SciTinyML - ICTP workshop

Scientific Use of Machine Learning on Low Power Devices

Setting up the software tools

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**)?

TinyML

Fastest-growing field of **ML**

Algorithms, hardware, software

On-device sensor analytics

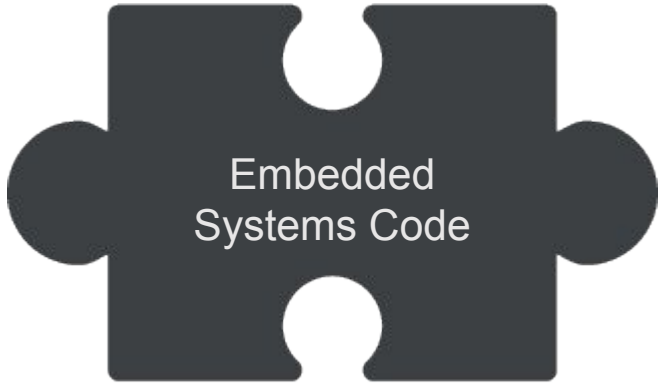
Low power consumption

Always-on ML

Battery-operated

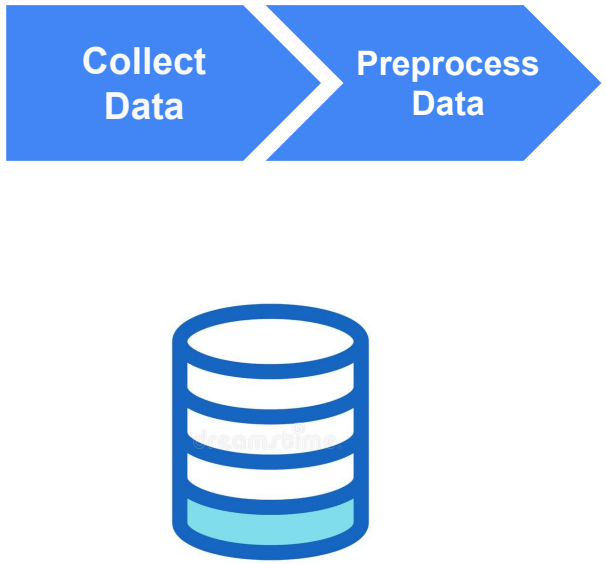
Source: TinyML4D seminar: "Why The Future of ML is Tiny and Bright" by Vijay Janapa Reddi

What Makes TinyML?

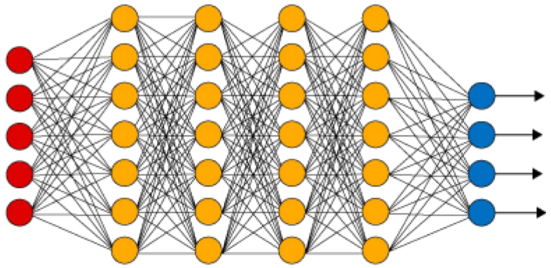


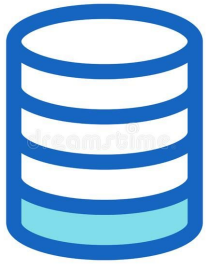
TinyML

Machine Learning Workflow



Machine Learning Workflow





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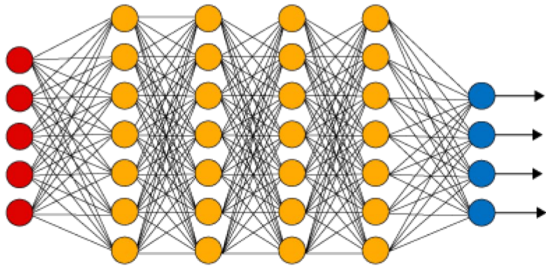
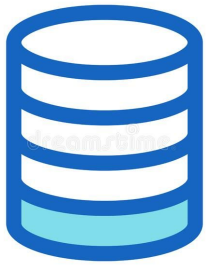
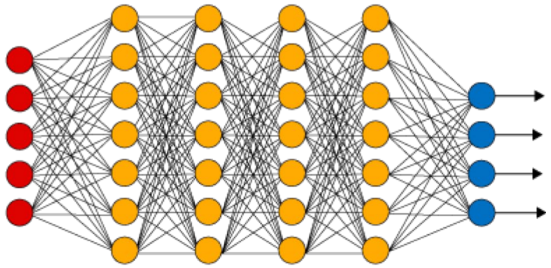
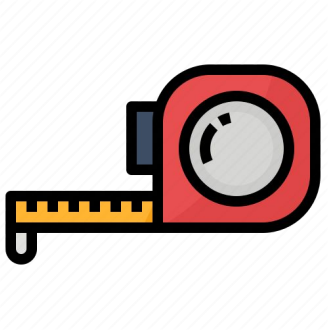


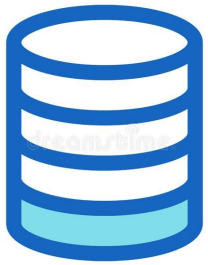


Machine Learning Workflow ("What")

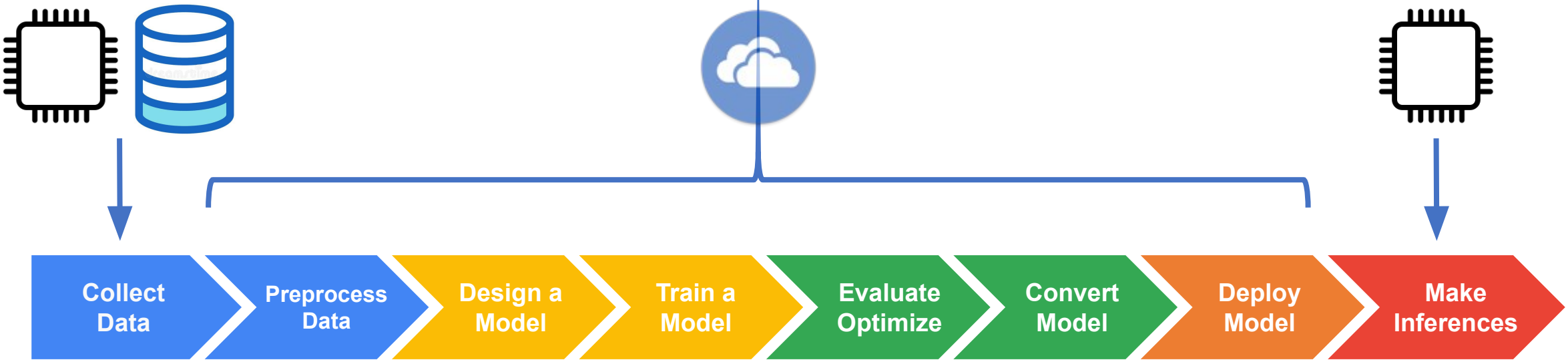




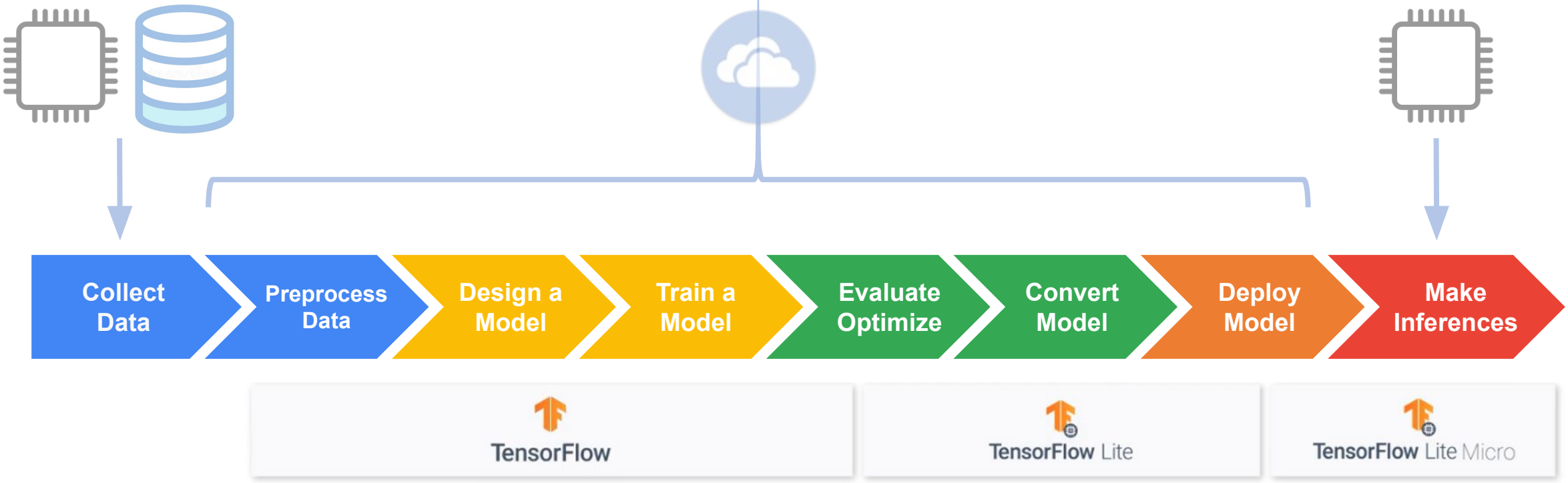
Collect Data → Preprocess Data → Design a Model → Train a Model → Evaluate Optimize → Convert Model → Deploy Model → Make Inferences



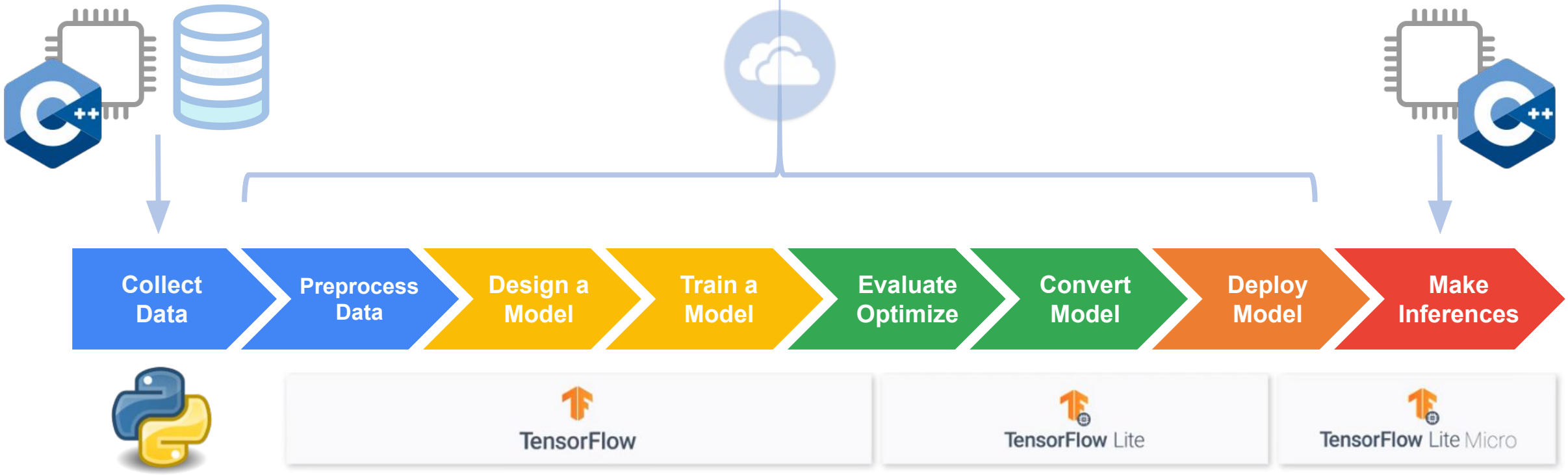
Machine Learning Workflow ("Where")



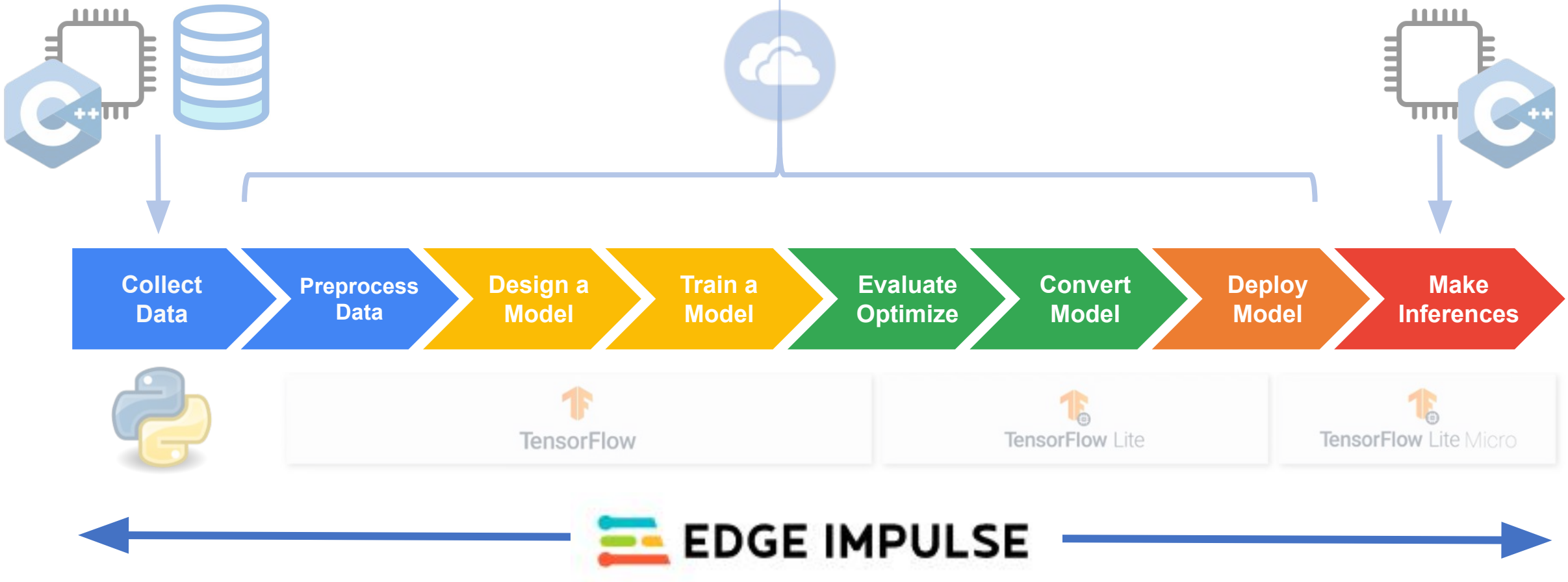
Machine Learning Workflow ("How")



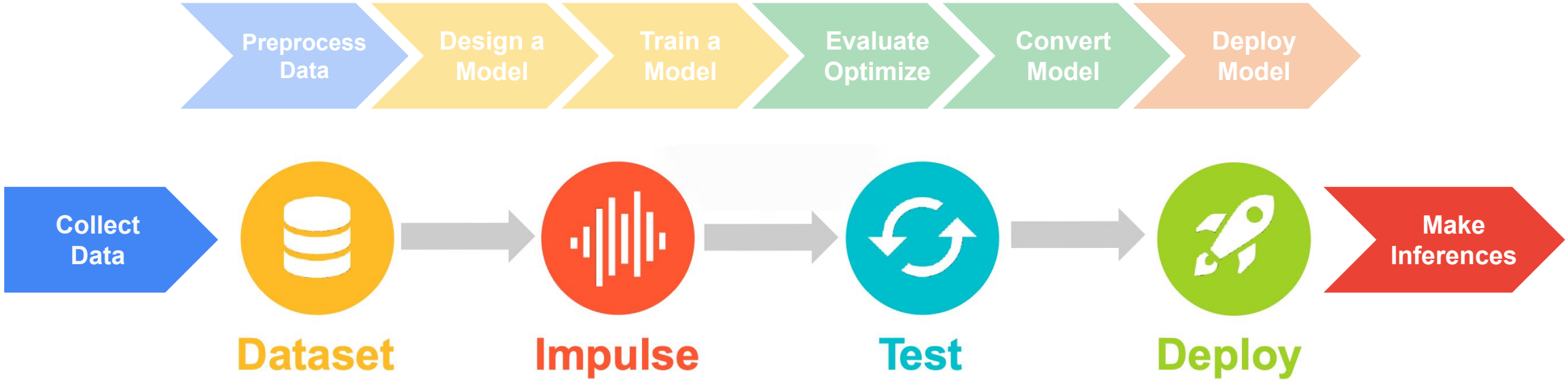
Machine Learning Workflow ("How")

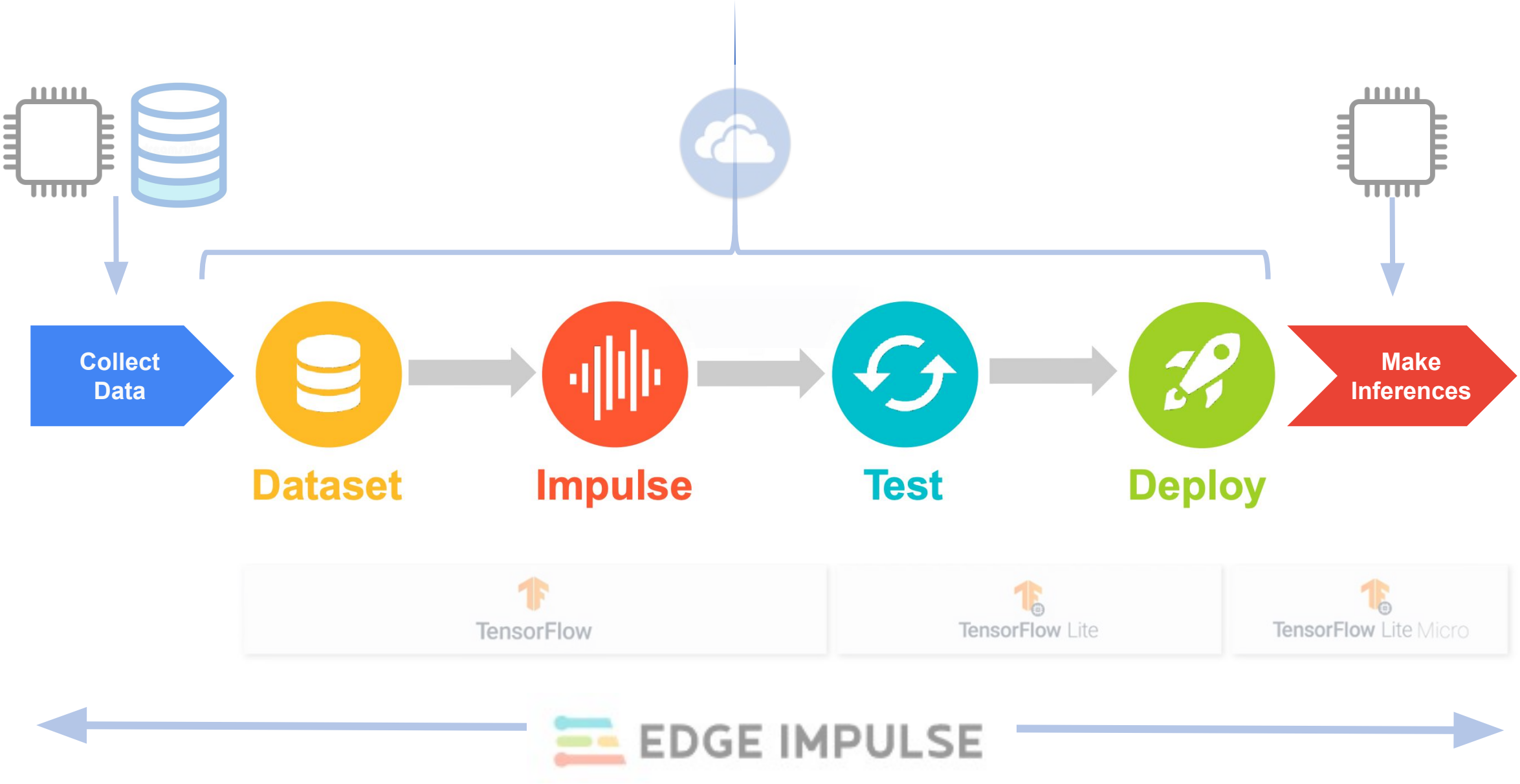


Machine Learning Workflow ("How")

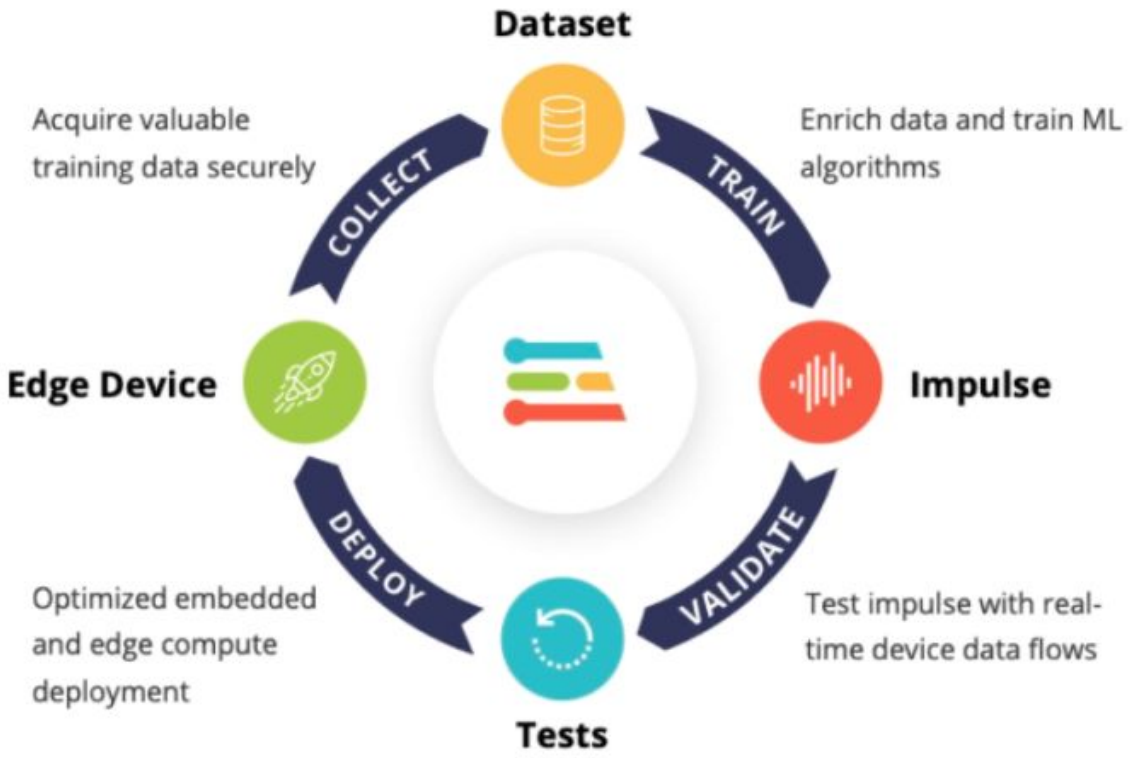


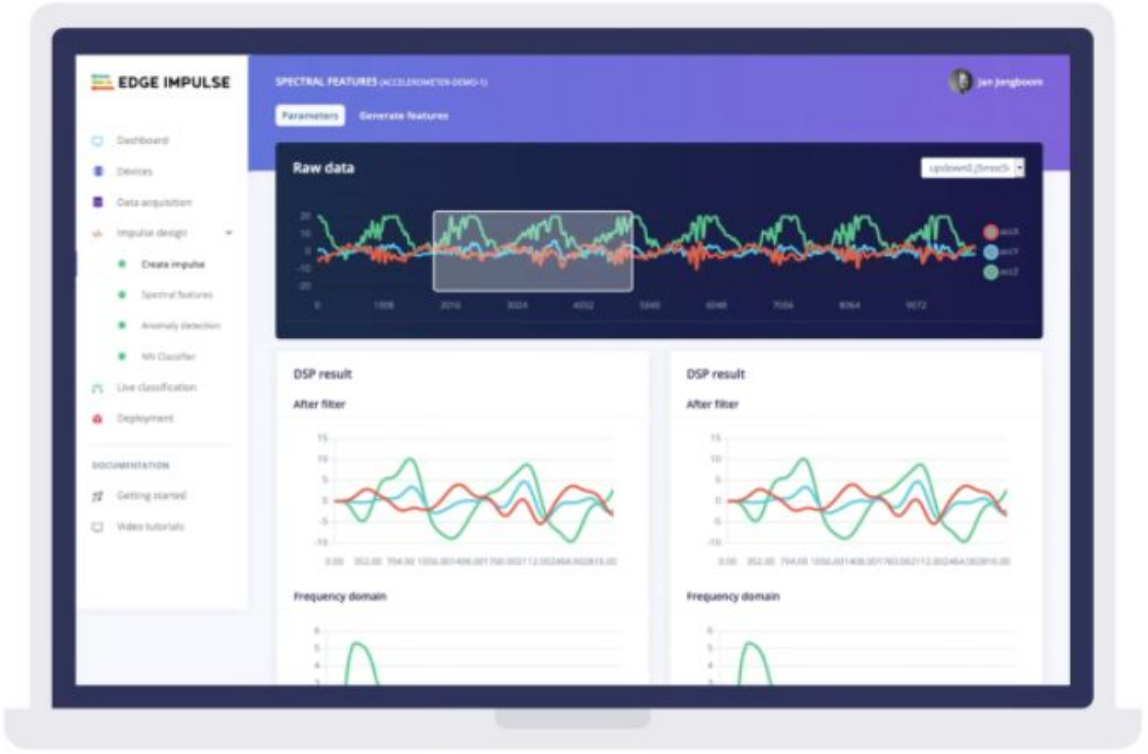

Collect Data
Preprocess Data
Design a Model
Train a Model
Evaluate Optimize
Convert Model
Deploy Model
Make Inferences


Preprocess Data
Design a Model
Train a Model
Evaluate Optimize
Convert Model
Deploy Model
Collect Data
Dataset
Impulse
Test
Deploy
Make Inferences

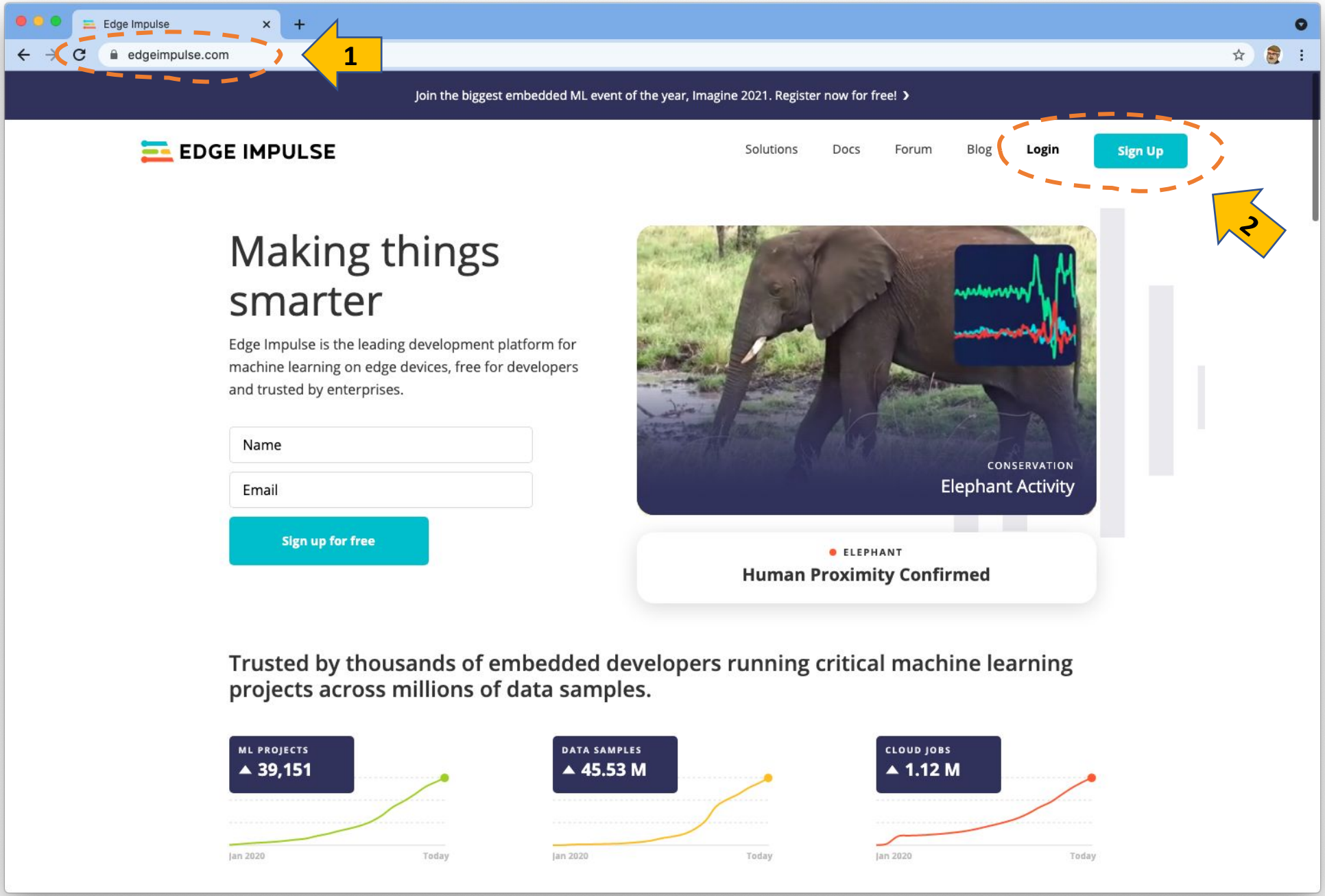

Collect Data
Dataset
Impulse
Test
Deploy
Make Inferences
TensorFlow
TensorFlow Lite
TensorFlow Lite Micro
EDGE IMPULSE

EI Studio - Embedded ML platform





Learn more at http://edgeimpulse.com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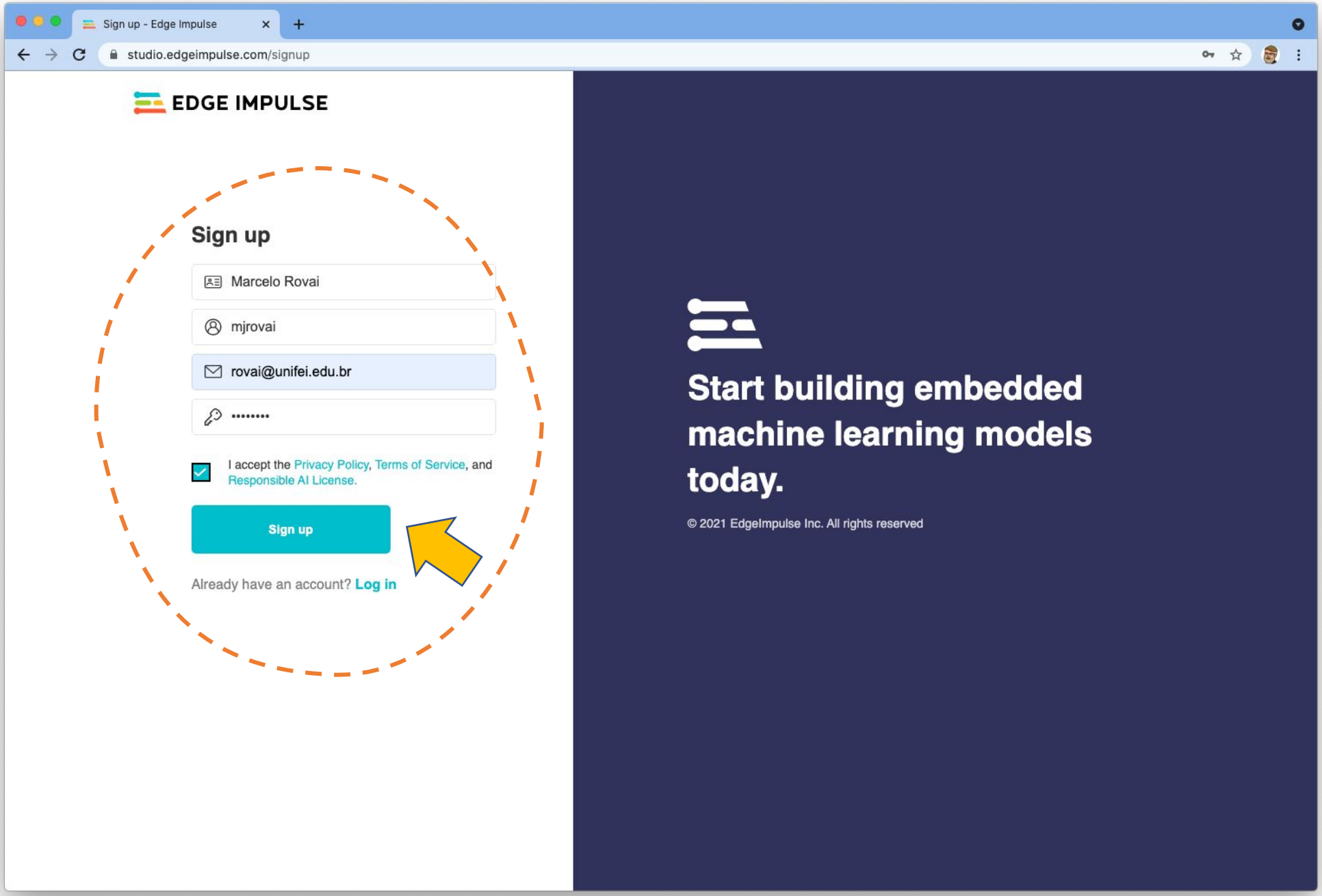
▲ 39,151
Jan 2020
Today
DATA SAMPLES
▲ 45.53 M
Jan 2020
Today
CLOUD JOBS
▲ 1.12 M
Jan 2020
Today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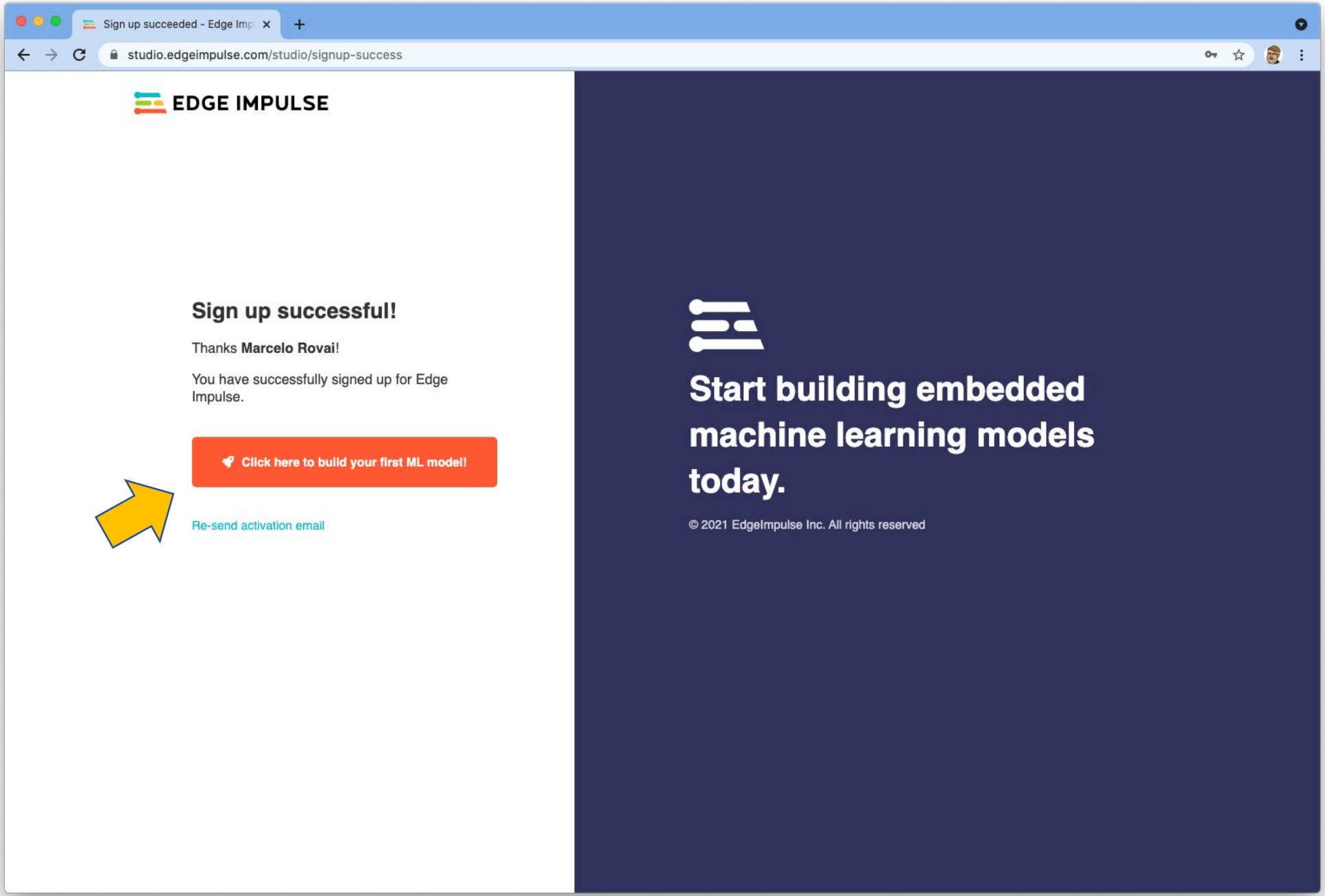
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Re-send activation email
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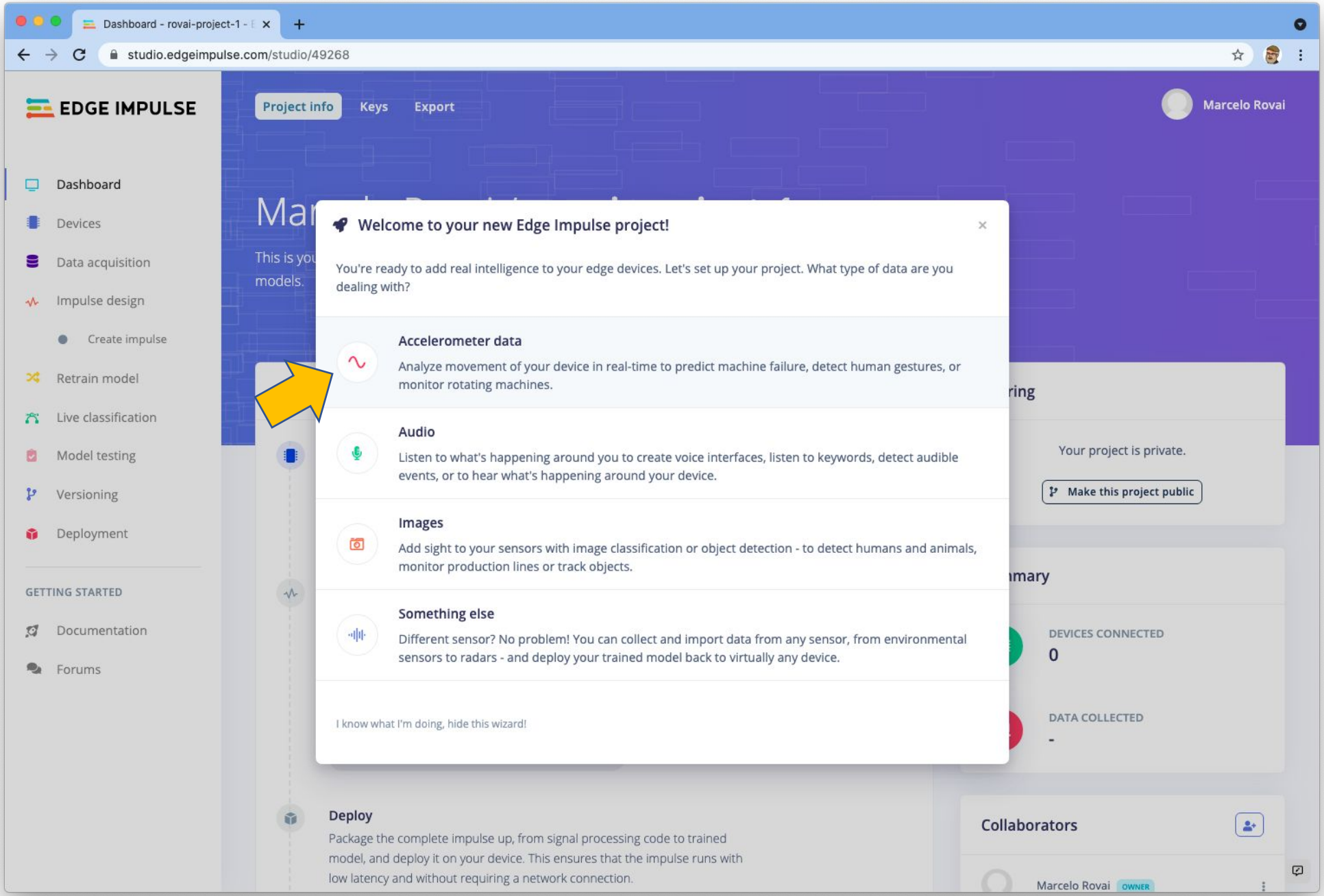
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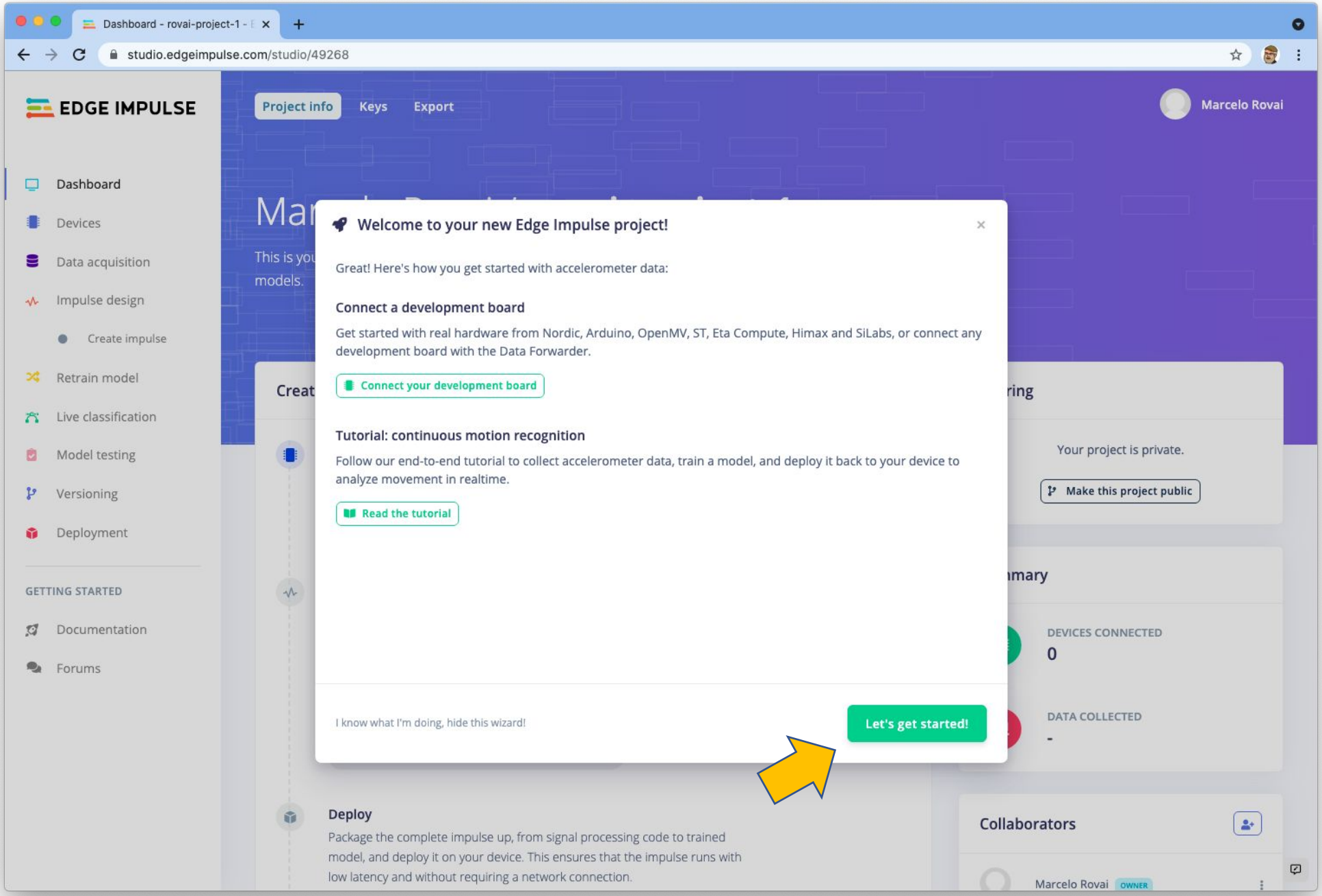
GETTING STARTED
Documentation
Forums
Welcome to your new Edge Impulse project!
You're ready to add real intelligence to your edge devices. Let's set up your project. What type of data are you dealing with?
Accelerometer data
Analyze movement of your device in real-time to predict machine failure, detect 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!
Your project is private.
Make this project public
DEVICES CONNECTED
0
DATA COLLECTED
-
Collaborators
Marcelo Rovai
OWNER
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.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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!
Your project is private.
Make this project public
DEVICES CONNECTED
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DATA COLLECTED
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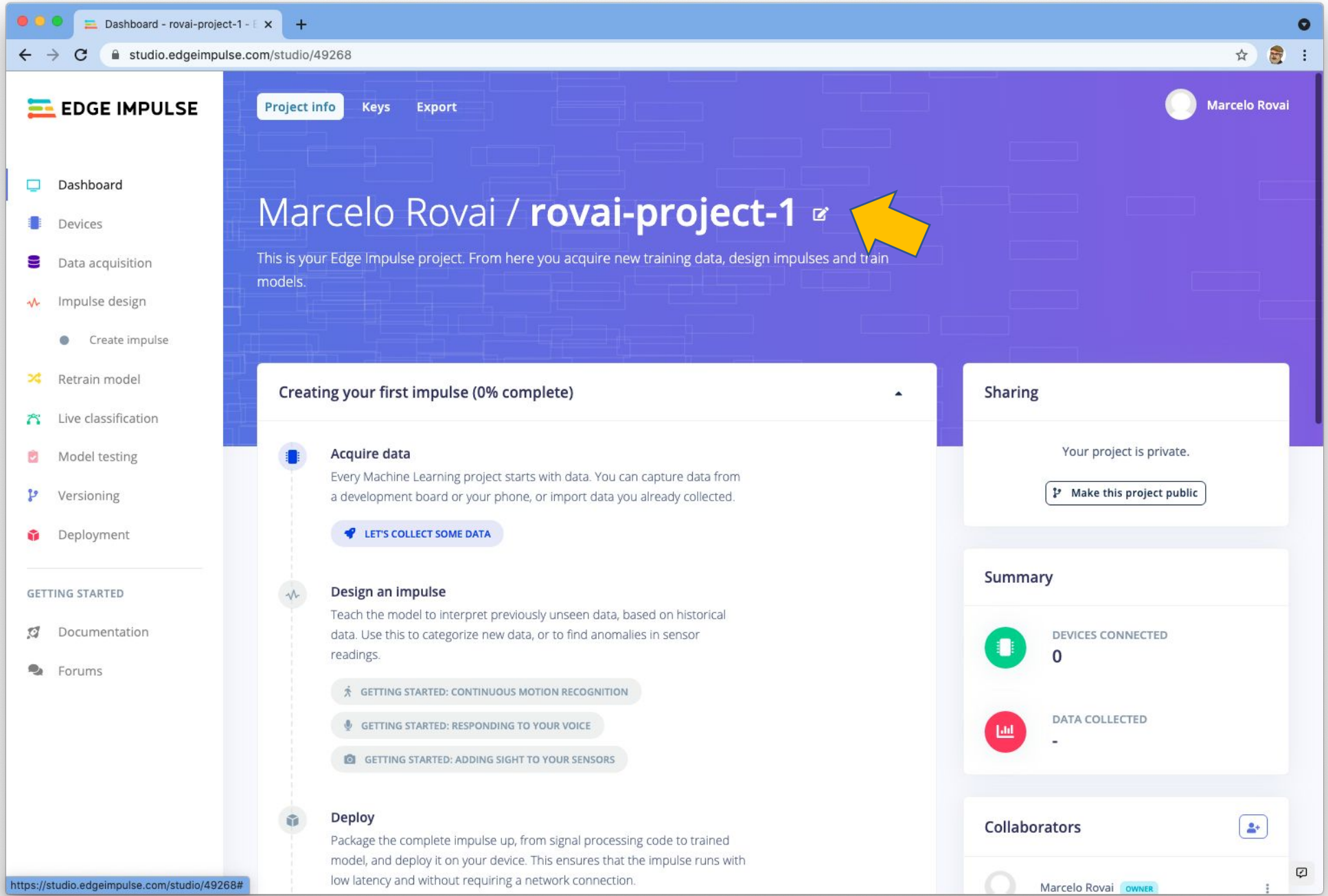
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Marcelo Rovai / rovai-project-1
This is your Edge Impulse project. From here you acquire new training data, design impulses and train models.
Creating your first impulse (0% complete)
Acquire data
Every Machine Learning project starts with data. You 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
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Sharing
Your project is private.
Make this project public
Summary
DEVICES CONNECTED
0
DATA COLLECTED
-
Collaborators
Marcelo Rovai
OWNER
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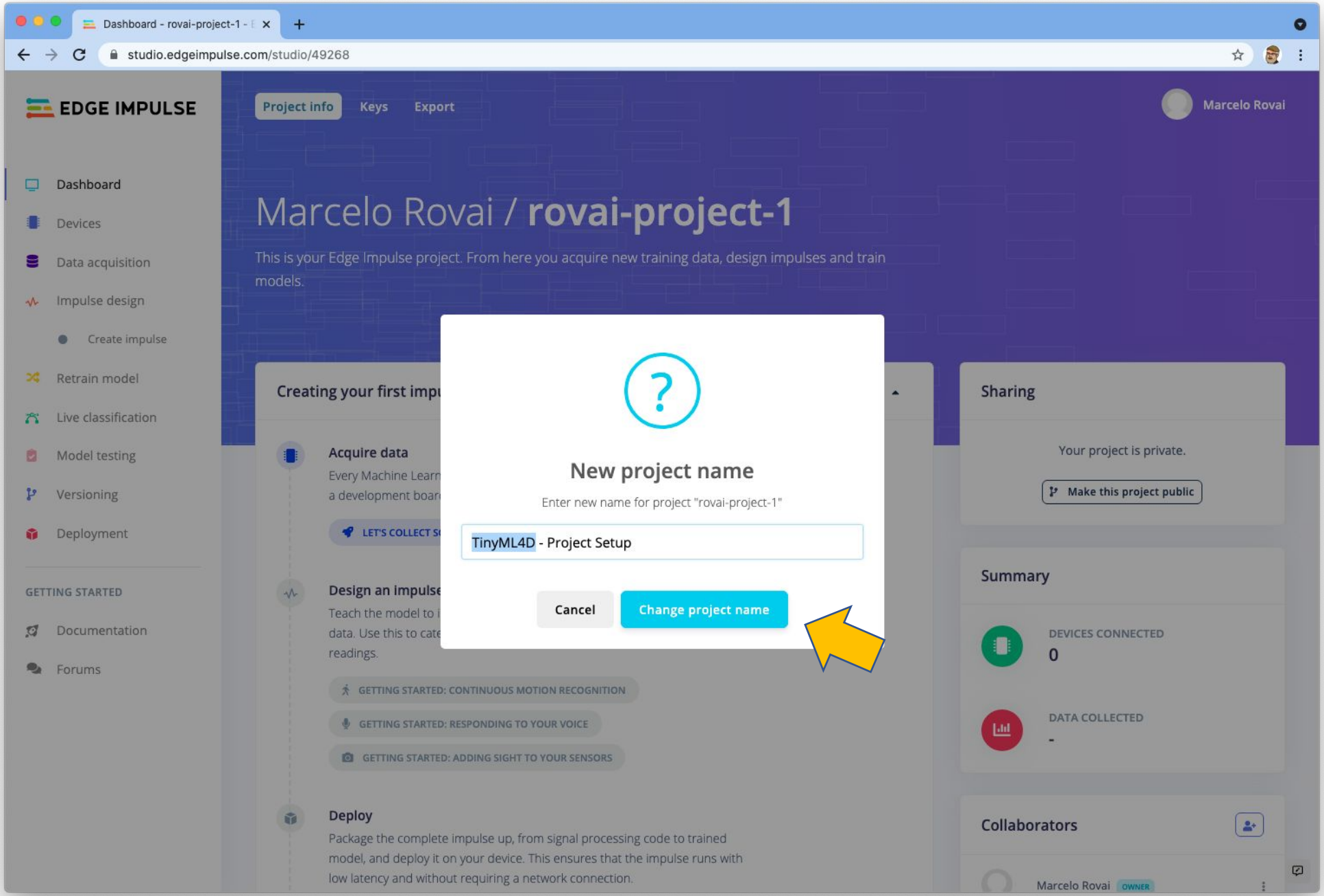
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New project name
Enter new name for project "rovai-project-1"
TinyML4D - Project Setup
Cancel
Change project name
Sharing
Your project is private.
Make this project public
Summary
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0
DATA COLLECTED
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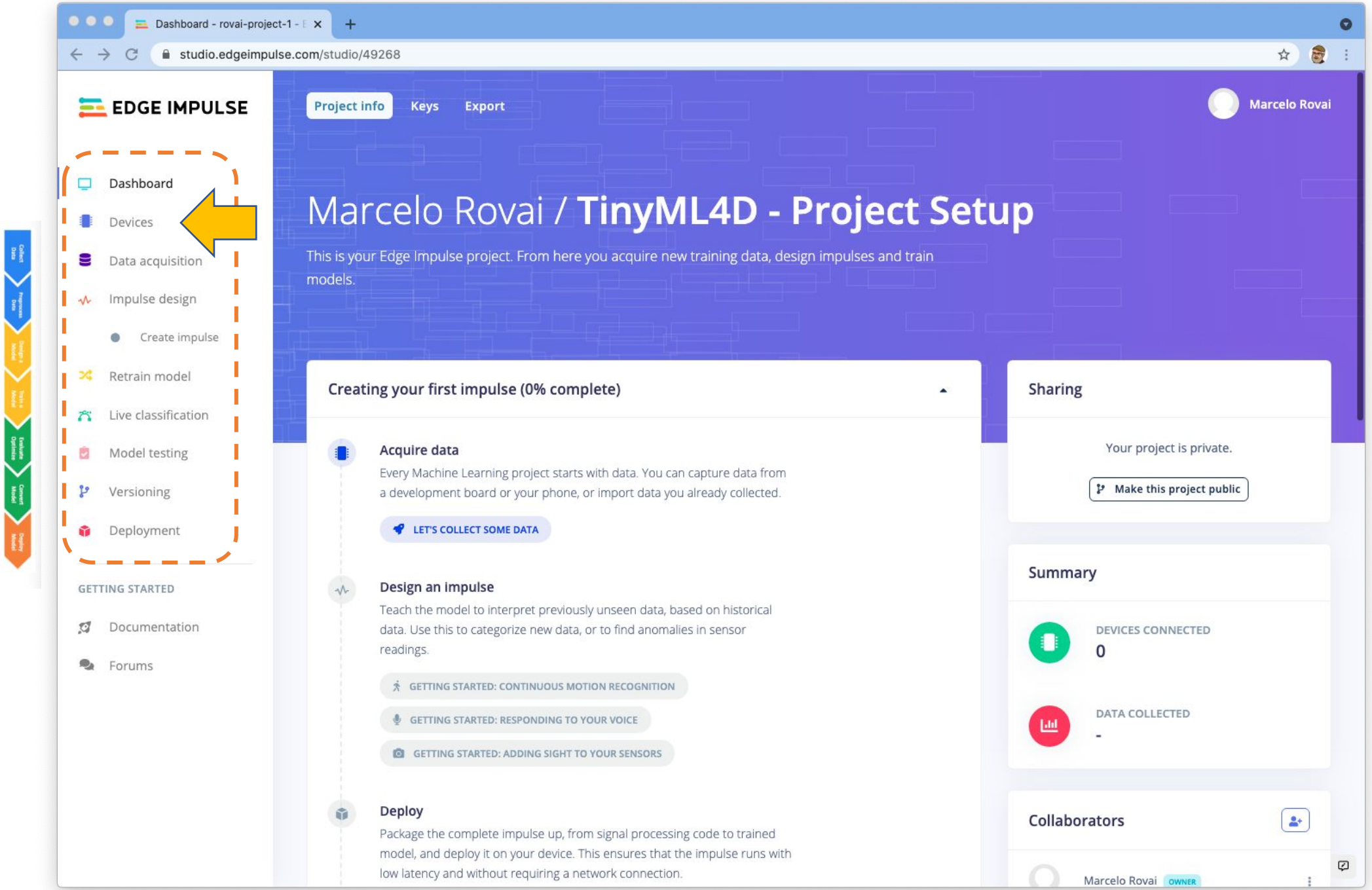
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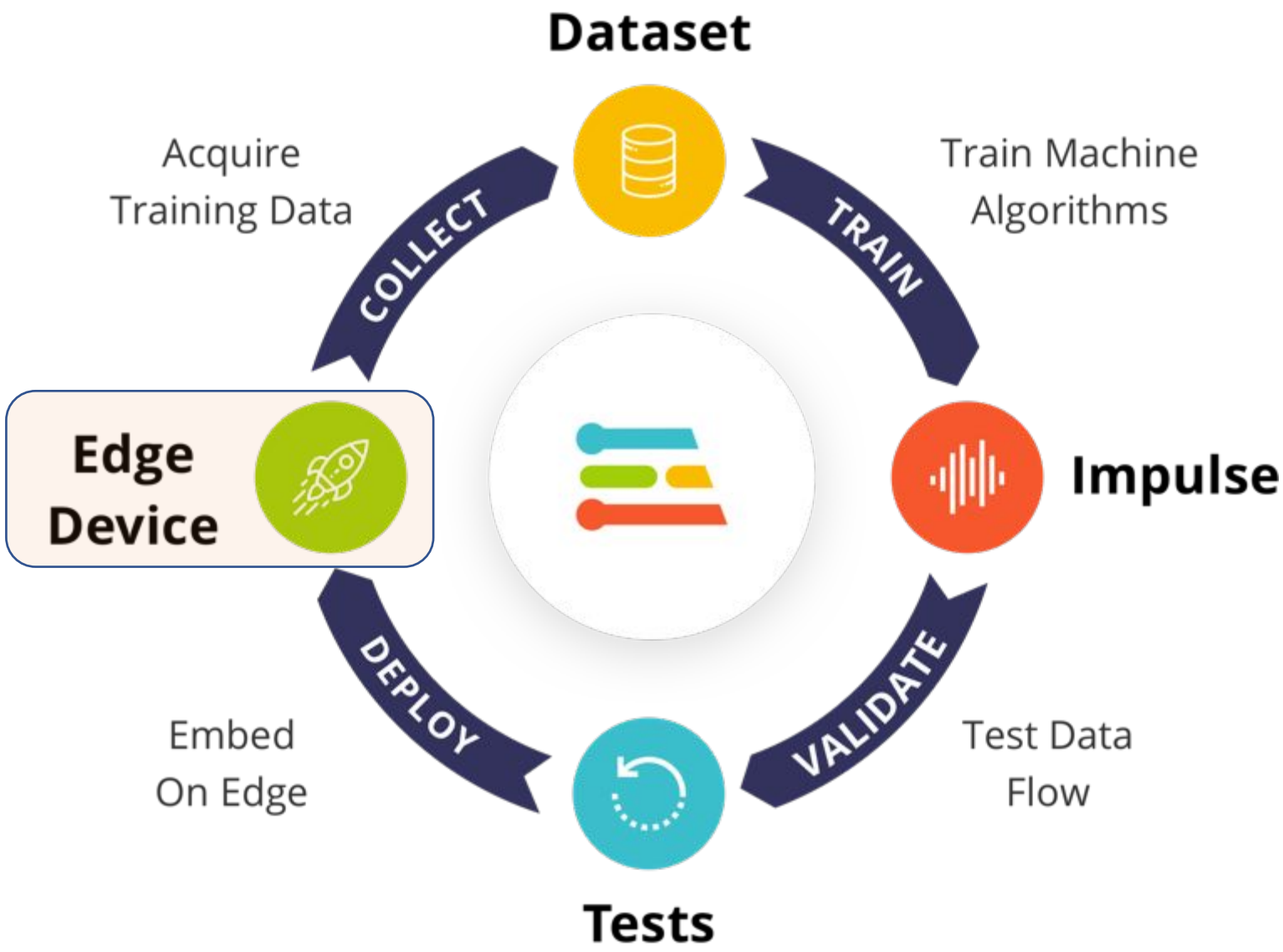
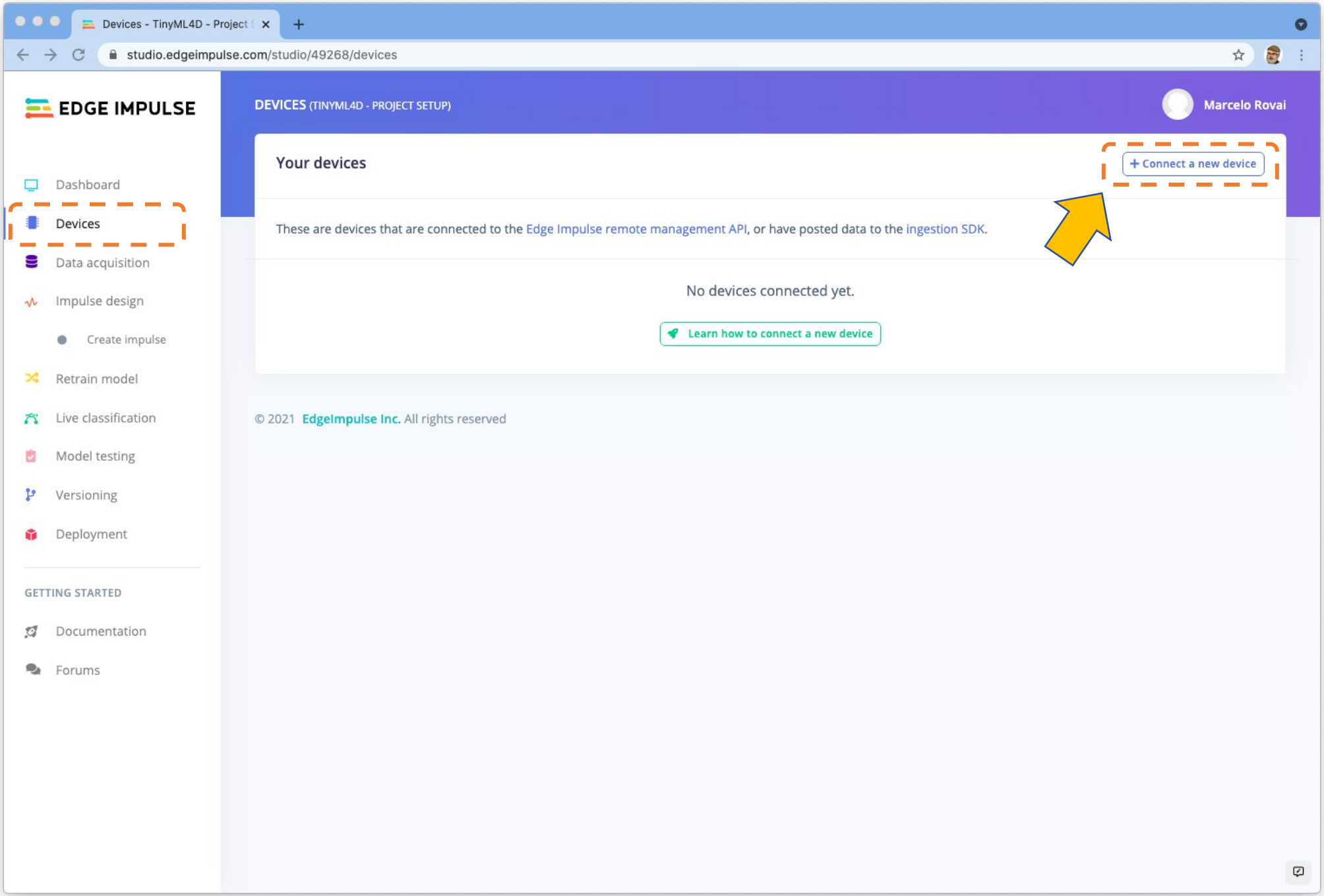


- Pre-Processing Data
- Design a Model
- Train a Model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+ Connect a new device
These are devices that are connected to the Edge Impulse remote management API, or have posted data to the ingestion SDK.
No devices connected yet.
Learn how to connect a new device
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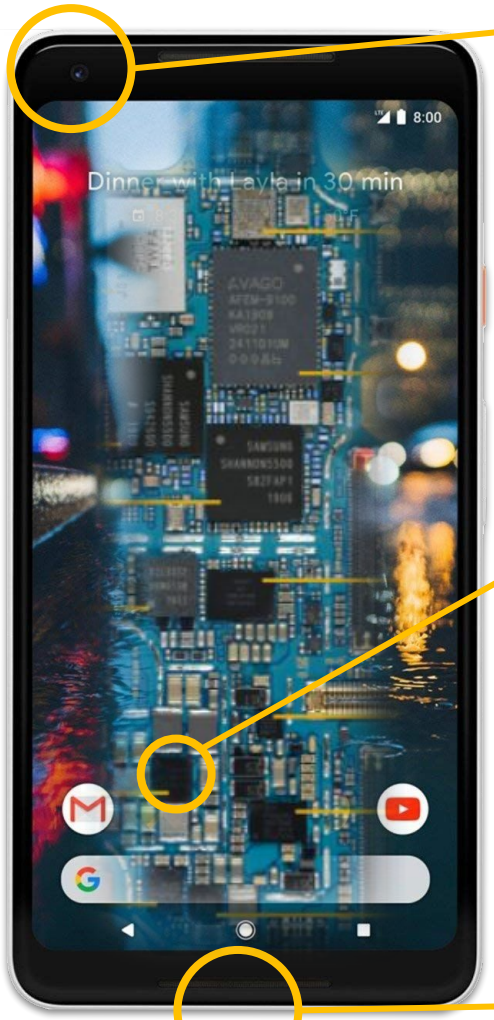
Edge Device & Sensors



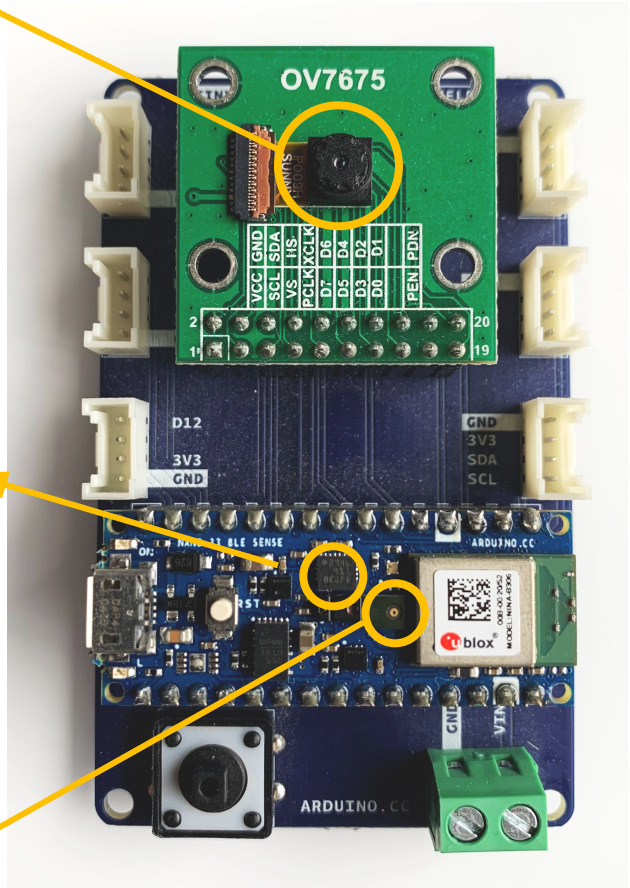
Camera

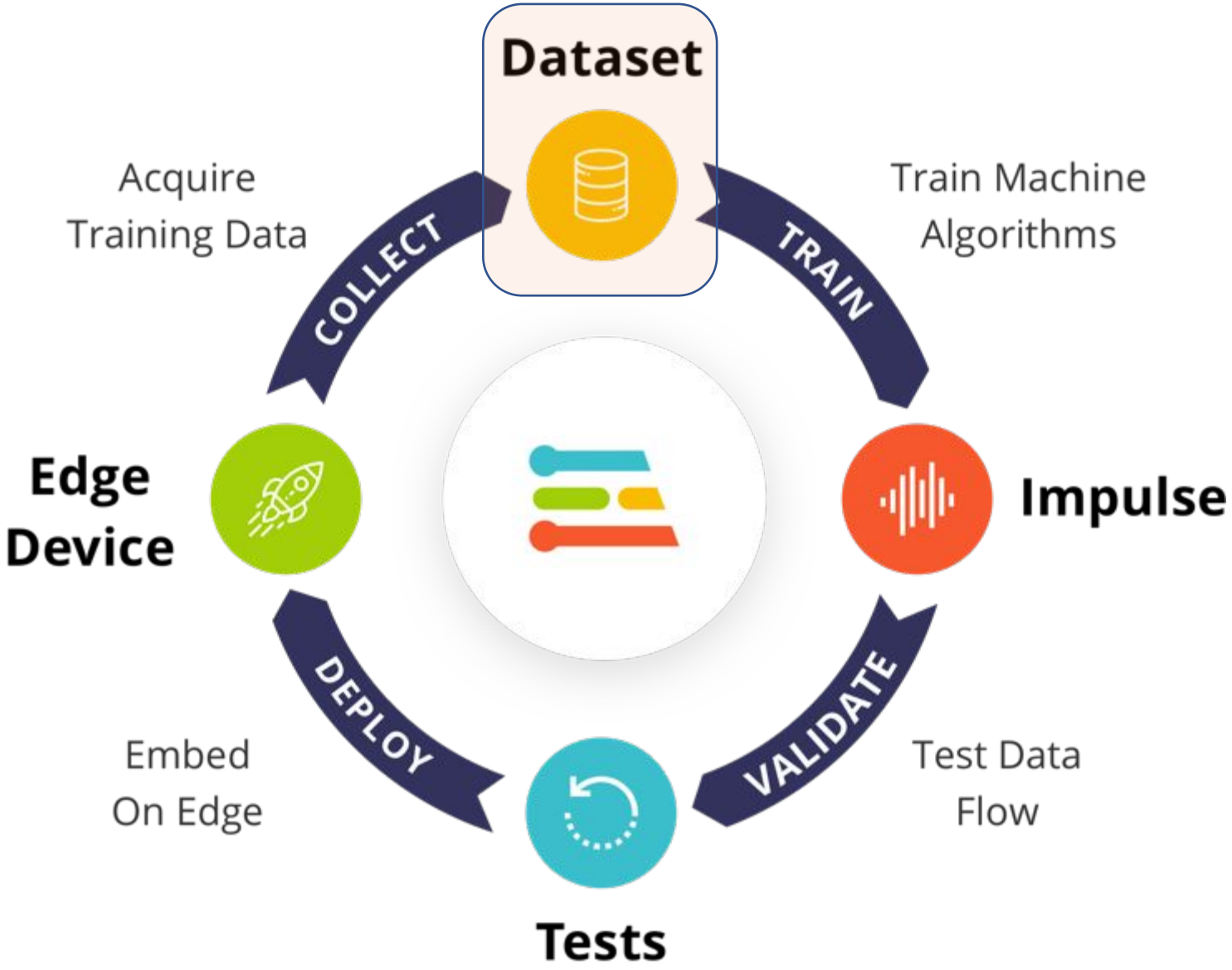
Accelerometer

Gyroscope

Magnetometer

Microphone





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

Gesture Classification

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

Gesture Classification

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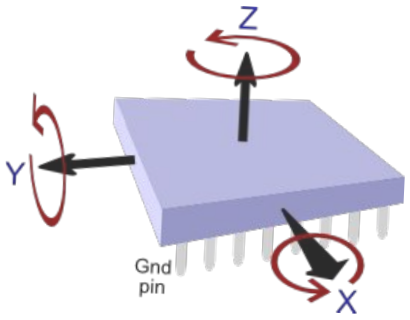
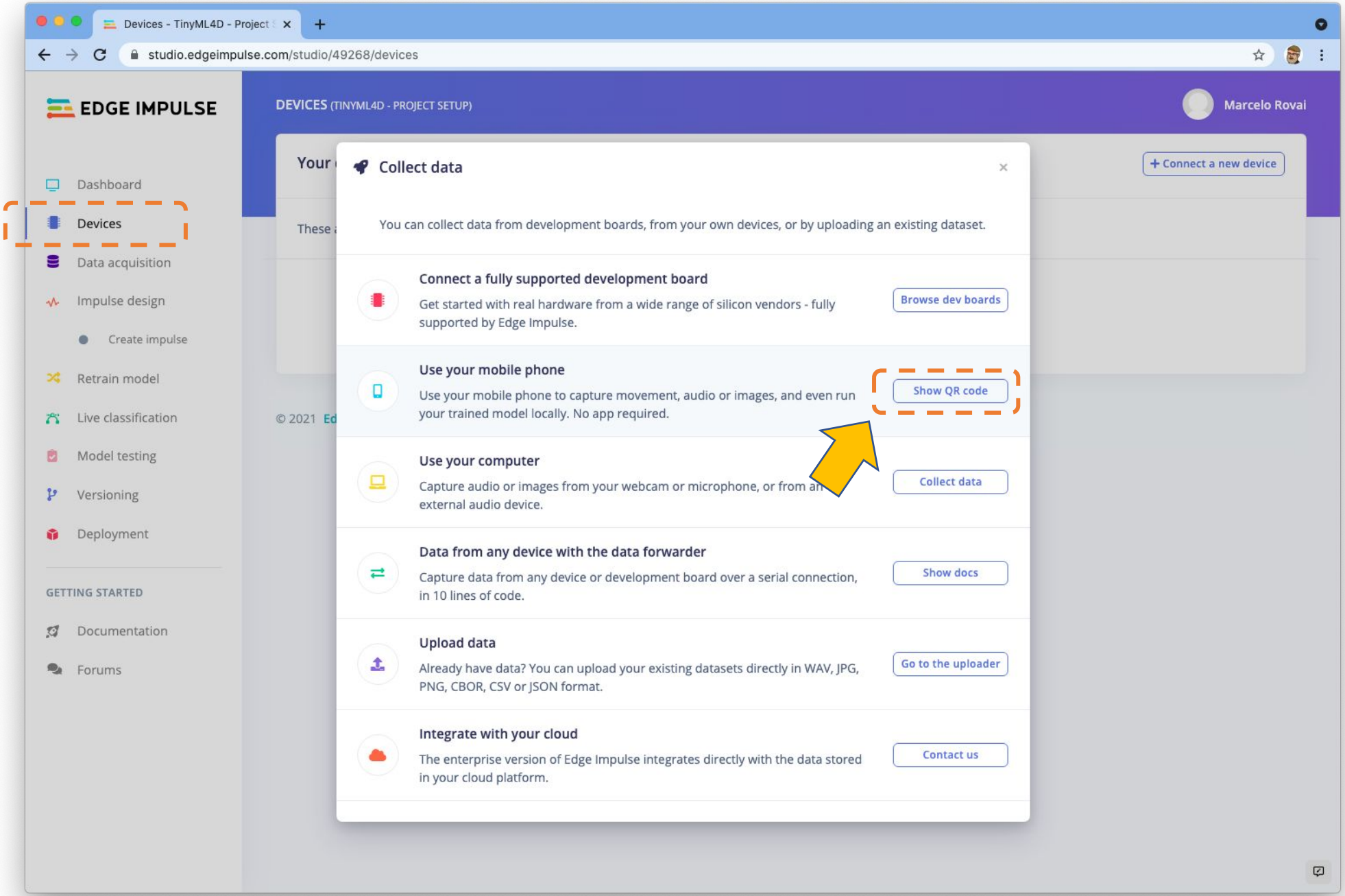
  - idle



- Data: collect & test using accelerometer as sensor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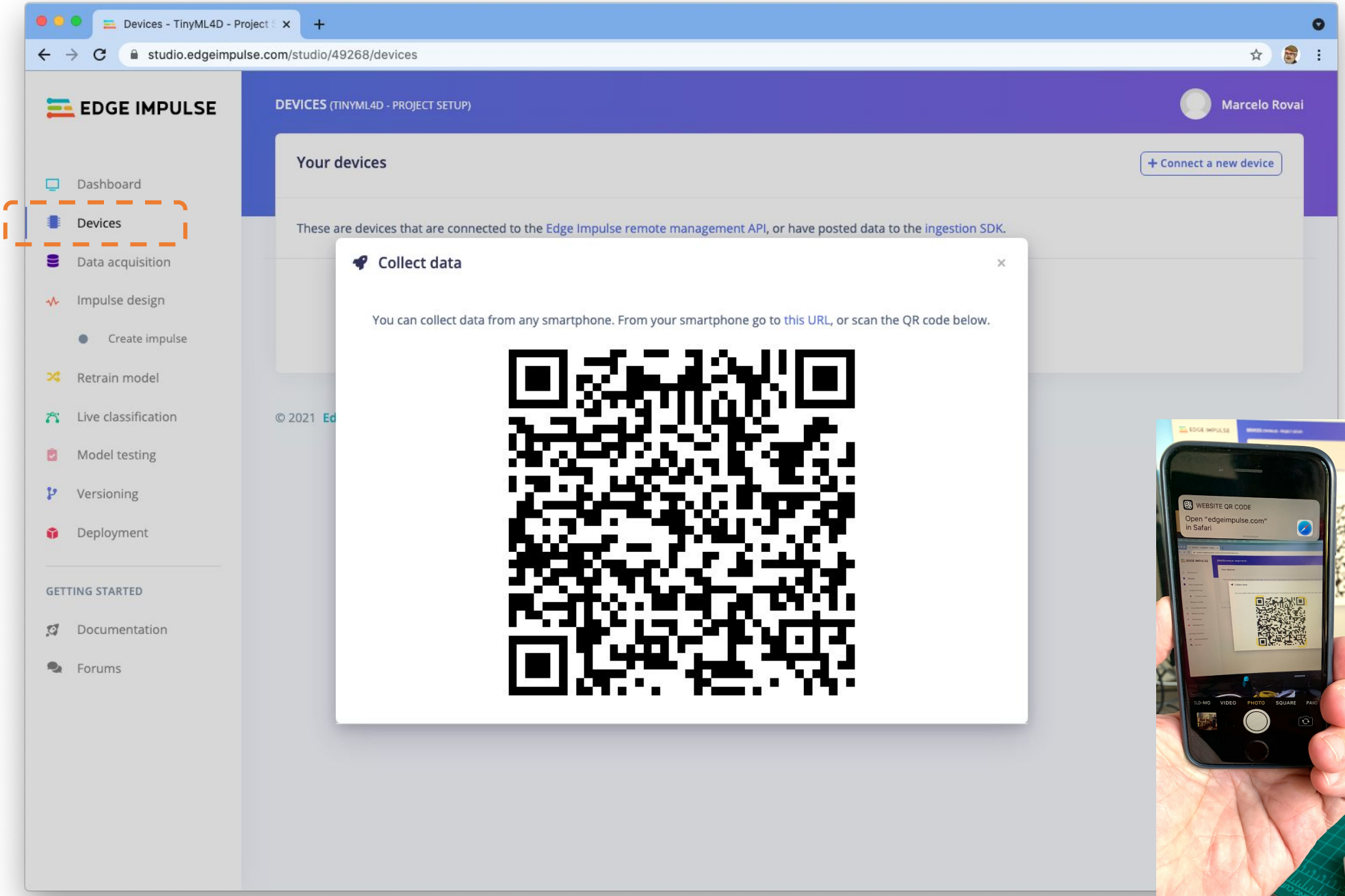
+ Connect a new device
Collect data
You can collect data from development boards, from your own devices, or by uploading an existing dataset.
Connect a fully supported development board
Get started with real hardware from a wide range of silicon vendors - fully supported by Edge Impulse.
Browse dev boards
Use your mobile phone
Use your 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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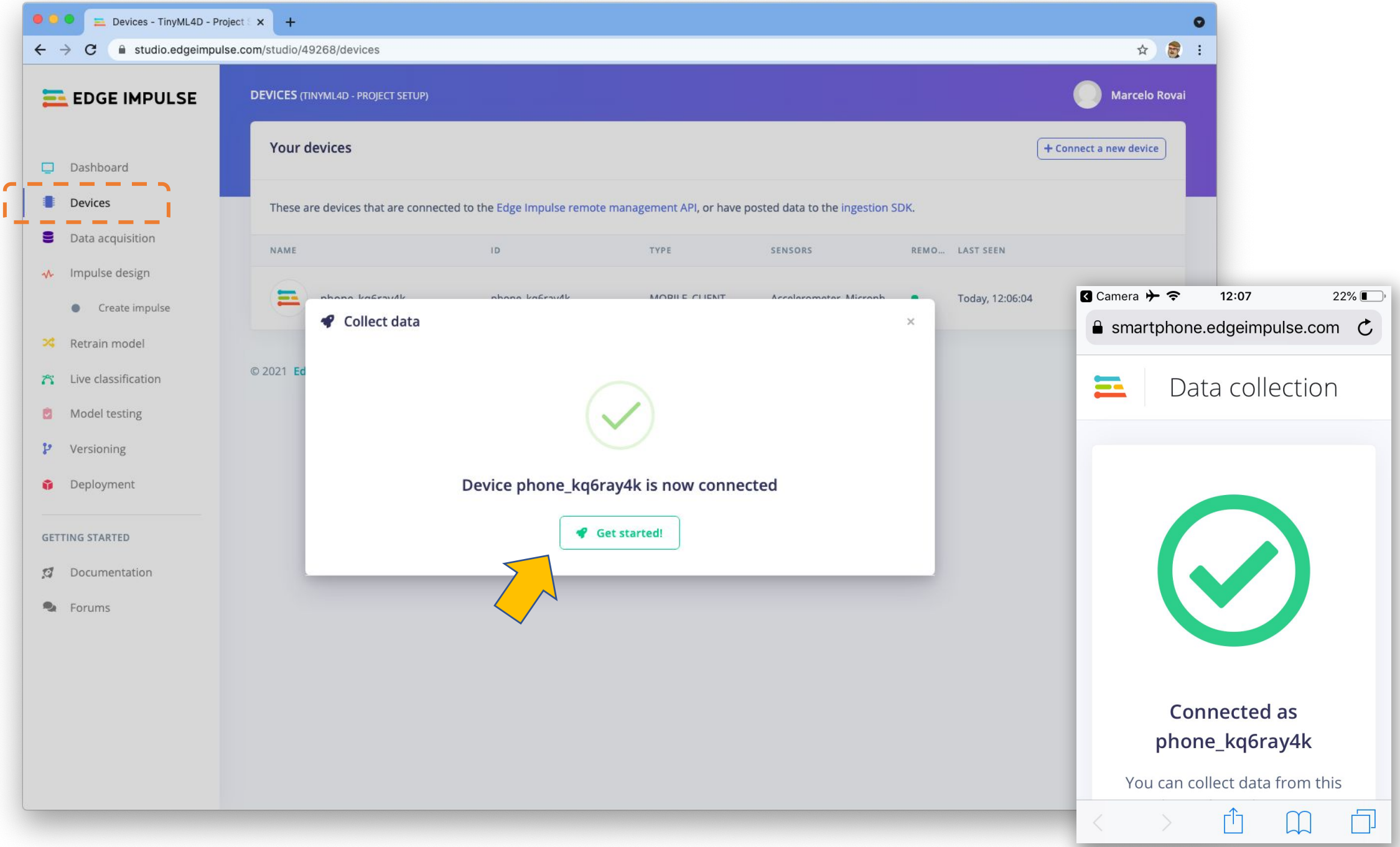
+ Connect a new device
These are devices that are connected to the Edge Impulse remote management API, or have posted data to the ingestion SDK.
Collect data
You can collect data from any smartphone. From your smartphone go to this URL, or scan the QR code below.
© 2021 Ed


WEBSITE QR CODE
Open "edgeimpulse.com" in Safari


Devices - TinyML4D - Project
studio.edgeimpulse.com/studio/49268/devices
EDGE IMPULSE
DEVICES (TINYML4D - PROJECT SETUP)
Marcelo Rovai
Dashboard
Devices
Data acquisition
Impulse design
Create impulse
Retrain model
Live classification
Model testing
Versioning
Deployment
GETTING STARTED
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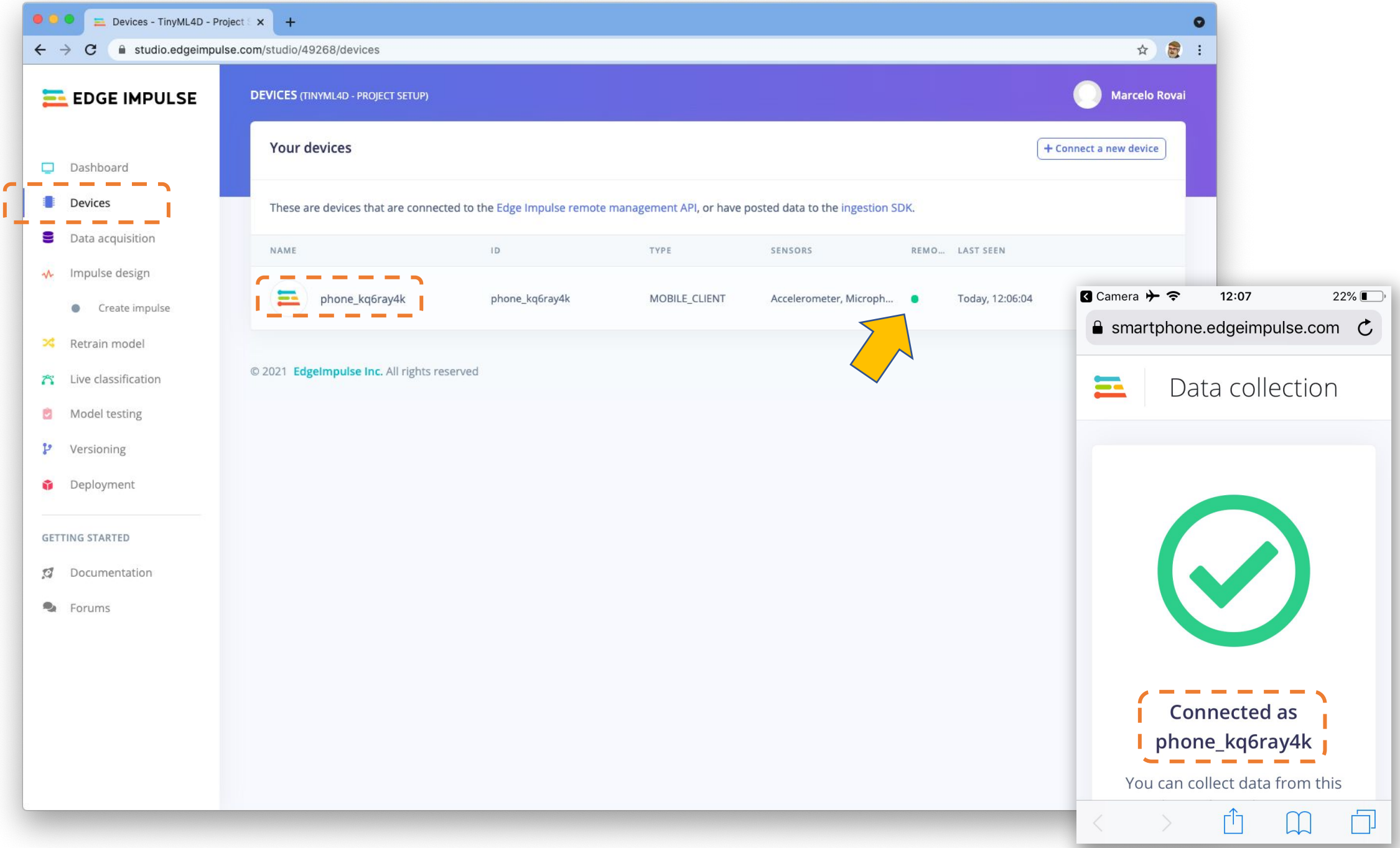
Forums
Your devices
+ Connect a new device
These are devices that are connected to the Edge Impulse remote management API, or have posted data to the ingestion SDK.
NAME
ID
TYPE
SENSORS
REMO...
LAST SEEN
Today, 12:06:04
© 2021
Collect data
Device phone_kq6ray4k is now connected
Get started!
Camera
12:07
22%
smartphone.edgeimpulse.com
Data collection
Connected as
phone_kq6ray4k
You can collect data from this


Devices - TinyML4D - Project
studio.edgeimpulse.com/studio/49268/devices
EDGE IMPULSE
DEVICES (TINYML4D - PROJECT SETUP)
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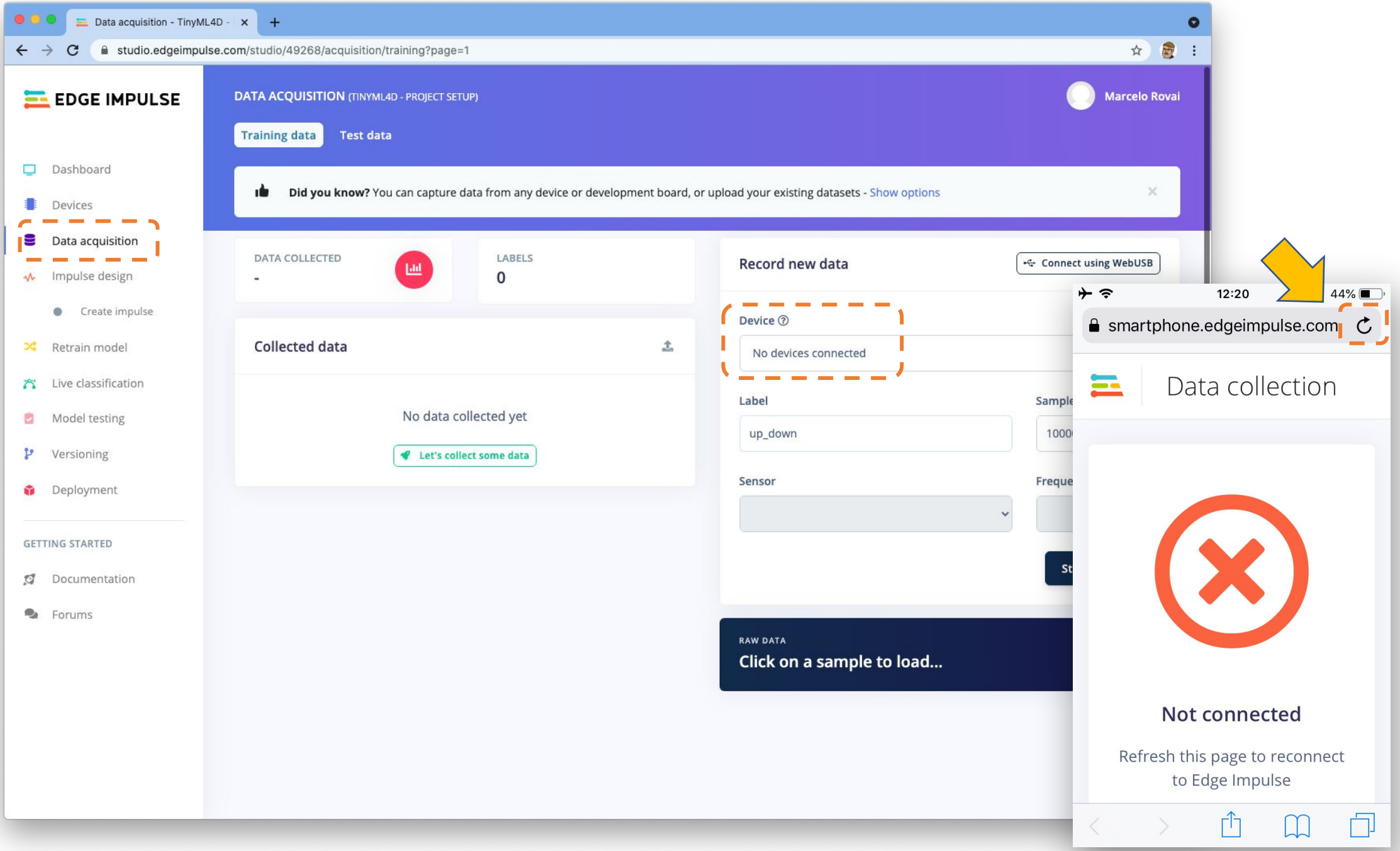
Your devices
+ Connect a new device
These are devices that are connected to the Edge Impulse remote management API, or have posted data to the ingestion SDK.
NAME
ID
TYPE
SENSORS
REMO...
LAST SEEN
phone_kq6ray4k
phone_kq6ray4k
MOBILE_CLIENT
Accelerometer, Microph...
Today, 12:06:04
© 2021 EdgeImpulse Inc. All rights reserved
Camera
12:07
22%
smartphone.edgeimpulse.com
Data collection
Connected as
phone_kq6ray4k
You can collect data from this


Data acquisition - TinyML4D -
studio.edgeimpulse.com/studio/49268/acquisition/training?page=1
EDGE IMPULSE
DATA ACQUISITION (TINYML4D - PROJECT SETUP)
Marcelo Rovai
Training data
Test data
Did you know? You can capture data from any device or development board, or upload your existing datasets - Show options
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Live classification
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Versioning
Deployment
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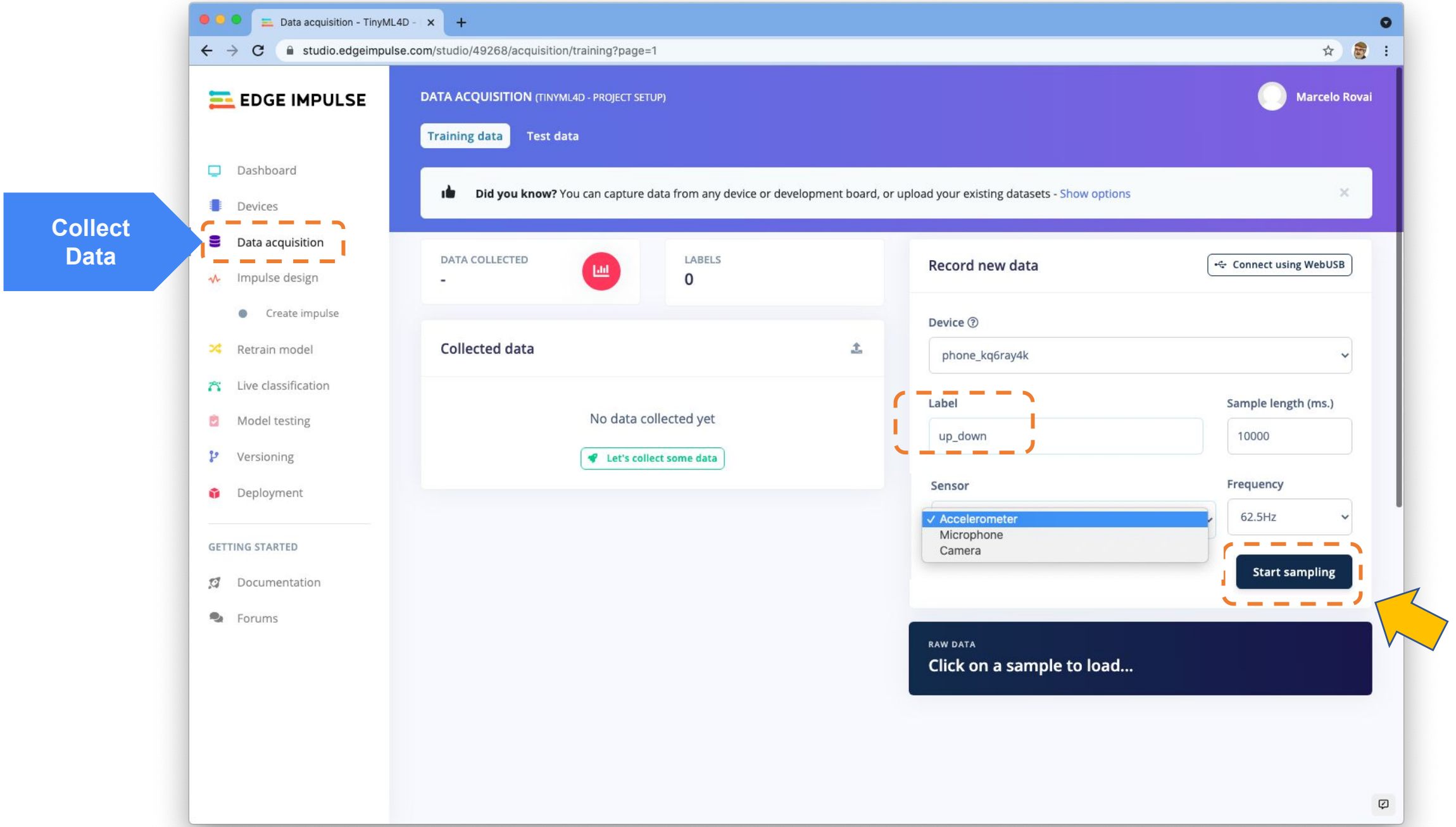
Forums
DATA COLLECTED
-
LABELS
0
Collected data
No data collected yet
Let's collect some data
Record new data
Connect using WebUSB
Device
No devices connected
Label
up_down
Sensor
RAW DATA
Click on a sample to load...
12:20
44%
smartphone.edgeimpulse.com
Data collection
Not connected
Refresh this page to reconnect to Edge Impulse


Collect Data
Data acquisition - TinyML4D -
studio.edgeimpulse.com/studio/49268/acquisition/training?page=1
EDGE IMPULSE
DATA ACQUISITION (TINYML4D - PROJECT SETUP)
Marcelo Rovai
Training data
Test data
Did you know? You can capture data from any device or development board, or upload your existing datasets - Show options
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Live classification
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DATA COLLECTED
-
LABELS
0
Collected data
No data collected yet
Let's collect some data
Record new data
Connect using WebUSB
Device
phone_kq6ray4k
Label
up_down
Sample length (ms.)
10000
Sensor
Accelerometer
Microphone
Camera
Frequency
62.5Hz
Start sampling
RAW DATA
Click on a sample to load...

Collect Data

Data acquisition - TinyML4D -

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

EDGE IMPULSE

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  - Create impulse
- Retrain model
- Live classification
- Model testing
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- Deployment

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DATA ACQUISITION (TINYML4D - PROJECT SETUP)

Marcelo Rovai

Training data | Test data

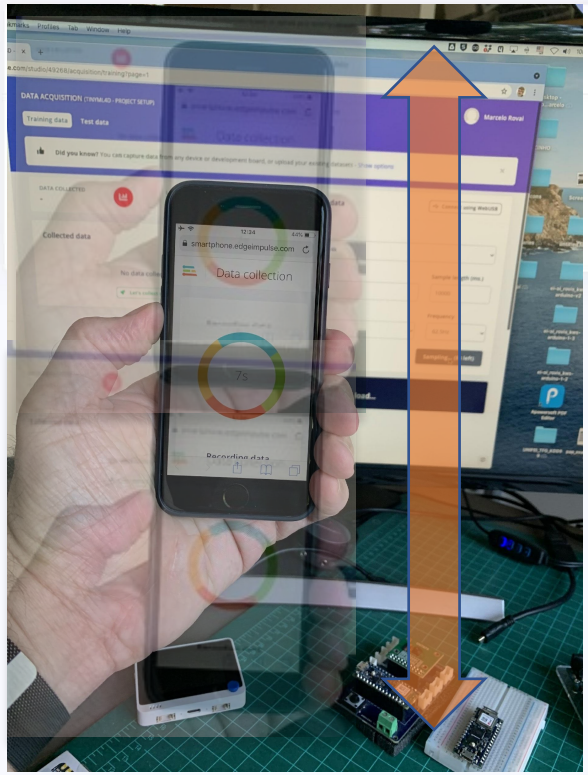
Did you know? You can capture data from any device or development board, or upload your existing datasets - Show options

DATA COLLECTED

-

LABELS

0



Record new data

Connect using WebUSB

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...

12:35 44%

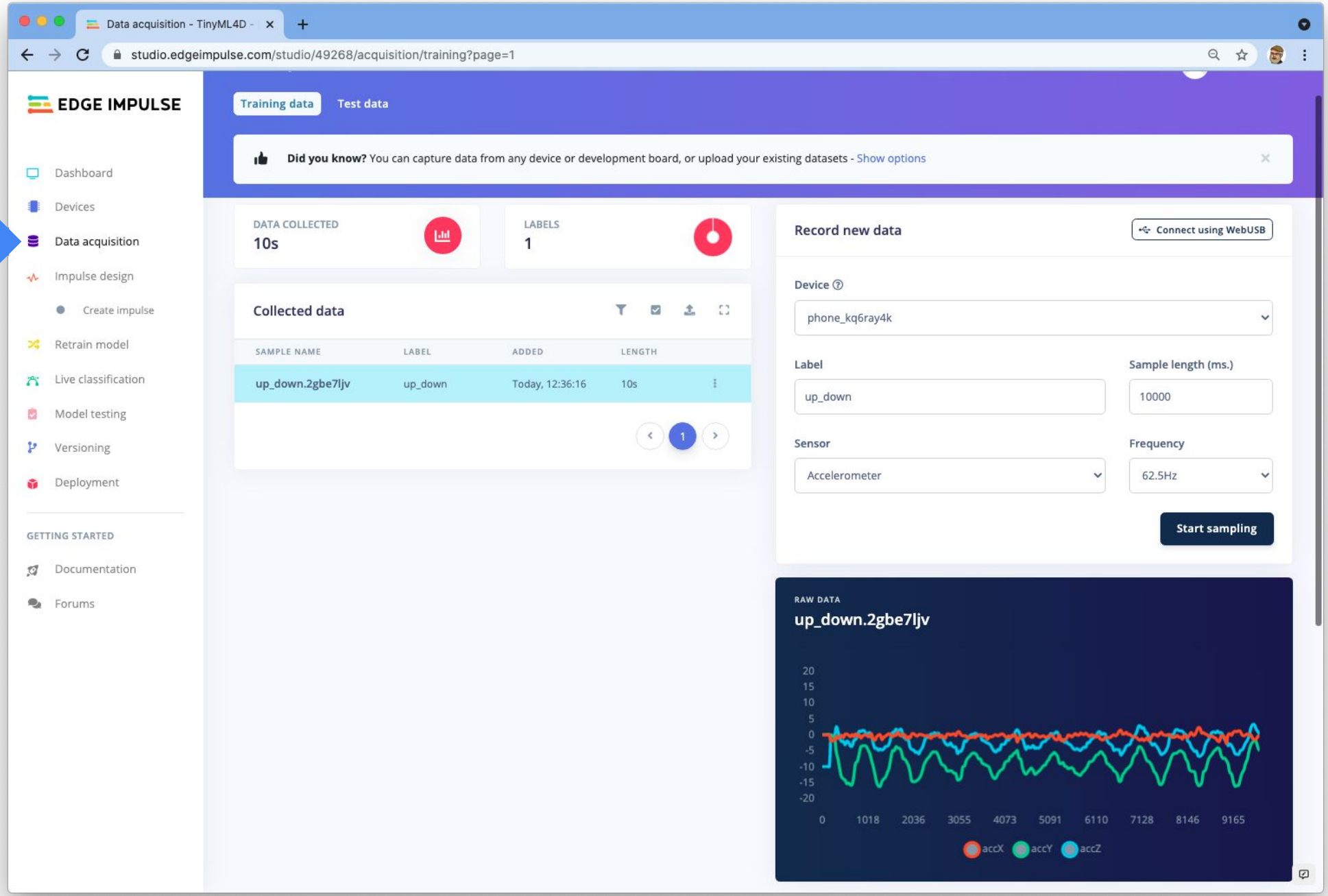
smartphone.edgeimpulse.com

Data collection

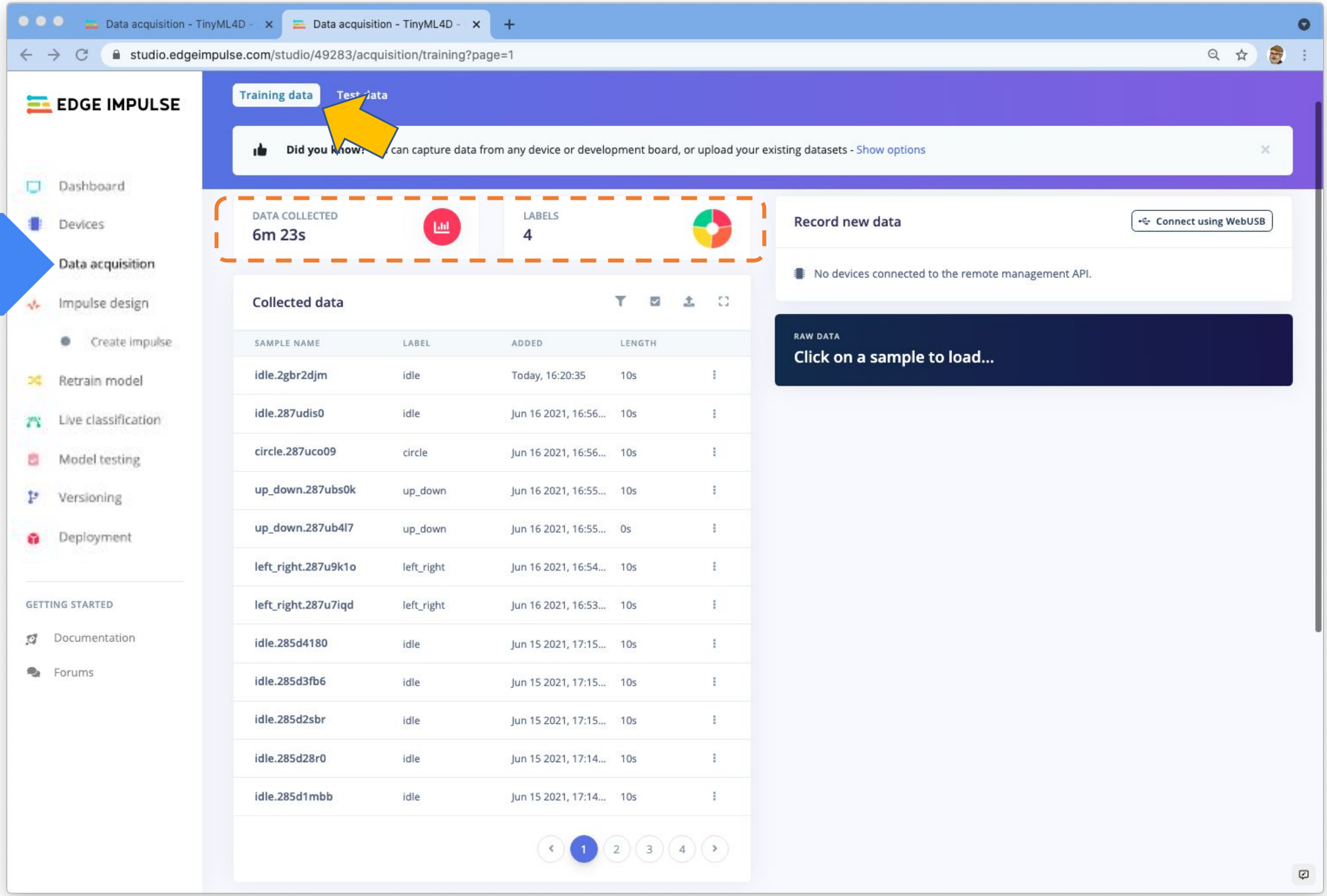
4s

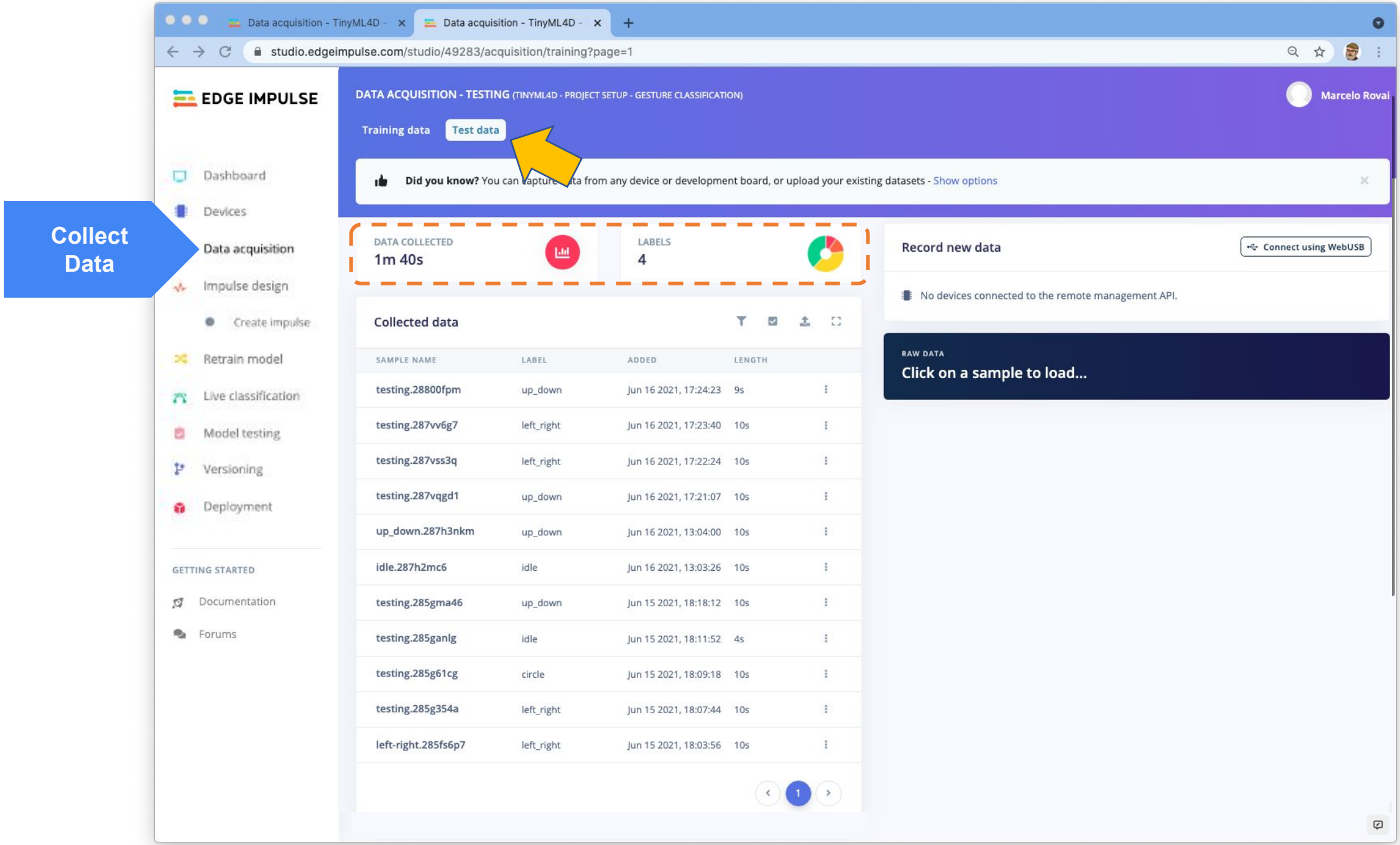
Recording data

Collect Data



Collect Data




Collect Data
Data acquisition - TinyML4D -
Data acquisition - TinyML4D -
studio.edgeimpulse.com/studio/49283/acquisition/training?page=1
EDGE IMPULSE
DATA ACQUISITION - TESTING (TINYML4D - PROJECT SETUP - GESTURE CLASSIFICATION)
Marcelo Rovai
Training data
Test data
Did you know? You can capture data from any device or development board, or upload your existing datasets - Show options
Dashboard
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Data acquisition
Impulse design
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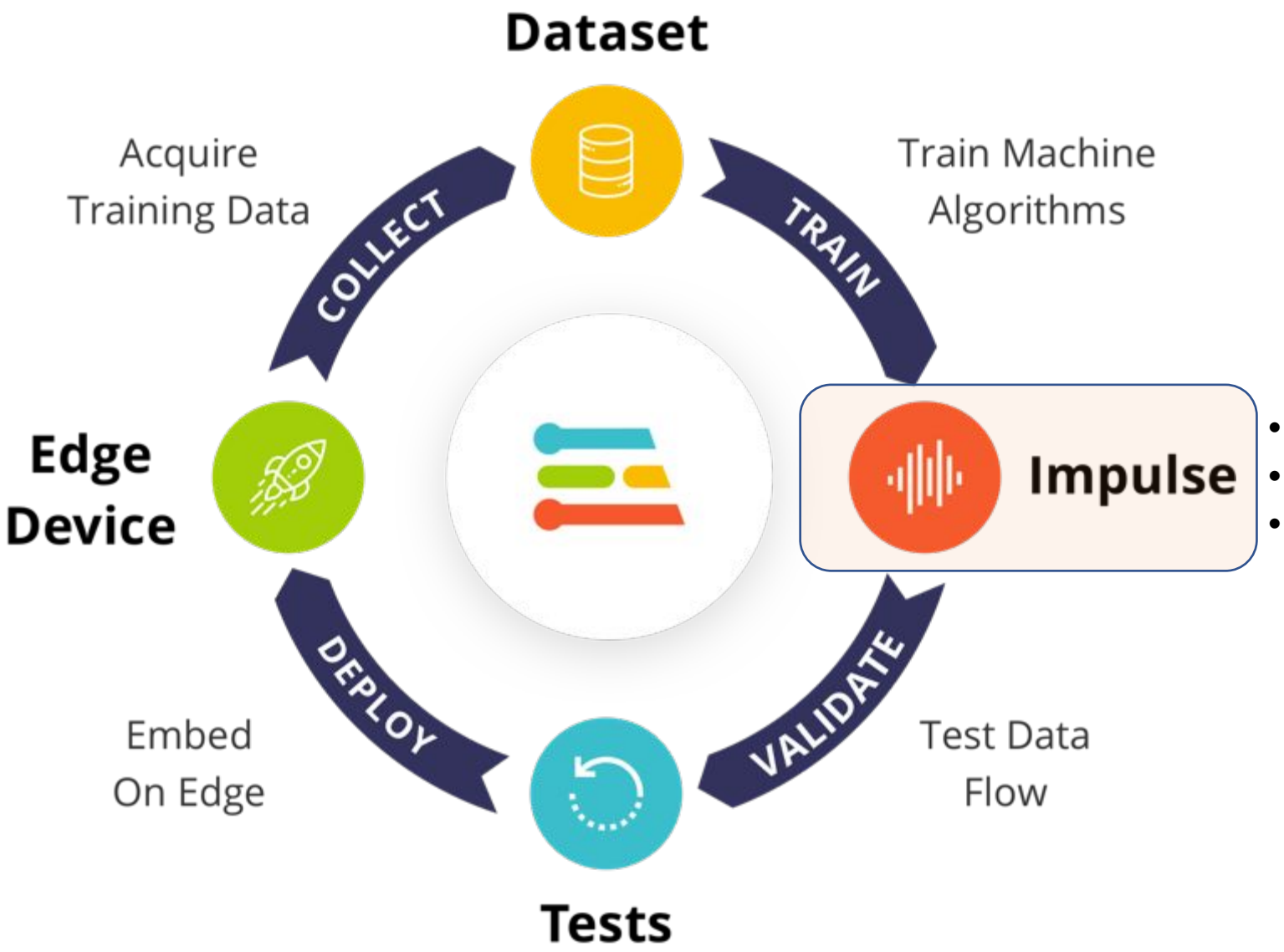
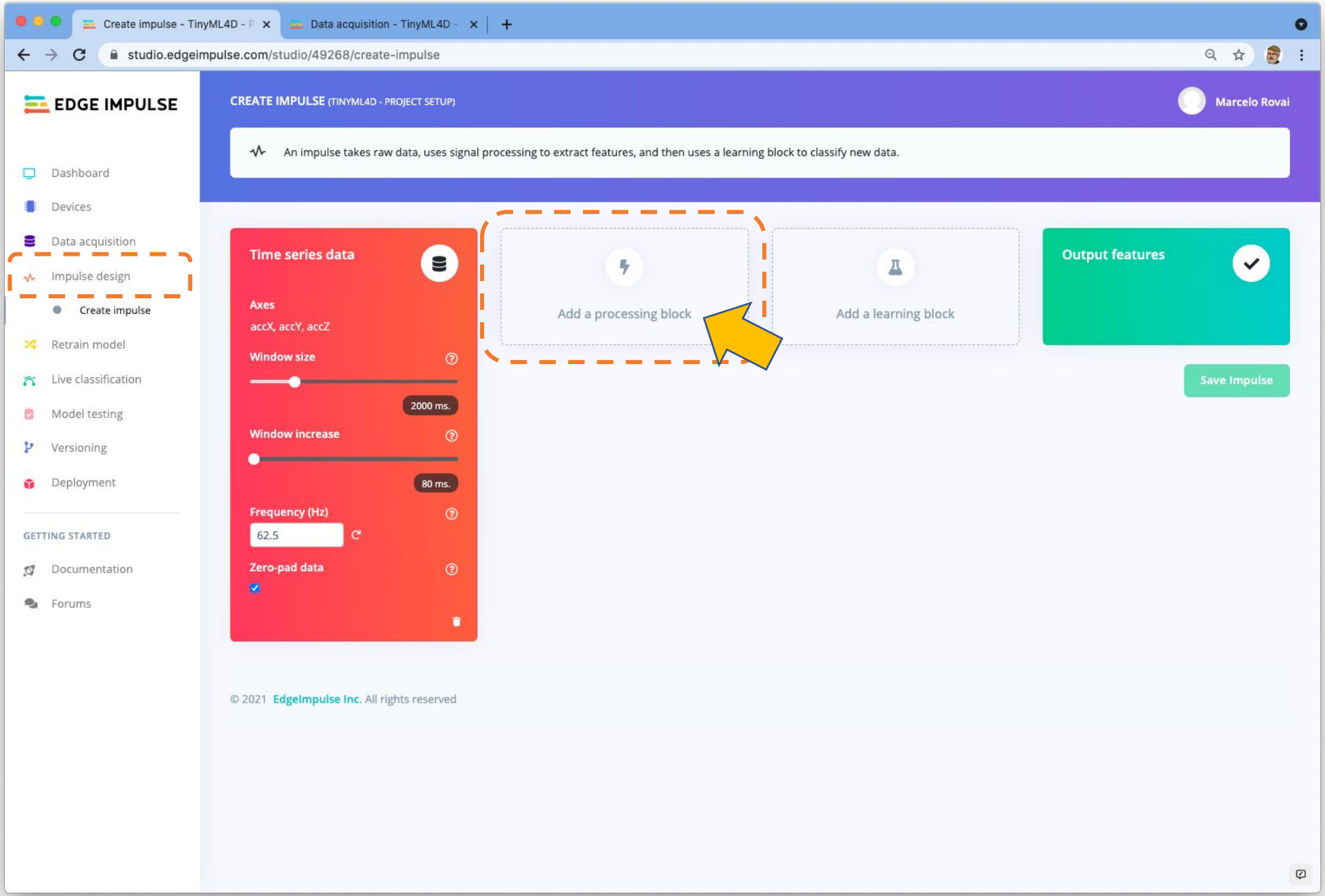
DATA COLLECTED
1m 40s
LABELS
4
Record new data
Connect using WebUSB
No devices connected to the remote management API.
Collected data
SAMPLE NAME
LABEL
ADDED
LENGTH
testing.28800fpm up_down Jun 16 2021, 17:24:23 9s
testing.287vv6g7 left_right Jun 16 2021, 17:23:40 10s
testing.287vss3q left_right Jun 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
1
RAW DATA
Click on a sample to load...



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


Create impulse - TinyML4D -
Data acquisition - TinyML4D -
studio.edgeimpulse.com/studio/49268/create-impulse
EDGE IMPULSE
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CREATE IMPULSE (TINYML4D - PROJECT SETUP)
Marcelo Rovai
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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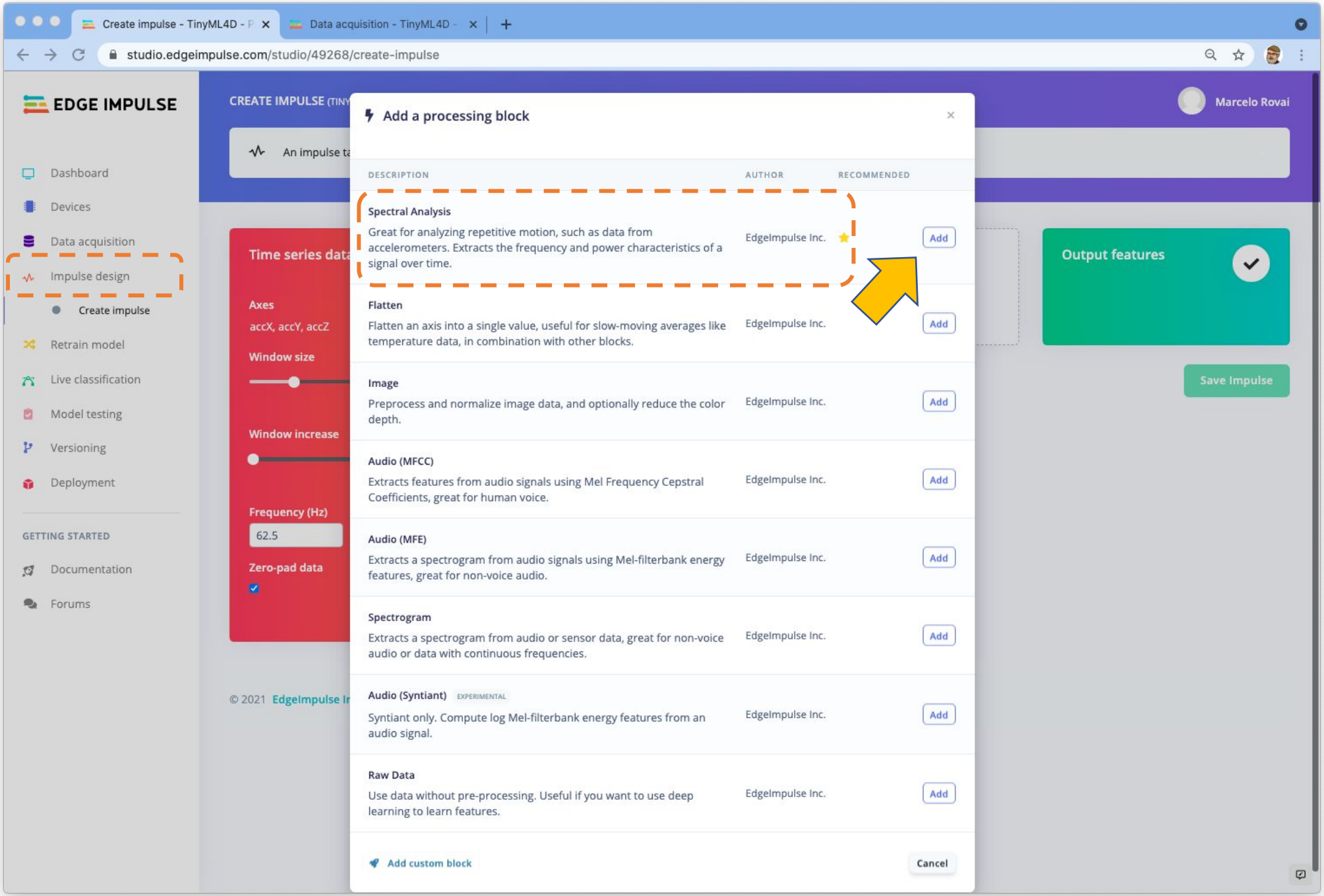
Create impulse - TinyML4D -
Data acquisition - TinyML4D -
studio.edgeimpulse.com/studio/49268/create-impulse
EDGE IMPULSE
Dashboard
Devices
Data acquisition
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Create impulse
Retrain model
Live classification
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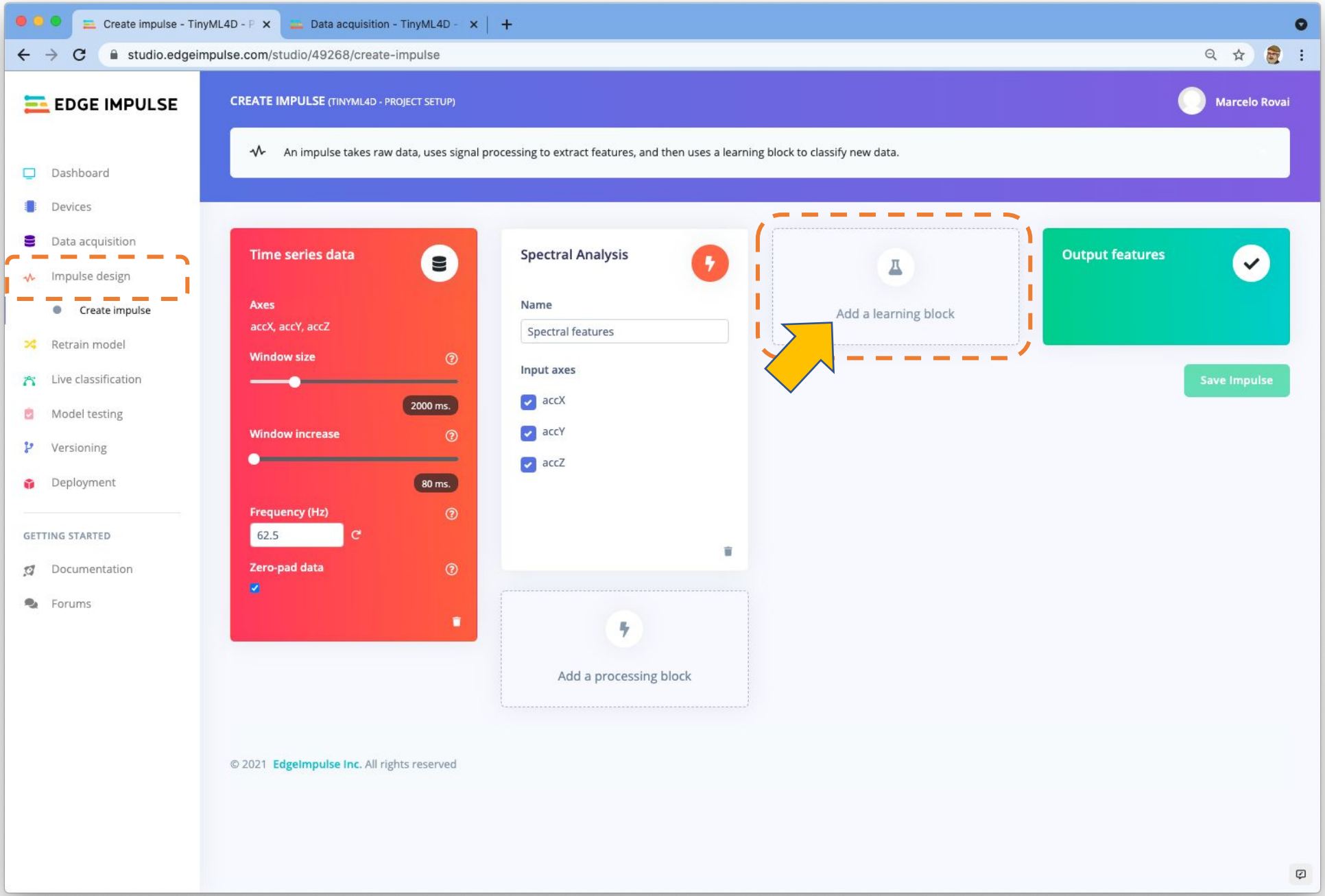
CREATE IMPULSE
Marcelo Rovai
Time series data
Axes
accX, accY, accZ
Window size
Window increase
Frequency (Hz)
62.5
Zero-pad data
Output features
Save Impulse
© 2021 EdgeImpulse
Add a processing block
DESCRIPTION
AUTHOR
RECOMMENDED
Spectral Analysis
Great for analyzing repetitive motion, such as data from accelerometers. Extracts the frequency and power characteristics of a signal over time.
EdgeImpulse Inc.
Add
Flatten
Flatten an axis into a single value, useful for slow-moving averages like temperature data, in combination with other blocks.
EdgeImpulse Inc.
Add
Image
Preprocess and normalize image data, and optionally reduce the color depth.
EdgeImpulse Inc.
Add
Audio (MFCC)
Extracts features from audio signals using Mel Frequency Cepstral Coefficients, great for human voice.
EdgeImpulse Inc.
Add
Audio (MFE)
Extracts a spectrogram from audio signals using Mel-filterbank energy features, great for non-voice audio.
EdgeImpulse Inc.
Add
Spectrogram
Extracts a spectrogram from audio or sensor data, great for non-voice audio or data with continuous frequencies.
EdgeImpulse Inc.
Add
Audio (Syntiant)
EXPERIMENTAL
Syntiant only. Compute log Mel-filterbank energy features from an audio signal.
EdgeImpulse Inc.
Add
Raw Data
Use data without pre-processing. Useful if you want to use deep learning to learn features.
EdgeImpulse Inc.
Add
Add custom block
Cancel


Create impulse - TinyML4D -
Data acquisition - TinyML4D -
studio.edgeimpulse.com/studio/49268/create-impulse
EDGE IMPULSE
CREATE IMPULSE (TINYML4D - PROJECT SETUP)
Marcelo Rovai
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
Retrain model
Live classification
Model testing
Versioning
Deployment
GETTING STARTED
Documentation
Forums
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 processing block
Add a learning block
Output features
Save Impulse
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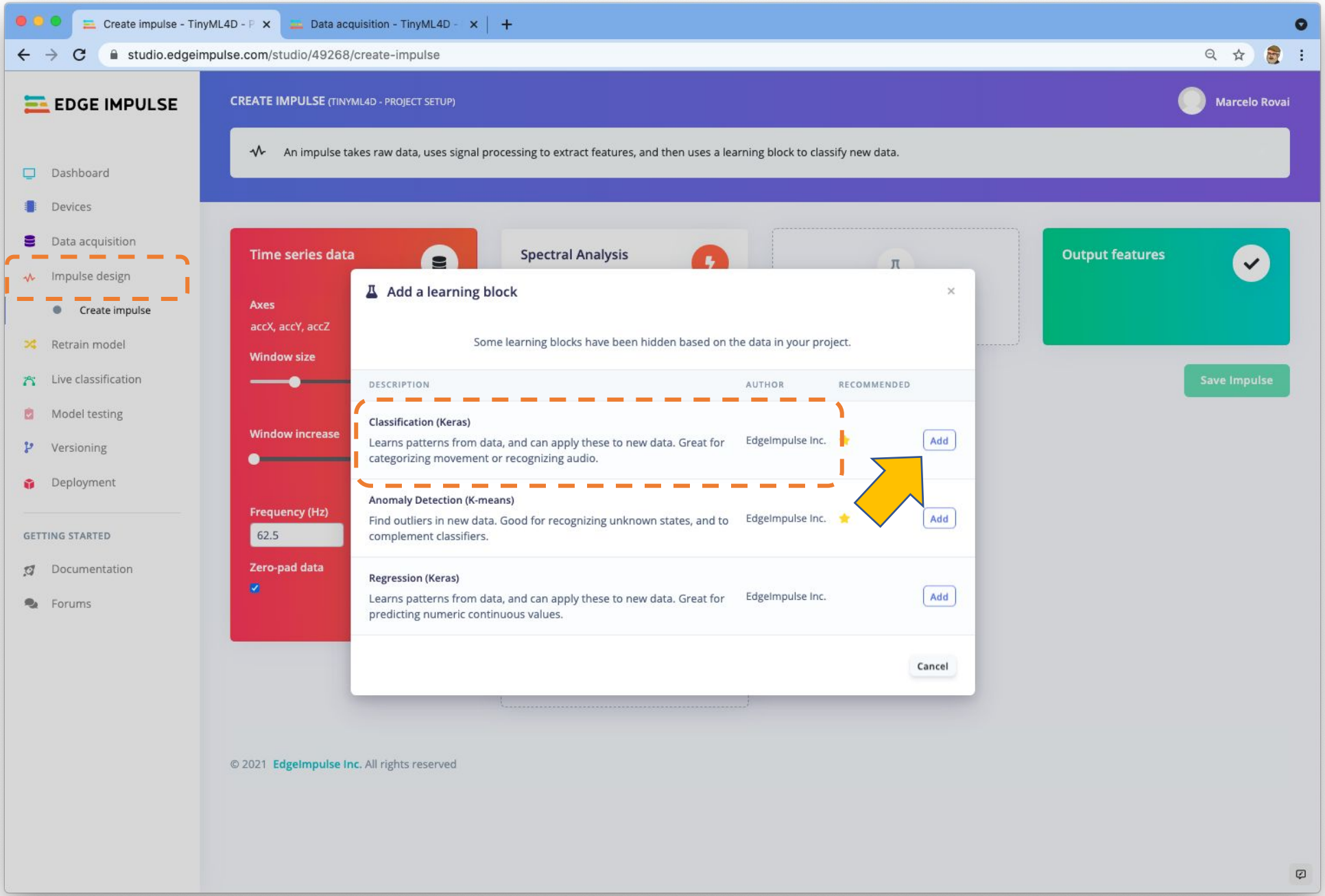
Create impulse - TinyML4D -
Data acquisition - TinyML4D -
studio.edgeimpulse.com/studio/49268/create-impulse
EDGE IMPULSE
CREATE IMPULSE (TINYML4D - PROJECT SETUP)
Marcelo Rovai
An impulse takes raw data, uses signal processing to extract features, and then uses a learning block to classify new data.
Dashboard
Devices
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Impulse design
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Live classification
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Versioning
Deployment
GETTING STARTED
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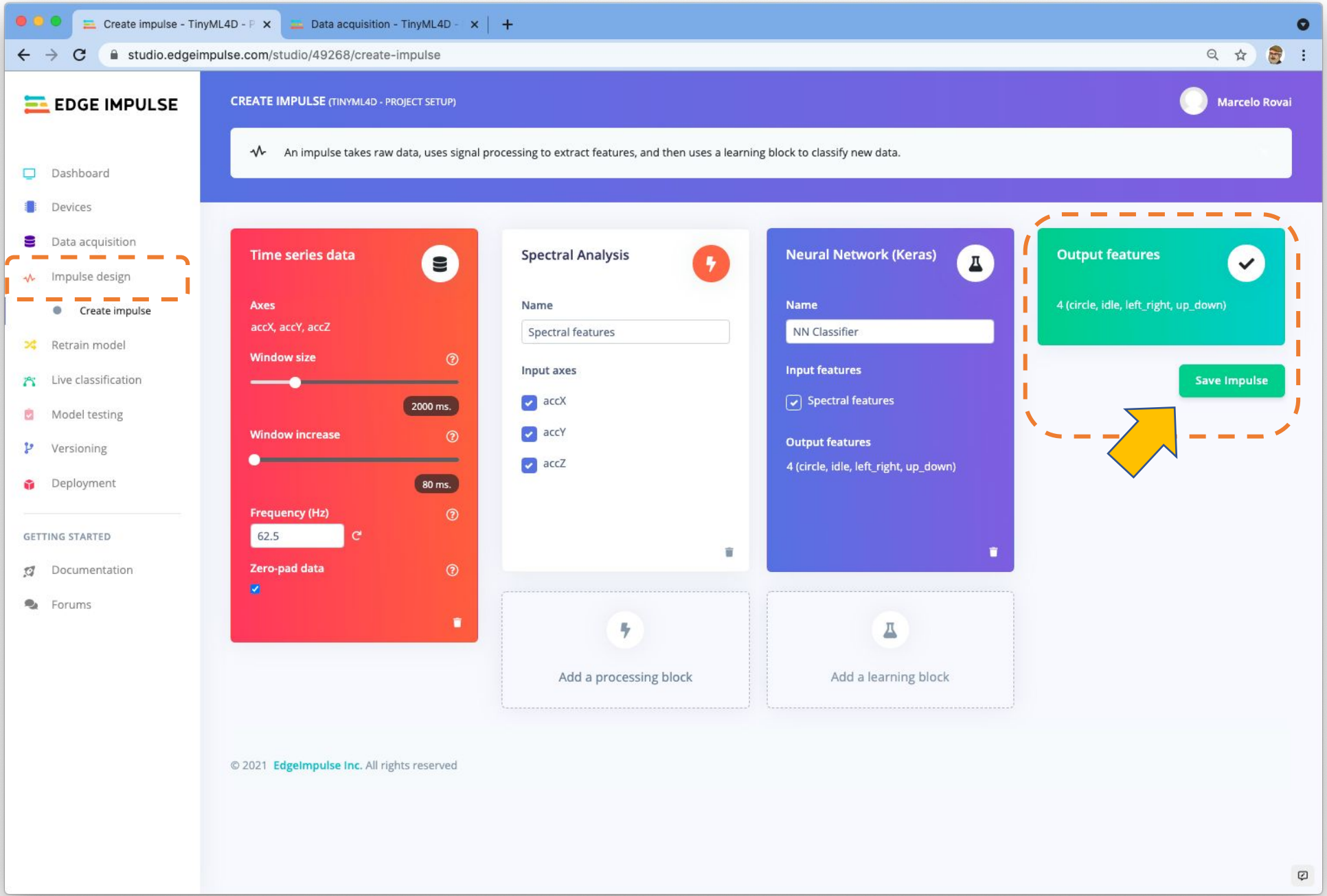
Time series data
Axes
accX, accY, accZ
Window size
Window increase
Frequency (Hz)
62.5
Zero-pad data
Spectral Analysis
Output features
Save Impulse
Add a learning block
Some learning blocks have been hidden based on the data in your project.
DESCRIPTION
AUTHOR
RECOMMENDED
Classification (Keras)
Learns patterns from data, and can apply these to new data. Great for categorizing movement or recognizing audio.
EdgeImpulse Inc.
Add
Anomaly Detection (K-means)
Find outliers in new data. Good for recognizing unknown states, and to complement classifiers.
EdgeImpulse Inc.
Add
Regression (Keras)
Learns patterns from data, and can apply these to new data. Great for predicting numeric continuous values.
EdgeImpulse Inc.
Add
Cancel
© 2021 EdgeImpulse Inc. All rights reserved


Create impulse - TinyML4D -
Data acquisition - TinyML4D -
studio.edgeimpulse.com/studio/49268/create-impulse
EDGE IMPULSE
Dashboard
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CREATE IMPULSE (TINYML4D - PROJECT SETUP)
Marcelo Rovai
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
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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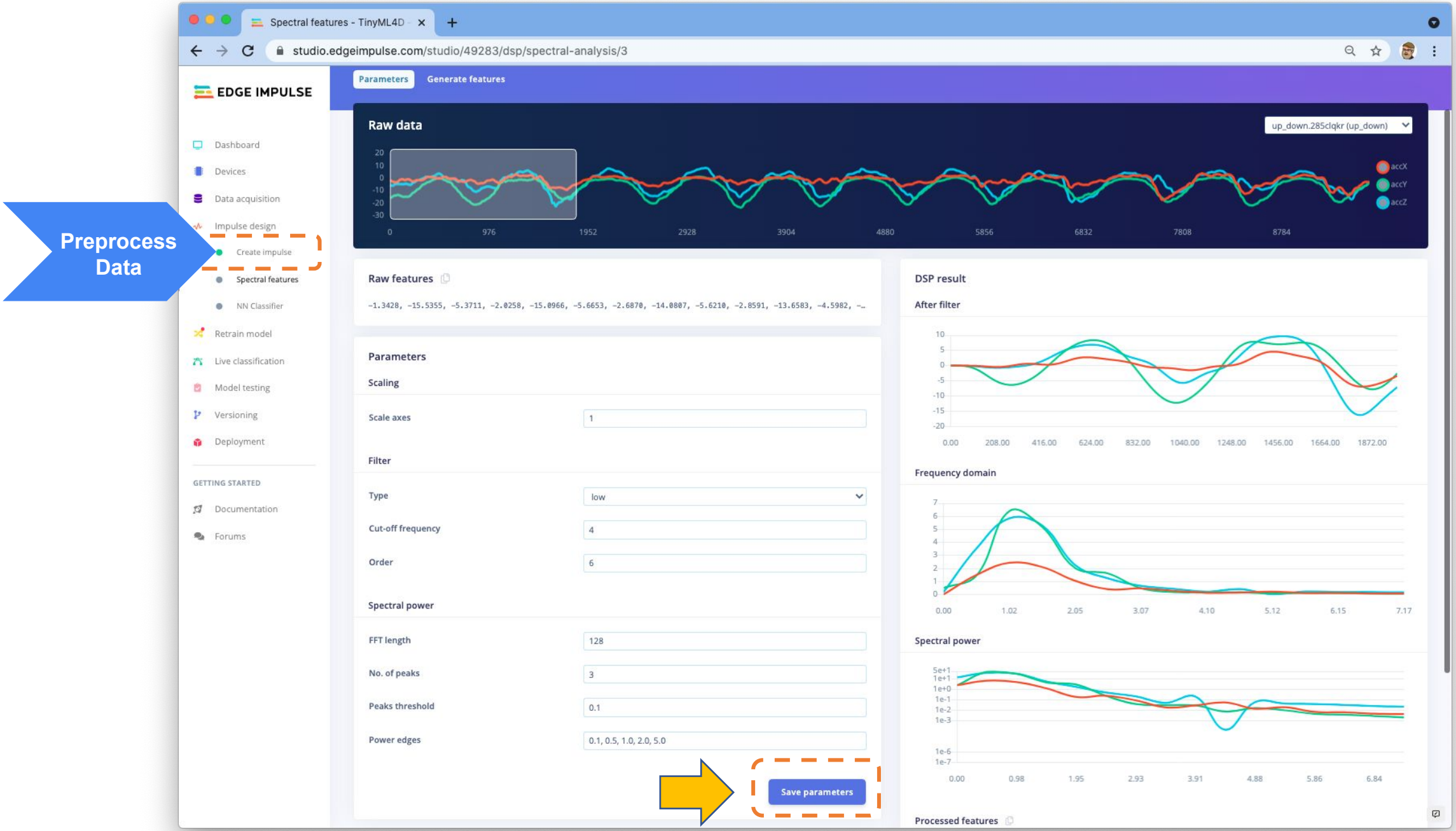
Preprocess Data
Spectral features - TinyML4D
studio.edgeimpulse.com/studio/49283/dsp/spectral-analysis/3
EDGE IMPULSE
Parameters
Generate features
Dashboard
Devices
Data acquisition
Impulse design
Create impulse
Spectral features
NN Classifier
Retrain model
Live classification
Model testing
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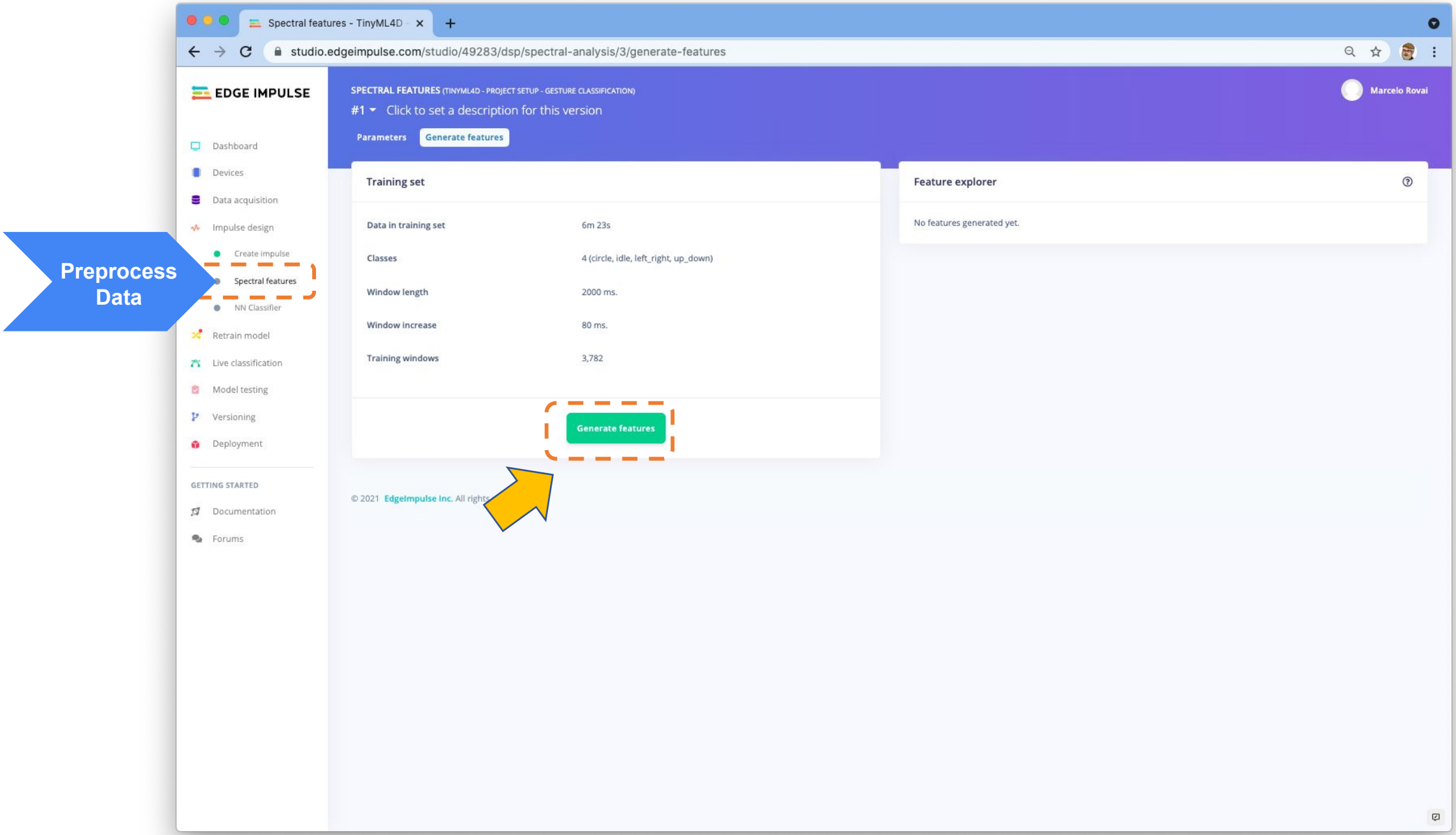
Raw data
up_down.285clqkr (up_down)
accX
accY
accZ
Raw features
Parameters
Scaling
Scale axes
1
Filter
Type
low
Cut-off frequency
4
Order
6
Spectral power
FFT length
128
No. of peaks
3
Peaks threshold
0.1
Power edges
0.1, 0.5, 1.0, 2.0, 5.0
Save parameters
DSP result
After filter
Frequency domain
Spectral power
Processed features


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
Marcelo Rovai
Dashboard
Devices
Data acquisition
Impulse design
Create impulse
Spectral features
NN Classifier
Retrain model
Live classification
Model testing
Versioning
Deployment
GETTING STARTED
Documentation
Forums
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
No features generated yet.
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Preprocess Data

Spectral features - TinyML4D

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

EDGE IMPULSE

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SPECTRAL FEATURES (TINYML4D - PROJECT SETUP - GESTURE CLASSIFICATION)

#1 Click to set a description for this version

Marcelo Rovai

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 generation output

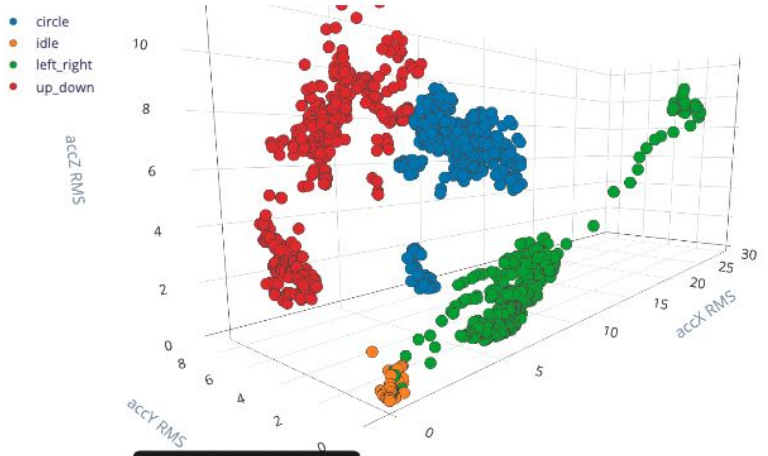
```
Scheduling job in cluster...
Job started
Creating windows from 42 files...
[ 1/42] Creating windows from files...
[42/42] Creating windows from files...
Created 3783 windows: circle: 870, idle: 1081, left_right: 969, up_down: 863

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
```

Feature explorer (3,783 samples)

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

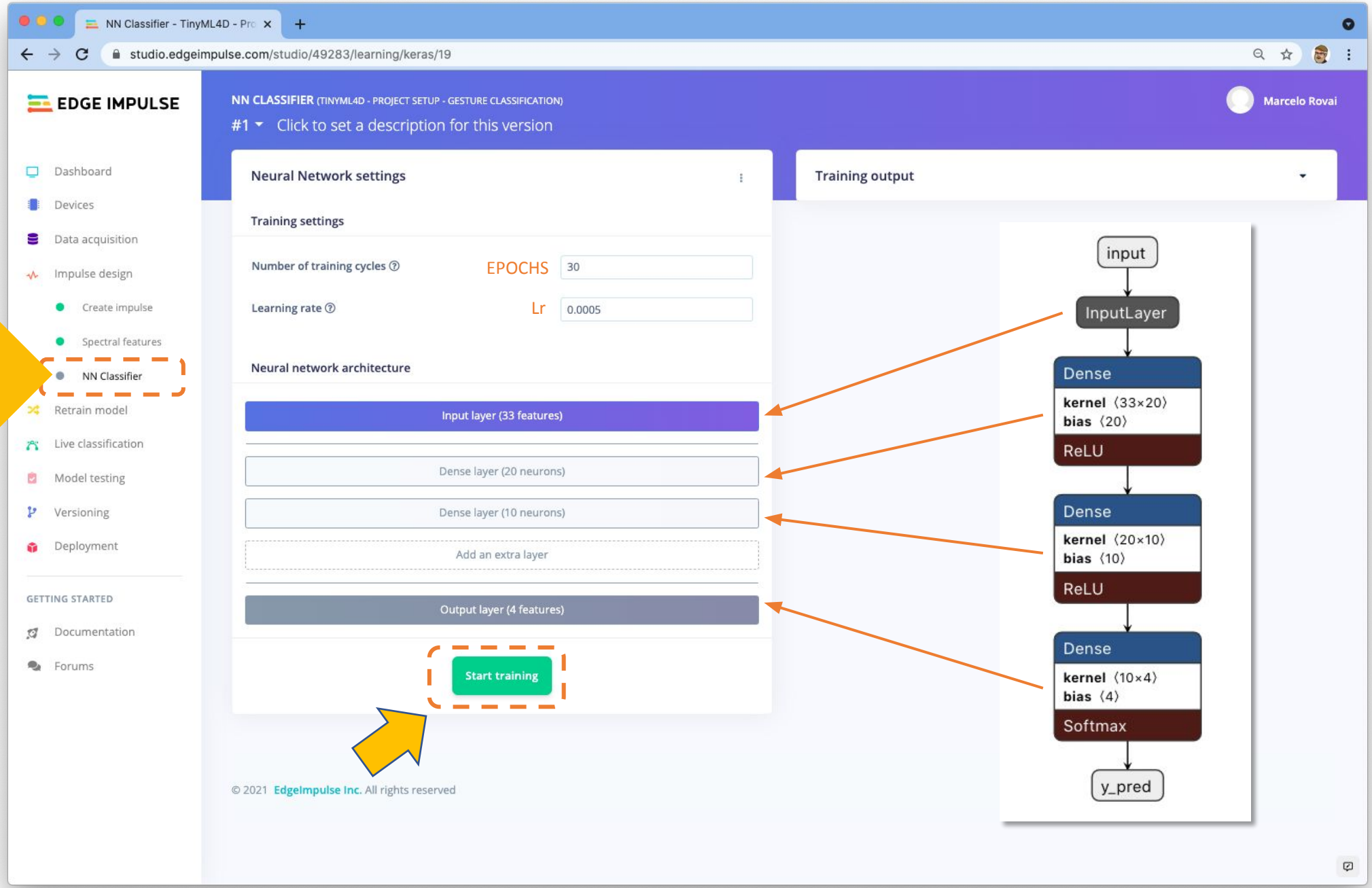


Estimate for calculating features on Cortex-M4F 80MHz

On-device performance

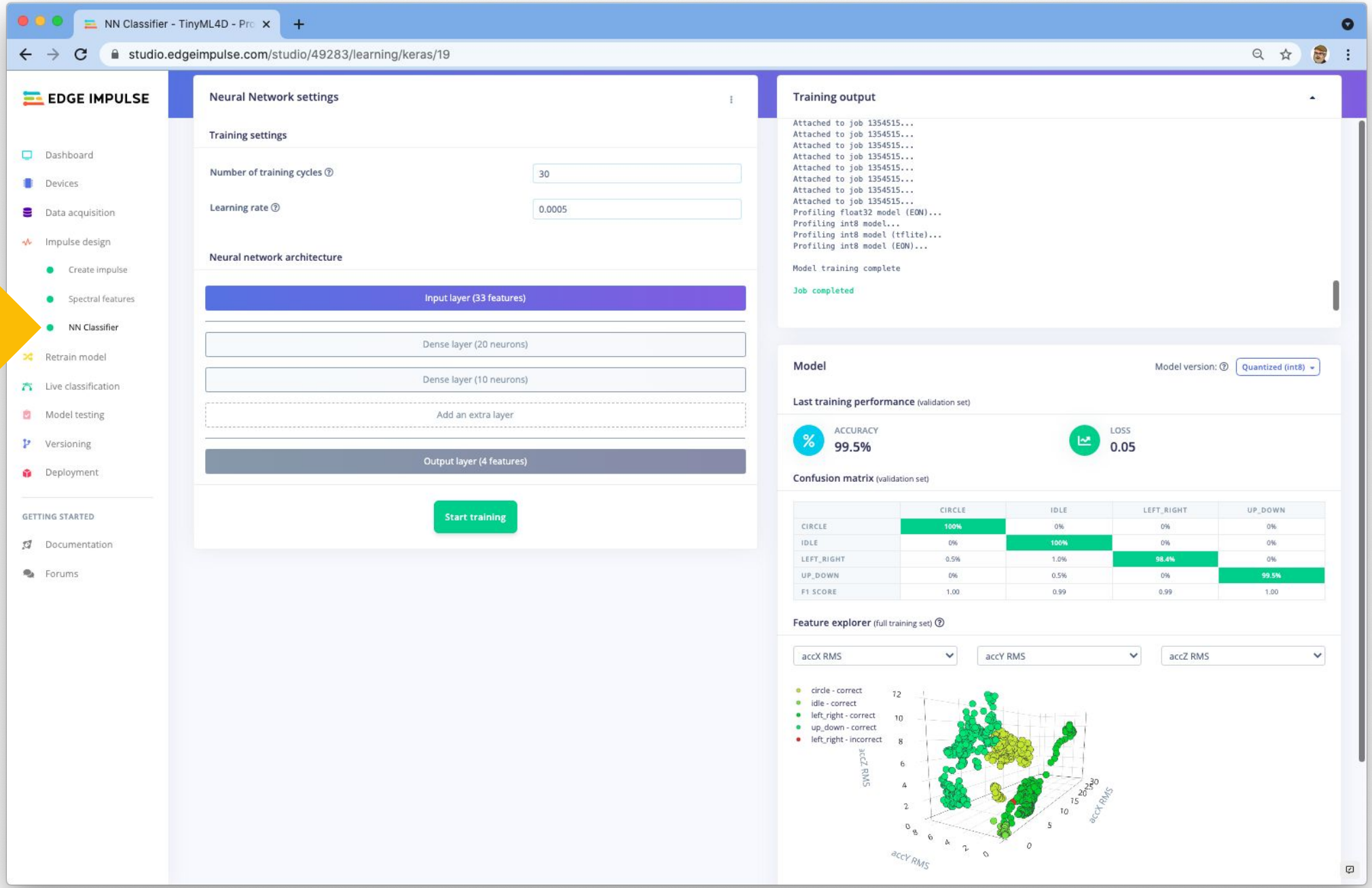
PROCESSING TIME
7 ms.

PEAK RAM USAGE
5 KB



Design a Model

Train a Model



NN Classifier - TinyML4D - Pro

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

EDGE IMPULSE

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GETTING STARTED

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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 99.5%

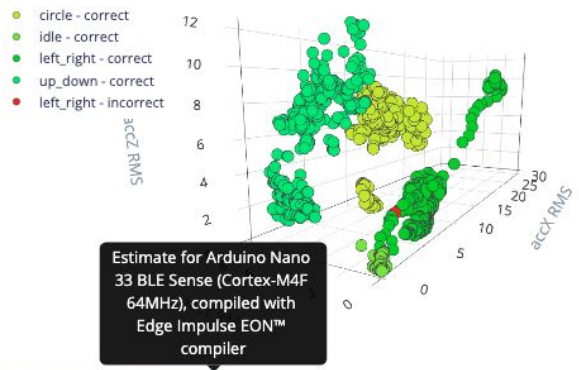
LOSS 0.05

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



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

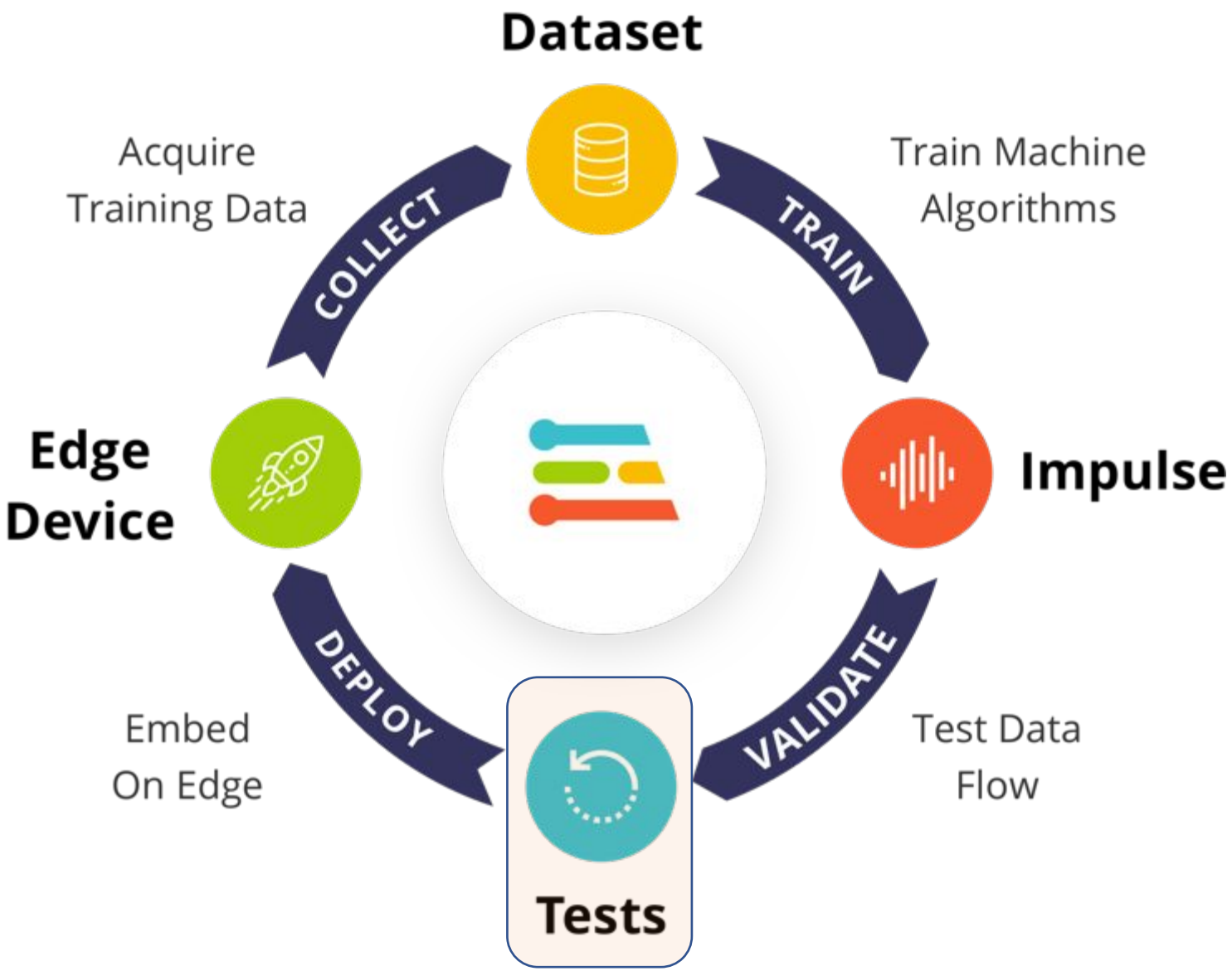
On-device performance

INFERENCING TIME 1 ms.

PEAK RAM USAGE 1.7K

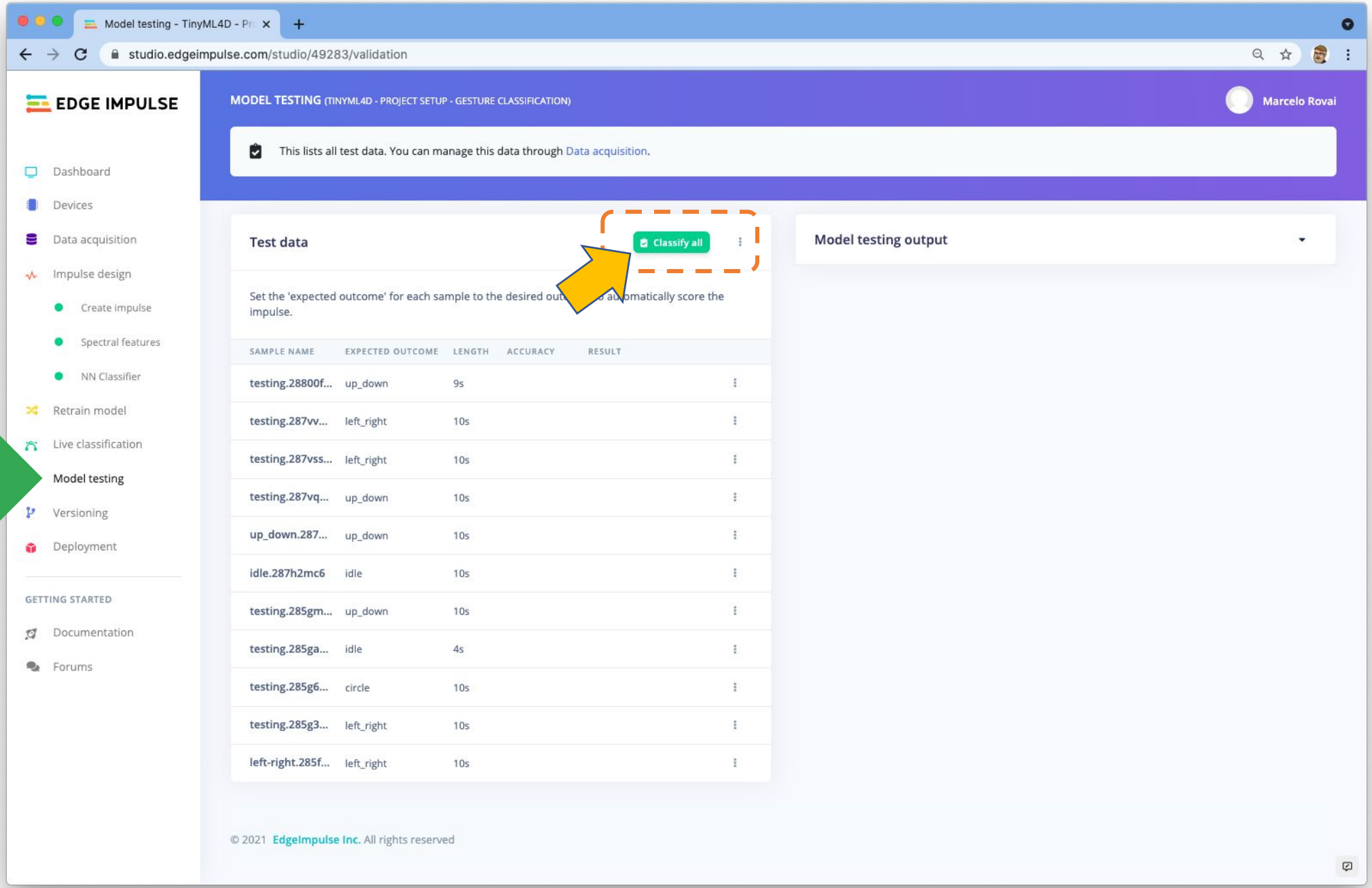
FLASH USAGE 17.9K

Evaluate
Optimize



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

Evaluate
Optimize



Evaluate
Optimize

Model testing - TinyML4D - Pr

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

Classify all

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
```

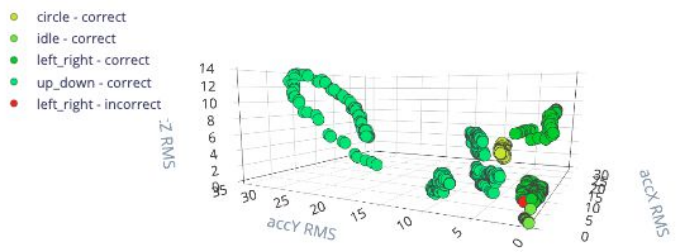
Model testing results

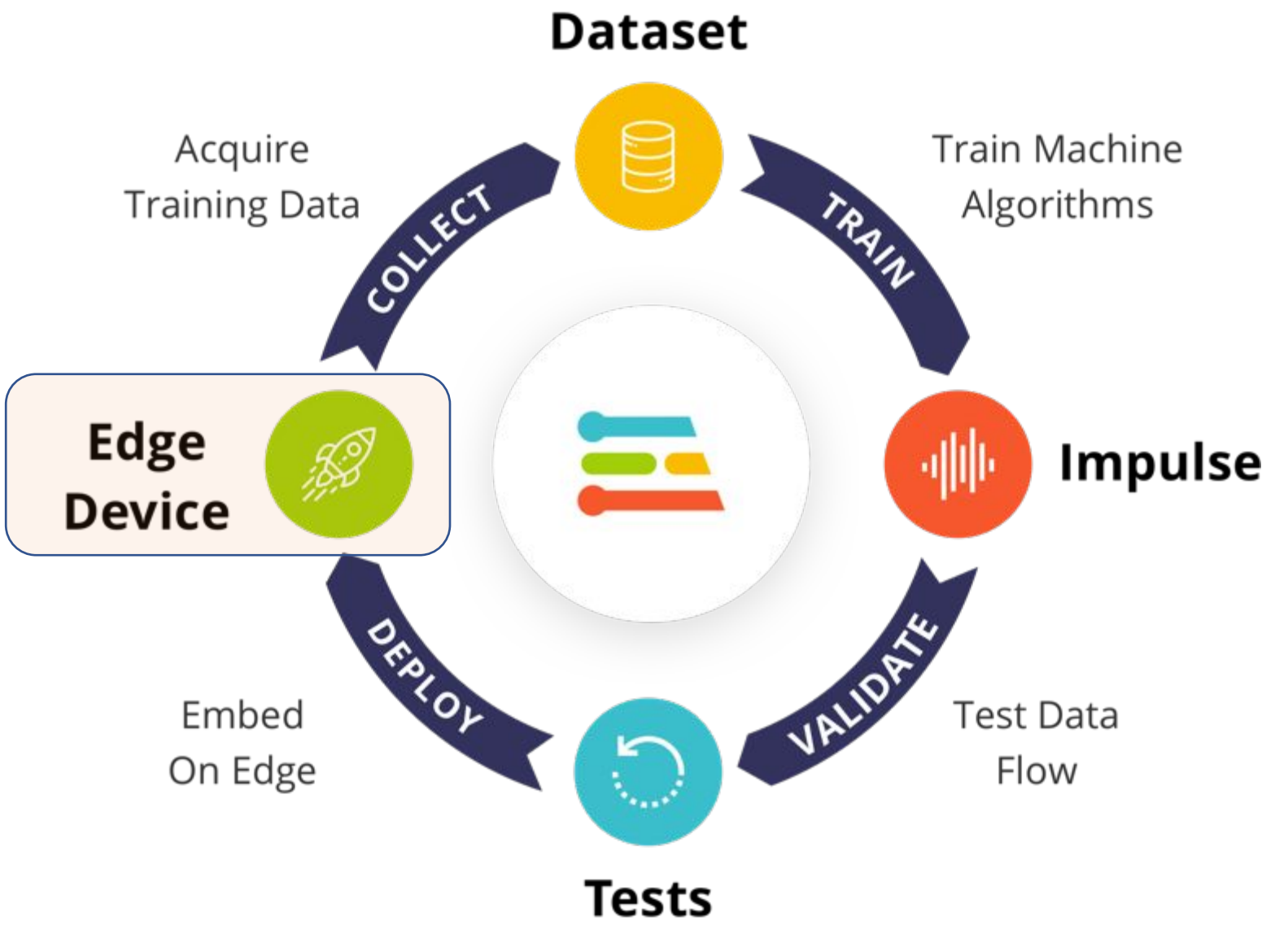
ACCURACY
99.90%

	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

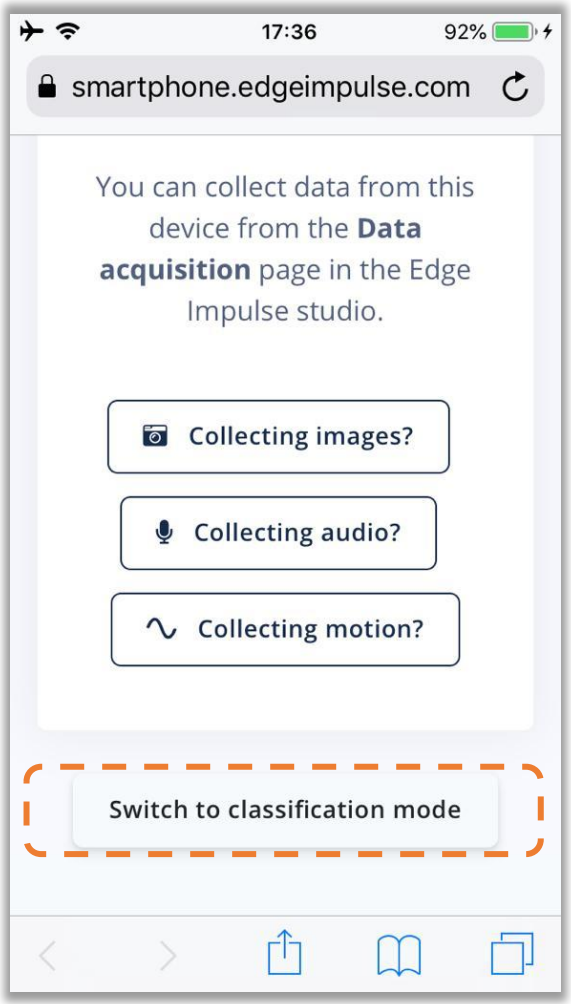
accX RMS | accY RMS | accZ RMS

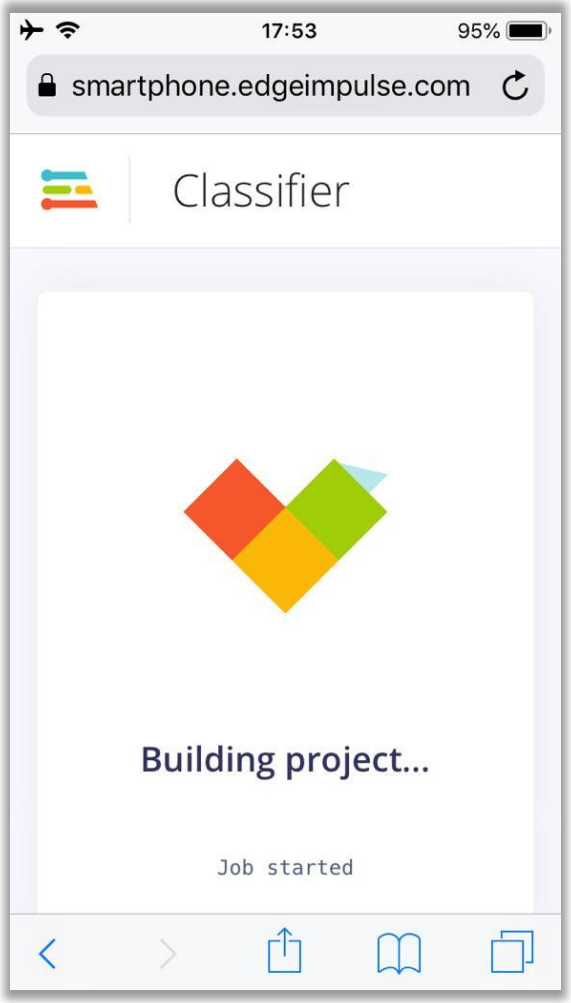




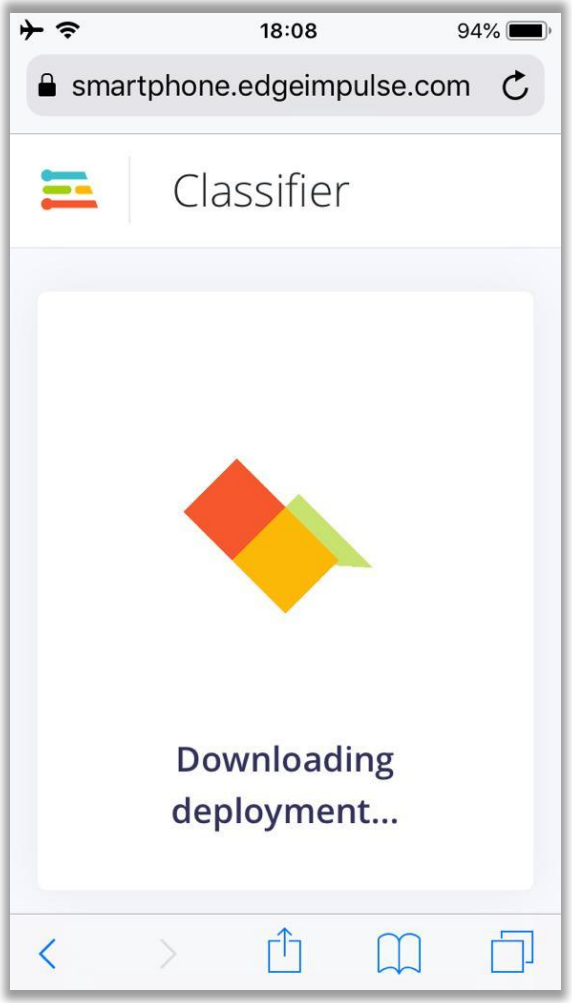
- Pre-Processing Data
- Design a Model
- Train a Model

Convert Model

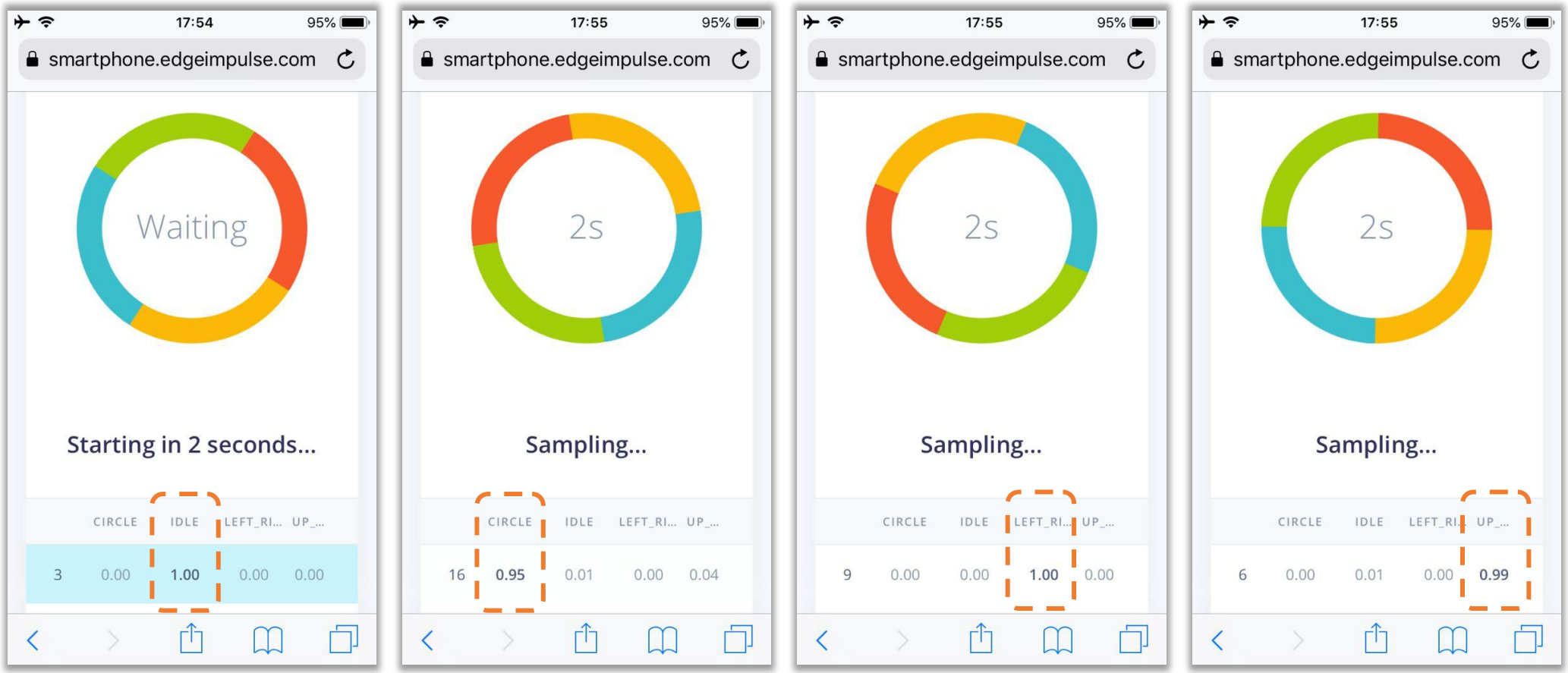




Deploy Model

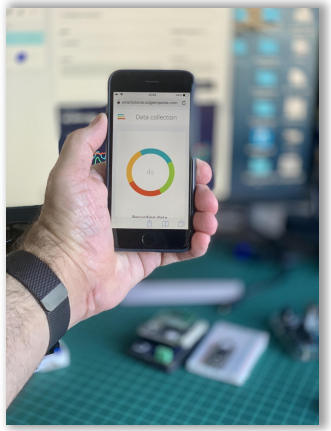


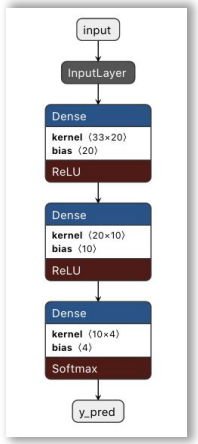
Make Inferences

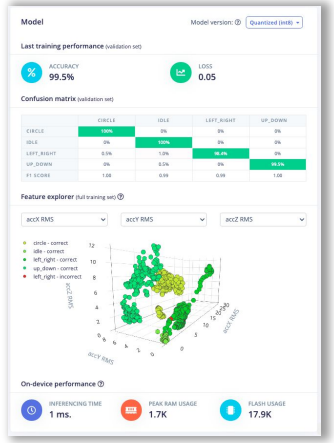


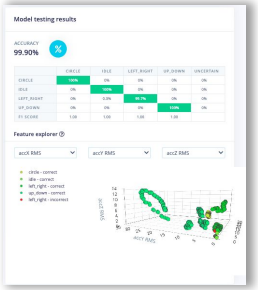
Summary

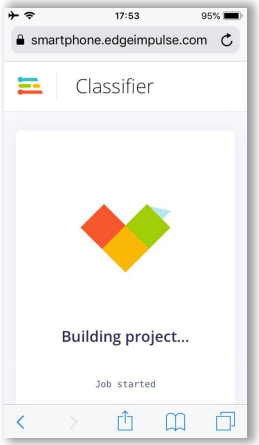
Collect Data → Preprocess Data → Design a Model → Train a Model → Evaluate Optimize → Convert Model → Deploy Model → Make Inferences

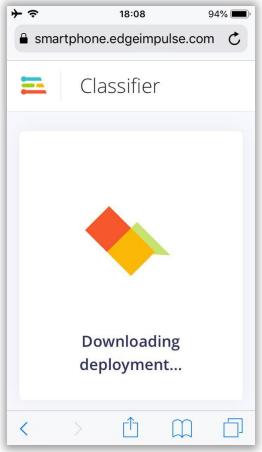


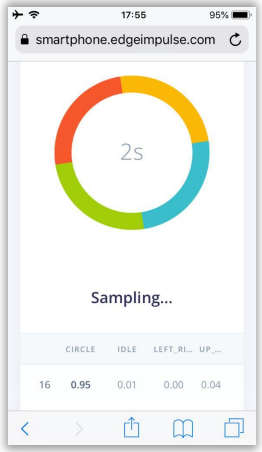












Additional Free Resources

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

Prof. Marcelo José Rovai
UNIFEI - Universidade Federal de Itajubá, Brazil
Web: https://github.com/Mjrovai