

# IESTI01 – TinyML

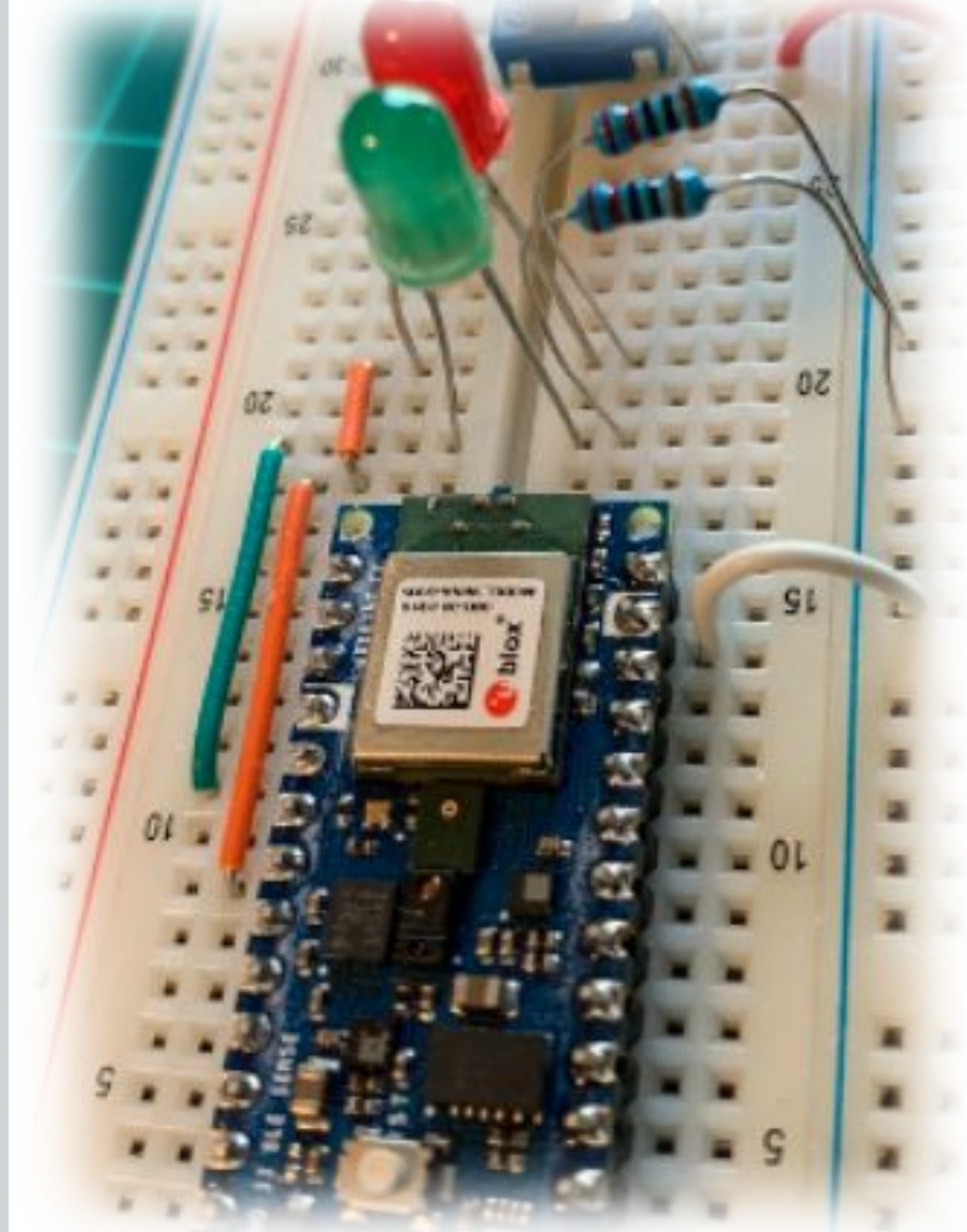
## Embedded Machine Learning

### 20. Anomaly Detection



Prof. Marcelo Rovai

UNIFEI

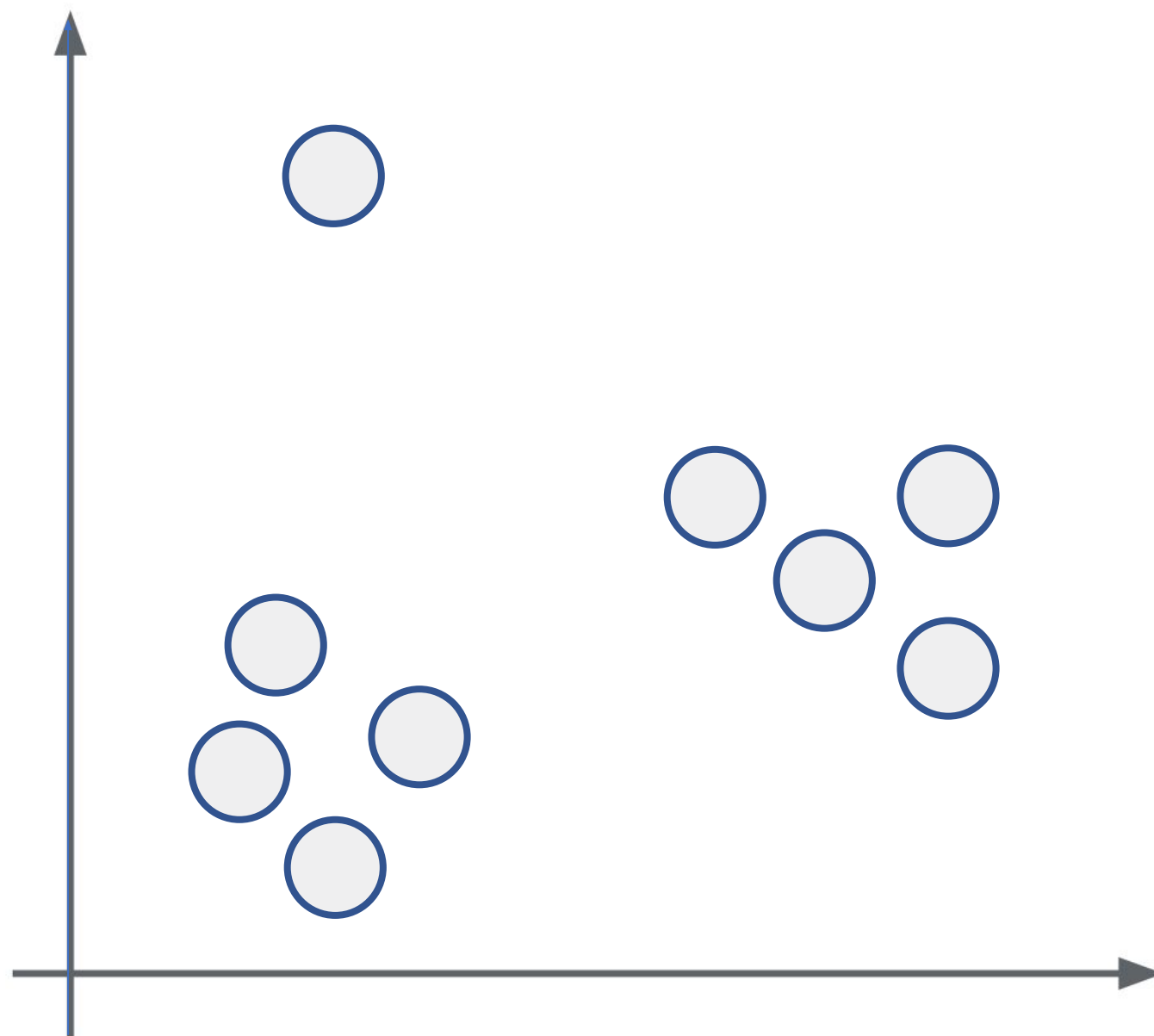


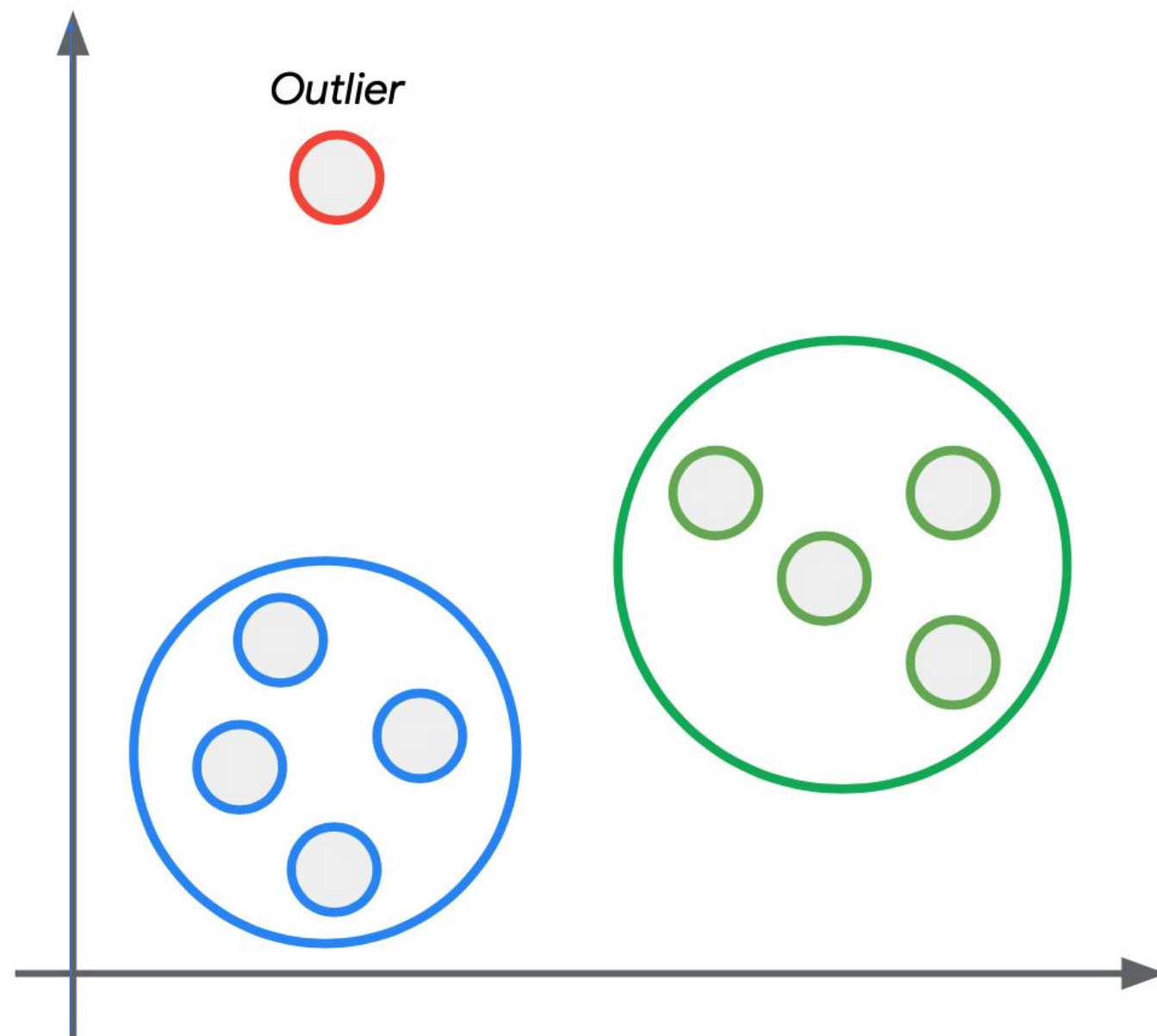
# Anomaly Detection



# 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**.





# Application: Factory machinery





# Application: Factory machinery

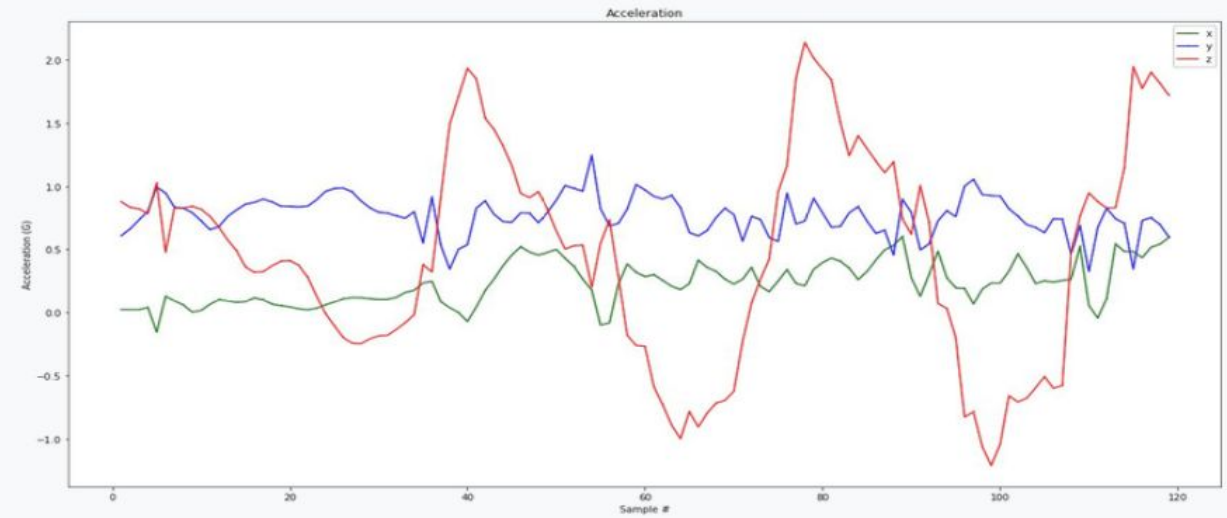
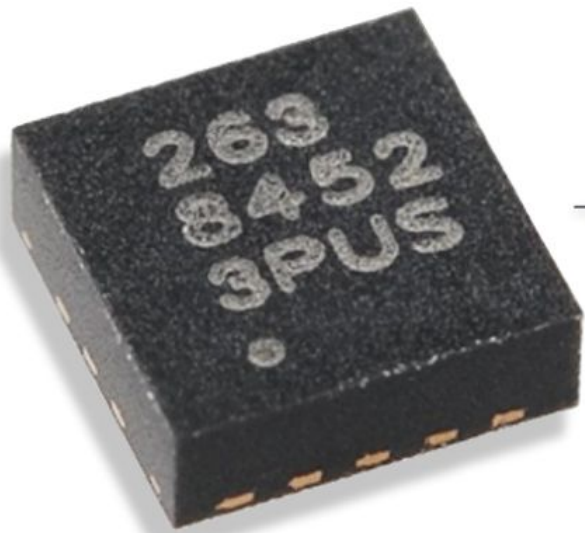


Ball Bearings



Accelerometer

# Sensor: Accelerometer





# Sensor: Accelerometer



$$2 \text{ bytes} \times 8 \times 20\text{kHz} = \mathbf{320} \text{ KB / sec}$$

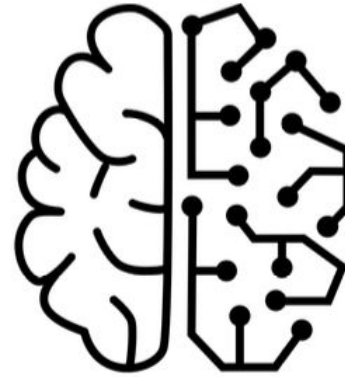
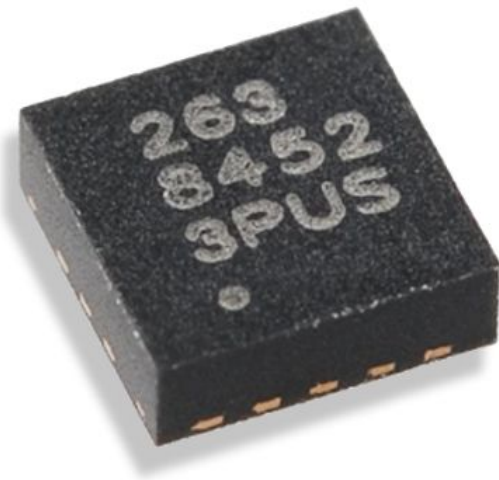
Measurement

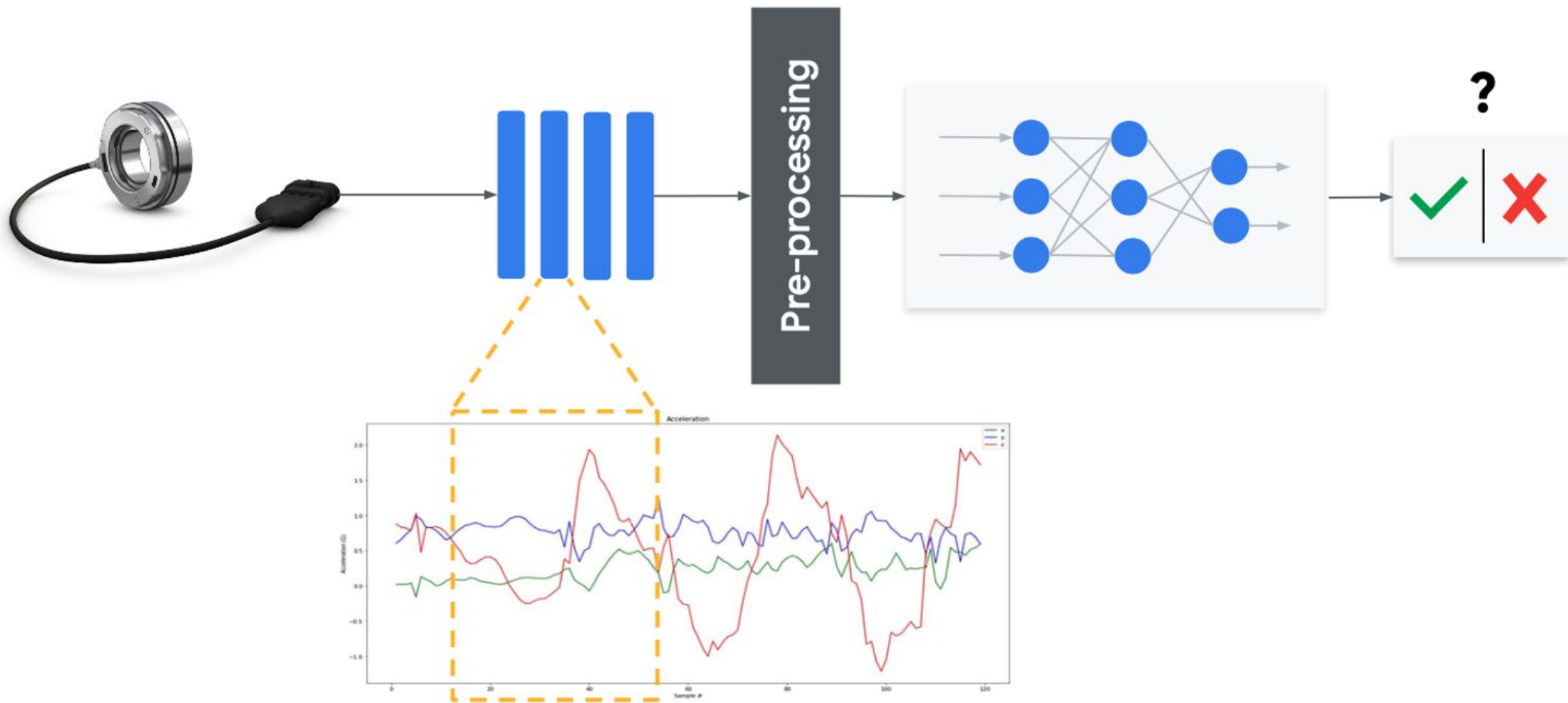
Sample Rate

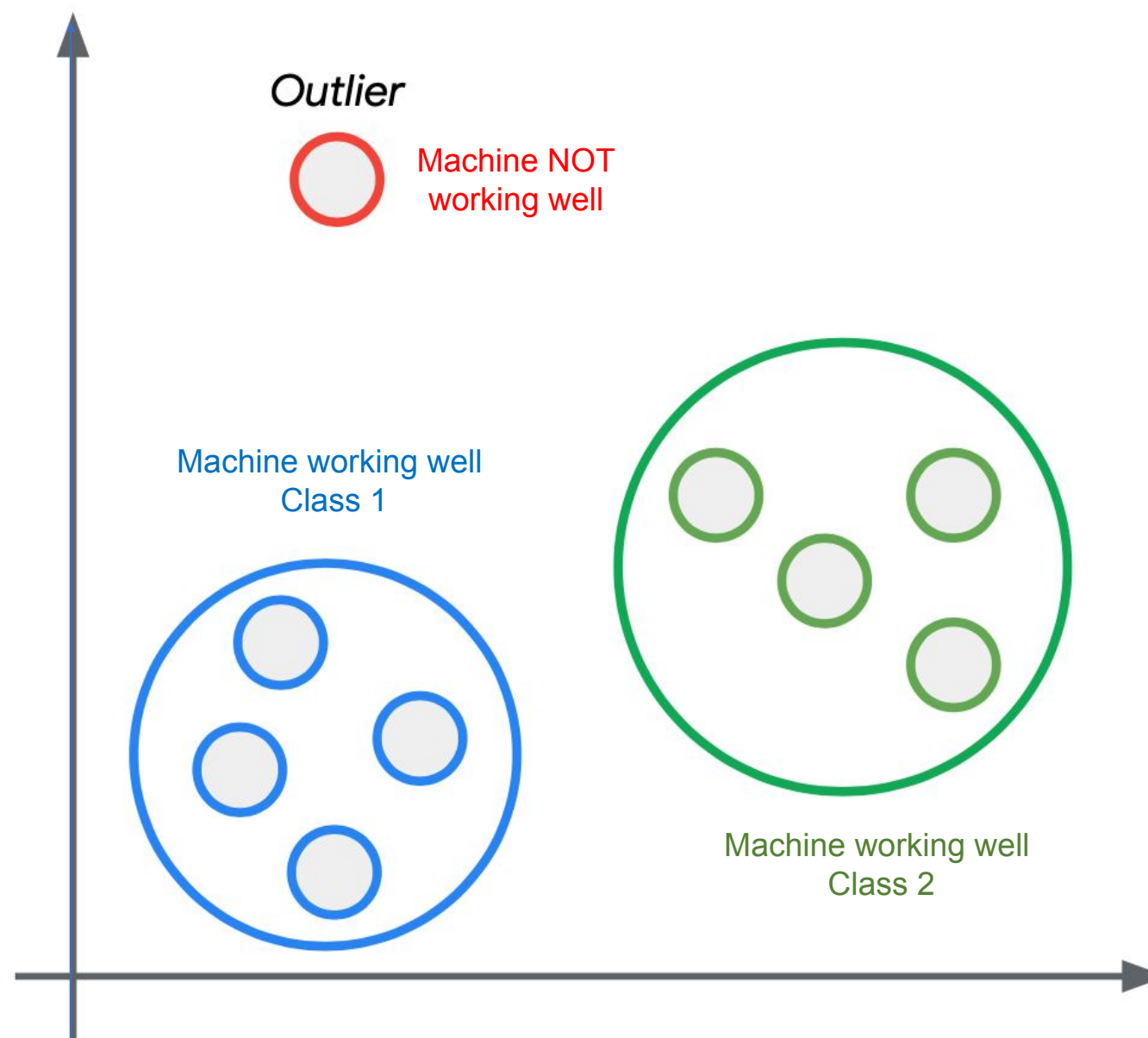
# Sensors

It's too expensive to stream to the cloud

Need “intelligence”  
*close* to sensors







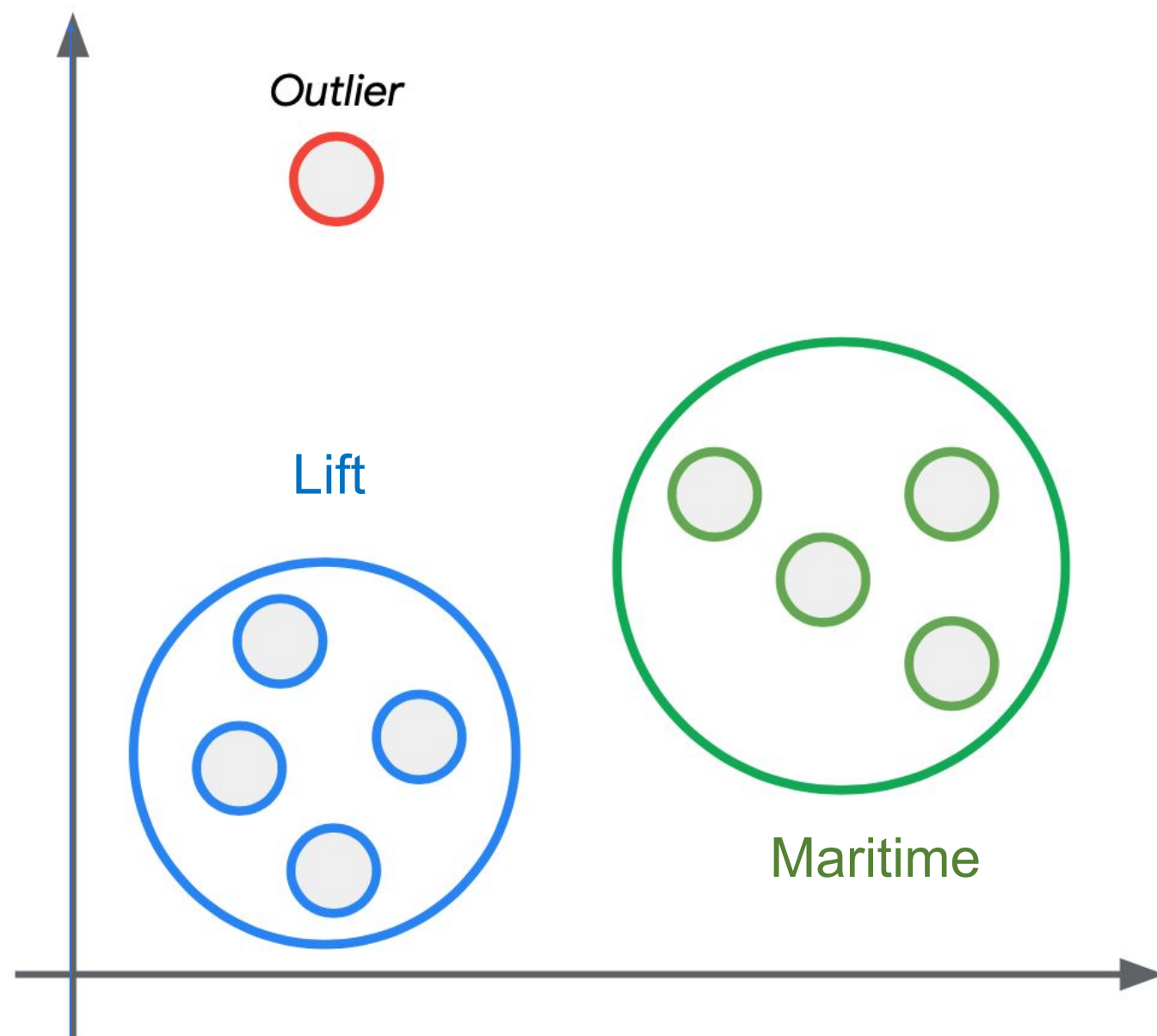
*Outlier*



Machine NOT  
working well

Machine working well  
Class 1

Machine working well  
Class 2

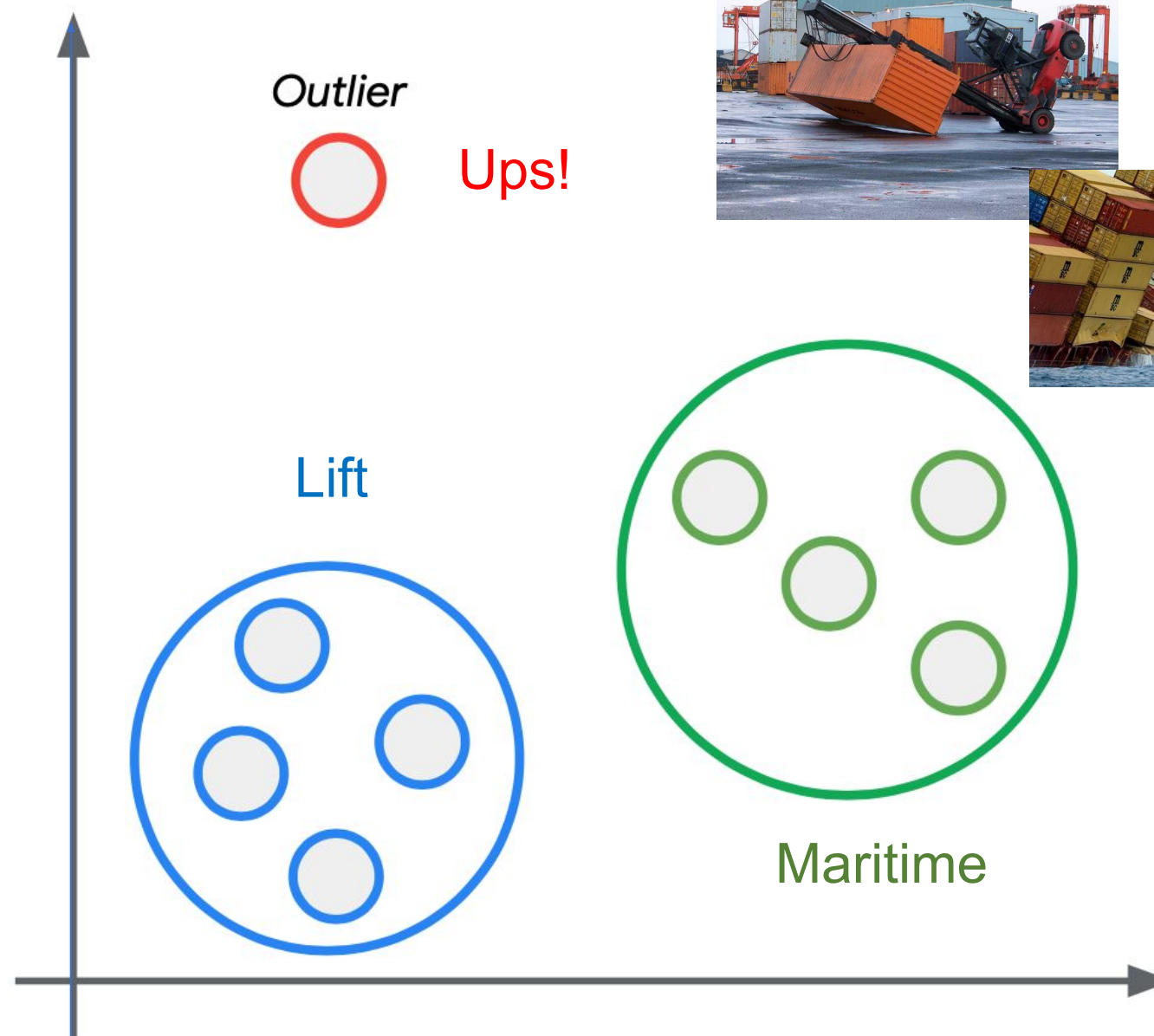


*Outlier*

Lift

Maritime





Outlier



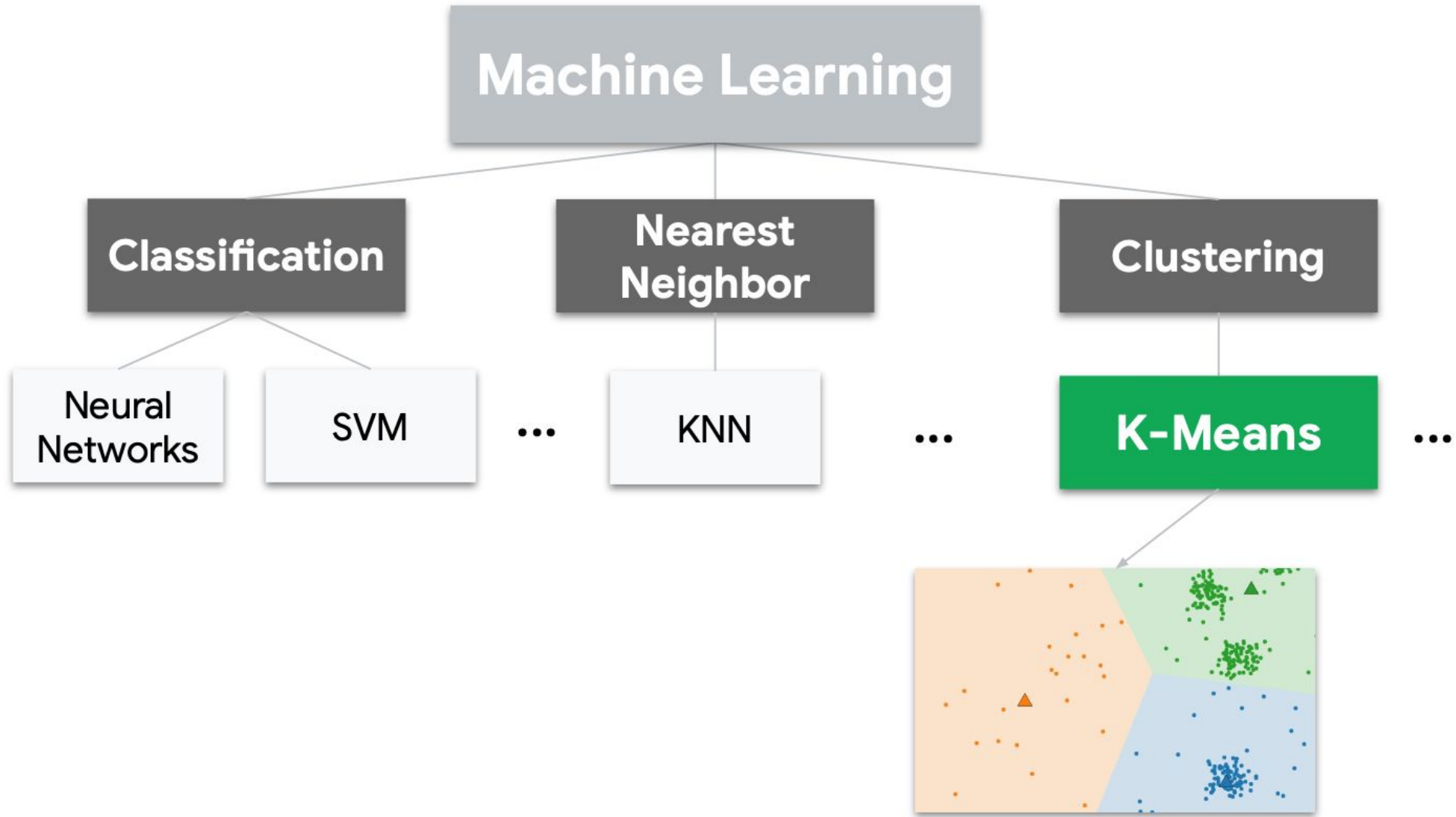
Ups!

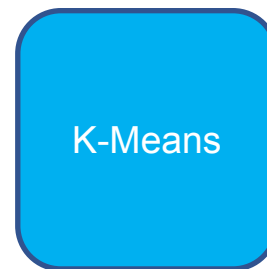
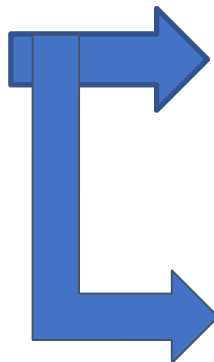


Lift

Maritime

# It's **not** all deep learning





### Classes

- Lift
- Terrestrial
- Maritime
- Idle

- Anomaly

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 |     |
|--|------------------|-------------|-----|
| <b>Classification (Keras)</b><br>Learns patterns from data, and can apply these to new data. Great for categorizing movement or recognizing audio. | EdgeImpulse Inc. | ★           | Add |
| <b>Anomaly Detection (K-means)</b><br>Find outliers in new data. Good for recognizing unknown states, and to complement classifiers.               | EdgeImpulse Inc. | ★           | Add |
| <b>Regression (Keras)</b><br>Learns patterns from data, and can apply these to new data. Great for predicting numeric continuous values.           | EdgeImpulse Inc. |             | Add |

Cancel

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

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EDGE IMPULSE

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NN Classifier

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ANOMALY DETECTION (SCITINYML-MOTION-ANOMALY-PROJECT)

#1 Click to set a description for this version

Anomaly detection settings

Cluster count

4

Axes

☒ 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

☒ 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

☒ 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

Select all axes

Start training

Anomaly explorer (3,230 samples)

X Axis

accX RMS

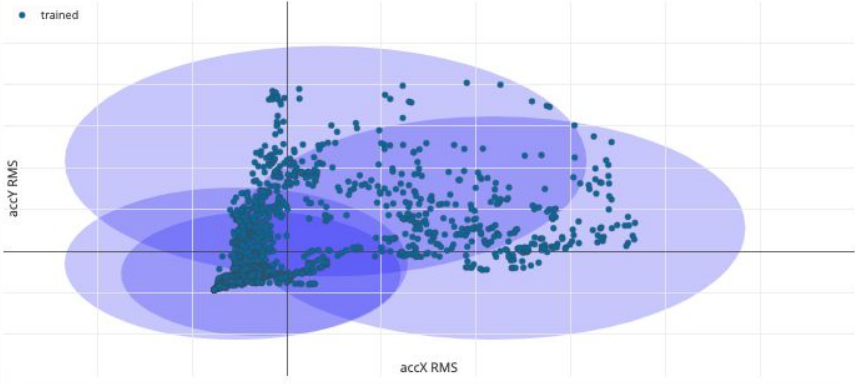
Y Axis

accY RMS

Test data

No test data

trained



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 0.94998646 1.12868147] var [1.53209261 1.05624885 1.21194617]  
trained\_clusters [{'center': [-0.5379795432090759, -0.30185389518737793, -0.8996922373771667], 'max\_error': 1.805067500641951}, {'center': [-0.2765962481498718, -0.5444689393043518, 0.5496397018432617], 'max\_error': 1.4696349225860046}, {'center': [0.4085573256015776, 2.160626173019409, 1.2495908737182617], 'max\_error': 2.7492433102802676}, {'center': [2.1753463745117188, 0.555717945098877, 1.391709804534912], 'max\_error': 2.6628344654985634}]  
  
Job completed

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ANOMALY DETECTION (SCITINYML-MOTION-ANOMALY-PROJECT)

#1 Click to set a description for this version

Anomaly detection settings

Cluster count

32

Axes

☒ 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

☐ 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

☒ 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

Select all axes

Start training

Anomaly explorer (3,230 samples)

X Axis

accX RMS

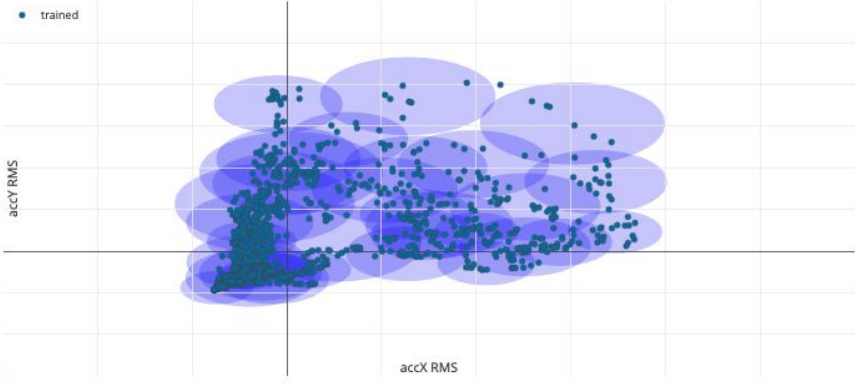
Y Axis

accY RMS

Test data

No test data

trained



Training output

```
0.6358923488456604), {'center': [0.2331821322441101, -0.44085508584976196, 1.193619966506958], 'max_error': 0.43379442394199896}, {'center': [-0.04211855307221413, 1.622160792350769, 1.563327558880615], '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': 0.750148069600636}, {'center': [1.3629376888275146, 0.8849844336509705, 1.6627943515777588], 'max_error': 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

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# EON Tuner

## Target

- Continuous motion
- Arduino Nano 33 BLE Sense (Cortex-M4F 64MHz)
- 100 ms
- 256 kB
- 1024 kB

## Filters

### Status

- ☒ Pending
- ☒ Running
- ☒ Completed
- ☒ Failed

### DSP type

- ☒ spectral-analysis

### Network type

- ☒ dense

## View

### Data set

- ☒ Validation
- ☐ Train
- ☐ Test

### Precision

## Sort

### General

- ☒ Accuracy
- ☐ Latency
- ☐ RAM
- ☐ ROM
- ☐ Last updated

### F1-score

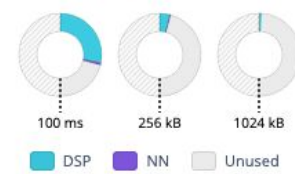
### Precision

### Recall

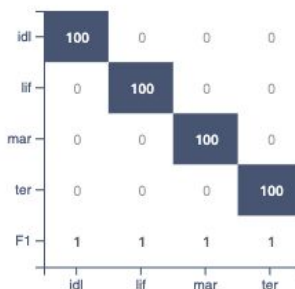
100% spectr-dense-d5f

Select

### PERFORMANCE



### ACCURACY



### INPUT

↔ 2000 ms | → 1000 ms

### SPECTRAL-ANALYSIS

↔ 1024

### KERAS

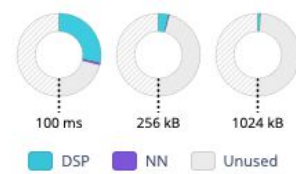
| Type    | Filters | Kernel | Rate |
|---------|---------|--------|------|
| dense   | 80      | -      | -    |
| dropout | -       | -      | 0.25 |
| dense   | 40      | -      | -    |
| dropout | -       | -      | 0.25 |
| dense   | 20      | -      | -    |
| dropout | -       | -      | 0.25 |

10/14/2021, 6:26:09 PM

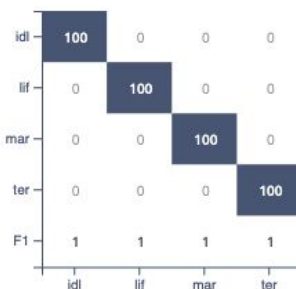
100% spectr-dense-d57

Select

### PERFORMANCE



### ACCURACY



### INPUT

↔ 2000 ms | → 1000 ms

### SPECTRAL-ANALYSIS

↔ 1024

### KERAS

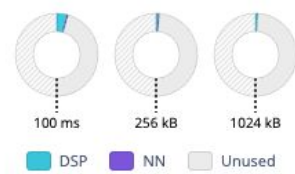
| Type    | Filters | Kernel | Rate |
|---------|---------|--------|------|
| dense   | 80      | -      | -    |
| dropout | -       | -      | 0.25 |
| dense   | 40      | -      | -    |
| dropout | -       | -      | 0.25 |

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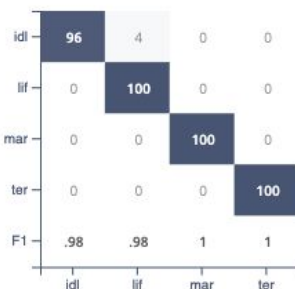
99% spectr-dense-e32

Select

### PERFORMANCE



### ACCURACY



### INPUT

↔ 2000 ms | → 500 ms

### SPECTRAL-ANALYSIS

↔ 128

### KERAS

| Type  | Filters | Kernel | Rate |
|-------|---------|--------|------|
| dense | 40      | -      | -    |
| dense | 20      | -      | -    |
| dense | 10      | -      | -    |

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# 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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