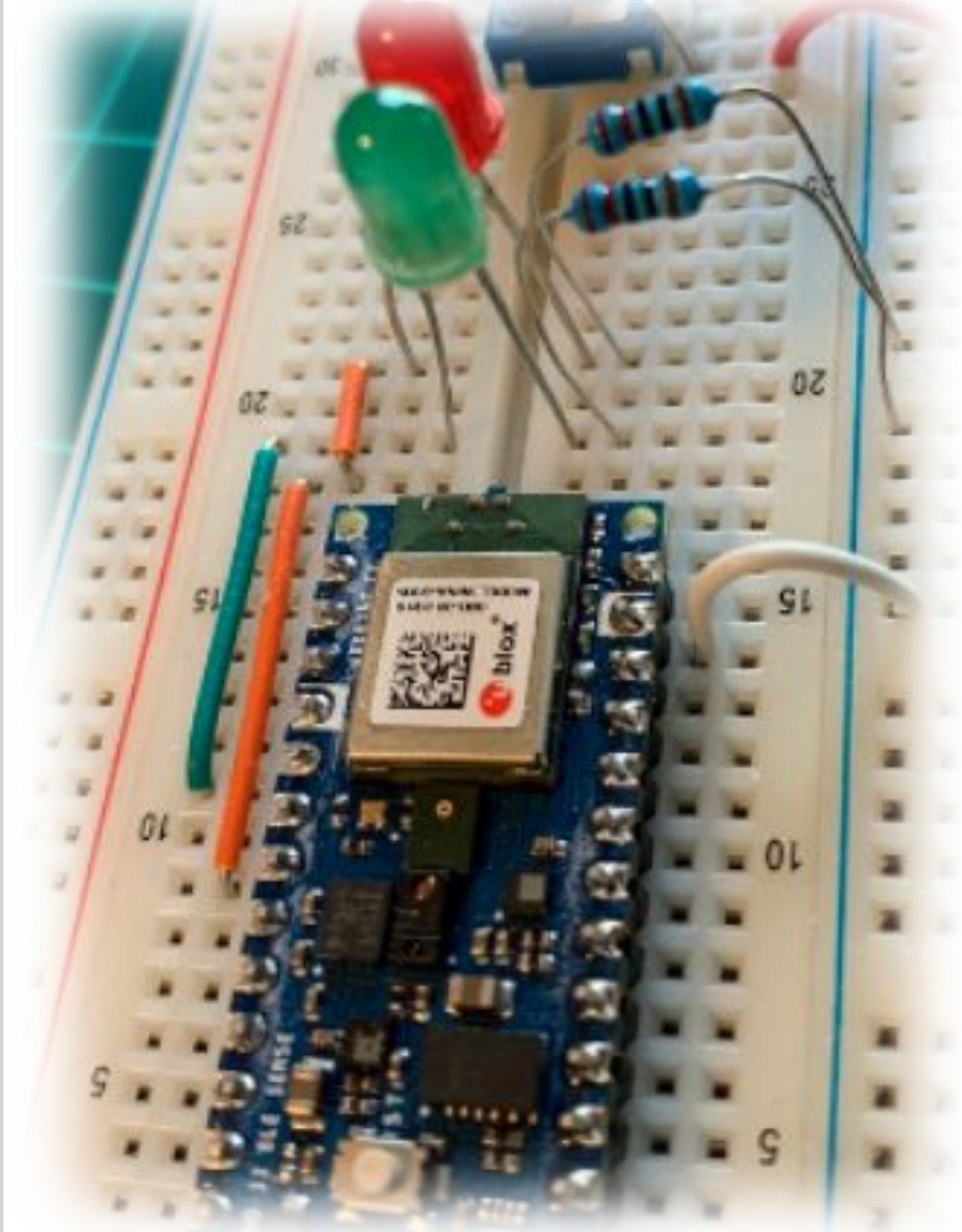
IESTI01 – TinyML

Embedded Machine Learning

20. Anomaly Detection

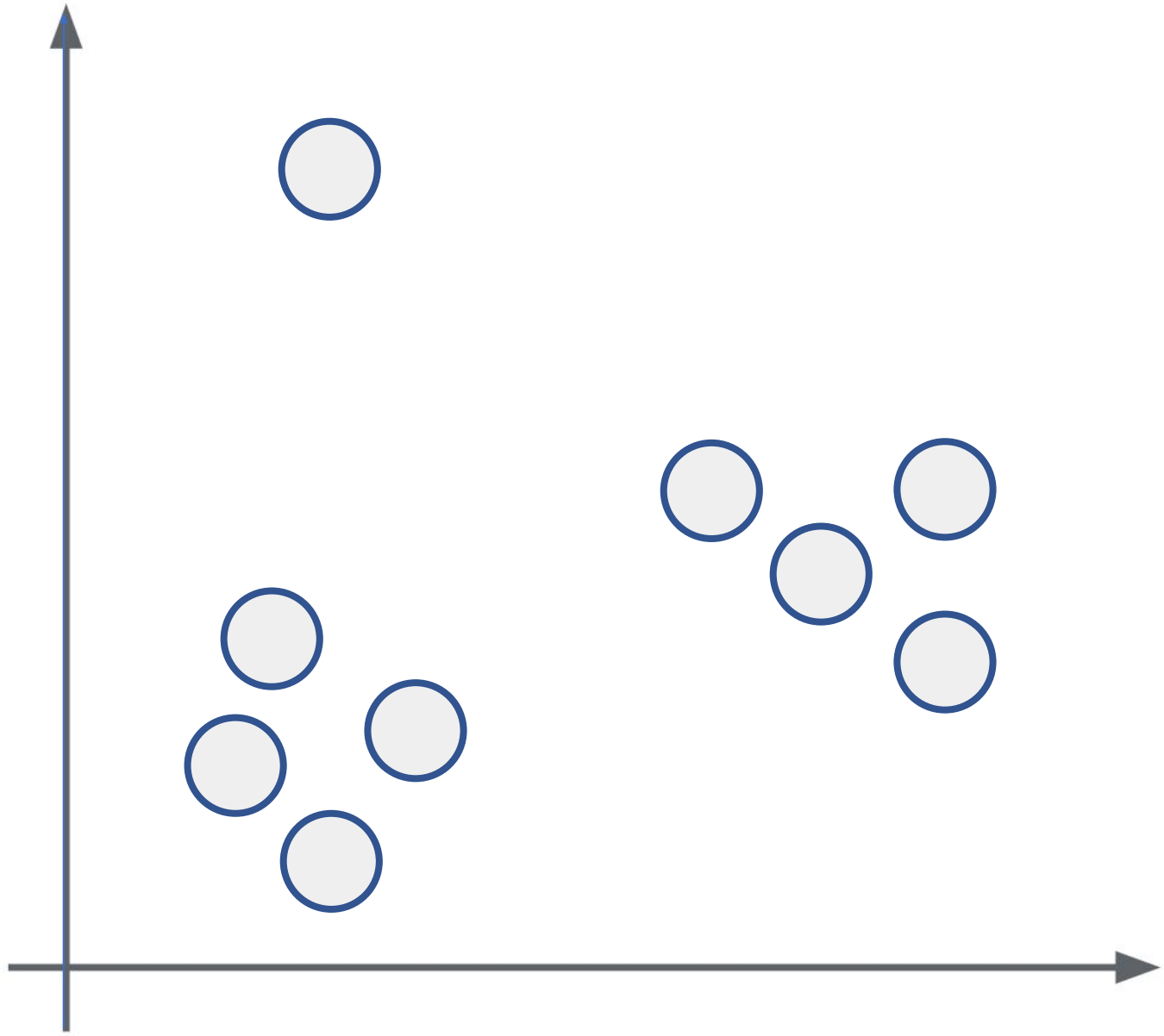


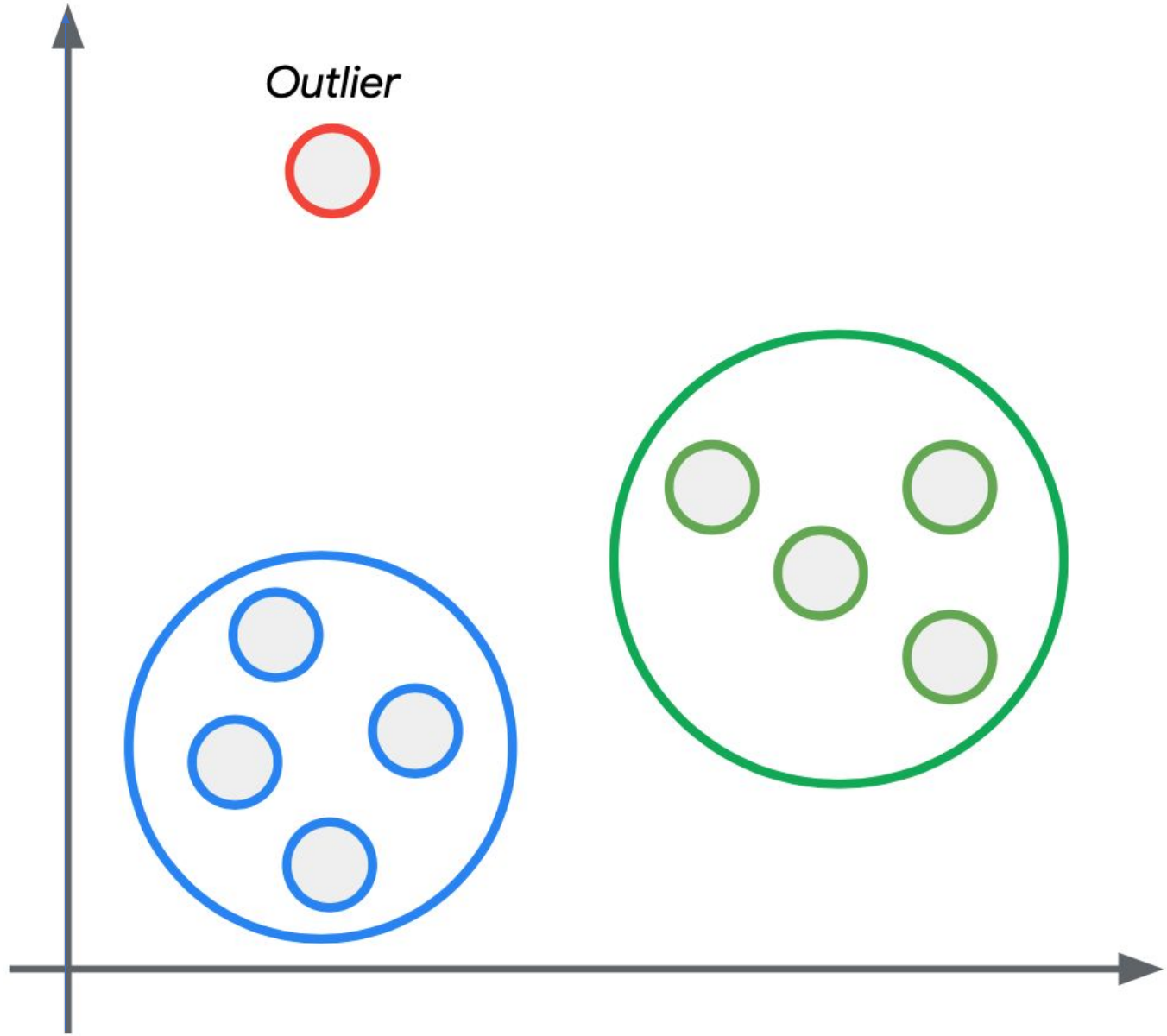
Prof. Marcelo Rovai
UNIFEI

Anomaly Detection

What is **Anomaly Detection**?

In **data analysis, anomaly detection** is the **identification of rare** items, events or observations which **raise suspicions** because they **differing significantly** from the **majority of the data**.




Outlier

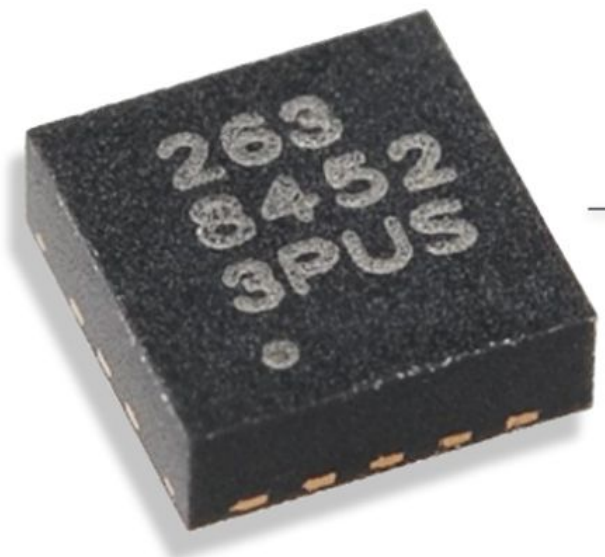
Application: Factory machinery

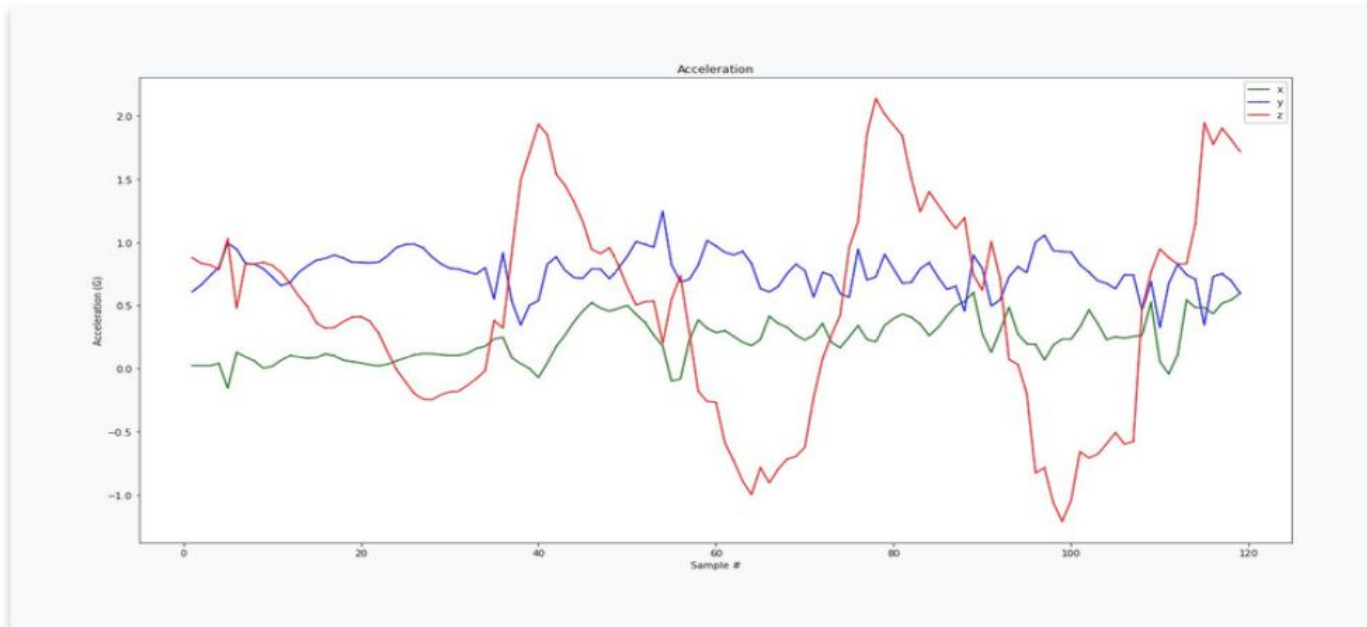
Application: Factory machinery

Ball Bearings

Accelerometer

Sensor: **Accelerometer**





Sensor: **Accelerometer**

2 bytes × 8 × 20kHz = **320** KB / sec

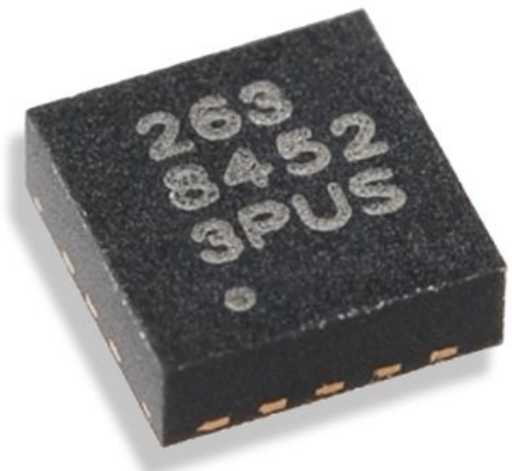
Measurement

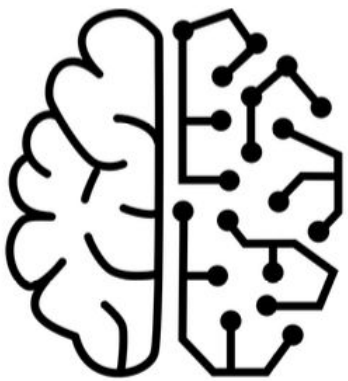
Sensors

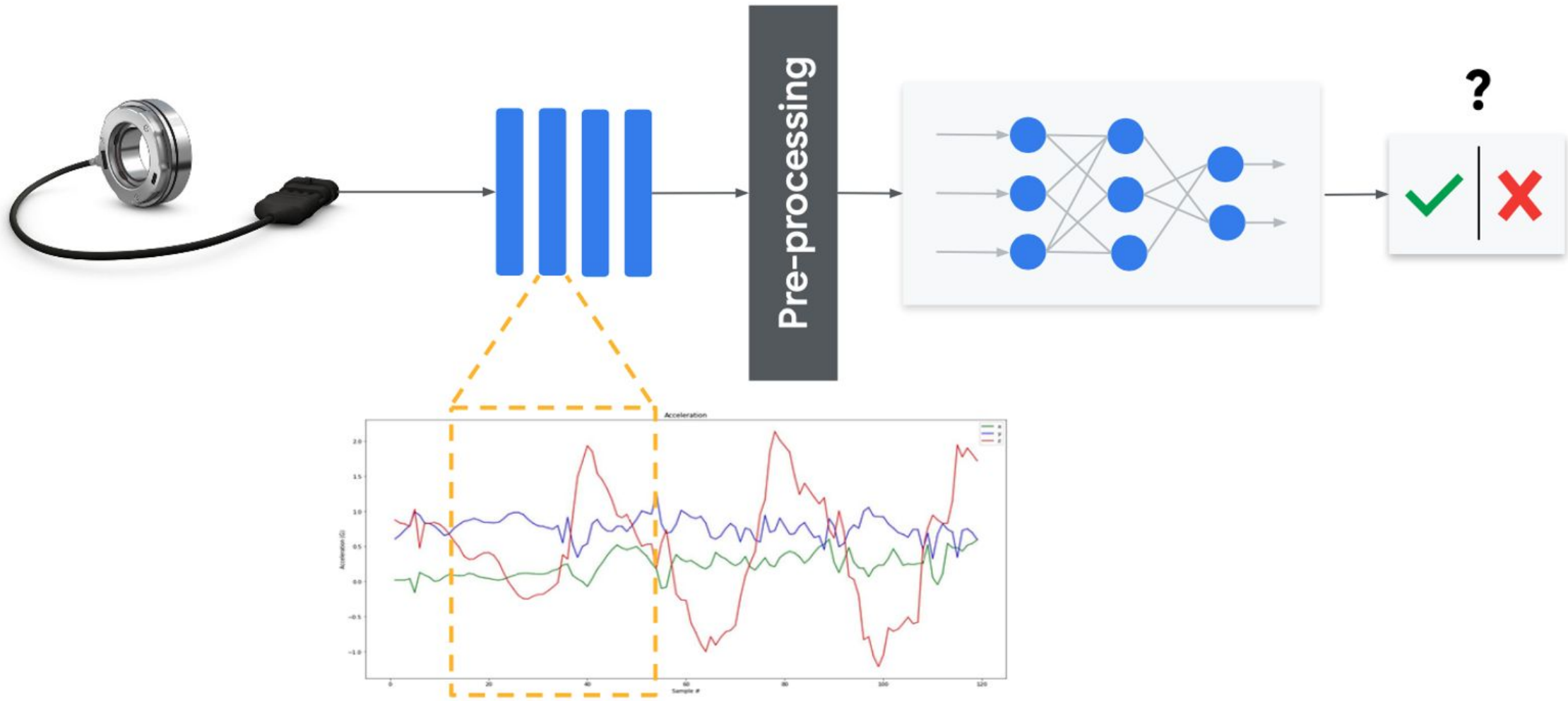
Sample Rate

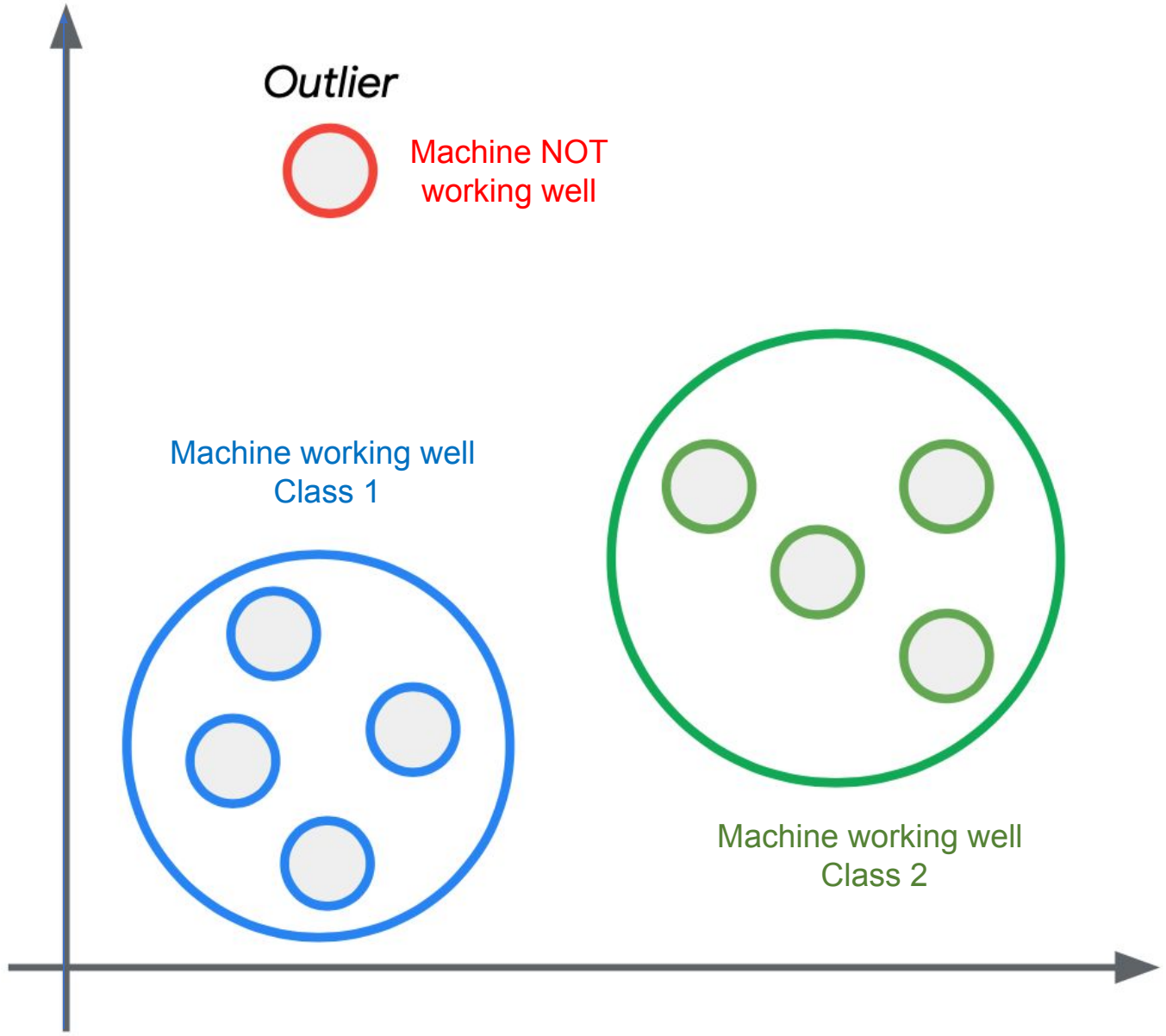
It’s too expensive to stream to the cloud

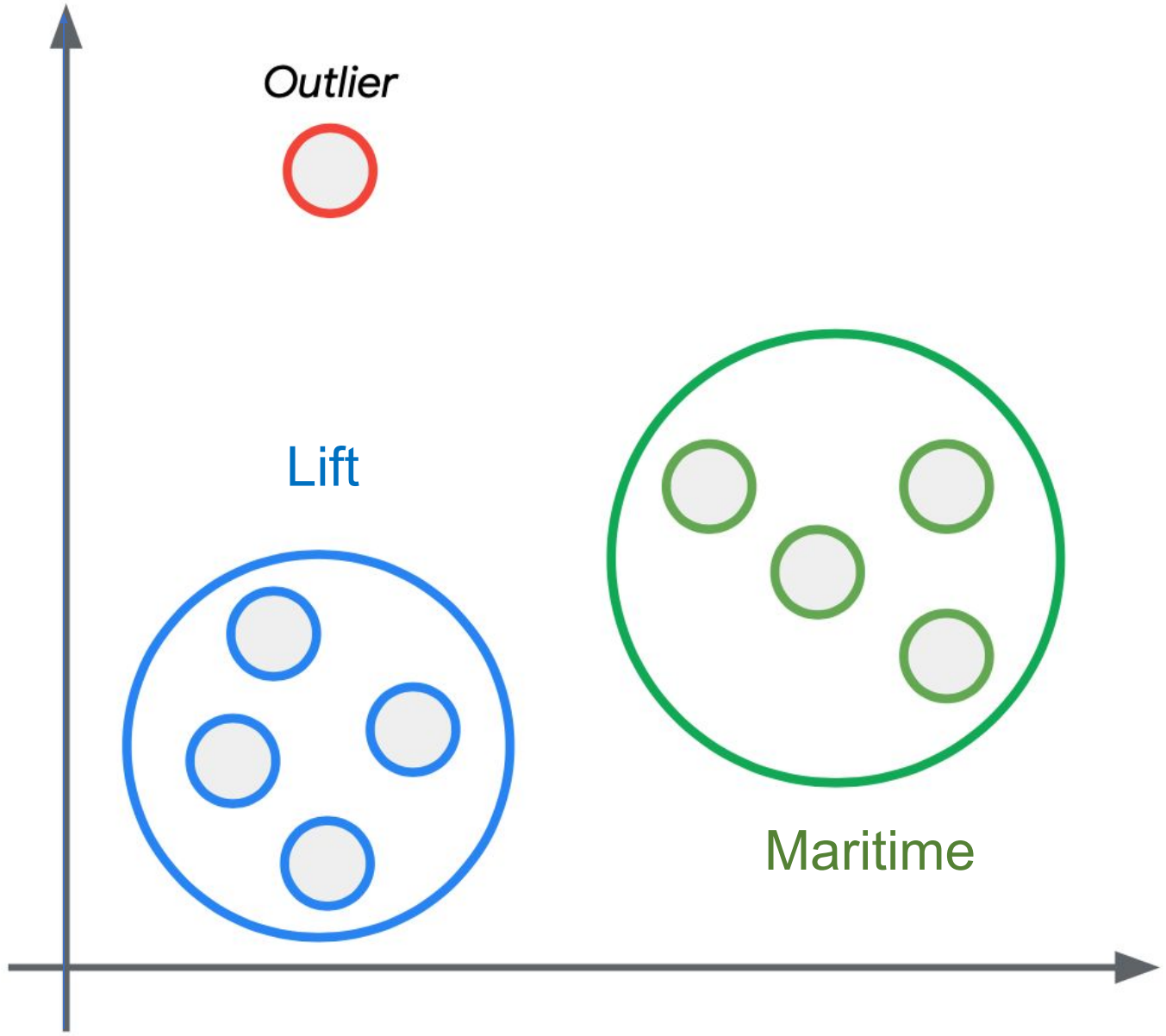
Need “**intelligence**” *close* **to sensors**

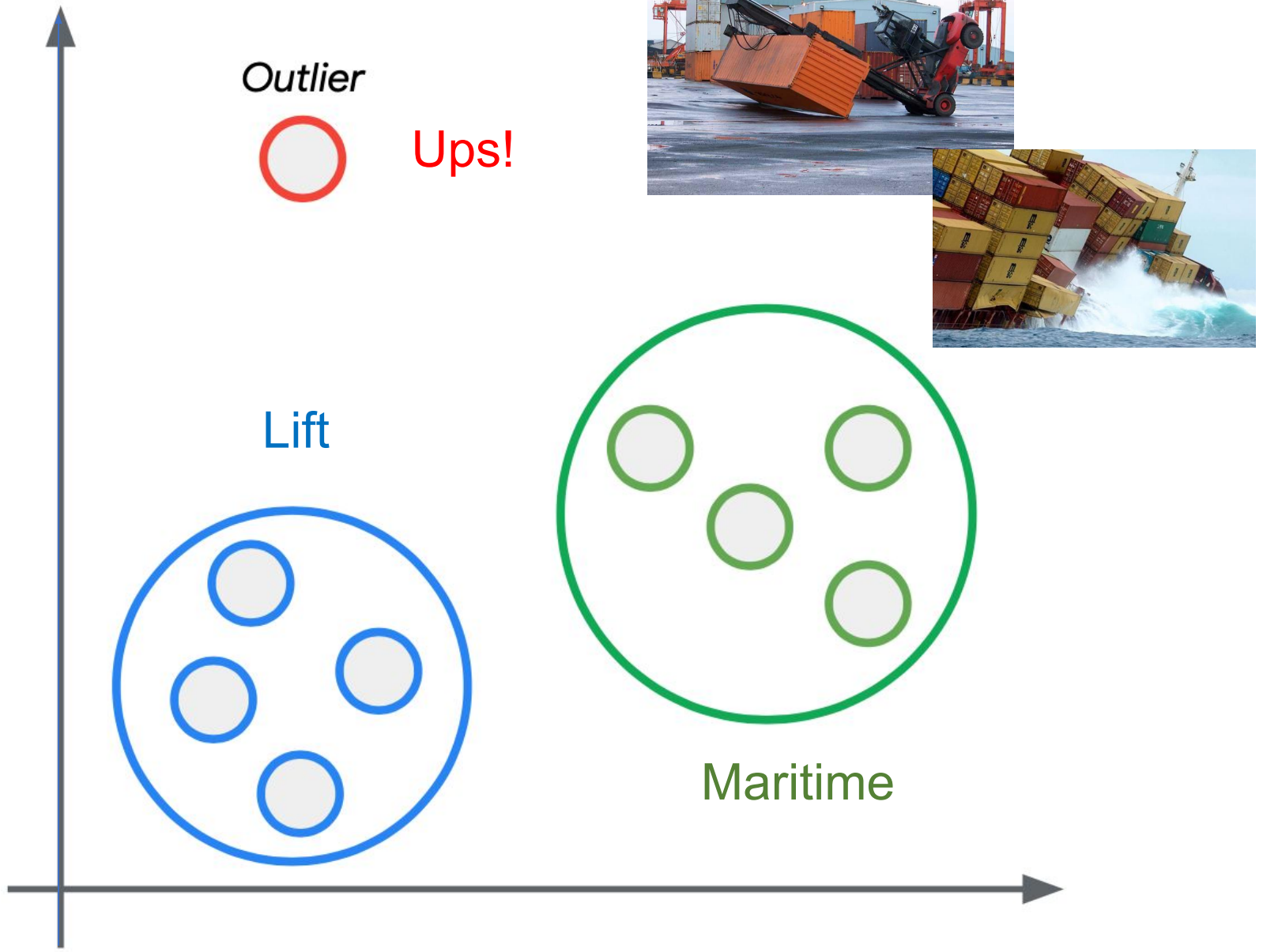




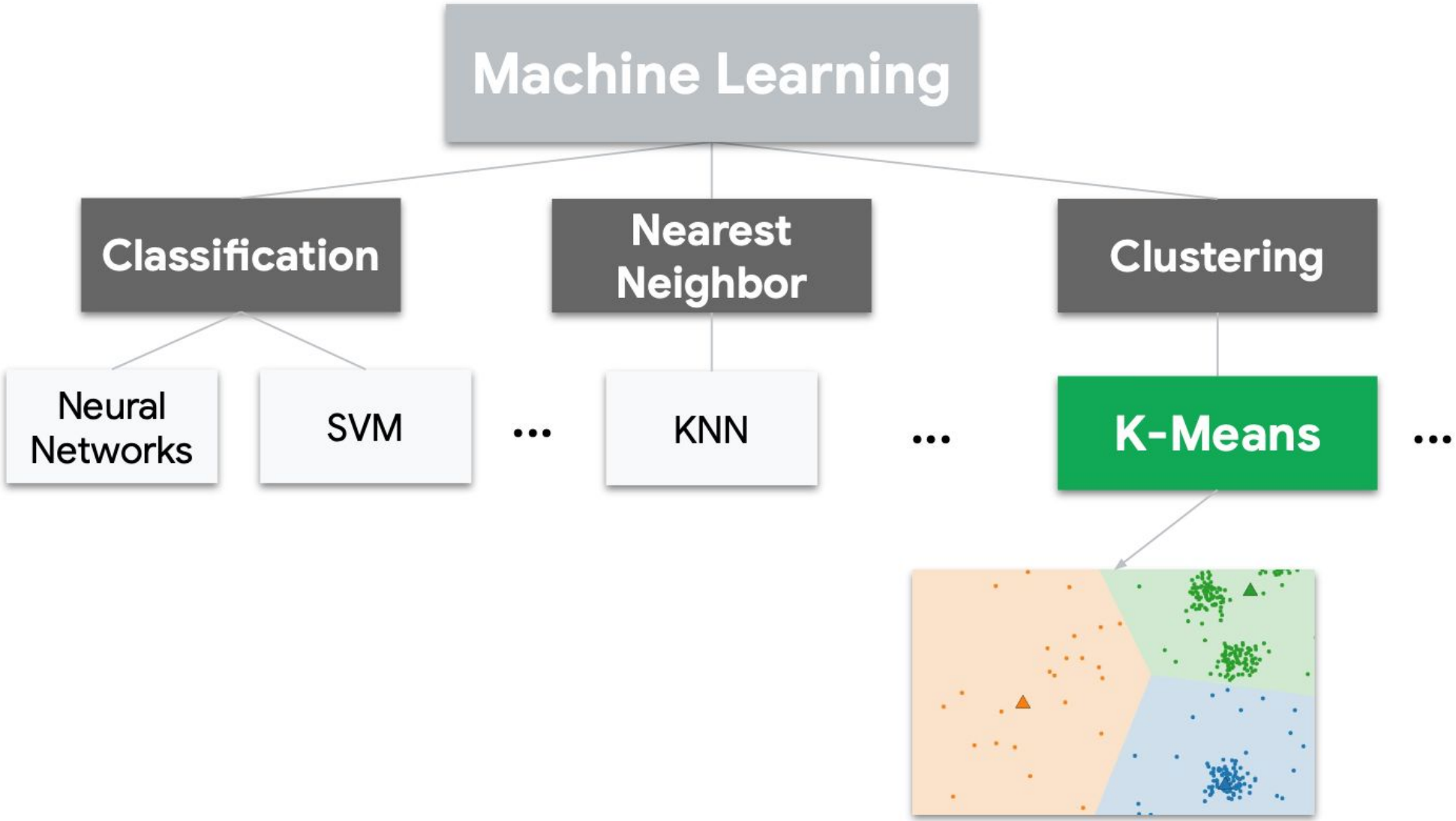

Pre-processing
?
Acceleration
Acceleration (G)
Sample #


Outlier
Machine NOT working well
Machine working well Class 1
Machine working well Class 2


Outlier
Lift
Maritime


Outlier
Ups!
Lift
Maritime

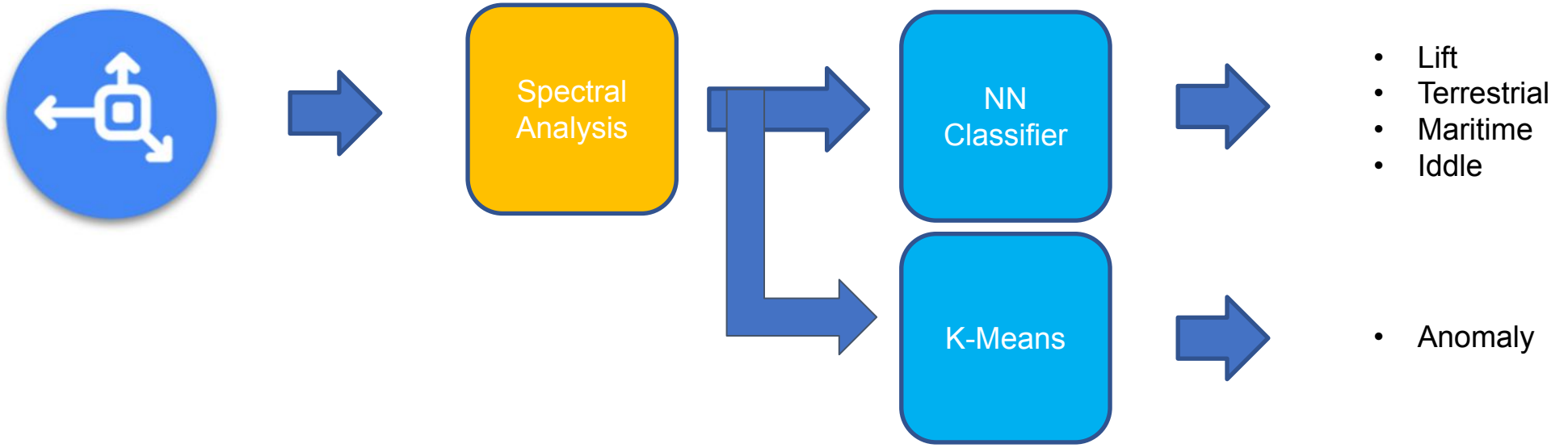
It's **not all** deep learning



K-means Clustering for Anomaly Detection

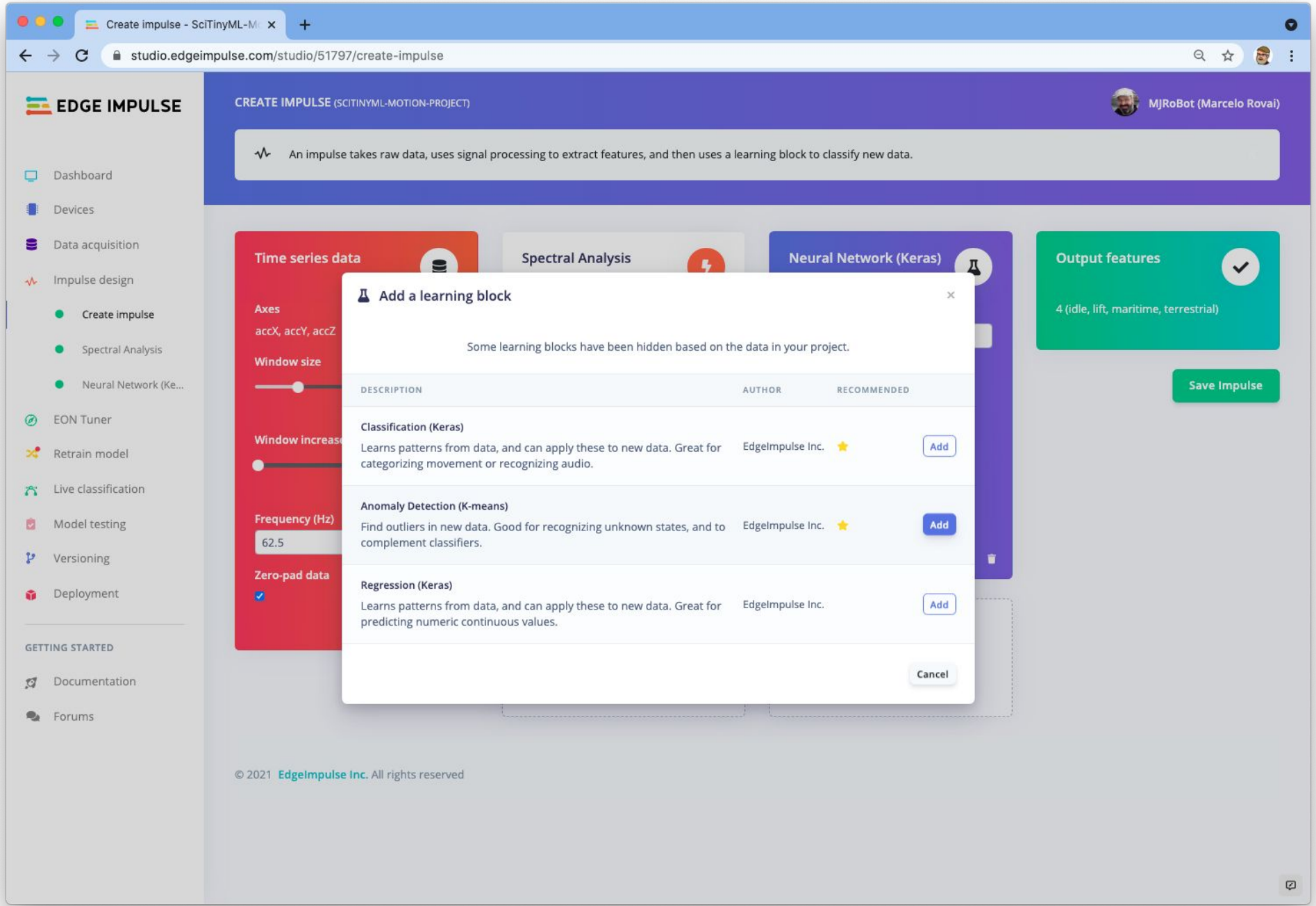
Code Time!

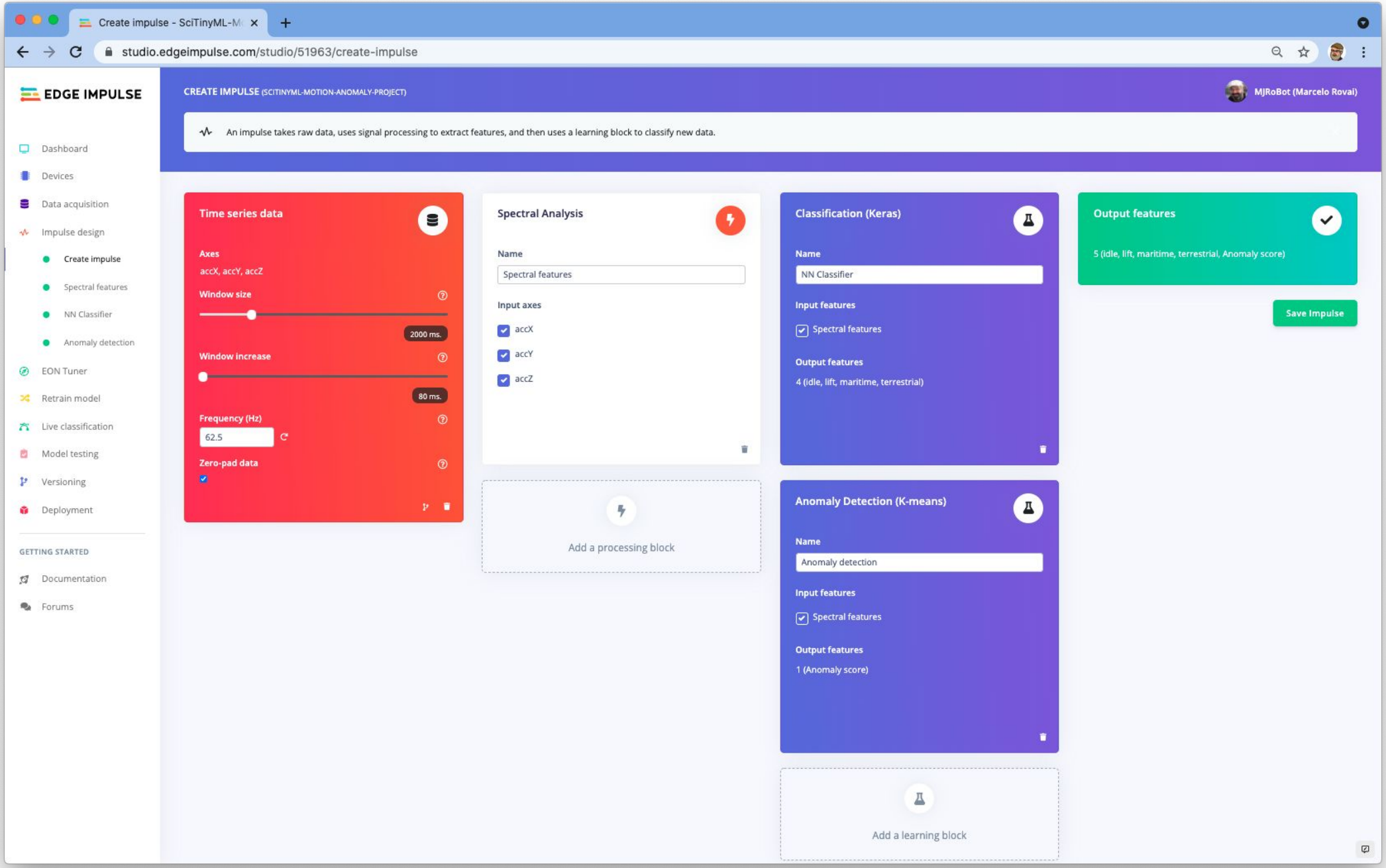
Anomaly_Detection_K_means.ipynb


Spectral Analysis
NN Classifier
K-Means
Classes
Lift
Terrestrial
Maritime
Iddle
Anomaly

Motion Classification – Anomaly Detection

Project Time!


Create impulse - SciTinyML-M
studio.edgeimpulse.com/studio/51797/create-impulse
EDGE IMPULSE
Dashboard
Devices
Data acquisition
Impulse design
Create impulse
Spectral Analysis
Neural Network (Ke...
EON Tuner
Retrain model
Live classification
Model testing
Versioning
Deployment
GETTING STARTED
Documentation
Forums
CREATE IMPULSE (SCITINYML-MOTION-PROJECT)
MJRoBot (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
Window increase
Frequency (Hz)
62.5
Zero-pad data
Spectral Analysis
Neural Network (Keras)
Output features
4 (idle, lift, maritime, terrestrial)
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 - SciTinyML-M
studio.edgeimpulse.com/studio/51963/create-impulse
EDGE IMPULSE
CREATE IMPULSE (SCITINYML-MOTION-ANOMALY-PROJECT)
MJRoBot (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
Spectral features
NN Classifier
Anomaly detection
EON Tuner
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
Classification (Keras)
Name
NN Classifier
Input features
Spectral features
Output features
4 (idle, lift, maritime, terrestrial)
Anomaly Detection (K-means)
Name
Anomaly detection
Input features
Spectral features
Output features
1 (Anomaly score)
Add a learning block
Output features
5 (idle, lift, maritime, terrestrial, Anomaly score)
Save Impulse

Anomaly detection - SciTinyML

studio.edgeimpulse.com/studio/51963/learning/anomaly/52

EDGE IMPULSE

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

GETTING STARTED

- Documentation
- Forums

ANOMALY DETECTION (SCITINYML-MOTION-ANOMALY-PROJECT)

#1 Click to set a description for this version

MJRoBot (Marcelo Rovai)

Anomaly detection settings

Cluster count

4

Axes

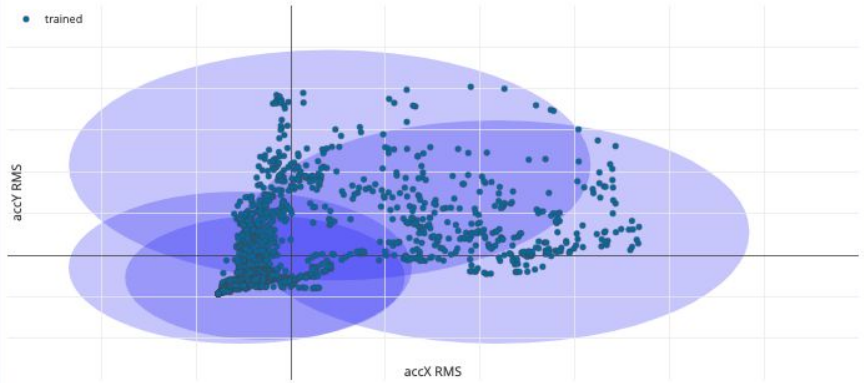
Select all axes

- [x] accX RMS
- [ ] accX Peak 1 Freq
- [ ] accX Peak 1 Height
- [ ] accX Peak 2 Freq
- [ ] accX Peak 2 Height
- [ ] accX Peak 3 Freq
- [ ] accX Peak 3 Height
- [ ] accX Spectral Power 0.1 - 0.5
- [ ] accX Spectral Power 0.5 - 1.0
- [ ] accX Spectral Power 1.0 - 2.0
- [ ] accX Spectral Power 2.0 - 5.0
- [x] accY RMS
- [ ] accY Peak 1 Freq
- [ ] accY Peak 1 Height
- [ ] accY Peak 2 Freq
- [ ] accY Peak 2 Height
- [ ] accY Peak 3 Freq
- [ ] accY Peak 3 Height
- [ ] accY Spectral Power 0.1 - 0.5
- [ ] accY Spectral Power 0.5 - 1.0
- [ ] accY Spectral Power 1.0 - 2.0
- [ ] accY Spectral Power 2.0 - 5.0
- [x] accZ RMS
- [ ] accZ Peak 1 Freq
- [ ] accZ Peak 1 Height
- [ ] accZ Peak 2 Freq
- [ ] accZ Peak 2 Height
- [ ] accZ Peak 3 Freq
- [ ] accZ Peak 3 Height
- [ ] accZ Spectral Power 0.1 - 0.5
- [ ] accZ Spectral Power 0.5 - 1.0
- [ ] accZ Spectral Power 1.0 - 2.0
- [ ] accZ Spectral Power 2.0 - 5.0

Start training

Anomaly explorer (3,230 samples)

X Axis: accX RMS | Y Axis: accY RMS | Test data: -- No test data



Training output

```
Copying features from processing blocks...
Copying features from DSP block...
Copying features from DSP block OK
Copying features from processing blocks OK

Training model
Job started
scaler scale [1.23777729 1.02773968 1.10088427] mean [0.95382248 0.94990646 1.12868147] var [1.53209261 1.05624885
1.21194617]
trained_clusters [{'center': [-0.5379795432090759, -0.30185389518737793, -0.8996922373771667], 'max_error':
1.8050675006641951}, {'center': [-0.2765962481498718, -0.5444689393043518, 0.5496397018432617], 'max_error':
1.4696349225868046}, {'center': [0.40855732560157776, 2.160626173019409, 1.2495908737182617], 'max_error':
2.7492433102802676}, {'center': [2.1753463745117188, 0.555717945098877, 1.391709804534912], 'max_error':
2.6628344654985634}]

Job completed
```

Anomaly detection - SciTinyML

studio.edgeimpulse.com/studio/51963/learning/anomaly/52

EDGE IMPULSE

- Dashboard
- Devices
- Data acquisition
- Impulse design
  - Create impulse
  - Spectral features
  - NN Classifier
  - Anomaly detection
- EON Tuner
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- Live classification
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GETTING STARTED

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- Forums

ANOMALY DETECTION (SCITINYML-MOTION-ANOMALY-PROJECT)

MJRoBot (Marcelo Rovai)

#1 Click to set a description for this version

Anomaly detection settings

Cluster count

32

Axes

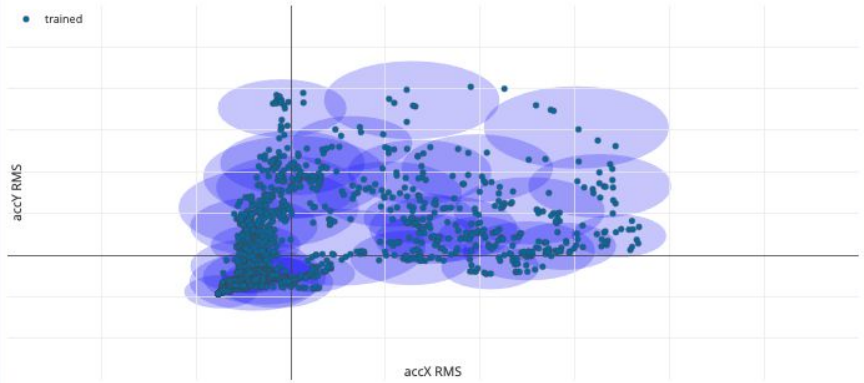
Select all axes

- [x] accX RMS
- [ ] accX Peak 1 Freq
- [ ] accX Peak 1 Height
- [ ] accX Peak 2 Freq
- [ ] accX Peak 2 Height
- [ ] accX Peak 3 Freq
- [ ] accX Peak 3 Height
- [ ] accX Spectral Power 0.1 - 0.5
- [ ] accX Spectral Power 0.5 - 1.0
- [ ] accX Spectral Power 1.0 - 2.0
- [ ] accX Spectral Power 2.0 - 5.0
- [x] accY RMS
- [ ] accY Peak 1 Freq
- [ ] accY Peak 1 Height
- [ ] accY Peak 2 Freq
- [ ] accY Peak 2 Height
- [ ] accY Peak 3 Freq
- [ ] accY Peak 3 Height
- [ ] accY Spectral Power 0.1 - 0.5
- [ ] accY Spectral Power 0.5 - 1.0
- [ ] accY Spectral Power 1.0 - 2.0
- [ ] accY Spectral Power 2.0 - 5.0
- [x] accZ RMS
- [ ] accZ Peak 1 Freq
- [ ] accZ Peak 1 Height
- [ ] accZ Peak 2 Freq
- [ ] accZ Peak 2 Height
- [ ] accZ Peak 3 Freq
- [ ] accZ Peak 3 Height
- [ ] accZ Spectral Power 0.1 - 0.5
- [ ] accZ Spectral Power 0.5 - 1.0
- [ ] accZ Spectral Power 1.0 - 2.0
- [ ] accZ Spectral Power 2.0 - 5.0

Start training

Anomaly explorer (3,230 samples)

X Axis: accX RMS | Y Axis: accY RMS | Test data: -- No test data



Training output

```
0.6358923488456604}, {'center': [0.2331821322441101, -0.44085508584976196, 1.193619966506958], 'max_error':
0.43379442394199896}, {'center': [-0.04211855307221413, 1.622160792350769, 1.5633275508880615], 'max_error':
0.7400662371471811}, {'center': [2.5153045654296875, 0.10167547315359116, 1.1958473920822144], 'max_error':
0.6889784598589724}, {'center': [0.6476534008979797, 2.6941537857055664, 1.7468148469924927], 'max_error':
0.6253040107657685}, {'center': [-0.09443876147270203, 3.532026529312134, 1.4222177267074585], 'max_error':
0.6722667084735653}, {'center': [2.1073172092437744, -0.2908220887184143, 0.9732017517089844], 'max_error':
0.5098888571637854}, {'center': [1.360011339187622, 2.0014262199401855, 0.6398685574531555], 'max_error':
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0.5872878607683915}, {'center': [1.6086387634277344, 0.635323166847229, 0.2745974659919739], 'max_error':
0.7719379326342638}, {'center': [2.8824524879455566, 0.21148265898227692, 1.768933892250061], 'max_error':
0.5465850786758827}, {'center': [3.2645251750946045, 1.6626498699188232, 1.3556557893753052], 'max_error':
0.7446547869773675}, {'center': [1.2767690420150757, 3.724461078643799, 1.341691255569458], 'max_error':
0.9180358736727107}, {'center': [3.0170180797576904, 3.0672569274902344, 0.8234216570854187], 'max_error':
0.9686505165548877}]

Job completed
```

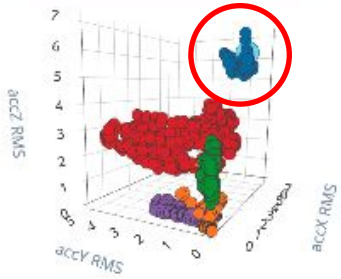
Spectral features (3,327 samples)

X Axis: accX RMS

Y Axis: accY RMS

Z Axis: accZ RMS

- classified
- idle
- lift
- maritime
- terrestrial
- classification 49



Processed features

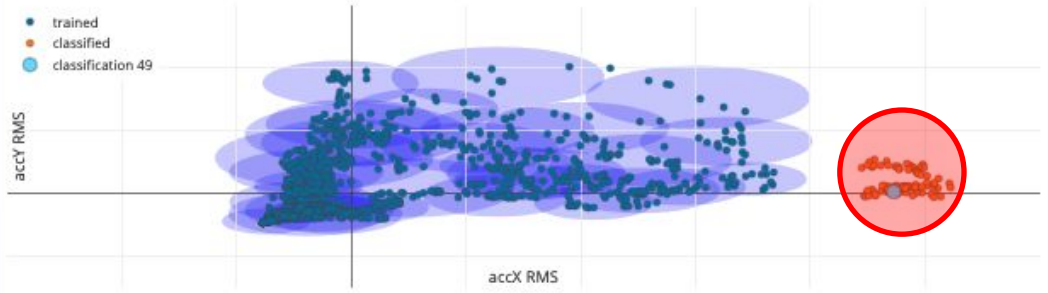
6.8037, 0.4960, 8.2240, 1.4881, 3.2398, 2.9762, 0.4911, 7.0271, 0.9133, 0.6076, 0.0159, 1.0079, 0.4960, 1.0556, 2.4802, 0.1…

Anomaly explorer (3,327 samples)

X Axis: accX RMS

Y Axis: accY RMS

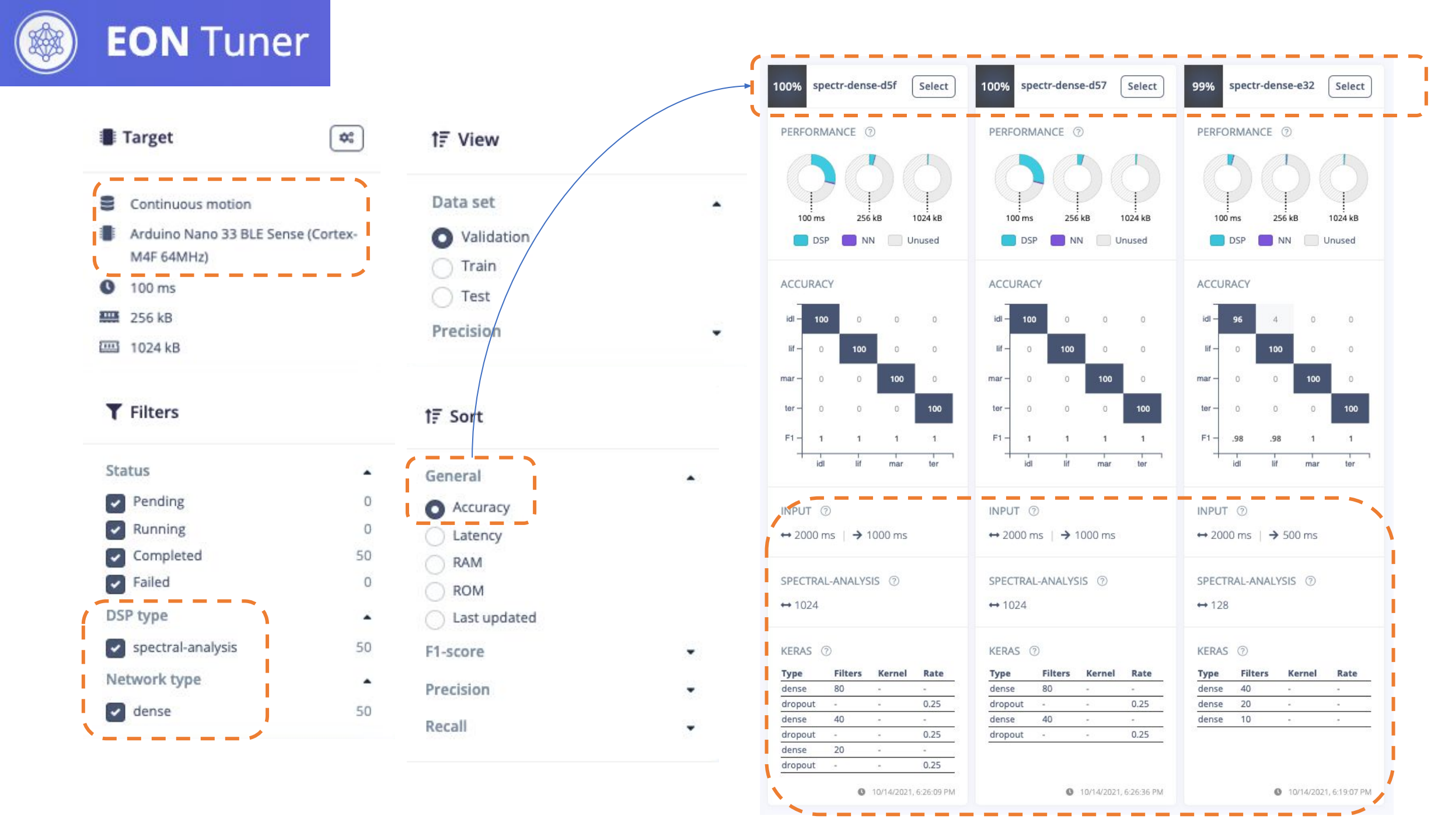
- trained
- classified
- classification 49



Distance from closest cluster

accX RMS: 1.2592, accY RMS: 0.4069, accZ RMS: 2.8992

EON Tuner


Target
Continuous motion
Arduino Nano 33 BLE Sense (Cortex-M4F 64MHz)
100 ms
256 kB
1024 kB
Filters
Status
Pending 0
Running 0
Completed 50
Failed 0
DSP type
spectral-analysis 50
Network type
dense 50
View
Data set
Validation
Train
Test
Precision
Sort
General
Accuracy
Latency
RAM
ROM
Last updated
F1-score
Precision
Recall
100% spectr-dense-d5f Select
100% spectr-dense-d57 Select
99% spectr-dense-e32 Select
PERFORMANCE
100 ms
256 kB
1024 kB
DSP
NN
Unused
ACCURACY
idl
lif
mar
ter
F1
INPUT
2000 ms | 1000 ms
2000 ms | 1000 ms
2000 ms | 500 ms
SPECTRAL-ANALYSIS
1024
1024
128
KERAS
Type Filters Kernel Rate
dense 80 - -
dropout - - 0.25
dense 40 - -
dropout - - 0.25
dense 20 - -
dropout - - 0.25
10/14/2021, 6:26:09 PM
Type Filters Kernel Rate
dense 80 - -
dropout - - 0.25
dense 40 - -
dropout - - 0.25
10/14/2021, 6:26:36 PM
Type Filters Kernel Rate
dense 40 - -
dense 20 - -
dense 10 - -
10/14/2021, 6:19:07 PM

Reading Material

Main references

- Harvard School of Engineering and Applied Sciences - CS249r: Tiny Machine Learning
- Professional Certificate in Tiny Machine Learning (TinyML) – edX/Harvard
- Introduction to Embedded Machine Learning (Coursera)
- Text Book: "TinyML" by Pete Warden, Daniel Situnayake

I want to thank Shawn Hymel and Edge Impulse, Pete Warden and Laurence Moroney from Google, and especially Harvard professor Vijay Janapa Reddi, Ph.D. student Brian Plancher and their staff for preparing the excellent material on TinyML that is the basis of this course at UNIFEI.

The IESTI01 course is part of the TinyML4D, an initiative to make TinyML education available to everyone globally.

Thanks

And stay safe!

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