idle.287h2mc6	idle	Jun 16 2021, 13:03:26	10s
testing.285gma46	up_down	Jun 15 2021, 18:18:12	10s
testing.285ganlg	idle	Jun 15 2021, 18:11:52	4s
testing.285g61cg	circle	Jun 15 2021, 18:09:18	10s
testing.285g354a	left_right	Jun 15 2021, 18:07:44	10s
left-right.285fs6p7	left_right	Jun 15 2021, 18:03:56	10s

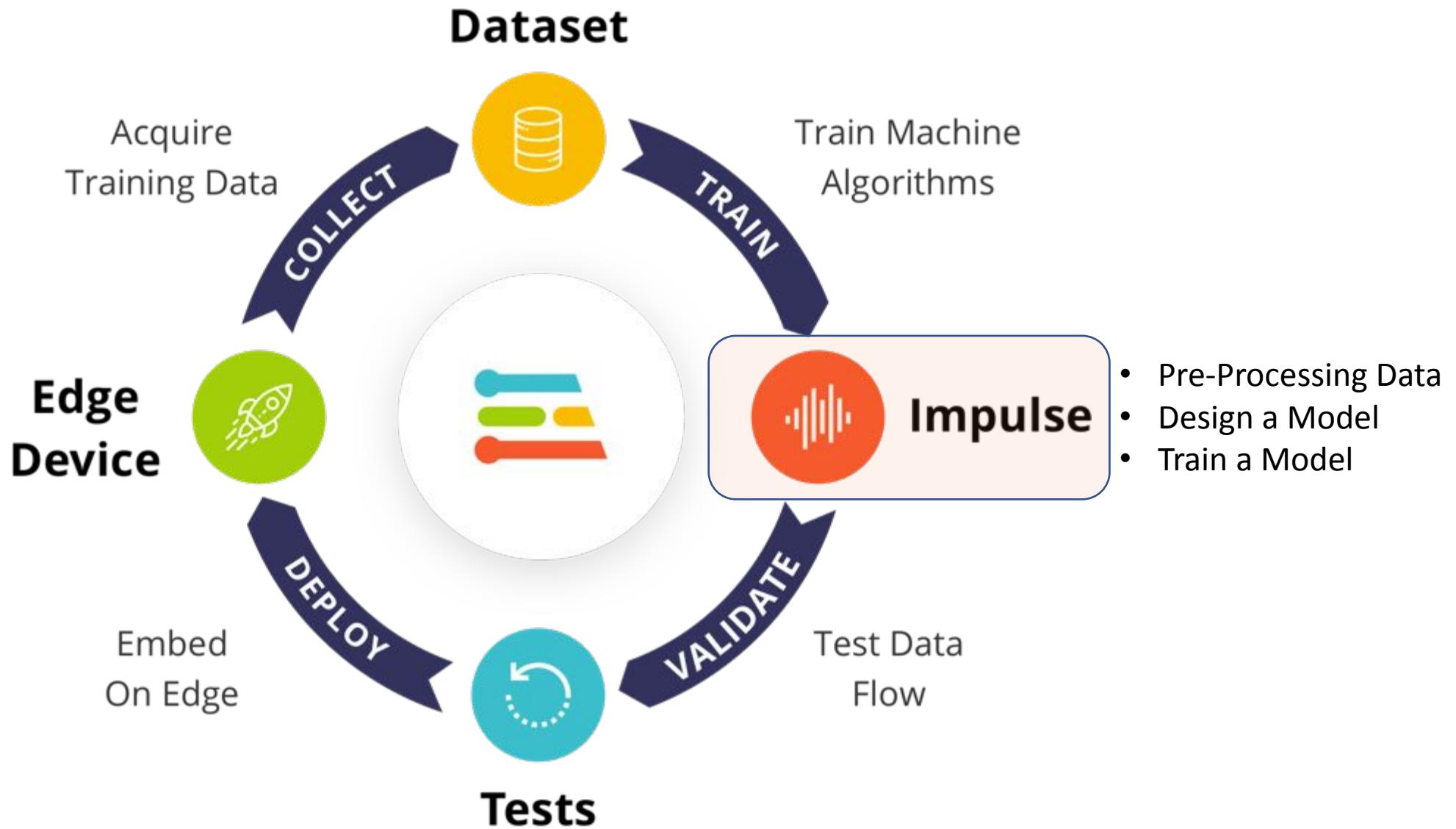
Record new data

No devices connected to the remote management API.

RAW DATA

Click on a sample to load...

Collect Data



Create impulse - TinyML4D - P X Data acquisition - TinyML4D - X + studio.edgeimpulse.com/studio/49268/create-impulse

EDGE IMPULSE

Dashboard Devices

Data acquisition

Impulse design

Create impulse

Retrain model

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CREATE IMPULSE (TINYML4D - PROJECT SETUP)

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

Time series data

Axes: accX, accY, accZ

Window size: 2000 ms.

Window increase: 80 ms.

Frequency (Hz): 62.5

Zero-pad data:

Add a processing block

Add a learning block

Output features

Save Impulse

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```
graph LR; TS[Time series data] --> APB[Add a processing block]; APB --> ALB[Add a learning block]; ALB --> OF[Output features]
```

Create impulse - TinyML4D - P X Data acquisition - TinyML4D - X + studio.edgeimpulse.com/studio/49268/create-impulse

EDGE IMPULSE

CREATE IMPULSE (TINYML4D)

An impulse template

Time series data

Axes  
accX, accY, accZ

Window size

Window increase

Frequency (Hz)  
62.5

Zero-pad data

DESCRIPTION AUTHOR RECOMMENDED

Spectral Analysis Great for analyzing repetitive motion, such as data from accelerometers. Extracts the frequency and power characteristics of a signal over time. Edgelimpulse Inc.  Add

Flatten Flatten an axis into a single value, useful for slow-moving averages like temperature data, in combination with other blocks. Edgelimpulse Inc. Add

Image Preprocess and normalize image data, and optionally reduce the color depth. Edgelimpulse Inc. Add

Audio (MFCC) Extracts features from audio signals using Mel Frequency Cepstral Coefficients, great for human voice. Edgelimpulse Inc. Add

Audio (MFE) Extracts a spectrogram from audio signals using Mel-filterbank energy features, great for non-voice audio. Edgelimpulse Inc. Add

Spectrogram Extracts a spectrogram from audio or sensor data, great for non-voice audio or data with continuous frequencies. Edgelimpulse Inc. Add

Audio (Syntiant) EXPERIMENTAL Syntiant only. Compute log Mel-filterbank energy features from an audio signal. Edgelimpulse Inc. Add

Raw Data Use data without pre-processing. Useful if you want to use deep learning to learn features. Edgelimpulse Inc. Add

Add custom block Cancel

Output features 

Save Impulse

Marcelo Rovai

CREATE IMPULSE (TINYML4D - PROJECT SETUP)

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

**Time series data**

Axes: accX, accY, accZ

Window size: 2000 ms.

Window increase: 80 ms.

Frequency (Hz): 62.5

Zero-pad data:

**Spectral Analysis**

Name: Spectral features

**Input axes**

accX  
 accY  
 accZ

Add a learning block

**Output features**

**Save Impulse**

Add a processing block

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CREATE IMPULSE (TINYML4D - PROJECT SETUP)

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

Time series data

Axes: accX, accY, accZ

Window size

Window increase

Frequency (Hz): 62.5

Zero-pad data:

Spectral Analysis

Output features

Add a learning block

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

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

Save Impulse

Cancel

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EDGE IMPULSE

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Marcelo Rovai

CREATE IMPULSE (TINYML4D - PROJECT SETUP)

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

**Time series data**

Axes: accX, accY, accZ

Window size: 2000 ms.

Window increase: 80 ms.

Frequency (Hz): 62.5

Zero-pad data:

**Spectral Analysis**

Name: Spectral features

Input axes: accX, accY, accZ

**Neural Network (Keras)**

Name: NN Classifier

Input features: Spectral features, accX, accY, accZ

Output features: 4 (circle, idle, left\_right, up\_down)

**Output features**

4 (circle, idle, left\_right, up\_down)

**Save Impulse**

Add a processing block

Add a learning block

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Marcelo Rovai

The screenshot shows the Edge Impulse studio interface for creating a project named "TINYML4D - PROJECT SETUP". The main area is titled "CREATE IMPULSE". A central text box explains that an impulse consists of raw data, signal processing, and a learning block. Below this, four components are shown in cards: "Time series data" (red card), "Spectral Analysis" (white card with a red lightning bolt icon), "Neural Network (Keras)" (purple card with a flask icon), and "Output features" (green card with a checkmark icon). The "Output features" card is highlighted with a dashed orange border and a large yellow arrow pointing towards it from the bottom right. The "Save Impulse" button is also located in this card. On the left sidebar, under the "Create impulse" section, there is a list of steps: Data acquisition, Impulse design, Create impulse, Retrain model, Live classification, Model testing, Versioning, Deployment, GETTING STARTED, Documentation, and Forums. The "Create impulse" step is currently selected. The bottom of the page includes a copyright notice for EdgeImpulse Inc. and a footer with a small square icon.

## Preprocess Data

Spectral features - TinyML4D - x + studio.edgeimpulse.com/studio/49283/dsp/spectral-analysis/3

EDGE IMPULSE

Parameters Generate features

Raw data

Raw features

Parameters

Scaling

Scale axes 1

Filter

Type low

Cut-off frequency 4

Order 6

Spectral power

FFT length 128

No. of peaks 3

Peaks threshold 0.1

Power edges 0.1, 0.5, 1.0, 2.0, 5.0

DSP result

After filter

Frequency domain

Spectral power

Processed features

Save parameters

The screenshot shows the Edge Impulse DSP spectral analysis interface. On the left, a sidebar lists various tools and documentation. The main area is divided into several sections: 'Raw data' (a waveform plot), 'Raw features' (a list of numerical values), 'Parameters' (with sub-sections for Scaling, Filter, and Spectral power), 'DSP result' (plots of 'After filter' and 'Frequency domain'), and 'Processed features' (a log-linear plot). A large blue arrow on the far left points towards the 'Parameters' section. A yellow arrow at the bottom points towards the 'Save parameters' button, which is highlighted with a dashed orange border.

## Preprocess Data

Spectral features - TinyML4D - studio.edgeimpulse.com/studio/49283/dsp/spectral-analysis/3/generate-features

EDGE IMPULSE

SPECTRAL FEATURES (TINYML4D - PROJECT SETUP - GESTURE CLASSIFICATION)

#1 ▾ Click to set a description for this version

Parameters Generate features

Training set

Data in training set	6m 23s
Classes	4 (circle, idle, left_right, up_down)
Window length	2000 ms.
Window increase	80 ms.
Training windows	3,782

Feature explorer

No features generated yet.

Generate features

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## Preprocess Data

Spectral features - TinyML4D - X + studio.edgeimpulse.com/studio/49283/dsp/spectral-analysis/3/generate-features

EDGE IMPULSE Marcelo Rovai

SPECTRAL FEATURES (TINYML4D - PROJECT SETUP - GESTURE CLASSIFICATION)  
#1 ▾ Click to set a description for this version

Parameters Generate features

Training set

Data in training set 6m 23s

Classes 4 (circle, idle, left\_right, up\_down)

Window length 2000 ms.

Window increase 80 ms.

Training windows 3,782

Generate features

Feature explorer (3,783 samples) ?

X Axis accX RMS Y Axis accY RMS Z Axis accZ RMS

● circle  
● idle  
● left\_right  
● up\_down

Estimate for calculating features on Cortex-M4F 80MHz

On-device performance ?

PROCESSING TIME 7 ms. PEAK RAM USAGE 5 KB

Feature generation output

Scheduling job in cluster...  
Job started  
Creating windows from 42 files...  
[ 1/42] Creating windows from files...  
[42/42] Creating windows from files...  
Created 3783 windows: circle: 870, idle: 1081, left\_right: 969, up\_down: 863

Creating features  
[ 1/3783] Creating features...  
[1064/3783] Creating features...  
[2125/3783] Creating features...  
[3189/3783] Creating features...  
[3783/3783] Creating features...  
Created features

Job completed

Design a Model

NN Classifier - TinyML4D - Pro

studio.edgeimpulse.com/studio/49283/learning/keras/19

EDGE IMPULSE

NN CLASSIFIER (TINYML4D - PROJECT SETUP - GESTURE CLASSIFICATION)

#1 ▾ Click to set a description for this version

Neural Network settings

Training settings

Number of training cycles ② EPOCHS 30

Learning rate ② Lr 0.0005

Neural network architecture

Input layer (33 features)

Dense layer (20 neurons)

Dense layer (10 neurons)

Add an extra layer

Output layer (4 features)

Start training

Training output

input → InputLayer → Dense (kernel 33x20, bias 20) → ReLU → Dense (kernel 20x10, bias 10) → ReLU → Dense (kernel 10x4, bias 4) → Softmax → y\_pred

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Train a Model

NN Classifier - TinyML4D - Pro

studio.edgeimpulse.com/studio/49283/learning/keras/19

### EDGE IMPULSE

**Neural Network settings**

**Training settings**

Number of training cycles: 30

Learning rate: 0.0005

**Neural network architecture**

- Input layer (33 features)
- Dense layer (20 neurons)
- Dense layer (10 neurons)
- Add an extra layer
- Output layer (4 features)

**Start training**

### Training output

Attached to job 1354515...  
Profiling float32 model (EON)...  
Profiling int8 model...  
Profiling int8 model (tflite)...  
Profiling int8 model (EON)...

Model training complete  
Job completed

### Model

Model version: Quantized (int8)

#### Last training performance (validation set)

ACCURACY 99.5%	LOSS 0.05
-------------------	--------------

#### Confusion matrix (validation set)

	CIRCLE	IDLE	LEFT_RIGHT	UP_DOWN
CIRCLE	100%	0%	0%	0%
IDLE	0%	100%	0%	0%
LEFT_RIGHT	0.5%	1.0%	98.4%	0%
UP_DOWN	0%	0.5%	0%	99.5%
F1 SCORE	1.00	0.99	0.99	1.00

#### Feature explorer (full training set)

accX RMS accY RMS accZ RMS

- circle - correct
- idle - correct
- left\_right - correct
- up\_down - correct
- left\_right - incorrect

NN Classifier - TinyML4D - Pro

studio.edgeimpulse.com/studio/49283/learning/keras/19

### Training settings

Number of training cycles: 30

Learning rate: 0.0005

### Neural network architecture

- Input layer (33 features)
- Dense layer (20 neurons)
- Dense layer (10 neurons)
- Add an extra layer
- Output layer (4 features)

**Start training**

### Model

Model version: Quantized (int8)

#### Last training performance (validation set)

	ACCURACY	LOSS
%	99.5%	0.05

#### Confusion matrix (validation set)

	CIRCLE	IDLE	LEFT_RIGHT	UP_DOWN
CIRCLE	100%	0%	0%	0%
IDLE	0%	100%	0%	0%
LEFT_RIGHT	0.5%	1.0%	98.4%	0%
UP_DOWN	0%	0.5%	0%	99.5%
F1 SCORE	1.00	0.99	0.99	1.00

#### Feature explorer (full training set)

accX RMS, accY RMS, accZ RMS

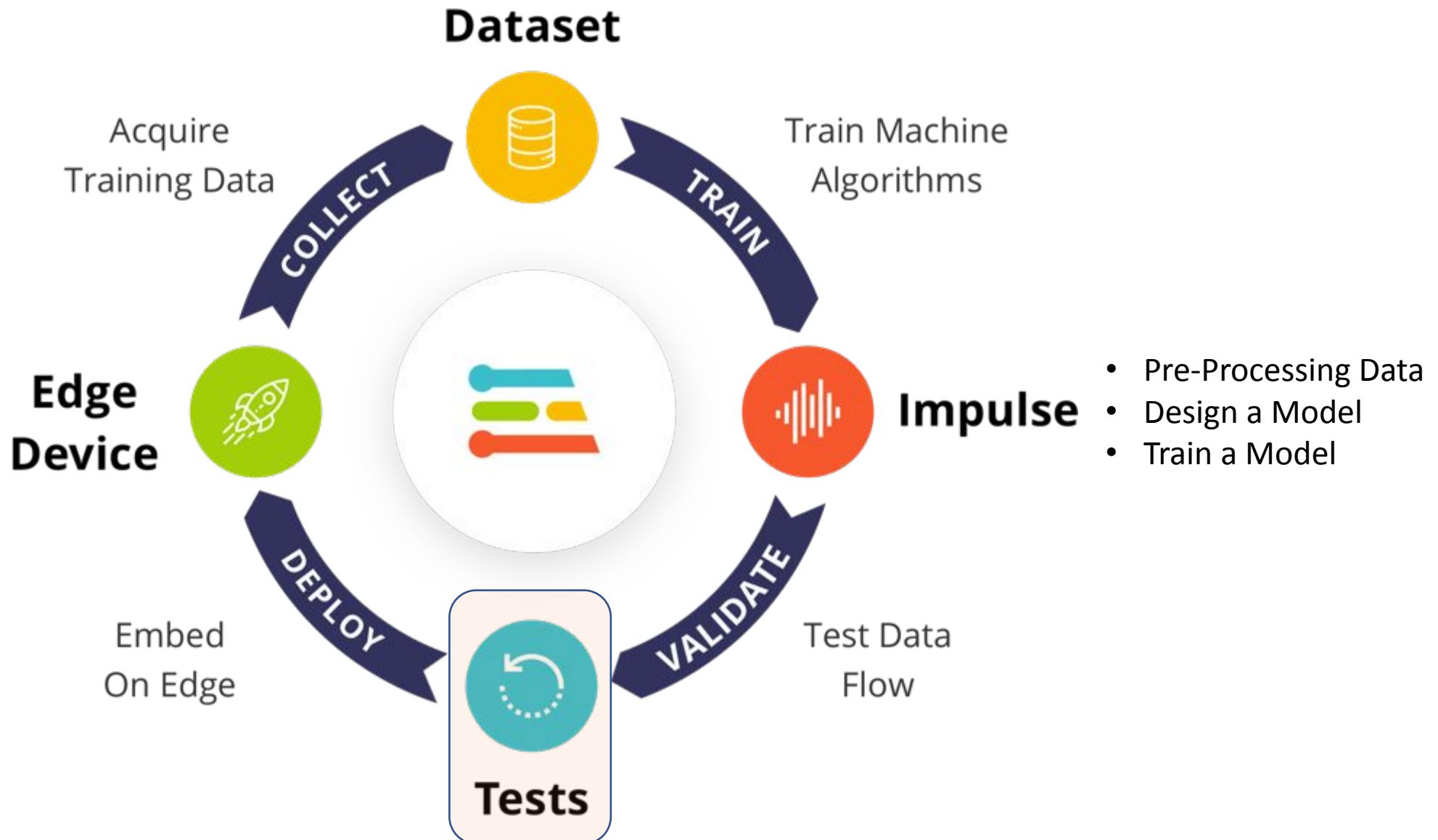
circle - correct, idle - correct, left\_right - correct, up\_down - correct, left\_right - incorrect

Estimate for Arduino Nano 33 BLE Sense (Cortex-M4F 64MHz), compiled with Edge Impulse EON™ compiler

#### On-device performance

	INFERRING TIME	PEAK RAM USAGE	FLASH USAGE
⌚	1 ms.	1.7K	17.9K

**Evaluate Optimize**



**Evaluate**

**Optimize**

Model testing - TinyML4D - Project setup

studio.edgeimpulse.com/studio/49283/validation

EDGE IMPULSE

Dashboard

Devices

Data acquisition

Impulse design

- Create impulse
- Spectral features
- NN Classifier

Retrain model

Live classification

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MODEL TESTING (TINYML4D - PROJECT SETUP - GESTURE CLASSIFICATION)

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

Test data

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

Classify all

Model testing output

SAMPLE NAME	EXPECTED OUTCOME	LENGTH	ACCURACY	RESULT
testing.28800f...	up_down	9s		
testing.287vv...	left_right	10s		
testing.287vss...	left_right	10s		
testing.287vq...	up_down	10s		
up_down.287...	up_down	10s		
idle.287h2mc6	idle	10s		
testing.285gm...	up_down	10s		
testing.285ga...	idle	4s		
testing.285g6...	circle	10s		
testing.285g3...	left_right	10s		
left-right.285f...	left_right	10s		

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Marcelo Rovai

**Model testing - TinyML4D - Pro**

[studio.edgeimpulse.com/studio/49283/validation](https://studio.edgeimpulse.com/studio/49283/validation)

**EDGE IMPULSE**

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

**GETTING STARTED**

- Documentation
- Forums

### Test data

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

SAMPLE NAME	EXPECTED OUTCOME	LENGTH	ACCURACY	RESULT	⋮
testing.28800f...	up_down	9s	100%	92 up_down	⋮
testing.287vv...	left_right	10s	100%	95 left_right	⋮
testing.287vss...	left_right	10s	100%	97 left_right	⋮
testing.287vq...	up_down	10s	100%	97 up_down	⋮
up_down.287...	up_down	10s	100%	97 up_down	⋮
idle.287h2mc6	idle	10s	100%	97 idle	⋮
testing.285gm...	up_down	10s	100%	97 up_down	⋮
testing.285ga...	idle	4s	100%	24 idle	⋮
testing.285g6...	circle	10s	100%	97 circle	⋮
testing.285g3...	left_right	10s	100%	97 left_right	⋮
left-right.285f...	left_right	10s	98%	95 left_right, 1 idle	⋮

### Model testing output

Classifying data for NN classifier...  
 Copying features from processing blocks...  
 Copying features from DSP block...  
 Copying features from DSP block OK  
 Copying features from processing blocks OK

Classifying data for float32 model...  
 Scheduling job in cluster...  
 Job started  
 Classifying data for NN Classifier OK

**Job completed**

### Model testing results

**ACCURACY 99.90%**

	CIRCLE	IDLE	LEFT_RIGHT	UP_DOWN	UNCERTAIN
CIRCLE	100%	0%	0%	0%	0%
IDLE	0%	100%	0%	0%	0%
LEFT_RIGHT	0%	0.3%	99.7%	0%	0%
UP_DOWN	0%	0%	0%	100%	0%
F1 SCORE	1.00	1.00	1.00	1.00	

### Feature explorer

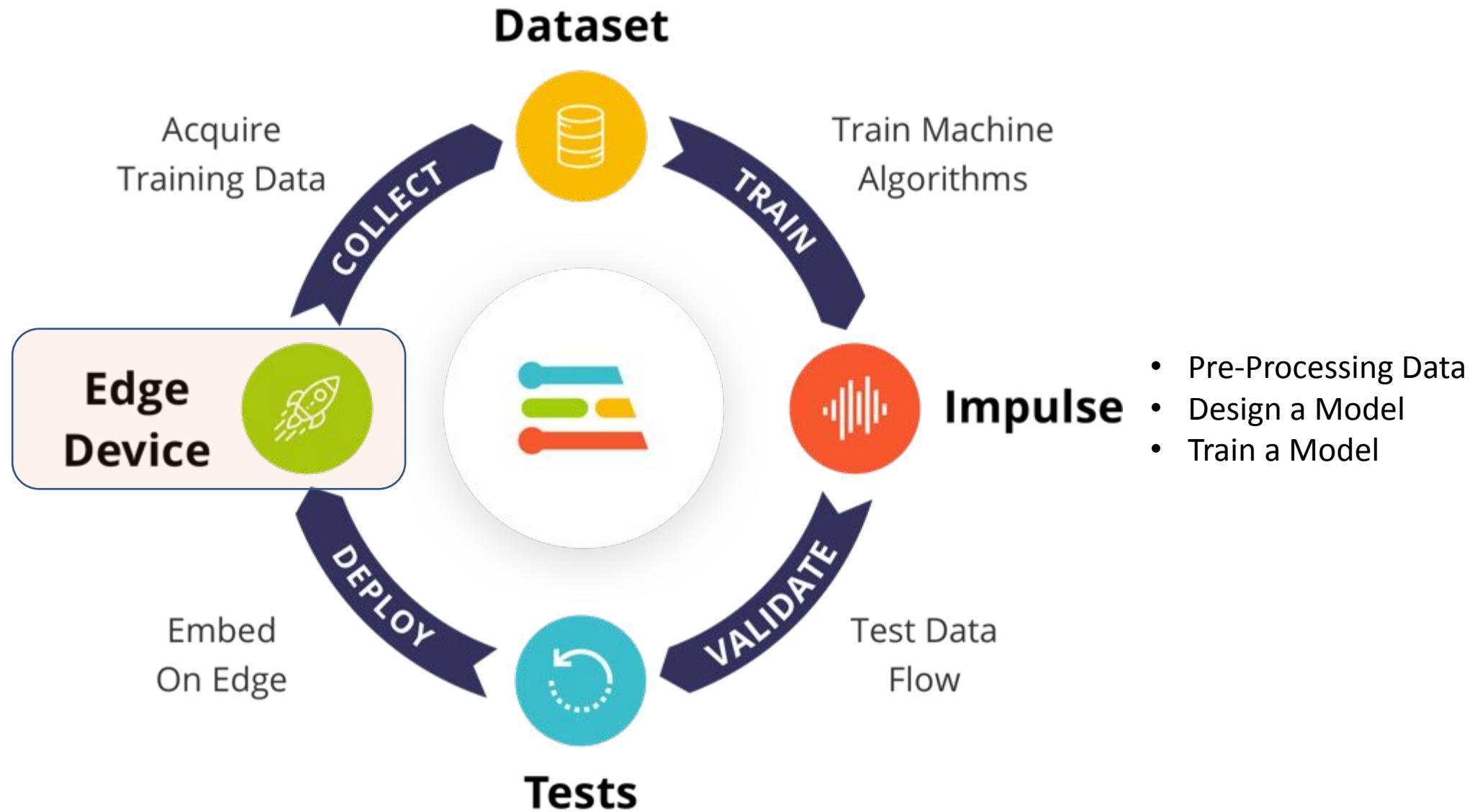
accX RMS   accY RMS   accZ RMS

Legend:

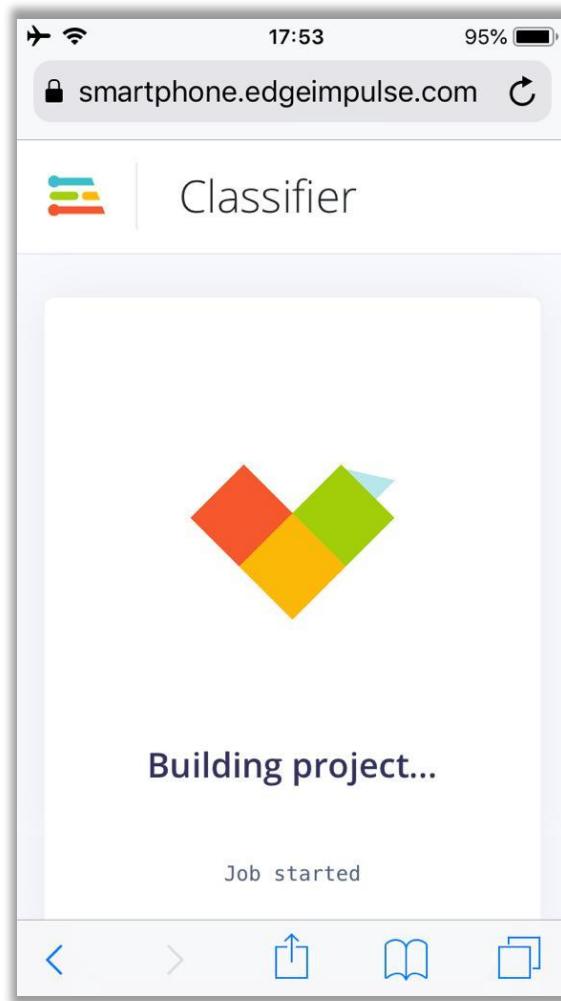
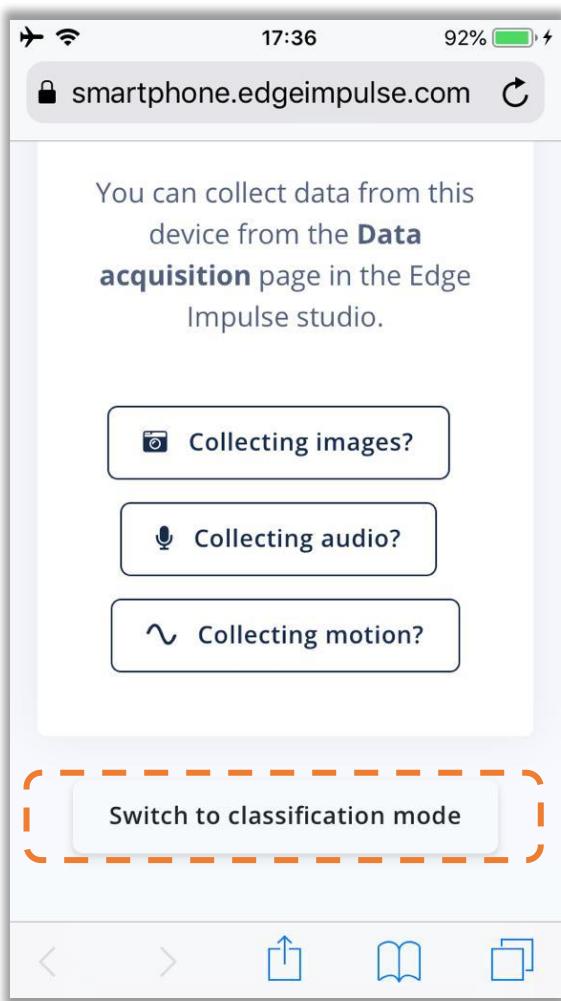
- circle - correct
- idle - correct
- left\_right - correct
- up\_down - correct
- left\_right - incorrect

The plot displays three main clusters of points corresponding to the four correct classes (circle, idle, left\_right, up\_down) and one small cluster of red points representing left\_right-incorrect samples. The axes are labeled accX RMS, accY RMS, and accZ RMS.

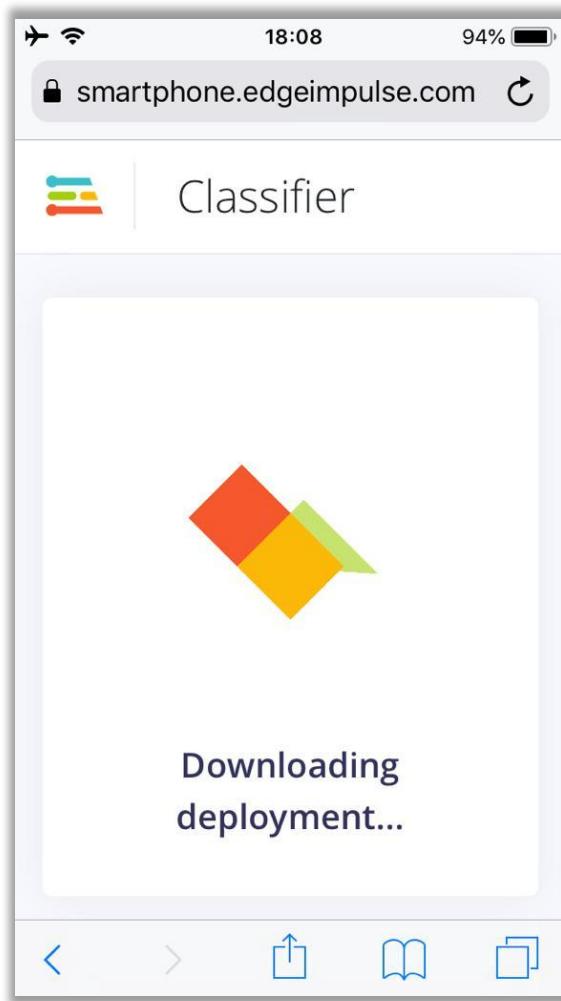
Evaluate  
Optimize



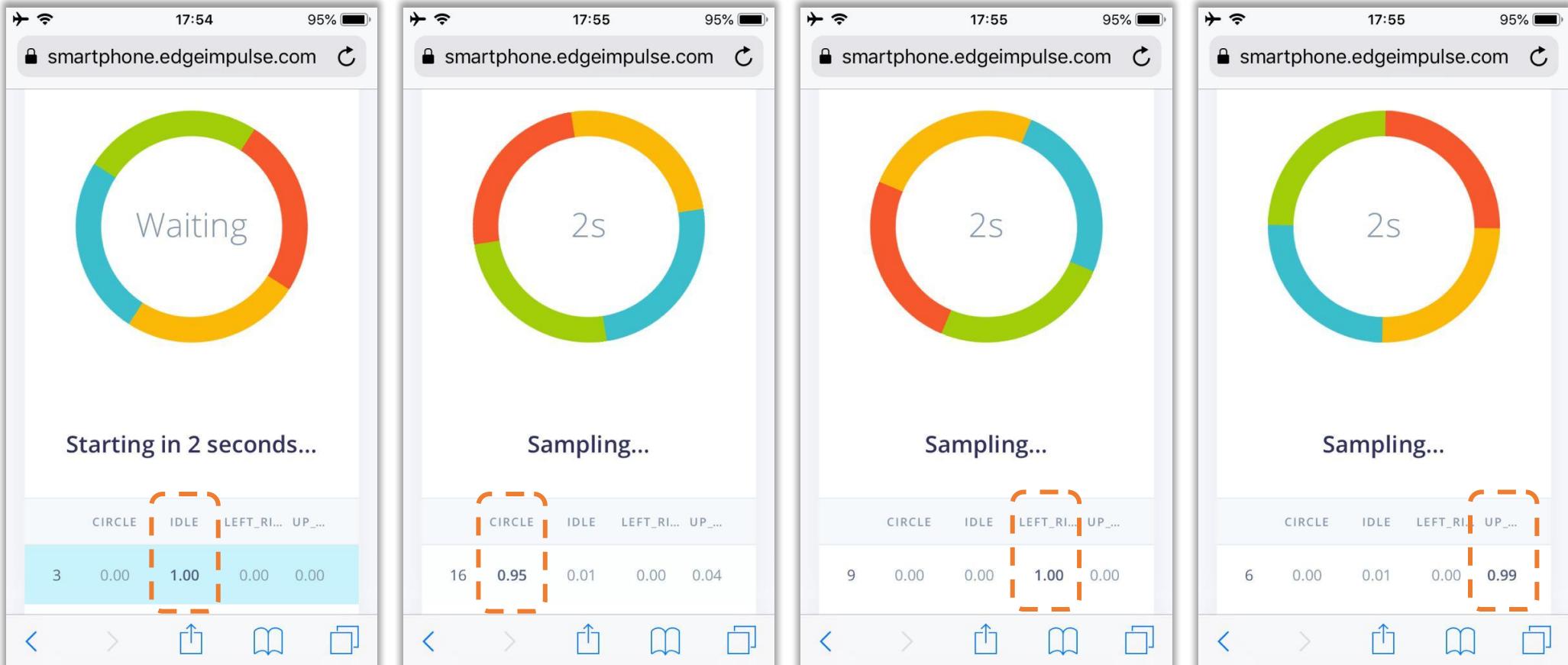
## Convert Model



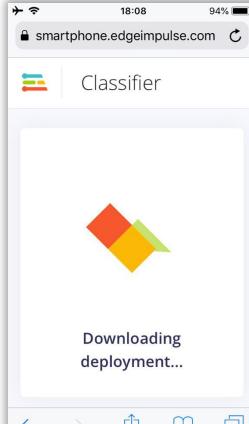
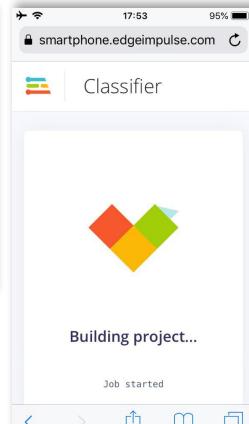
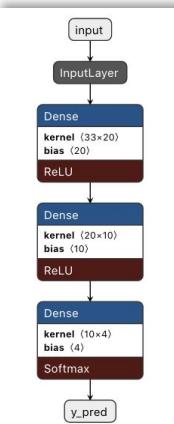
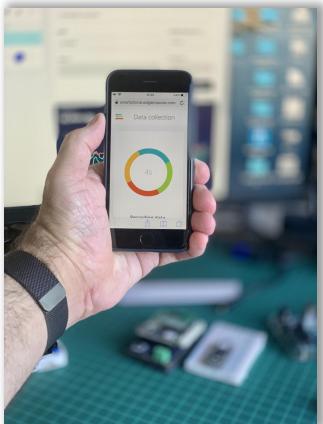
## Deploy Model



Make  
Inferences



# Summary



# Additional Free Resources

## Google CoLab

Google Colaboratory or [CoLab](#) for short, allows you to write and execute Python in your browser, with zero configuration required, free access to GPUs and easy sharing. Google Colab is also an online integrated developer environment to design, train, and test our machine learning models. Here is an introduction to Google Colab. [Watch Jake VanderPlas from Google give a wonderful intro to Colab.](#)

## Python for Data Science and ML Review

- A Whirlwind Tour of Python by Jake VanderPlas ([e-book content](#))
- Learn the most important language for data science: [Kaggle Python Tutorial](#)
- Use TensorFlow and Keras to build and train neural networks for structured data: [Kaggle Intro to Deep Learning](#)

## Hackster TinyML Tutorials

- ["Listening Temperature" with Arduino Nano \(Audio\)](#)
- [Motion Recognition Using Raspberry Pi Pico \(Accelerometers\)](#)
- [Coffee disease classification with Seeed Maix Bit RISC-V board \(Vision\)](#)

## [Imagine 2021 Day 3: Community Showcase](#)

# SciTinyML - ICTP workshop

## Scientific Use of Machine Learning on Low Power Devices

### Setting up the software tools

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