

# When IoT meets AI: The marvelous world of TinyML

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**UNIFEI**

# IoT



# Internet of Things (IoT)

“The IoT can be viewed as a global **infrastructure** for the information society, enabling advanced services by interconnecting (**physical** and **virtual**) things based on existing and evolving interoperable information and communication technologies (ICT).”— Recommendation ITU-T Y.2060

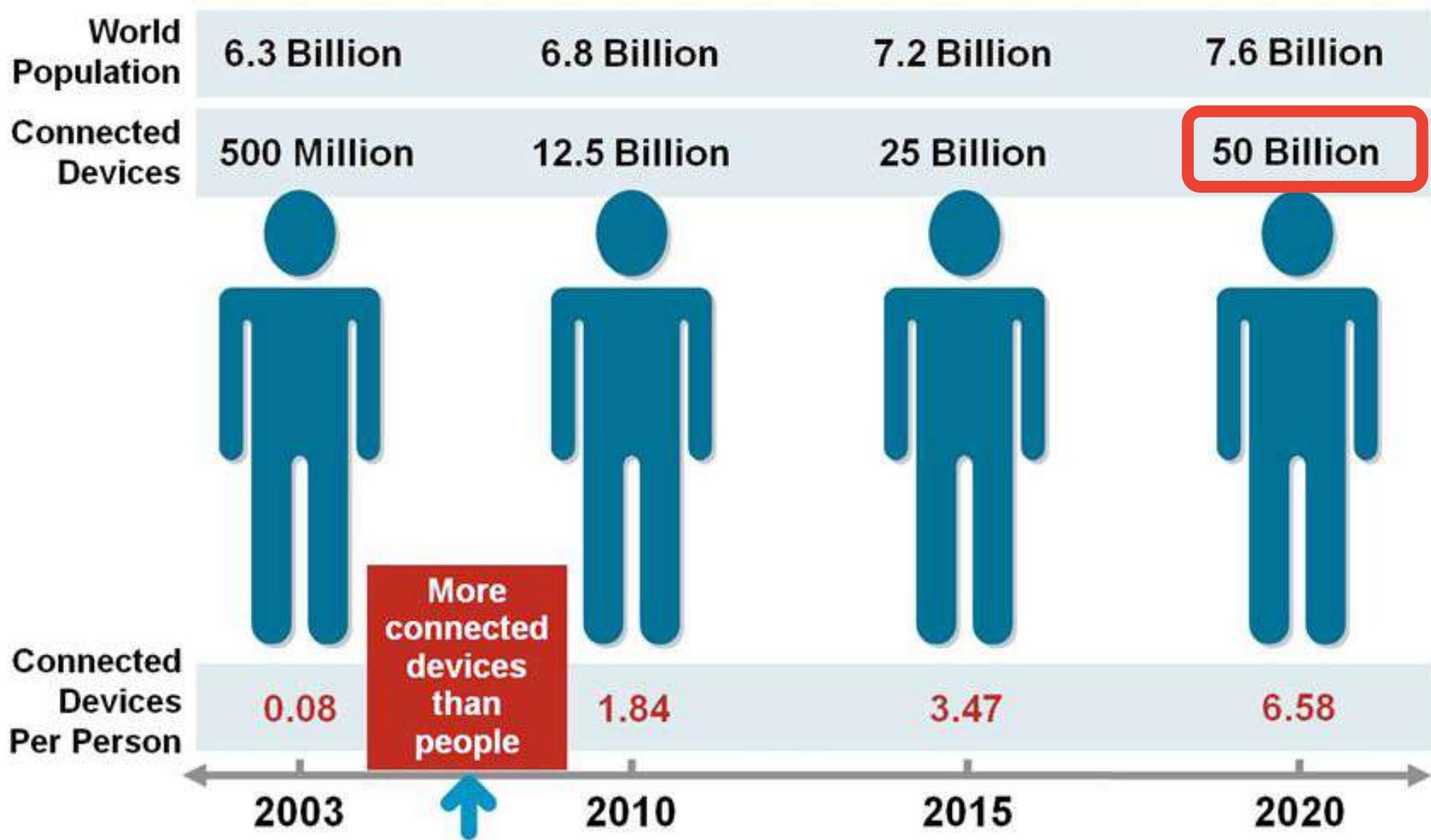
# Device — ITU definition

“A device is a piece of equipment with the **mandatory capabilities of communication** and optional capabilities of sensing, actuation, data capture, data storage and data processing. Some devices also execute operations based on information received from the information and communication networks.”

— Recommendation ITU-T Y.2060

# Fundamental characteristics — ITU

**Enormous scale:** The number of devices that need to be managed and that communicate with each other will be at least an order of magnitude larger than the devices connected to the current Internet. The ratio of communication triggered by devices as compared to communication triggered by humans will noticeably shift towards device-triggered communication.

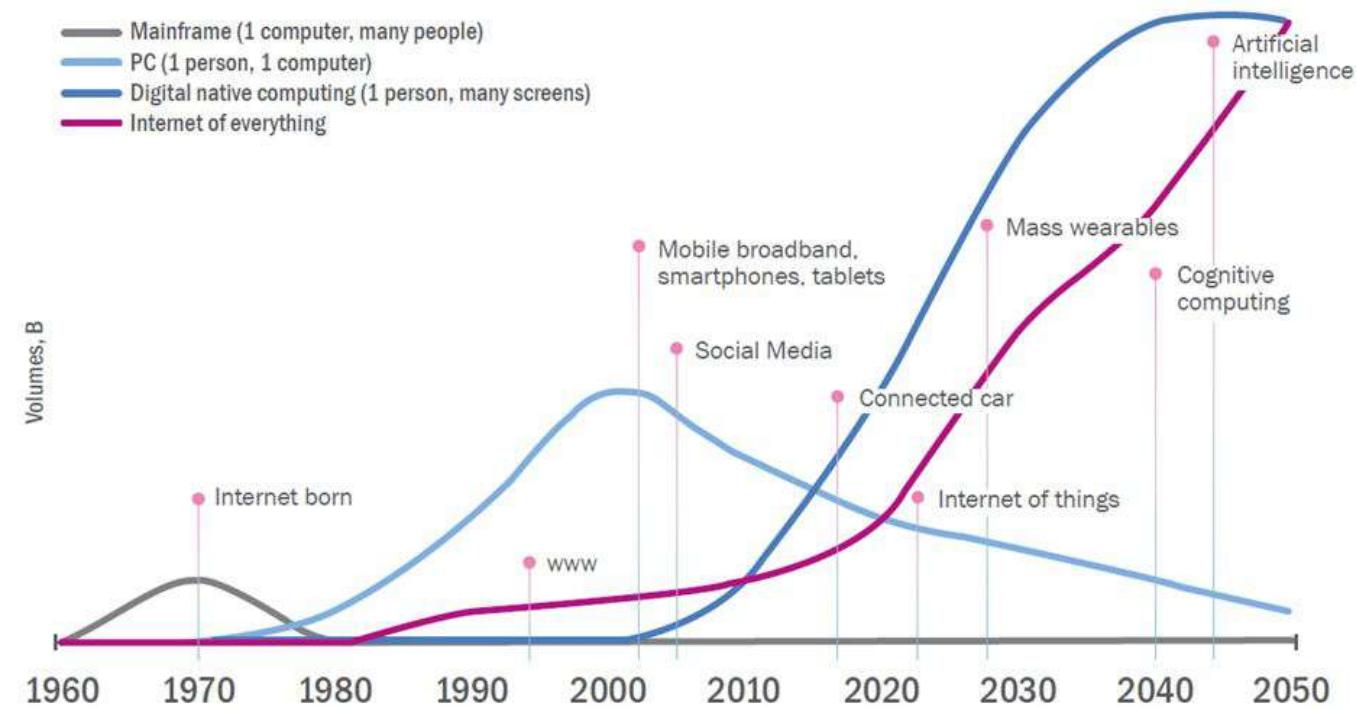


Source: Cisco IBSG, April 2011

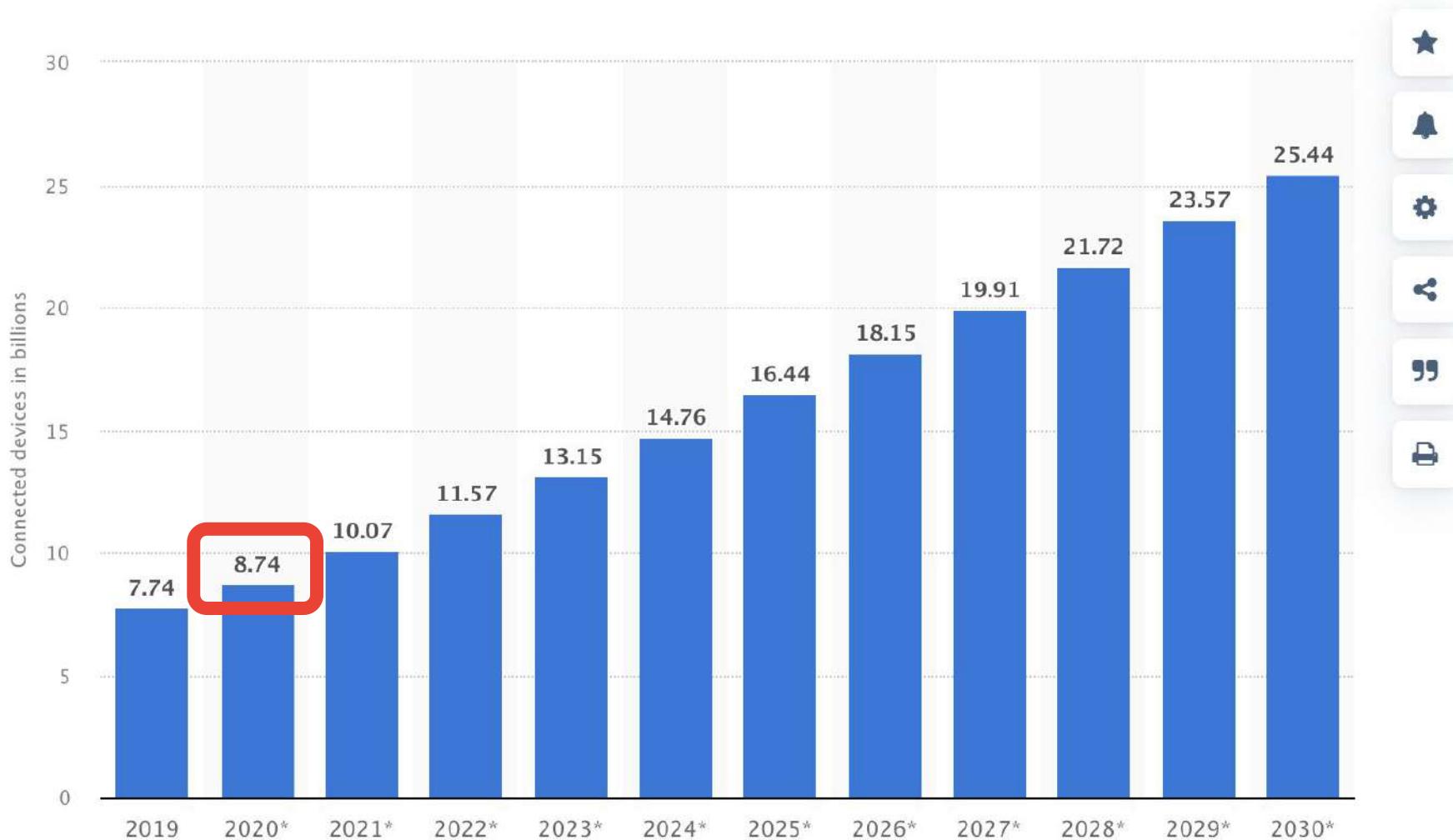
# One to many to any

## History of the future

One to many to any: ICTs from happy few to the masses



# 2020 statistics



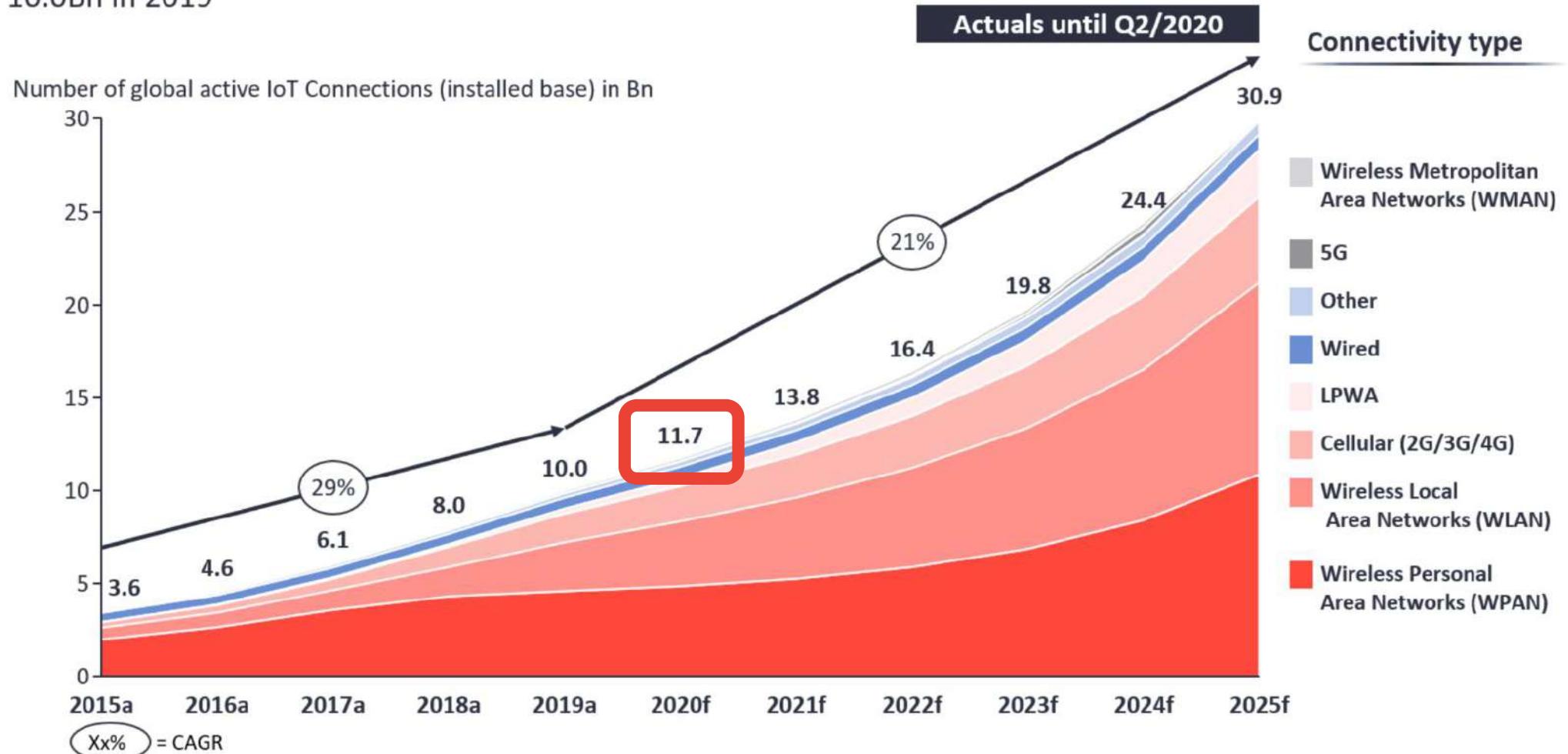
# 2020 statistics



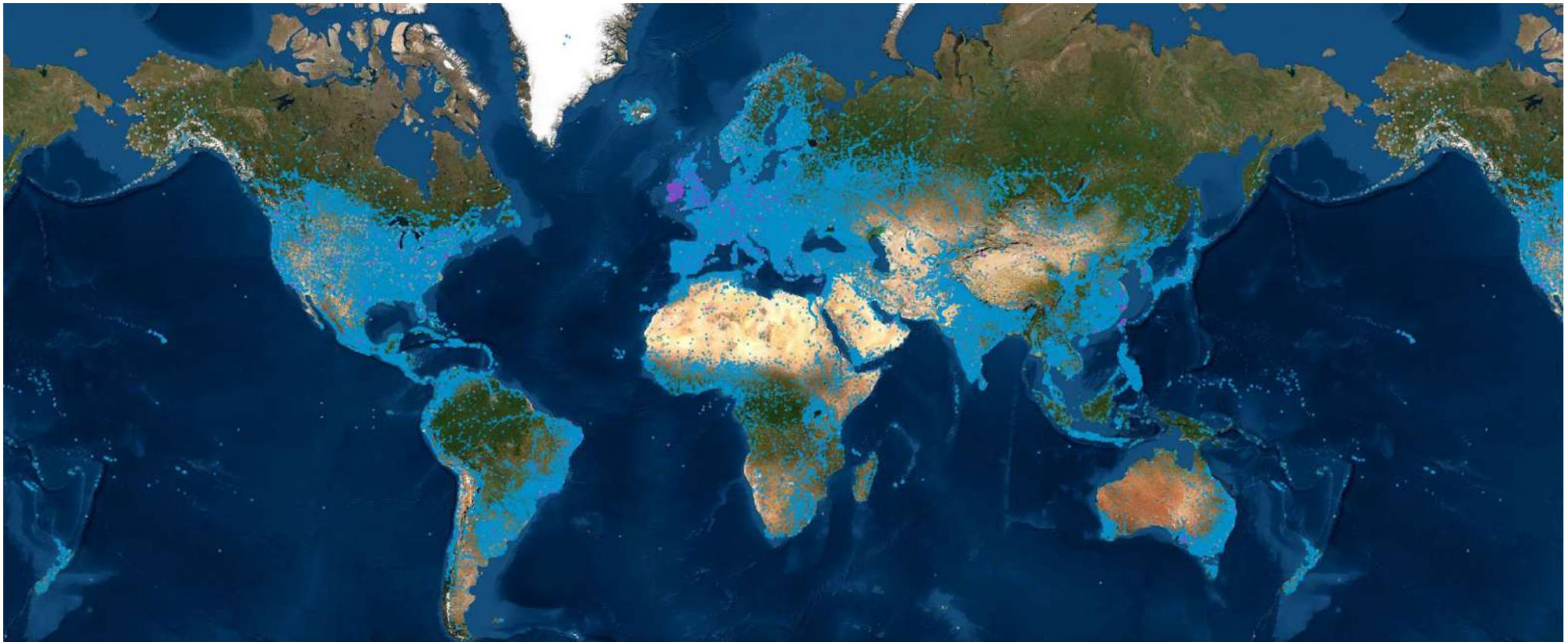
Insights that empower you to understand IoT

## Global Number of Connected IoT Devices

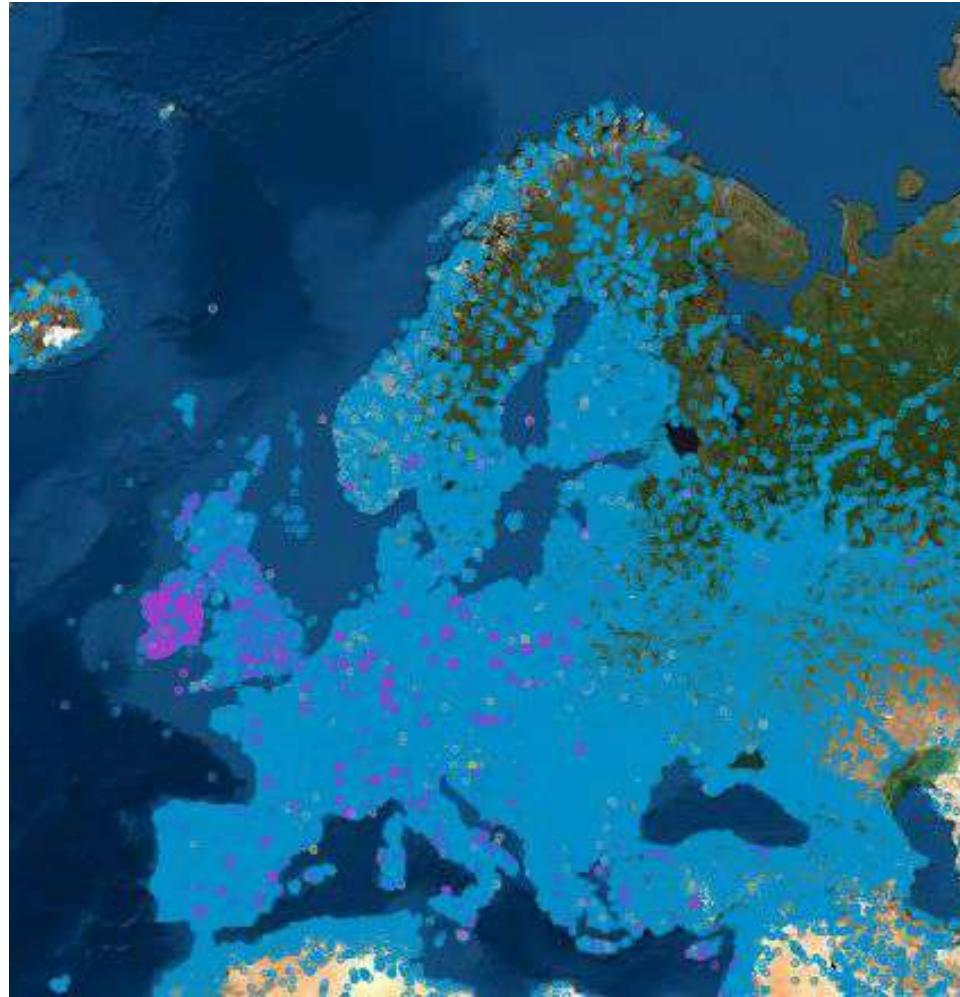
10.0Bn in 2019



# Worldwide distribution



# Worldwide distribution



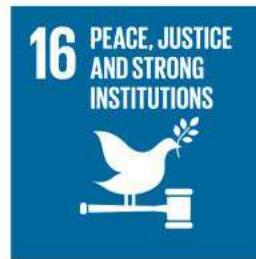
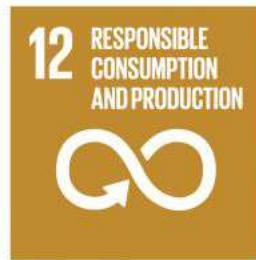
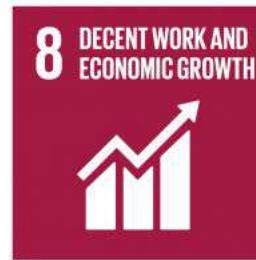
Credit: <https://www.thingful.net>

# Worldwide distribution



Credit: <https://www.thingful.net>

# IoT and SDG



# IoT and SDG

## ➤ SDG 2: ZERO HUNGER:

An estimated 821 million people were undernourished in 2017. Annual cereal production will need to rise to about 3 billion tonnes and annual meat production will need to rise by over 200 million tonnes to reach 470 million tonnes to feed 9.1 billion people by 2050.

## ➤ SDG 13 & 15: CLIMATE ACTION and LIFE ON LAND:

Given current concentrations and on-going emissions of greenhouse gases, it is likely that by the end of this century, the increase in global temperature will exceed 1.5°C. Global emissions of carbon dioxide (CO<sub>2</sub>) have increased by almost 50 per cent since 1990

# Drivers and obstacles for IoT

- ↑ Low cost of devices (MCU and sensors)
- ↑ Wireless standards
  
- ↓ Lack of Internet connectivity
- ↓ Lack of IoT infrastructure
- ↓ Complex ecosystem

# Device — ITU definition

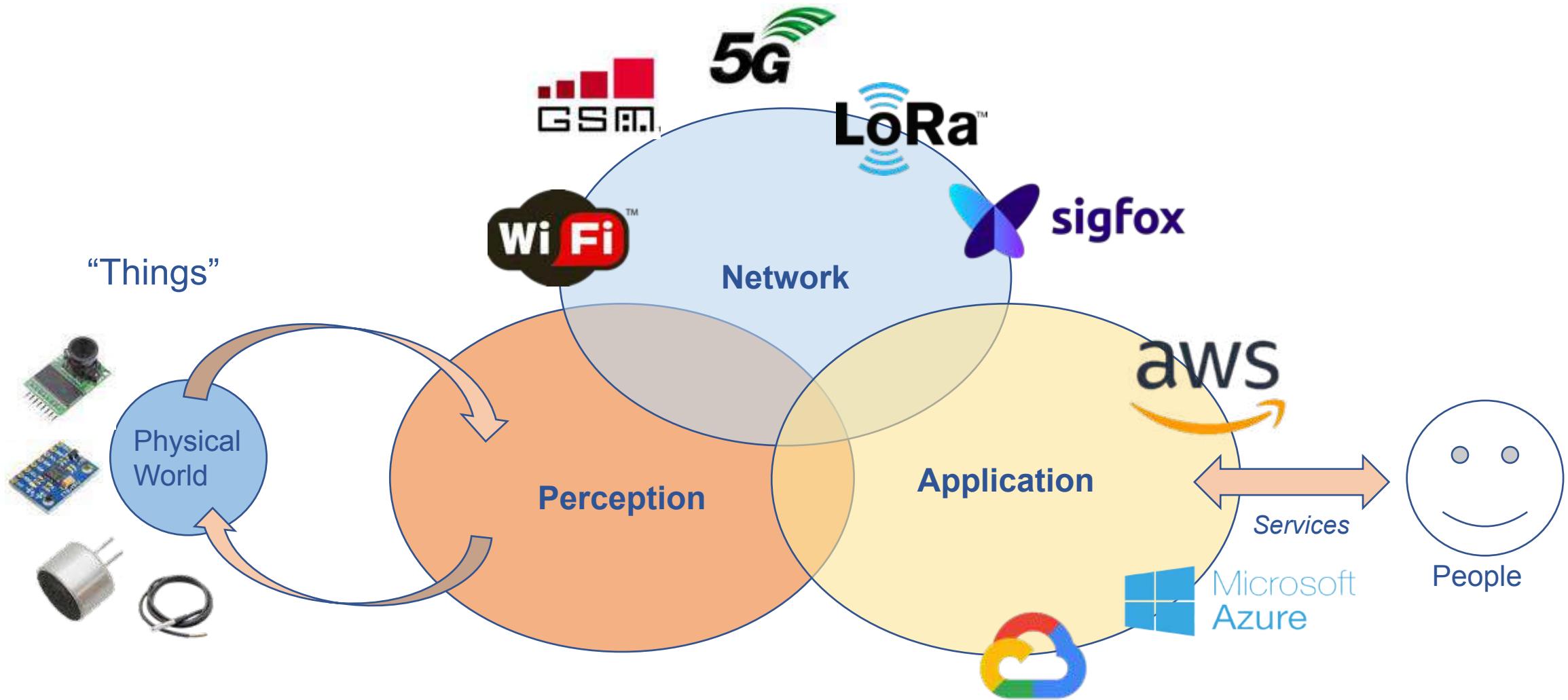
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# IoT

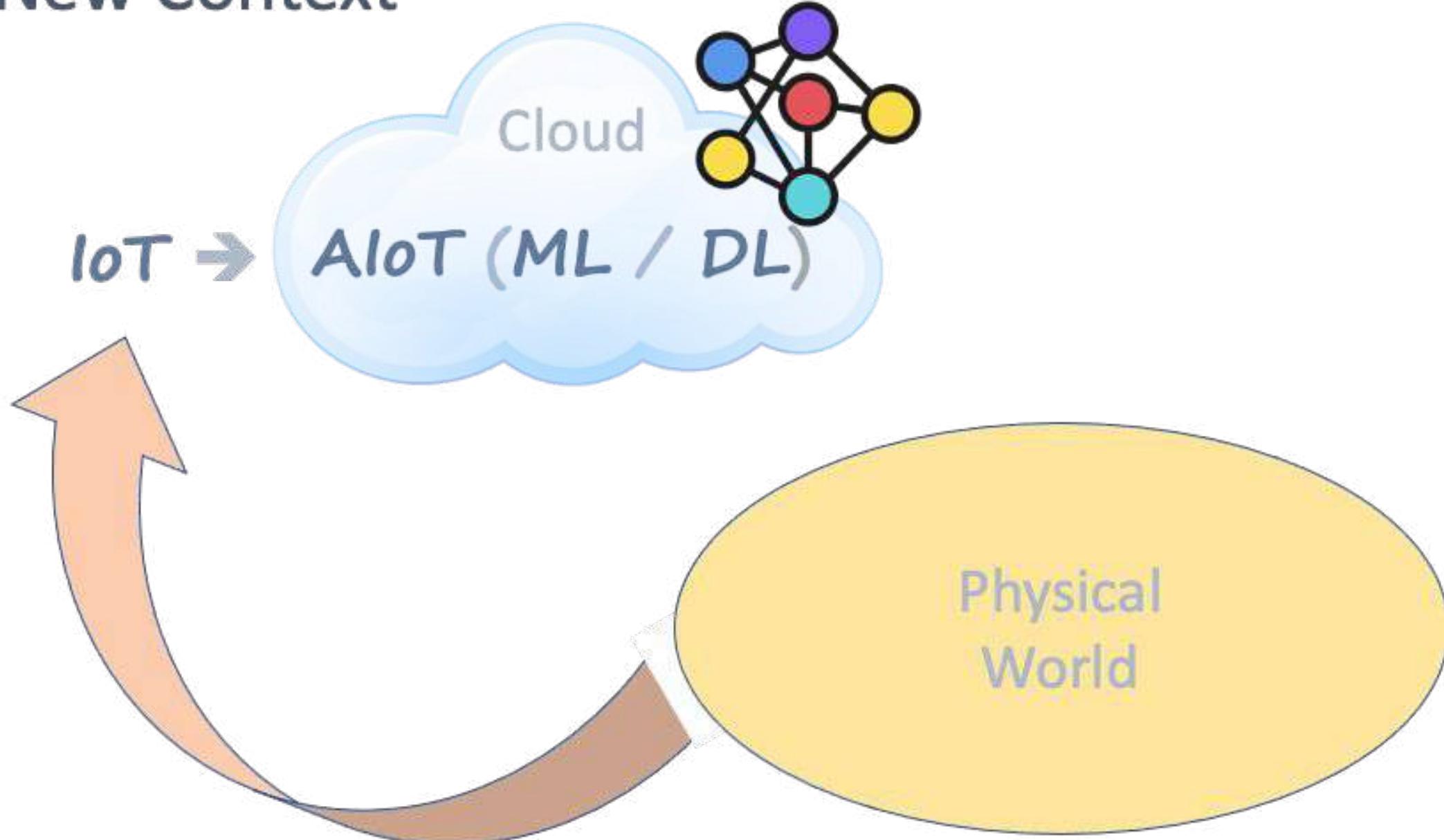


# Classical IoT Architecture

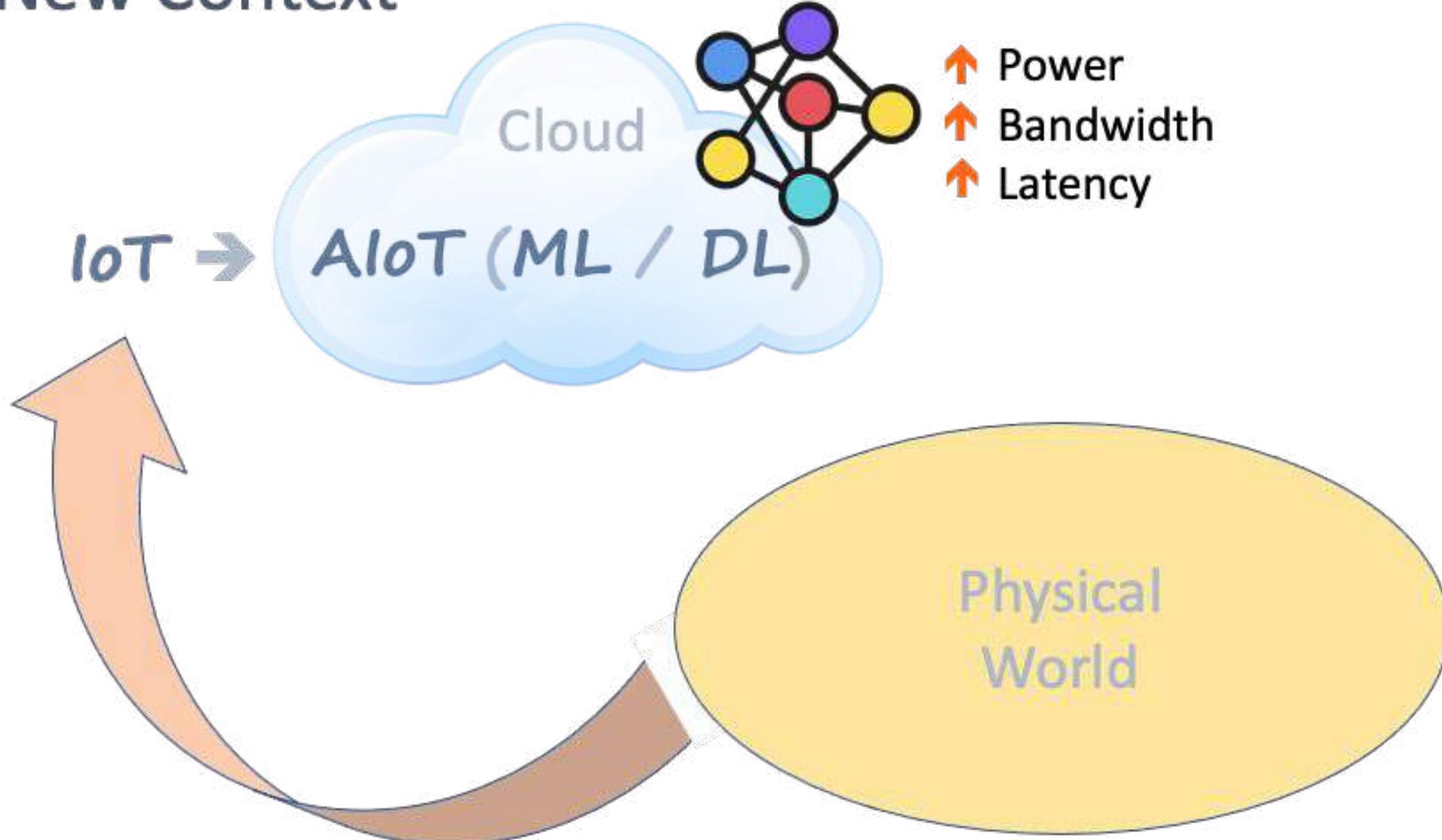


5 Quintillion bytes of data produced every day by IoT, but less than 1% is used. HBR/CISCO

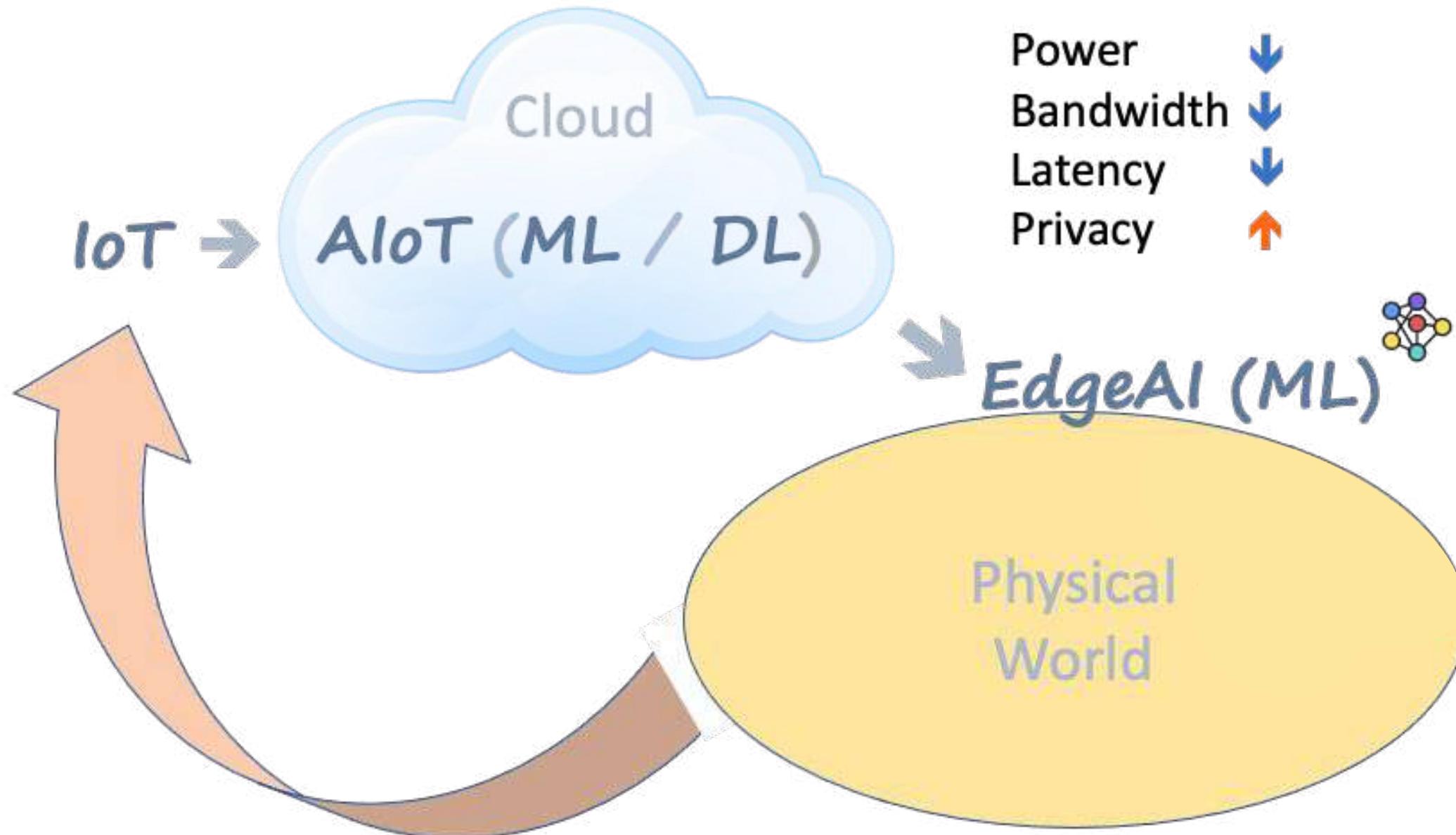
# New Context



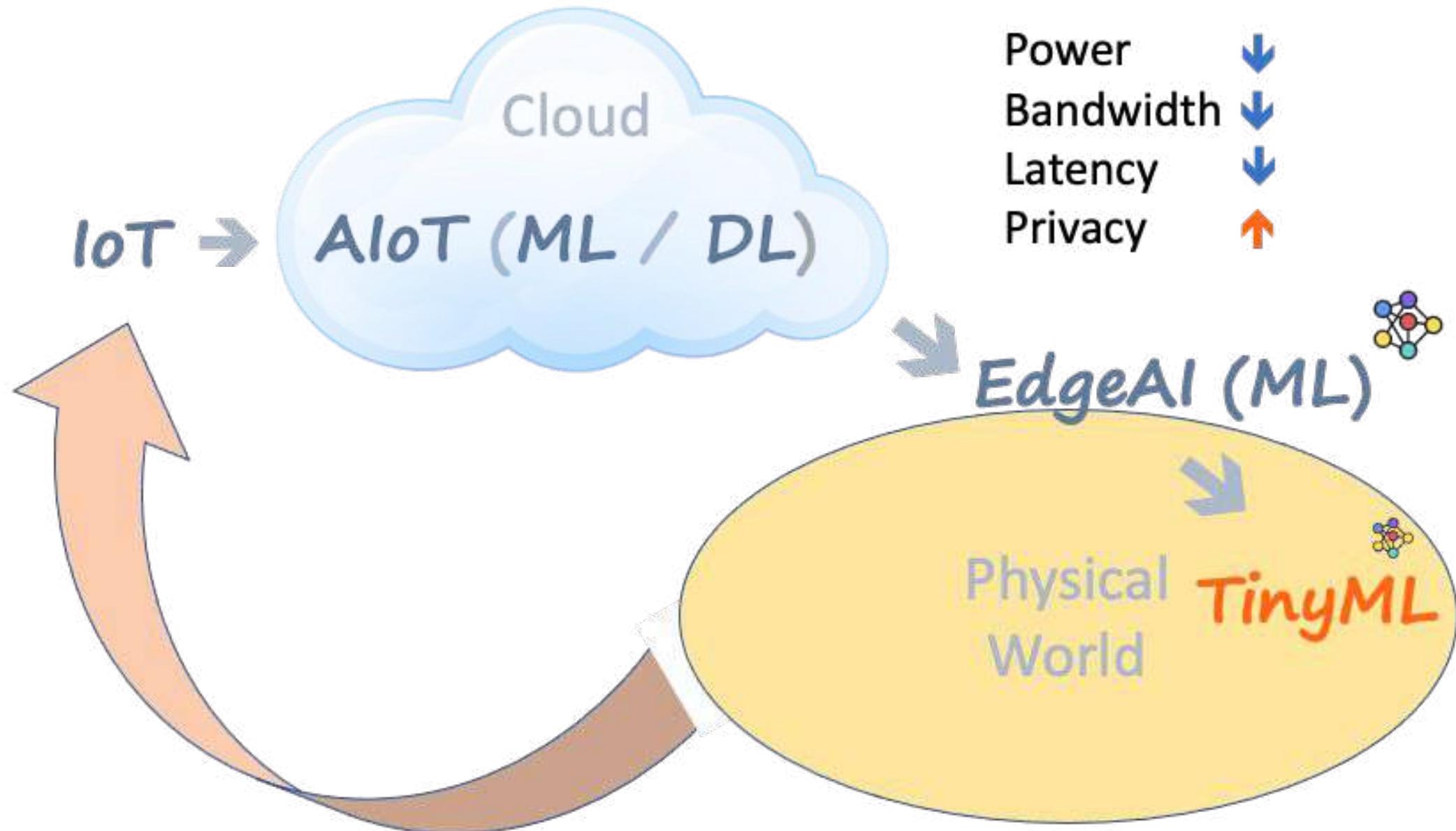
# New Context



# New Context



# New Context



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

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**TinyML**



Fastest-growing field of **ML**



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

**TinyML**

Fastest-growing field of **ML**



Algorithms, hardware, software

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

**TinyML**

Fastest-growing field of **ML**



On-device sensor analytics



Algorithms, hardware, software

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

**TinyML**

Fastest-growing field of **ML**



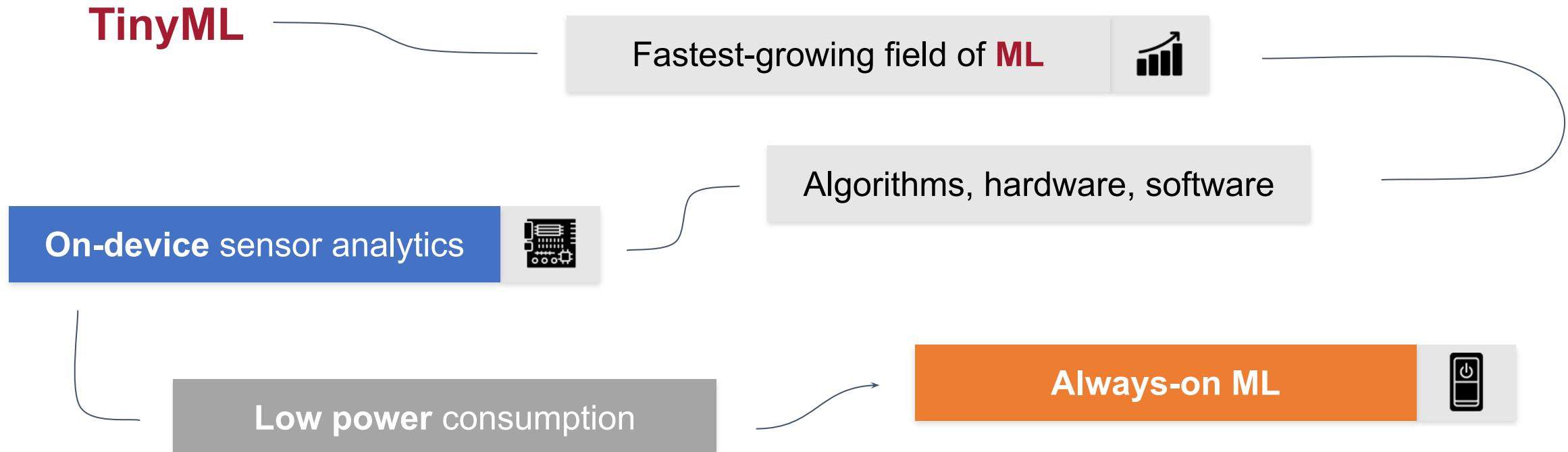
On-device sensor analytics



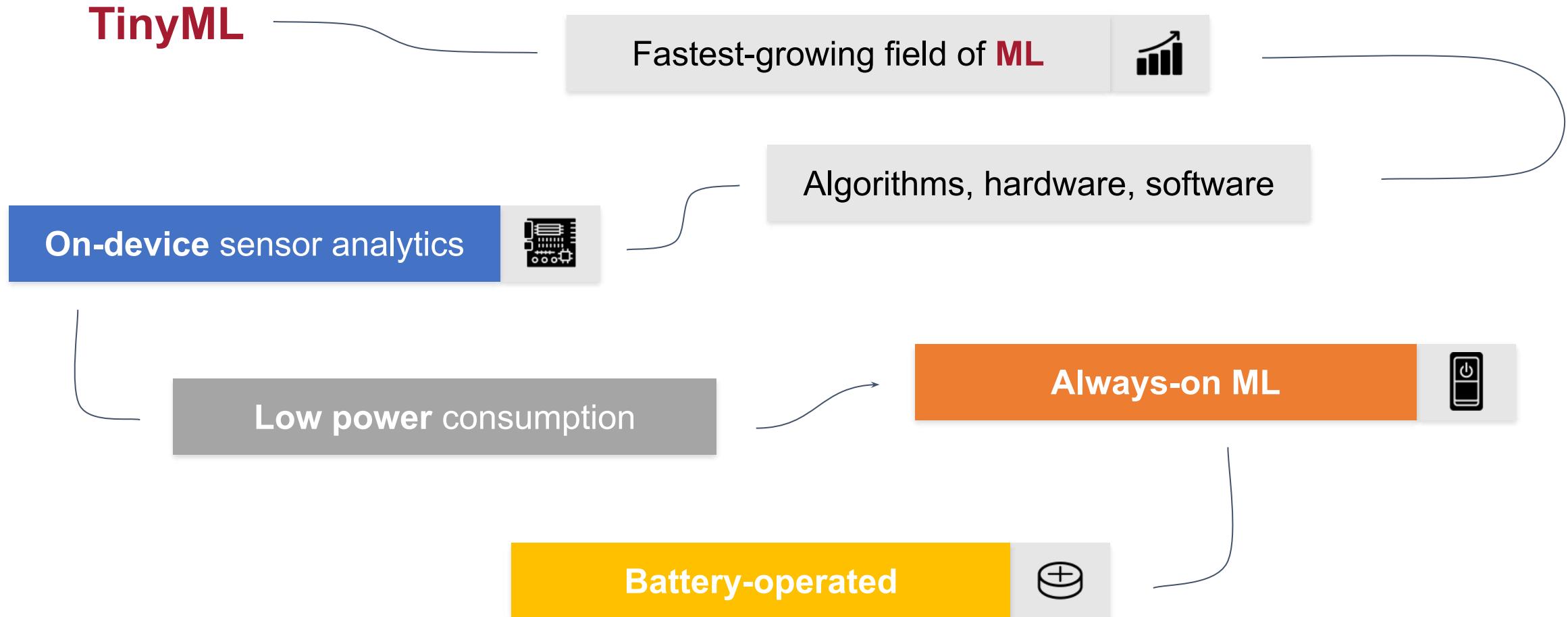
Algorithms, hardware, software

Low power consumption

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



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# EdgeML (P<sup>↑</sup>)

Autonomous Car Control



Image Recognition



# EdgeML (P $\uparrow$ )

Autonomous Car Control



Image Recognition



# TinyML (P $\downarrow$ )

KeyWord Spotting



Environmental Control



Image Spot



Motion & biometric



# TinyML Application Areas



## Predictive Maintenance



Motion, current, audio and camera

- Industrial
- White goods
- Infrastructure
- Automotive

## Asset Tracking & Monitoring



Motion, temp, humidity, position, audio and camera

- Logistics
- Infrastructure
- Buildings

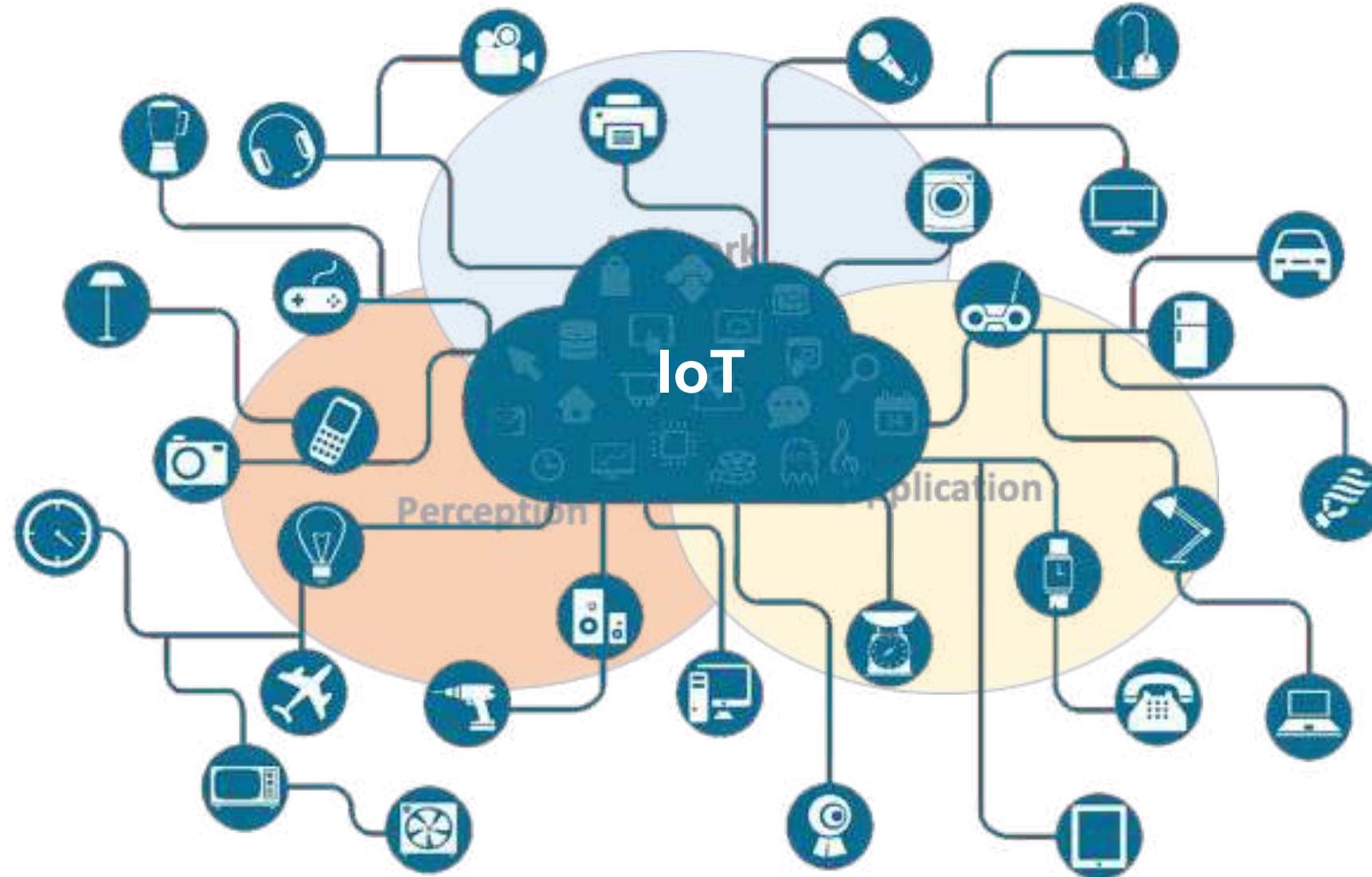
## Human & Animal Sensing



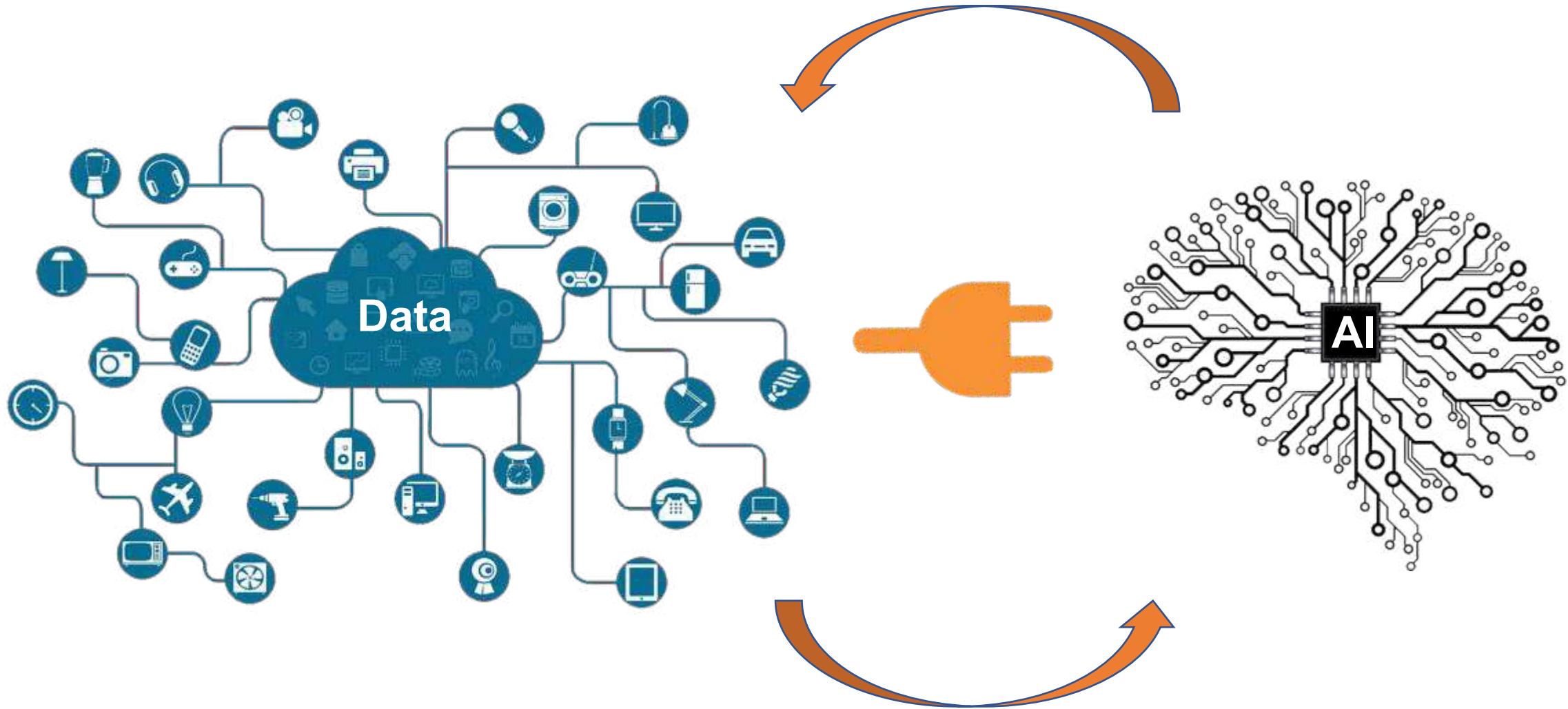
Motion, radar, audio, PPG, ECG

- Health
- Consumer
- Industrial

# IoT - Architecture



# Endpoints devices → Data + AI → Value



# Endpoints Have Sensors, Tons of Sensors

## Motion Sensors

Gyroscope, radar,  
magnetometer, accelerator

## Acoustic Sensors

Ultrasonic, Microphones,  
Geophones, Vibrometers

## Environmental Sensors

Temperature, Humidity,  
Pressure, IR, etc.

## Touchscreen Sensors

Capacitive, IR

## Image Sensors

Thermal, Image

## Biometric Sensors

Fingerprint, Heart rate, etc.

## Force Sensors

Pressure, Strain

## Rotation Sensors

Encoders

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Encoders

# Biometric Sensors



Non-invasive Glucose Monitoring



Fingerprint + Photoplethysmography (PPG)



ECG Sensor

Atrial Fibrillation Detection with TinyML:  
<https://youtu.be/y5gMA3tBZmY>

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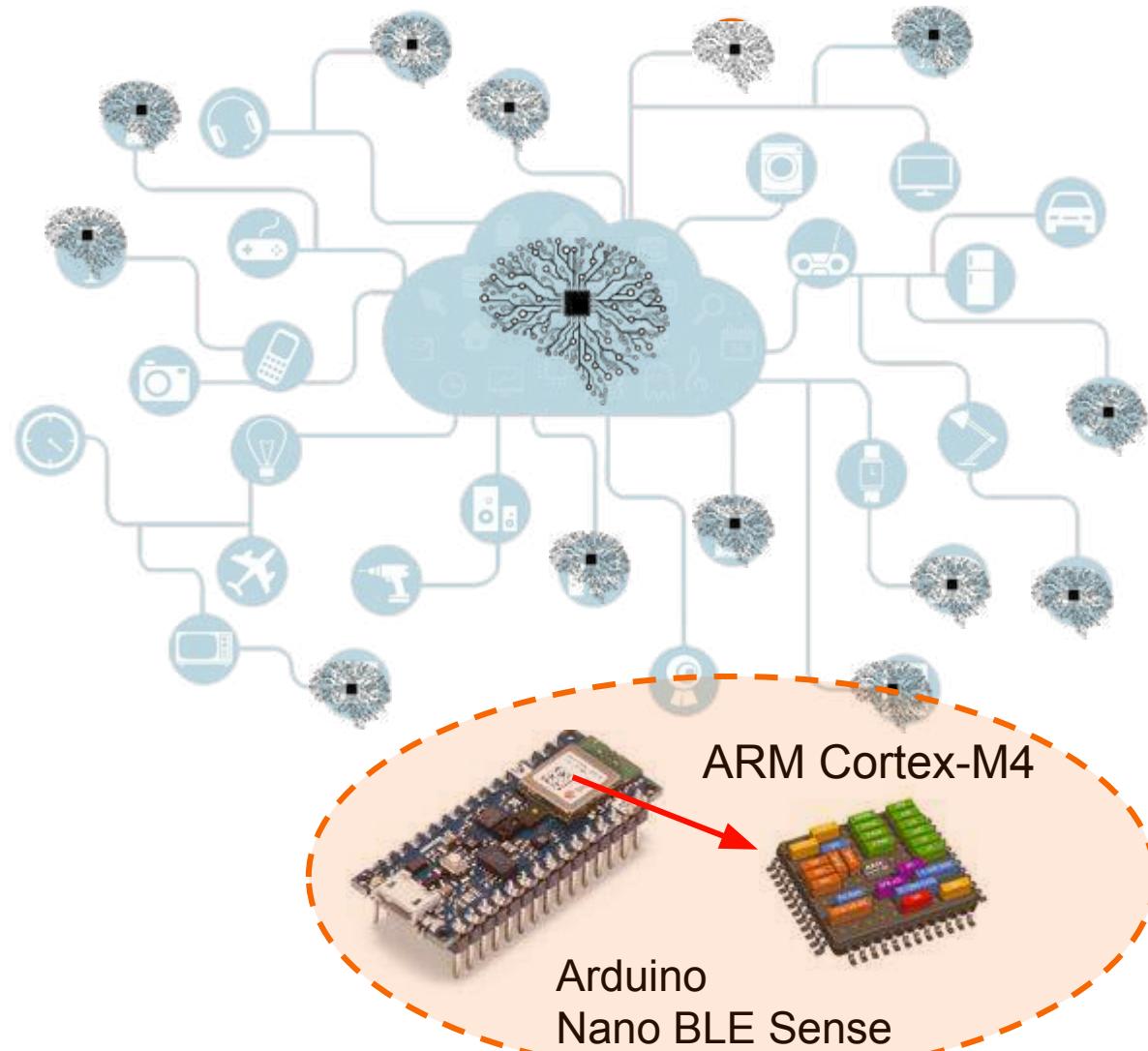
## Force Sensors

Pressure, Strain

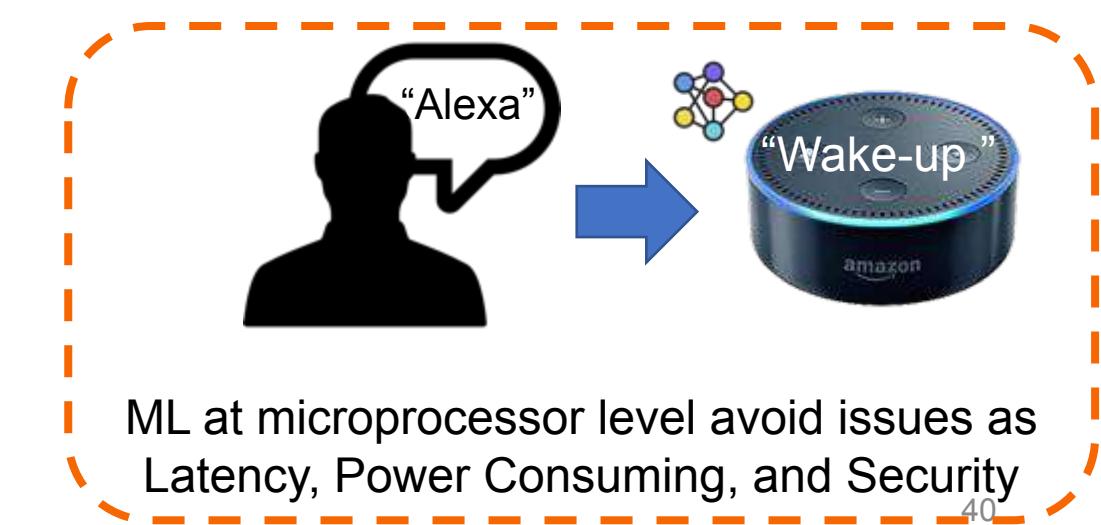
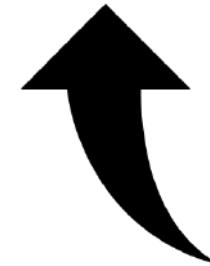
## Rotation Sensors

Encoders

# ML (AI) at the “edge of the edge” → TinyML

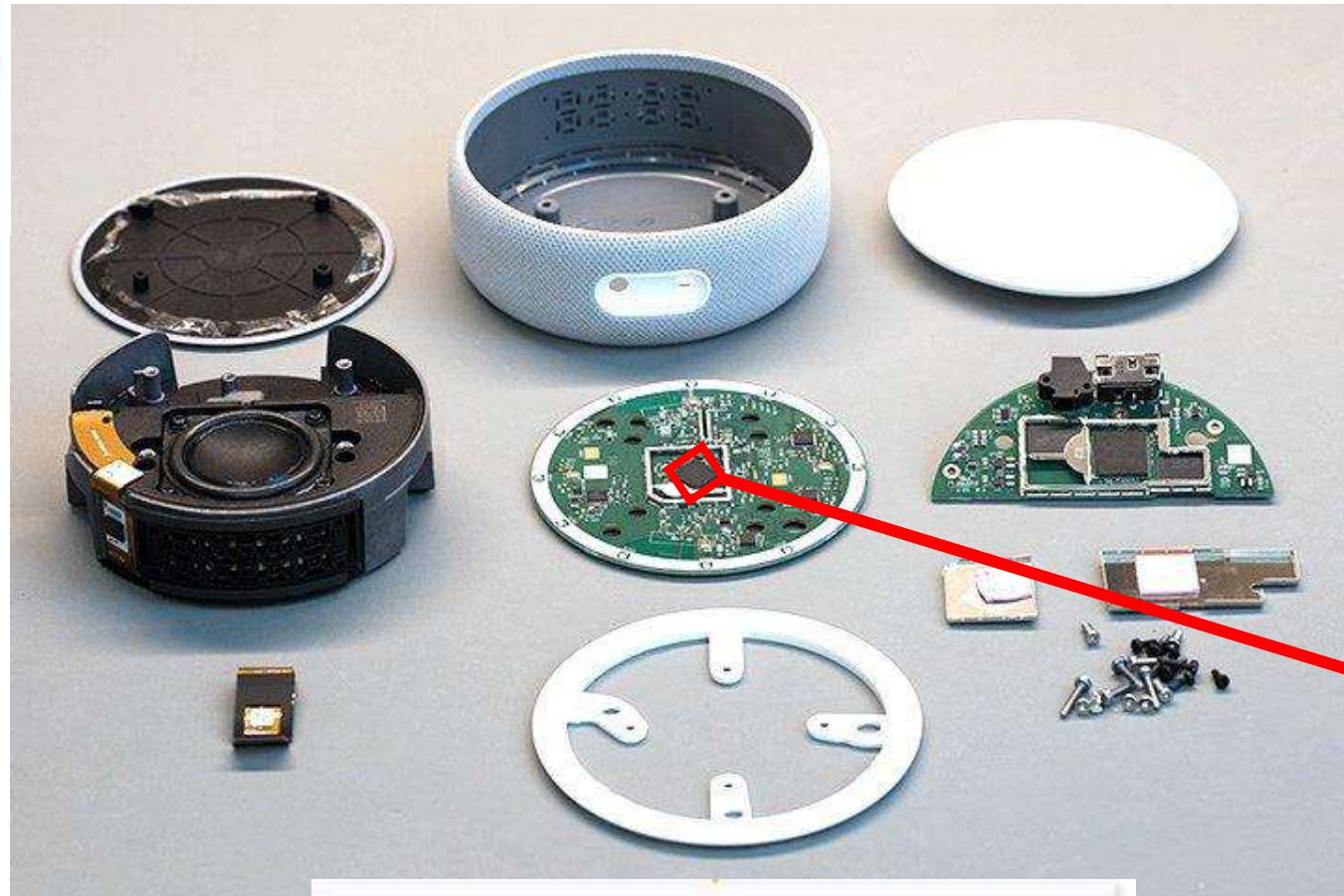


TinyML enables machine intelligence right next to the physical world



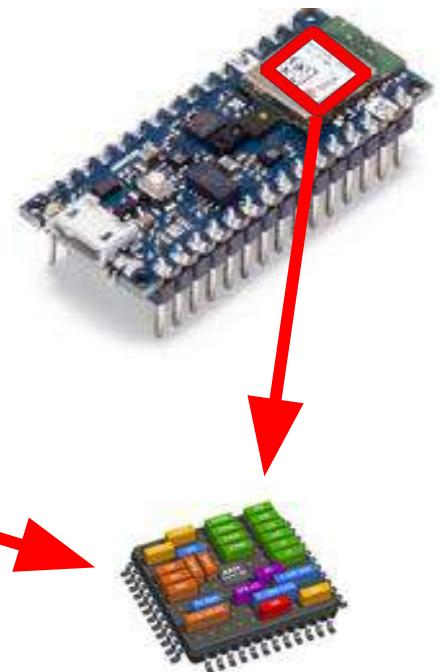
ML at microprocessor level avoid issues as Latency, Power Consuming, and Security

# Echo-Dot Teardown vs Arduino Nano BLE Sense



MediaTek 7658CSN: Wi-Fi +ARM® Cortex-R4

Nordic nRF52840-M4

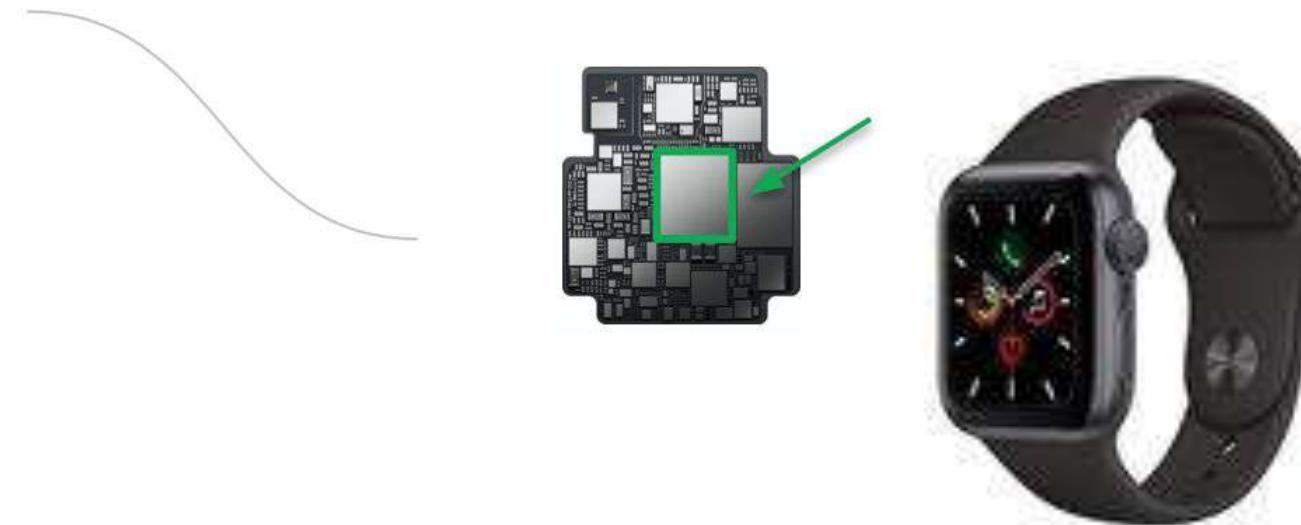


# MCUs enable **TinyML**

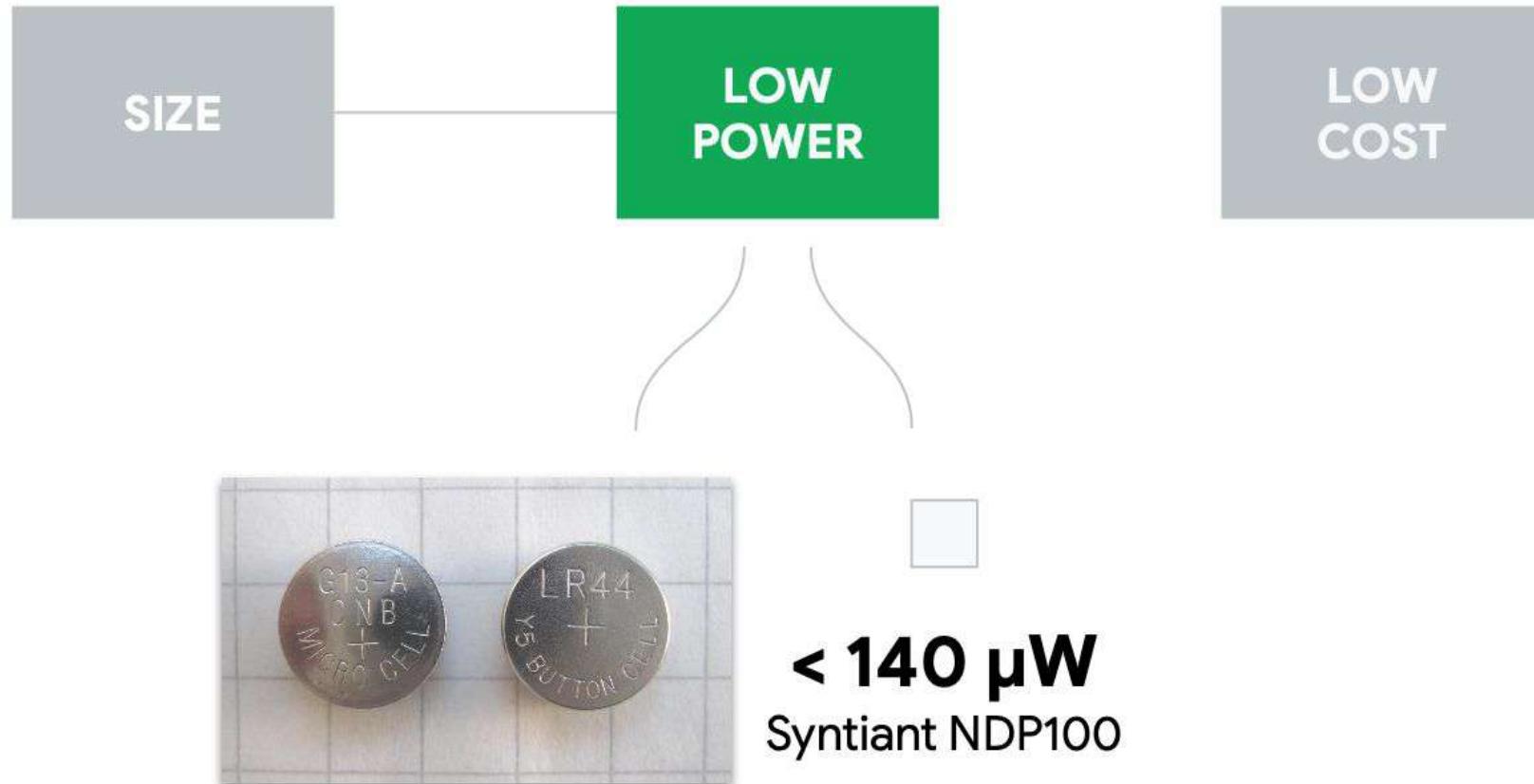
SIZE

LOW  
POWER

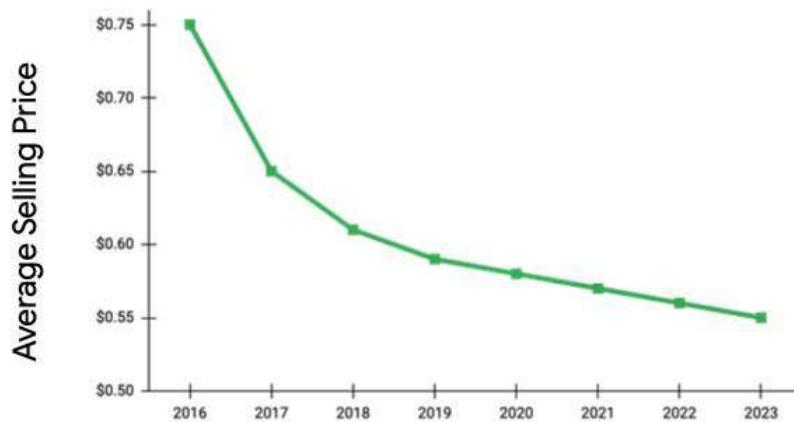
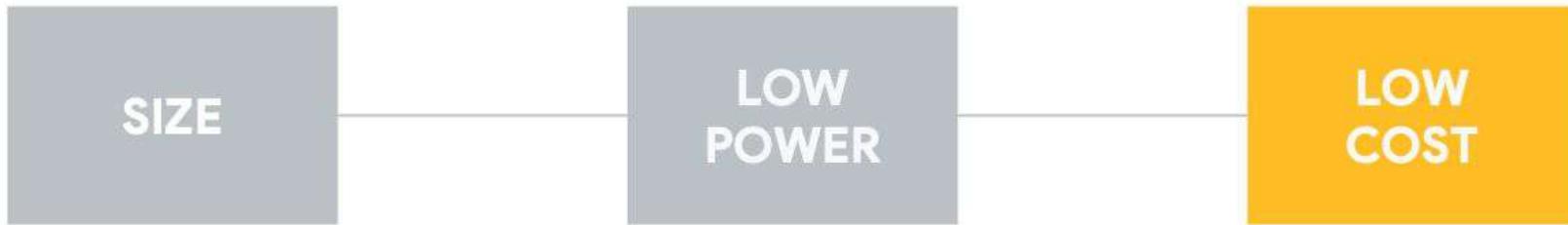
LOW  
COST



# MCUs enable **TinyML**



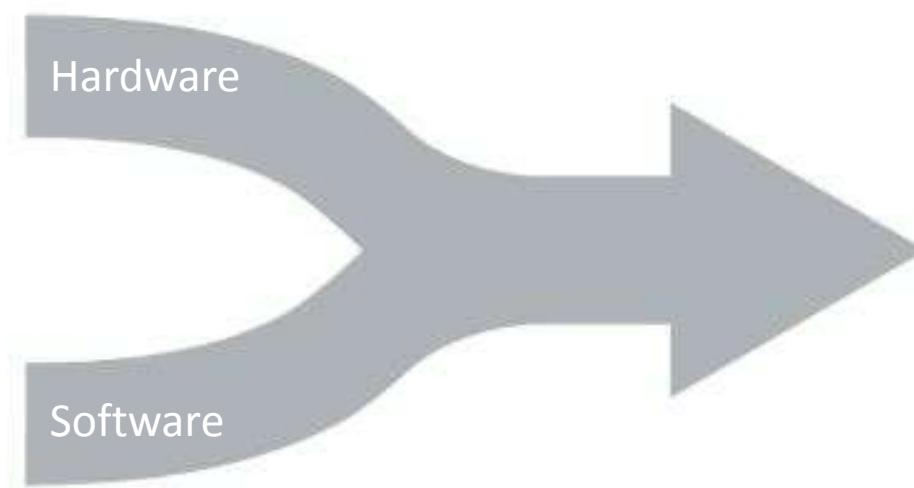
# MCUs enable **TinyML**



# What Makes **TinyML**?

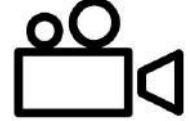
**Embedded  
Systems**

**Machine  
Learning**



**TinyML**

# Hardware



Anomaly Detection  
Sensor Classification  
20 KB



Rpi-Pico  
(Cortex-M0+)



Arduino Nano  
(Cortex-M4)



Arduino Pro  
(Cortex-M7)

Source: Edge Impulse

# EdgeML

## TinyML

KeyWord Spotting  
Audio Classification  
50 KB

Image  
Classification  
250 KB+



Video  
Classification  
2 MB+

Object Detection  
Complex Voice  
Processing  
1 MB+



RaspberryPi  
(Cortex-A)

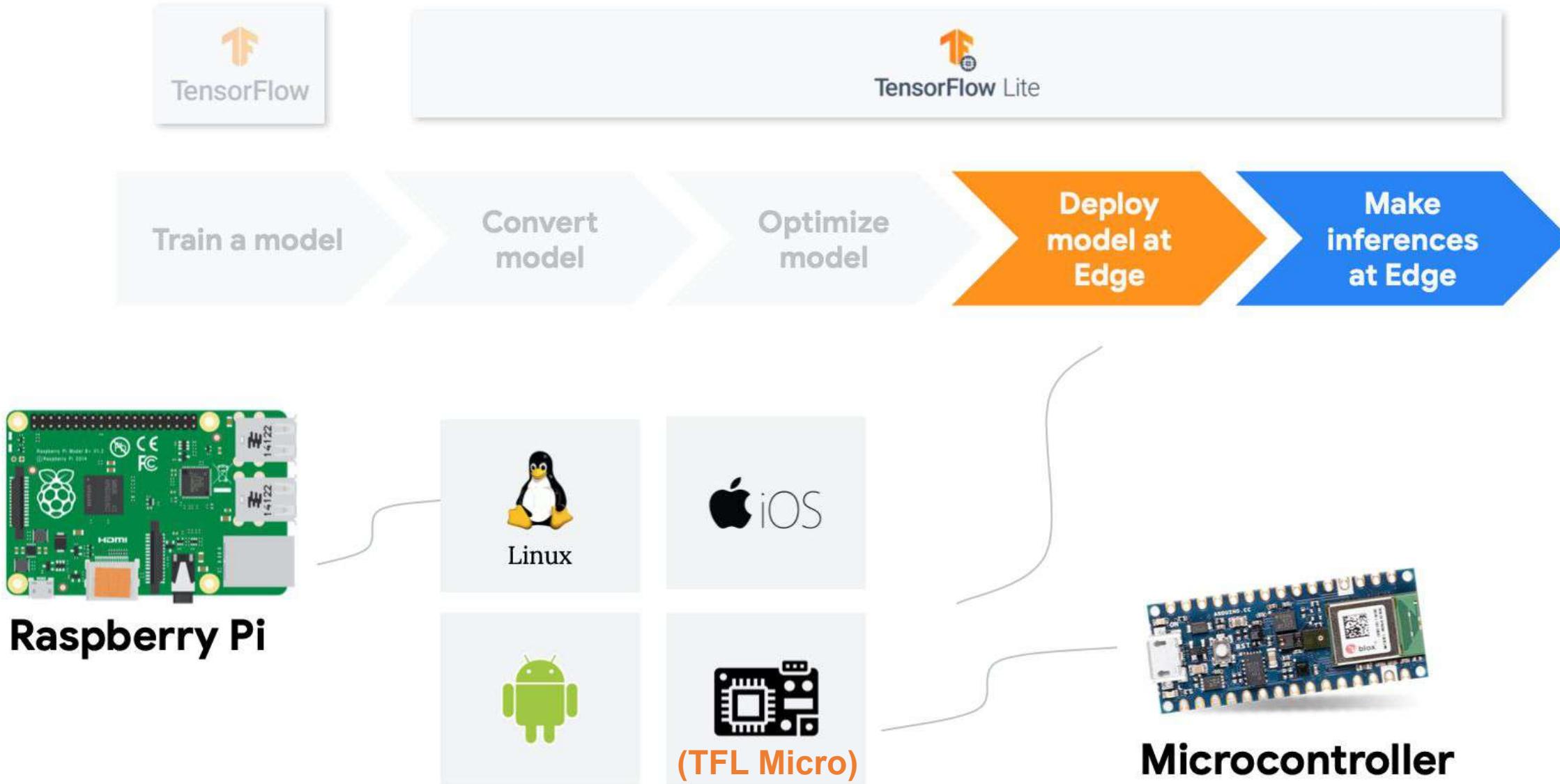


SmartPhone  
(Cortex-A)



Jetson Nano  
(Cortex-A + GPU)

# Software



# TinyML Application Examples

## Sound



## Vibration



## Vision



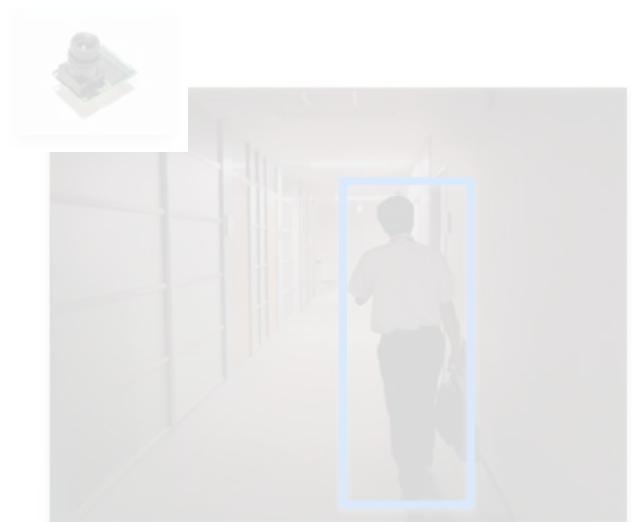
# Sound



# Vibration



# Vision









# More than just voice

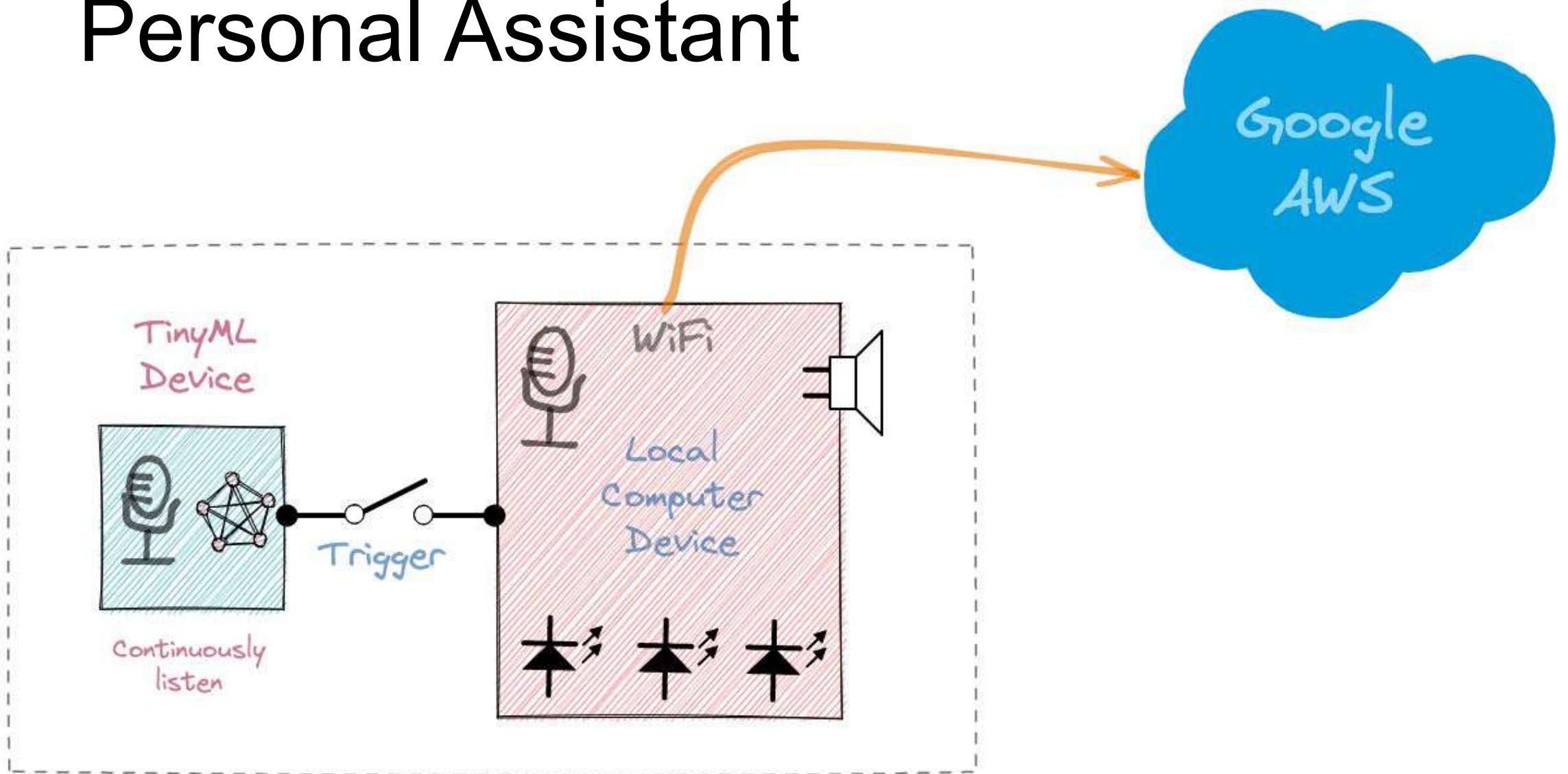
- Security (Broken Glass)
- Industry (Anomaly Detection)
- Medical (Snore, Toss)
- Nature (Bee, Mosquito sound)



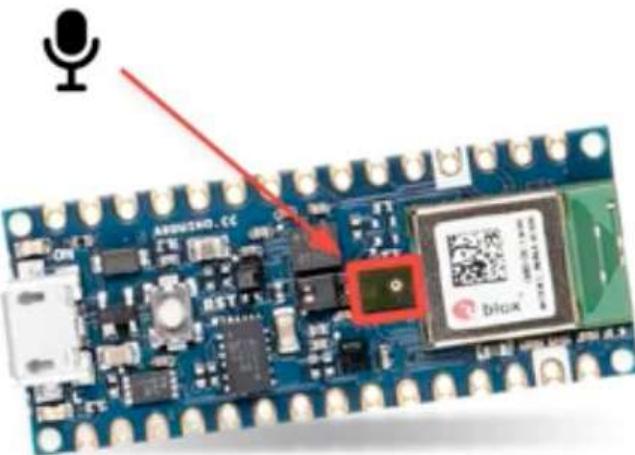
# Personal Assistant



# Personal Assistant



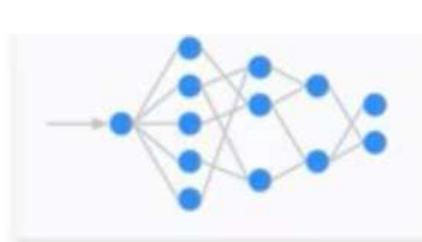
# “Cascade” Detection: multi-stage model



- 1 Continuously listen on the microcontroller

2

- Process the data with **TinyML** at the edge



3

- Process on a secondary larger model on a larger local device

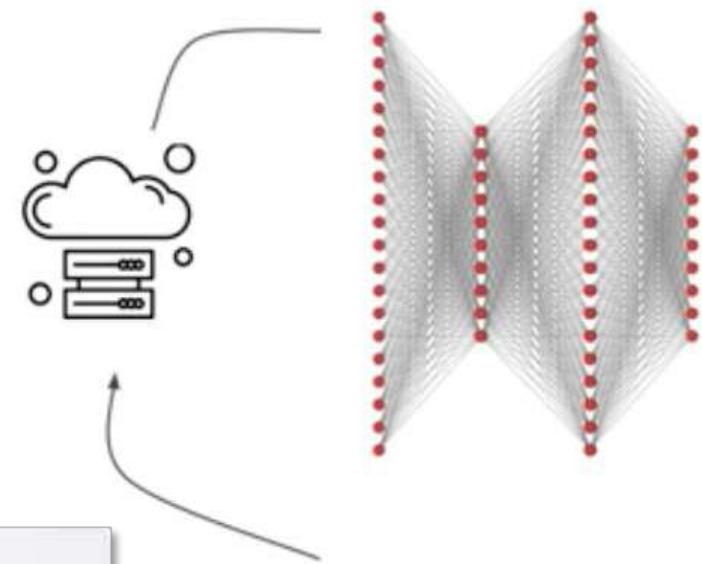


4

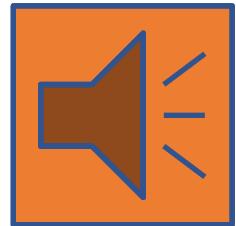
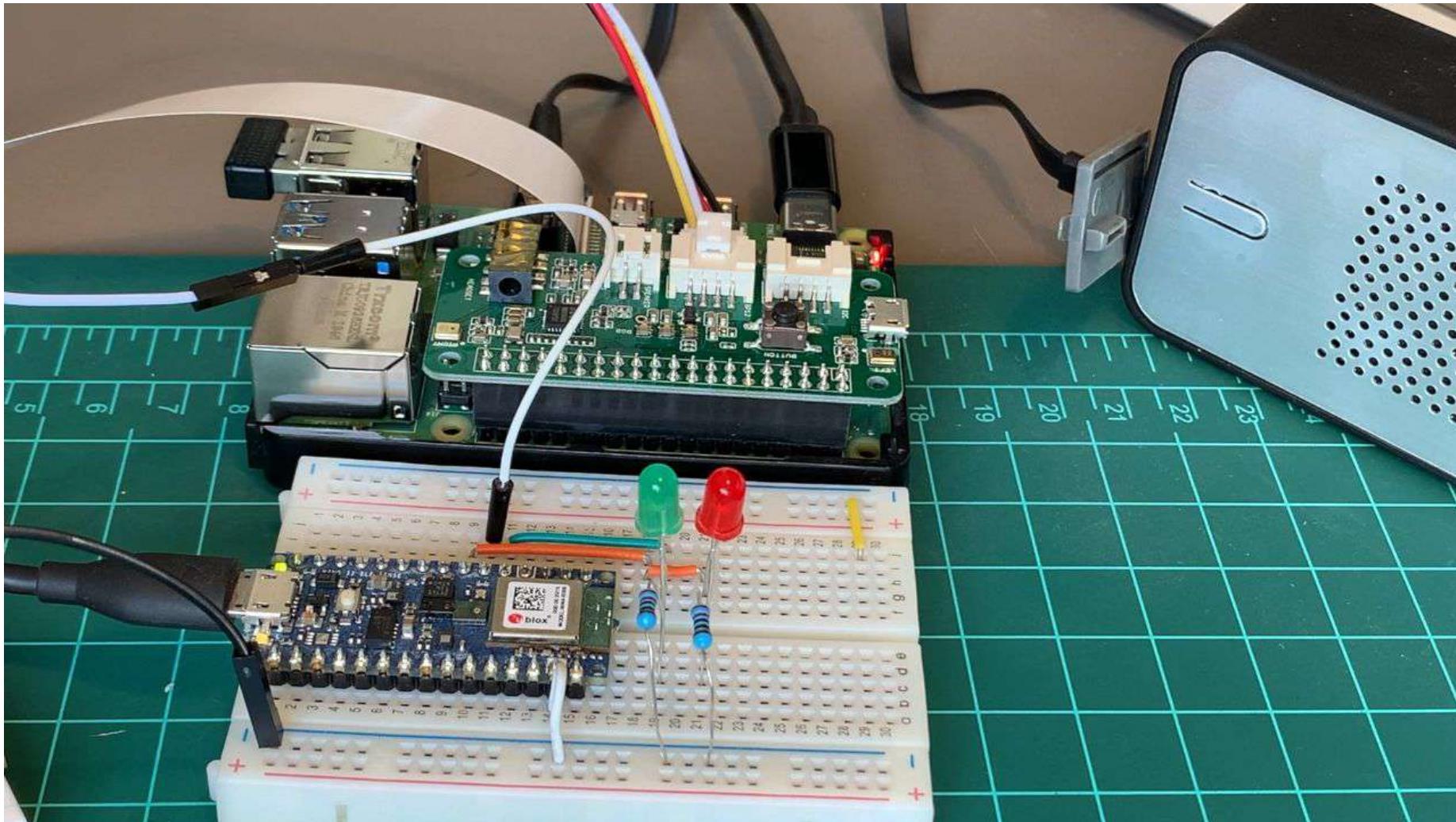
- Send the data to the cloud when triggered

5

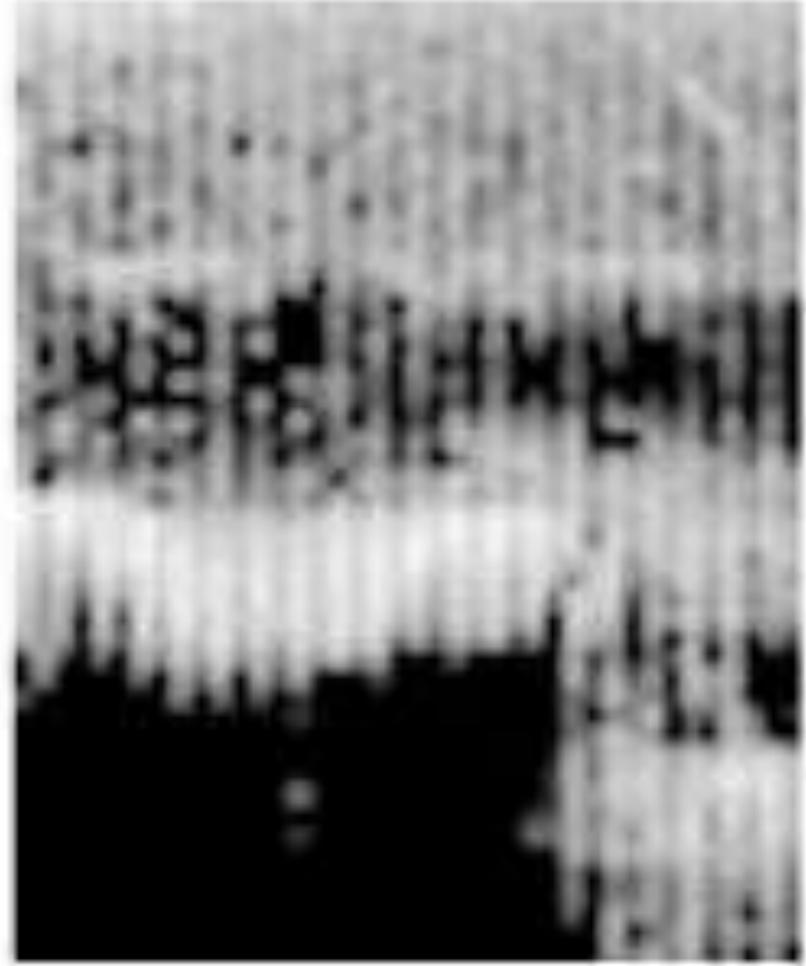
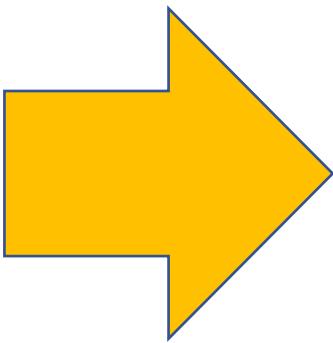
- Process the full speech data with a large model in the cloud



# KeyWord Spotting (KWS)



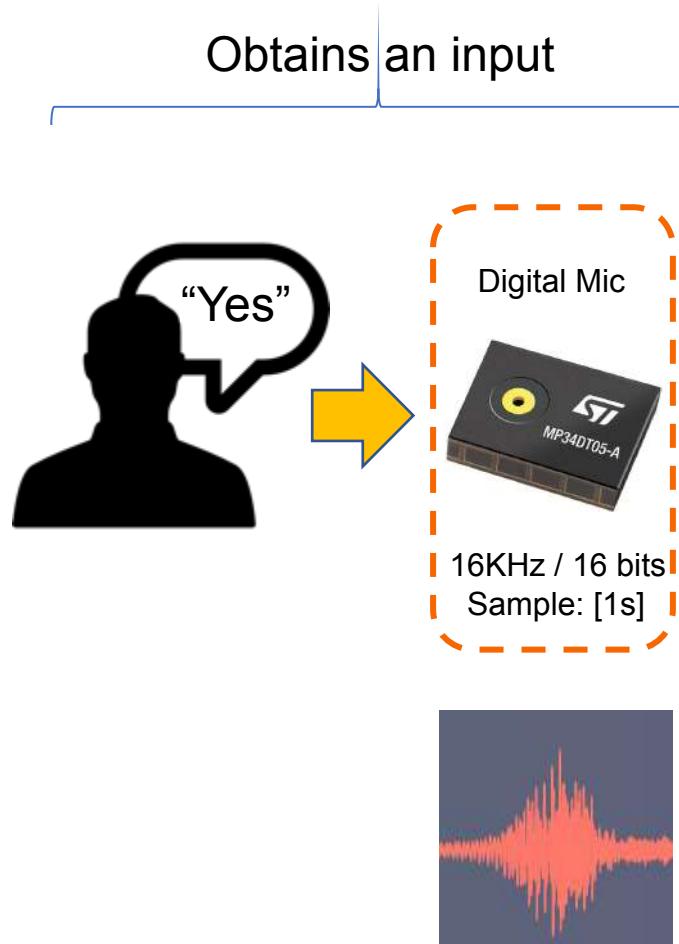
<https://mijrobot.org/2021/01/27/building-an-intelligent-voice-assistant-from-scratch/>



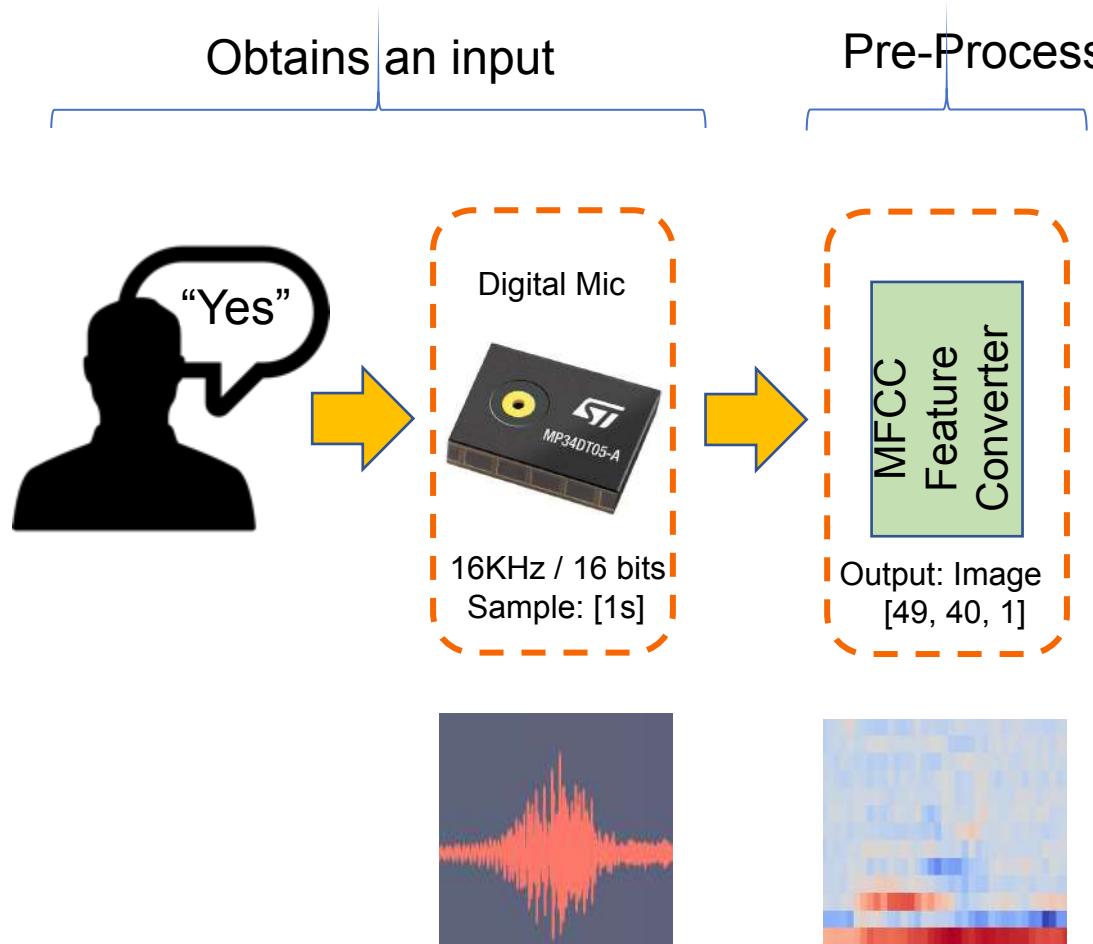
Sound

Image

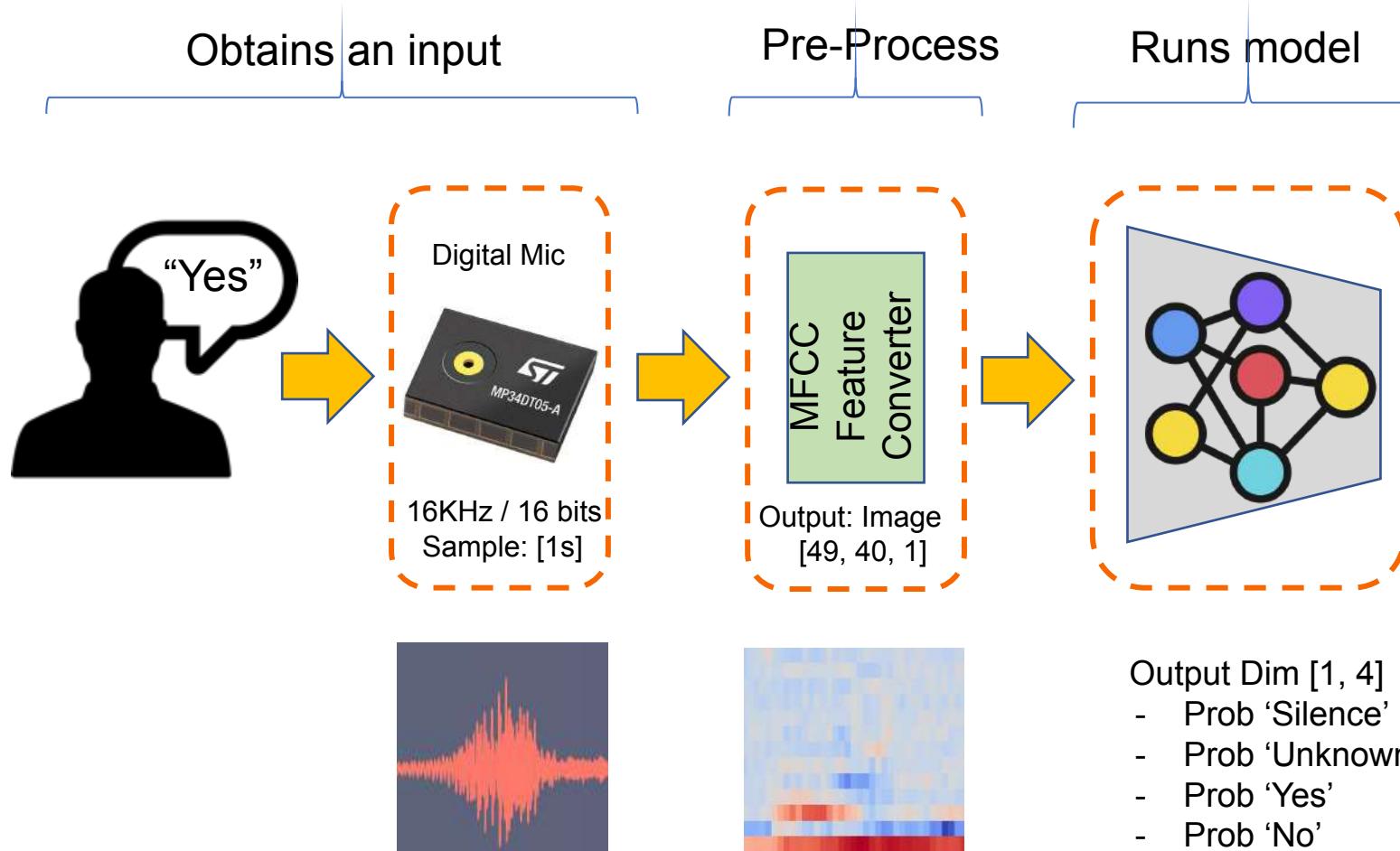
# KeyWord Spotting (KWS) - Inference



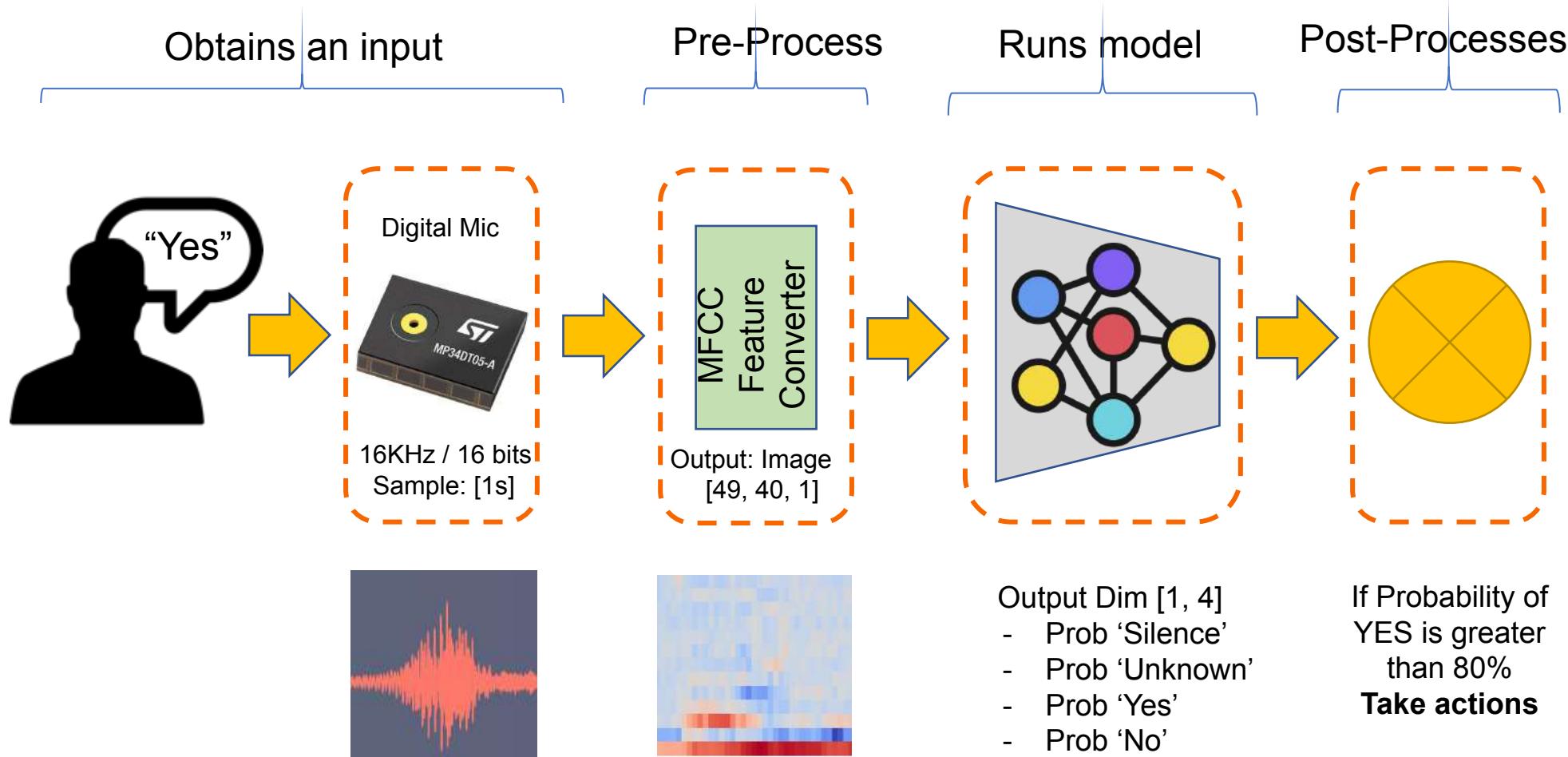
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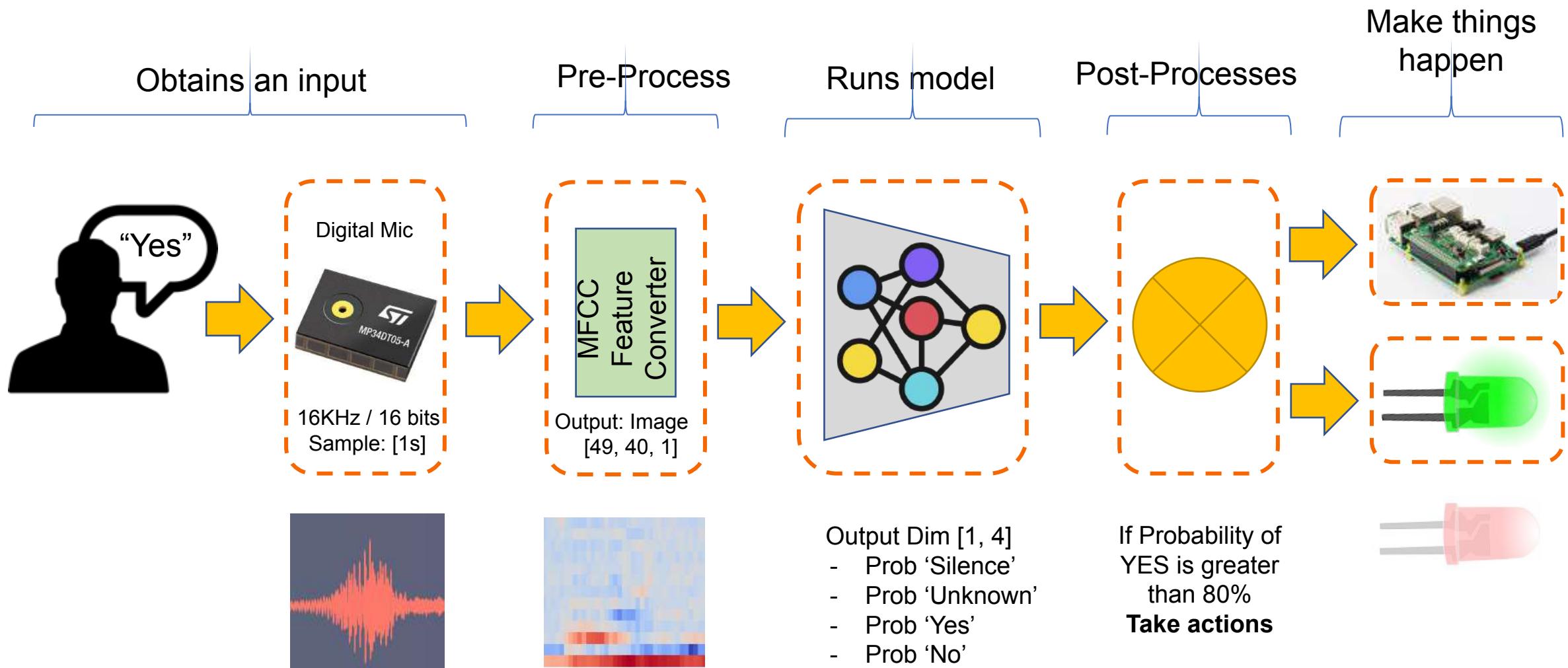
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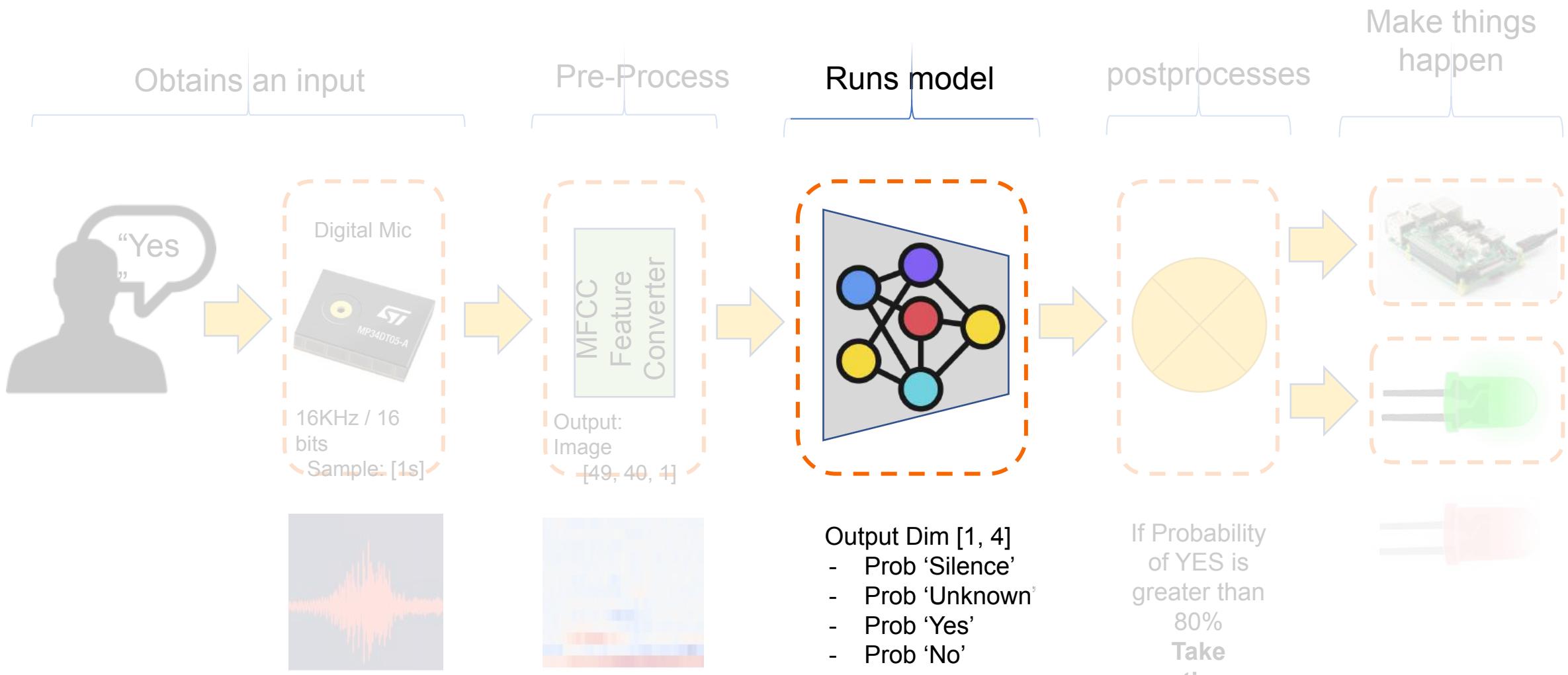
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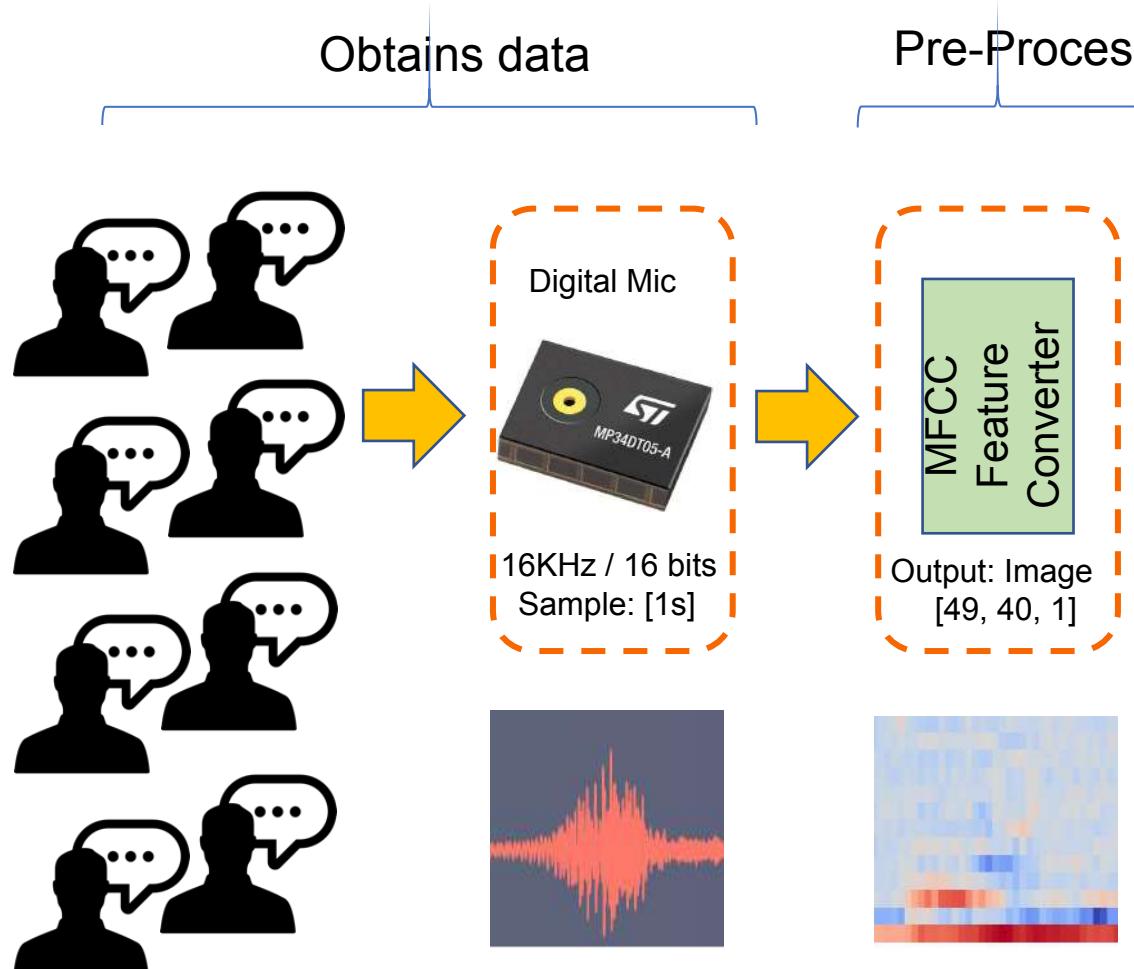
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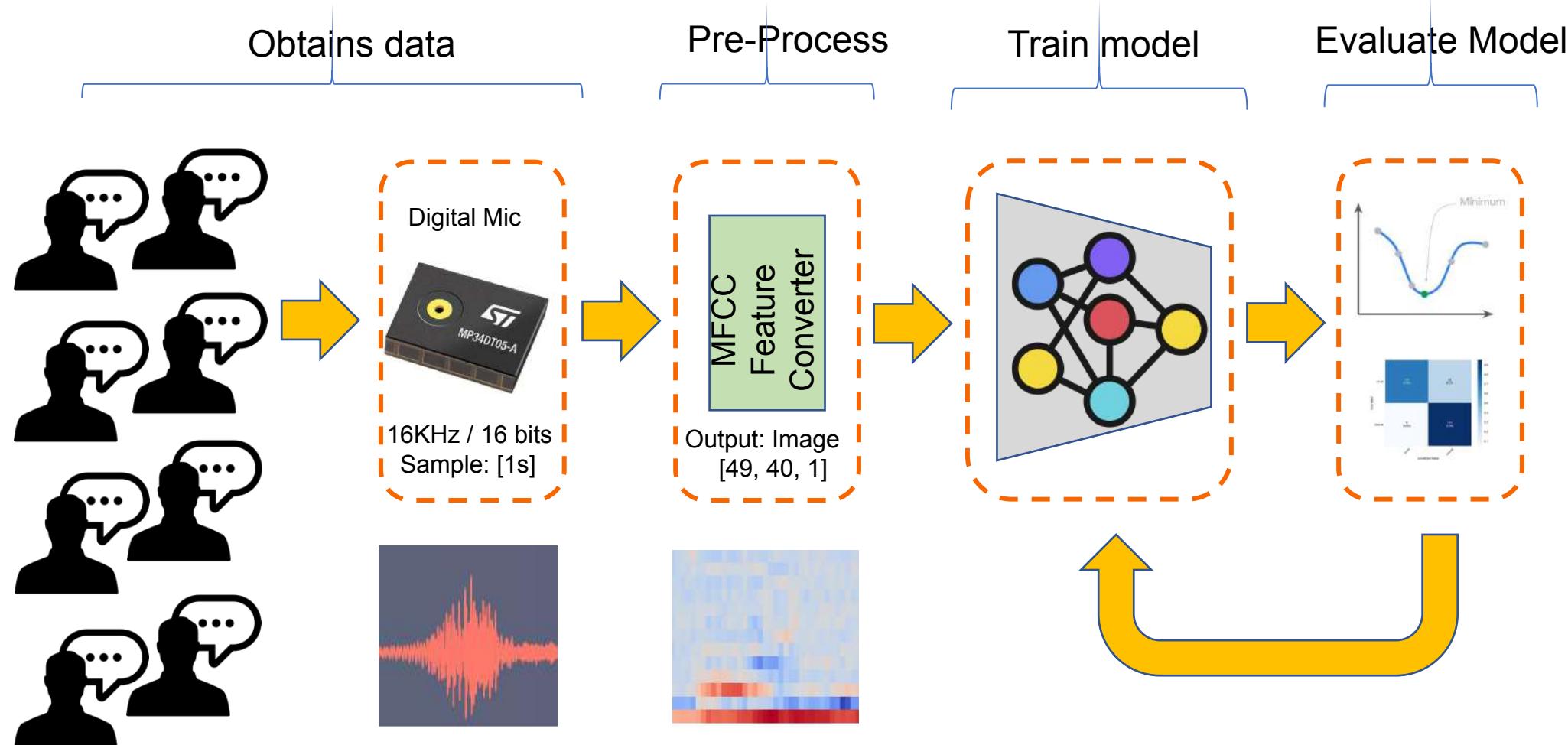
# KeyWord Spotting (KWS) - Model



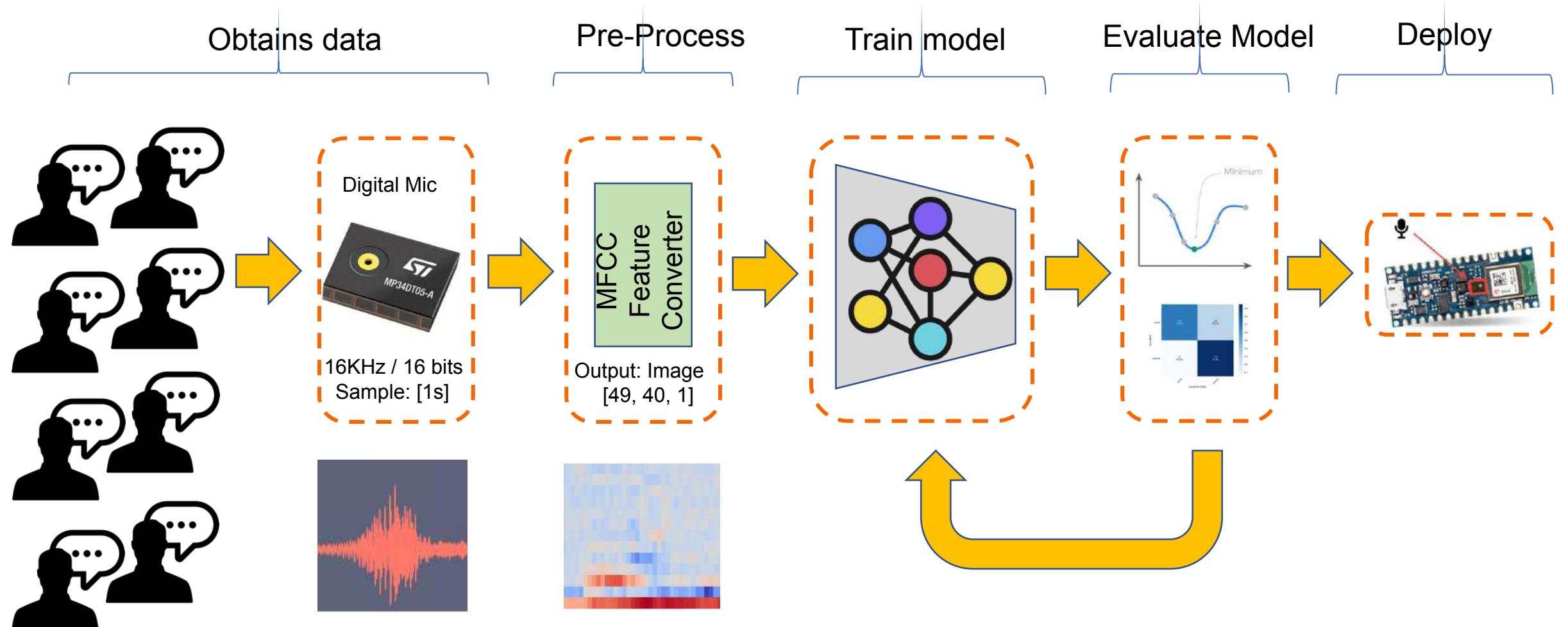
# KeyWord Spotting (KWS) – Create Model (Training)



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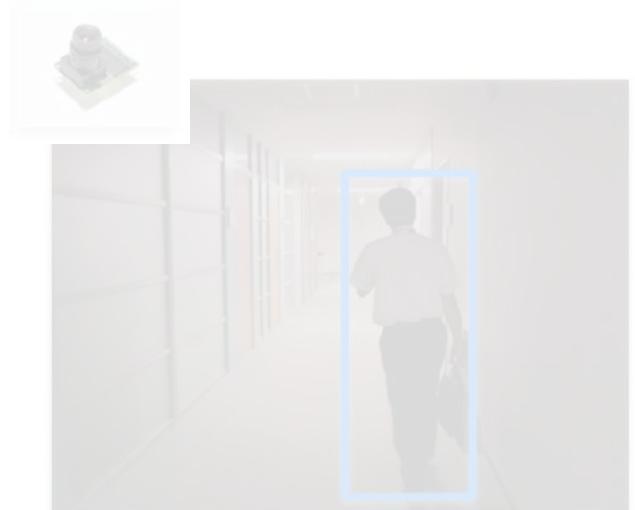
# Sound



# Vibration



# Vision



# Cow Monitoring

## Using the Internet of Things for Agricultural Monitoring

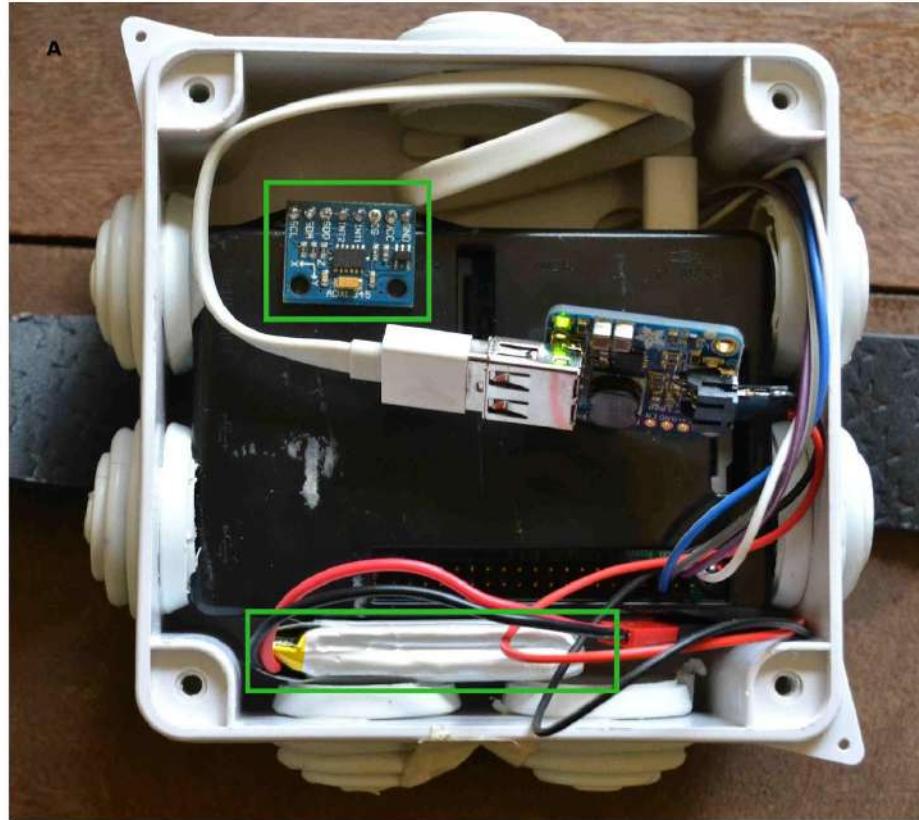
"We aim to deploy a variety of sensors for agricultural monitoring. One of the projects involves using **accelerometer sensors** to monitor activity levels in dairy cows with a view to determining when the cows are on heat or when they are sick."



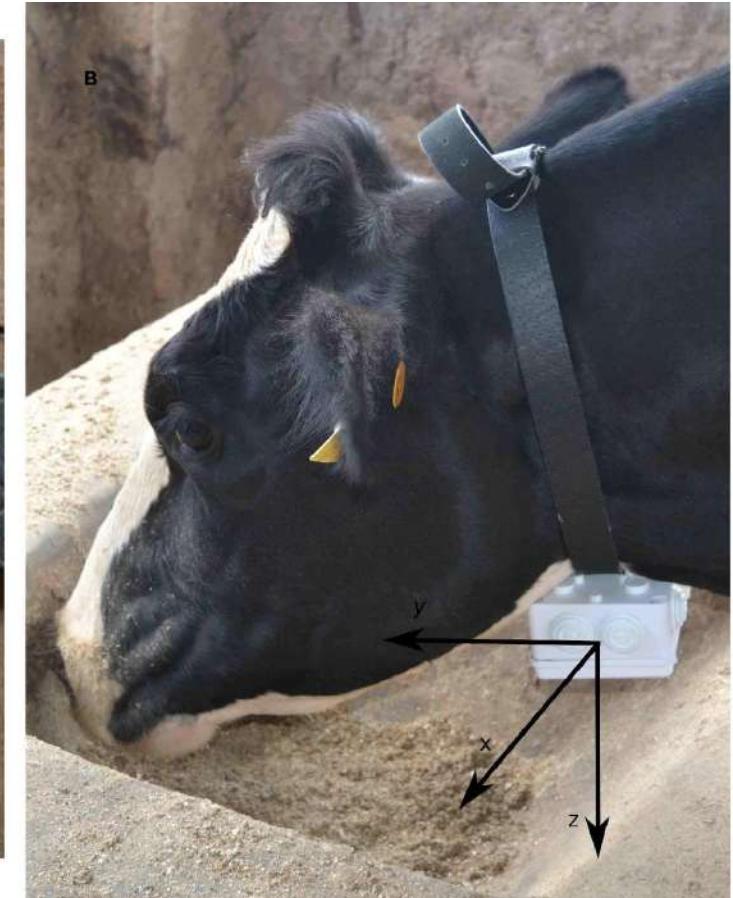
Ciira wa Maina, Ph.D.

Senior Lecturer  
Department of Electrical and Electronic Engineering  
Dedan Kimathi University of Technology  
Nyeri Kenya  
Email: ciira.maina@dkut.ac.ke

Kenia



<https://sites.google.com/site/cwamainadekut/research>



# Predict and classify common Elephant behavior



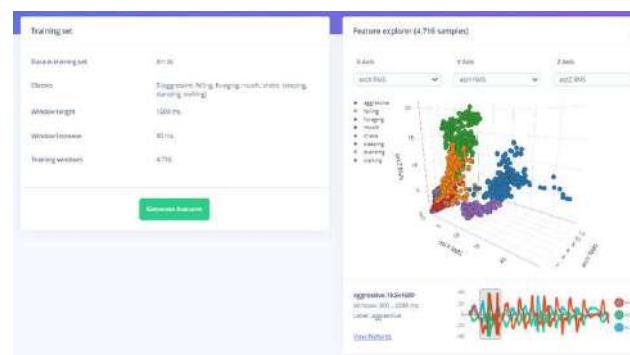
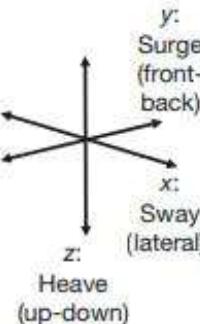
Aggressive



Standing



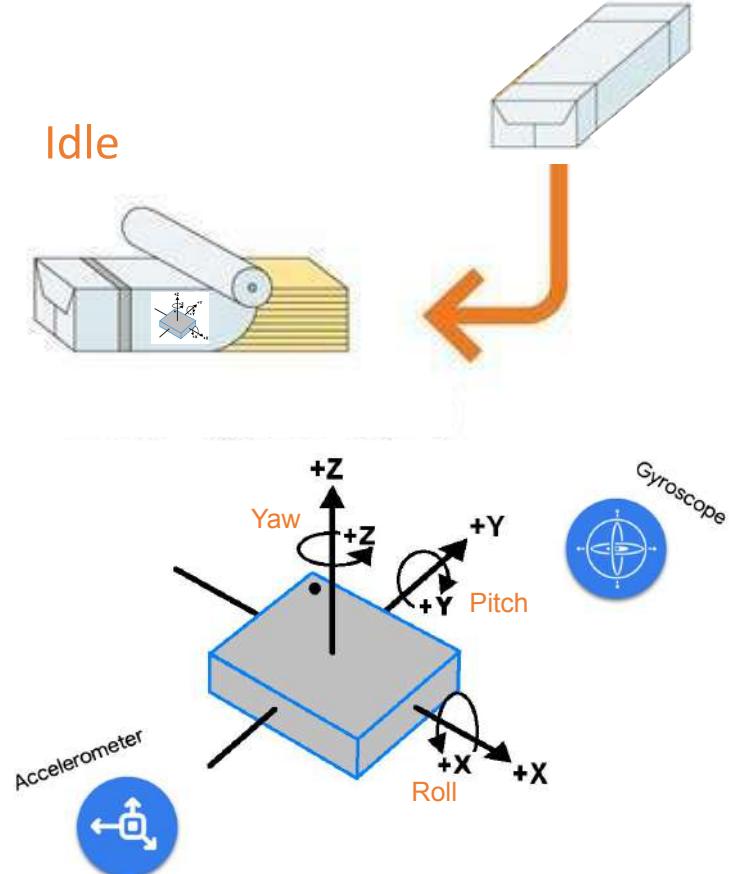
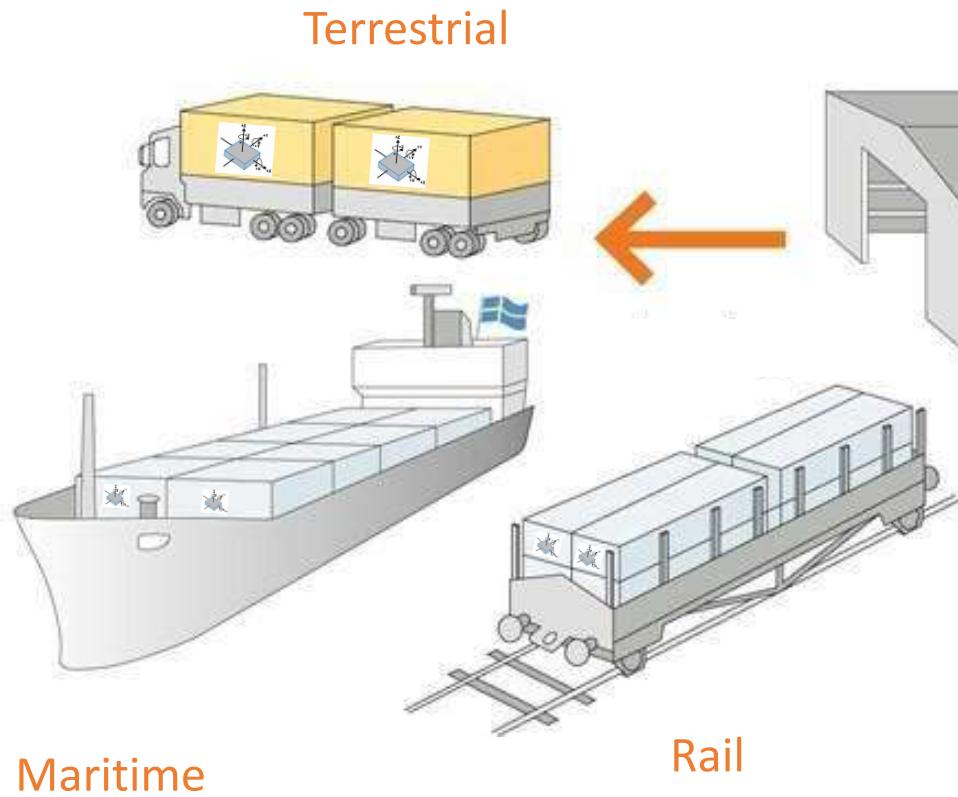
Sleeping

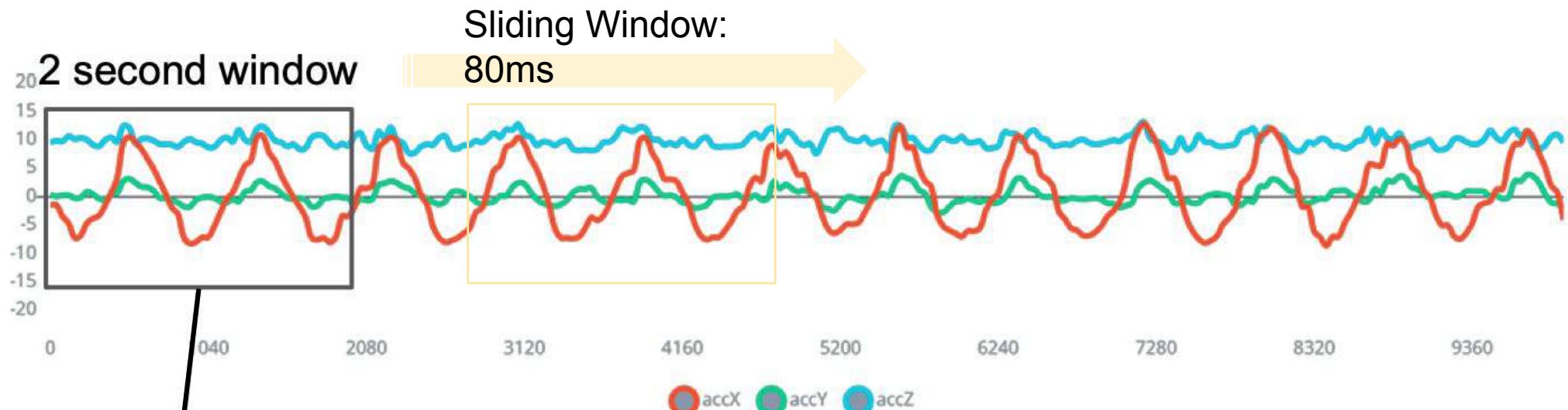
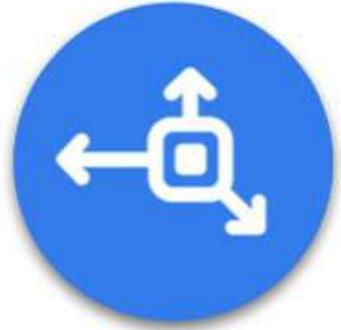


[https://www.hackster.io/dhruvsheth\\_electet-tinyml-and-iot-based-smart-wildlife-tracker-c03e5a](https://www.hackster.io/dhruvsheth_electet-tinyml-and-iot-based-smart-wildlife-tracker-c03e5a)



# Mechanical Stresses in Transport





### Manual Feature Extraction

375 Raw Features

- Raw Data from sensor



33 Features

- RMS
- PSD



### Classes

- Terrestrial
- Maritime
- Fork-Lift
- Rail
- Idle

# Application: Factory machinery

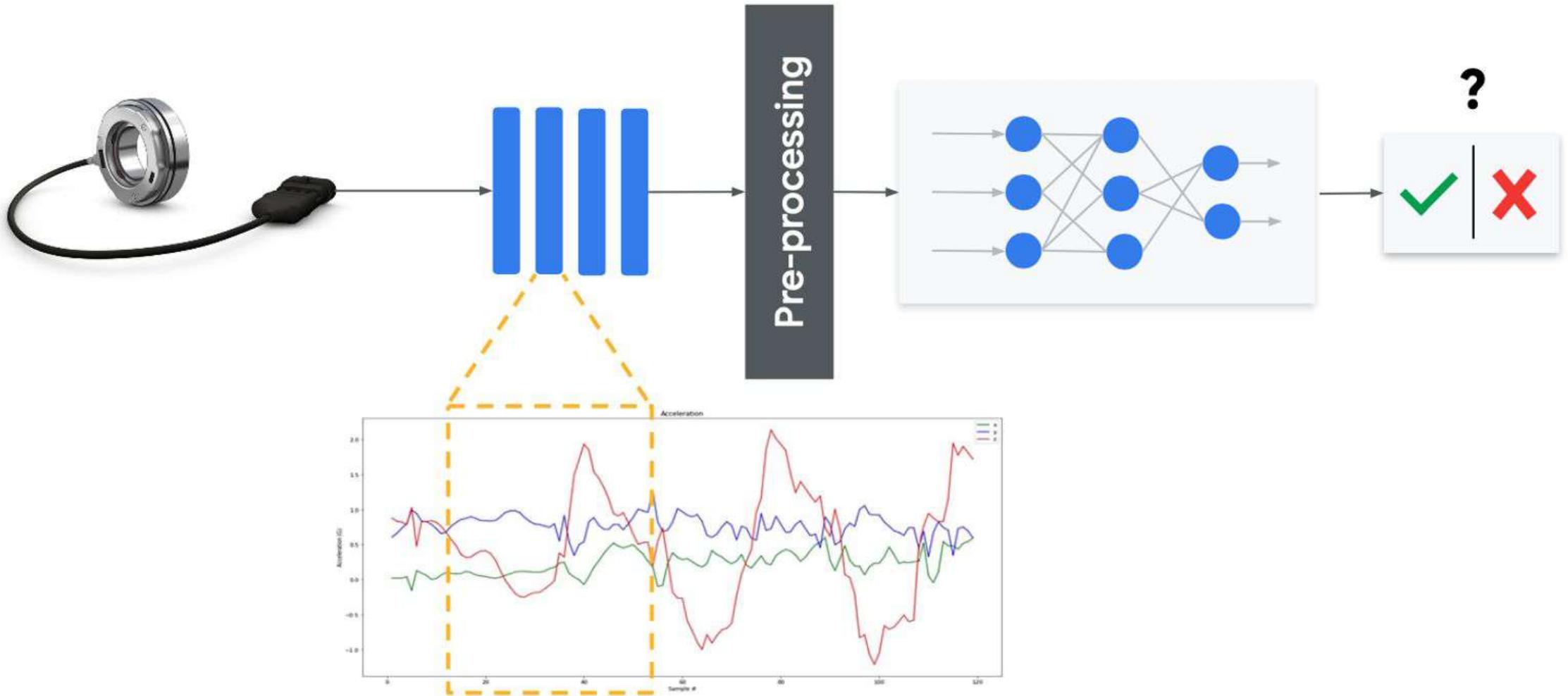


Ball Bearings



Accelerometer

# Anomaly Detection



## Sound



## Vibration



## Vision



# Detecting Diseases in the Bean plants



AIR Lab Makerere University  
UGANDA



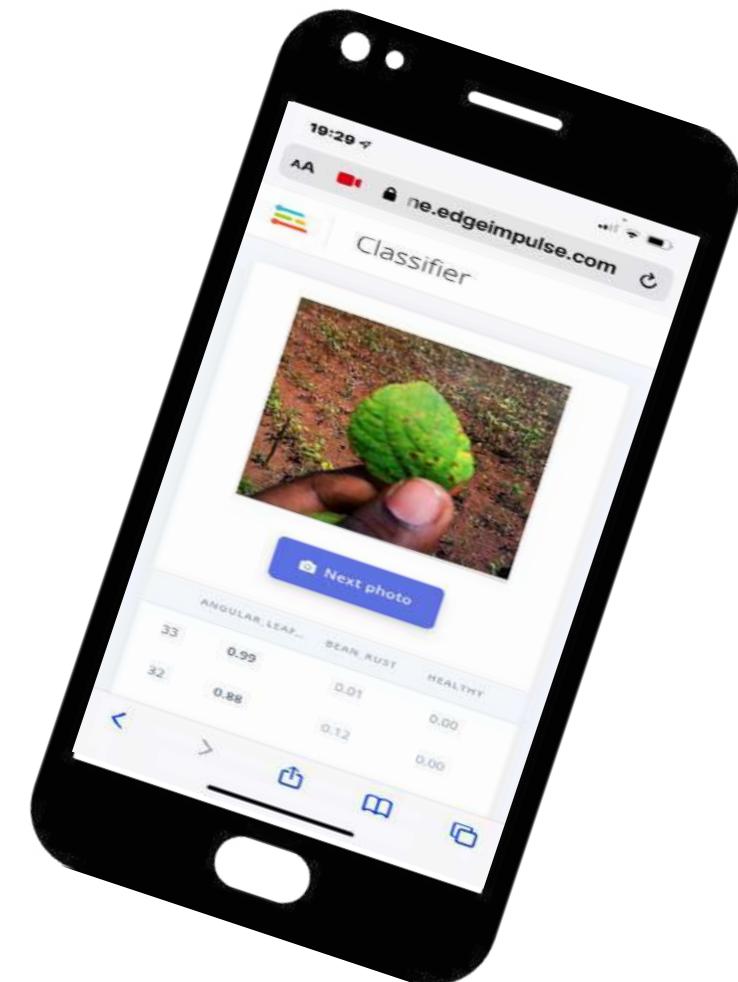
Angular Leaf Spot



Bean Rust

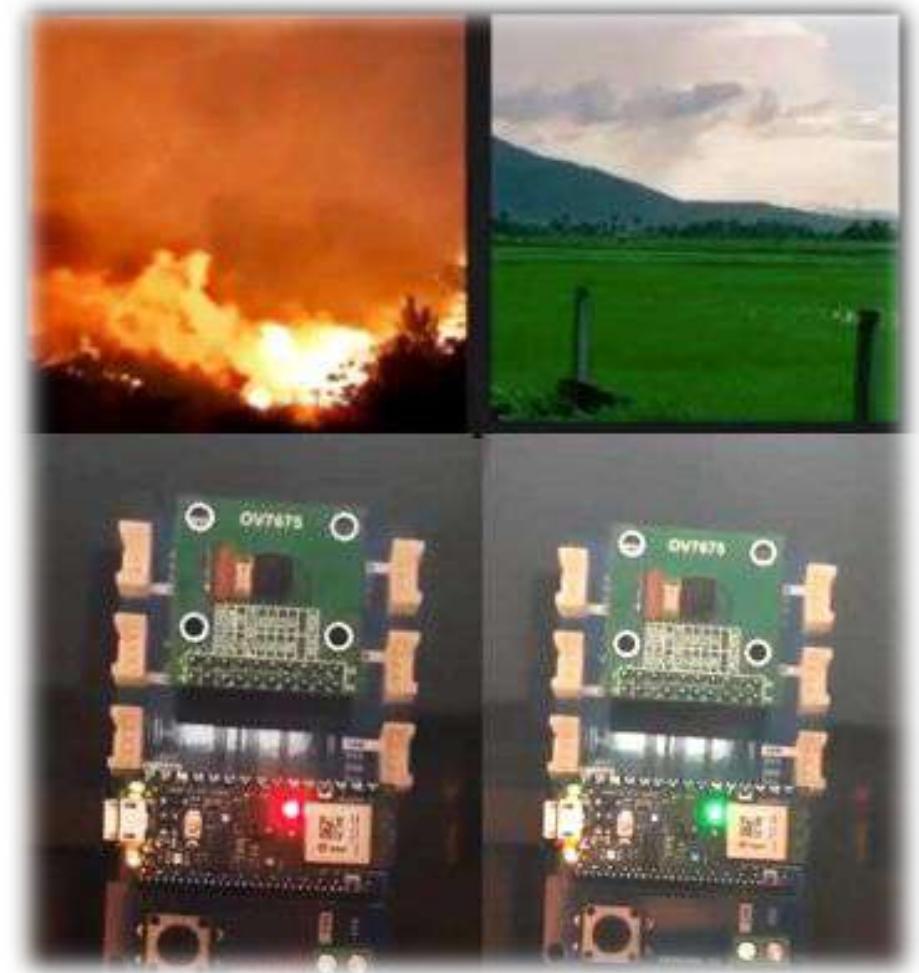
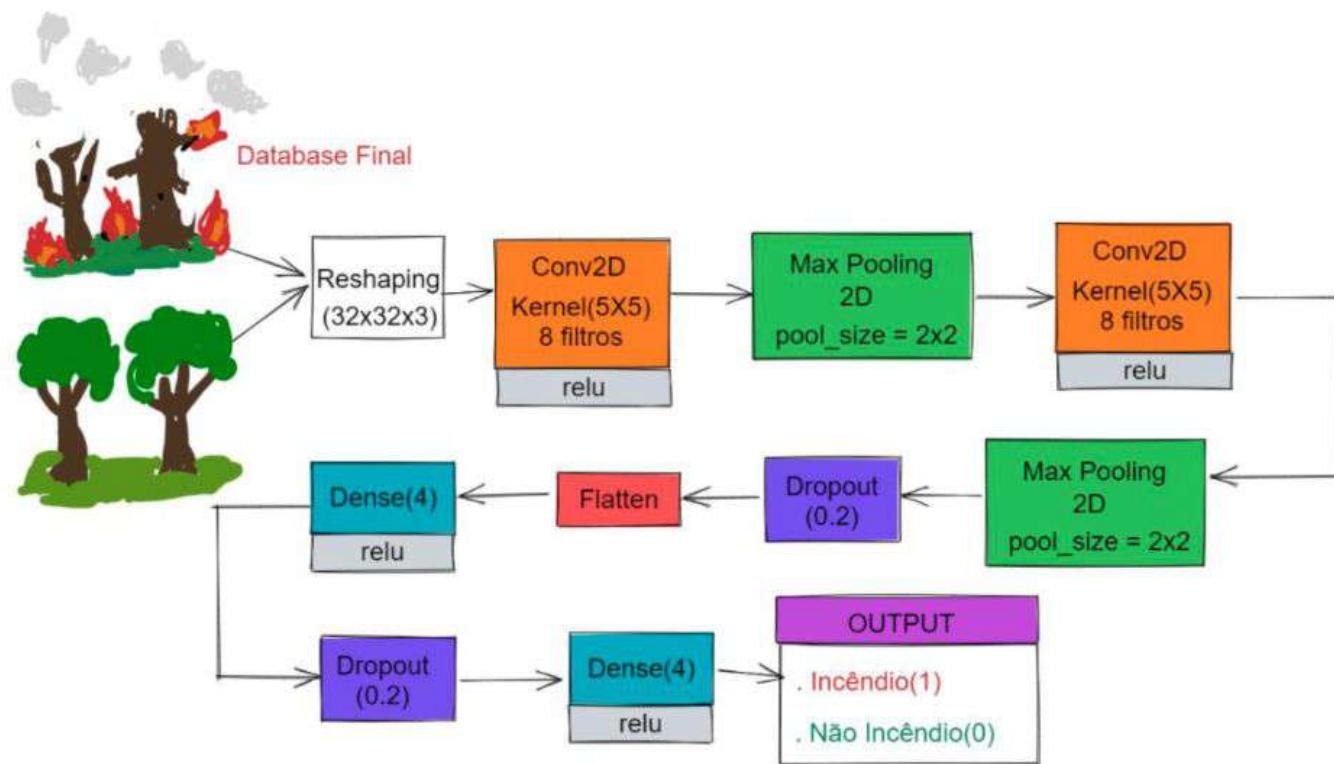


Healthy



Dataset: <https://github.com/AI-Lab-Makerere/ibean/>

# Forest Fire Detection

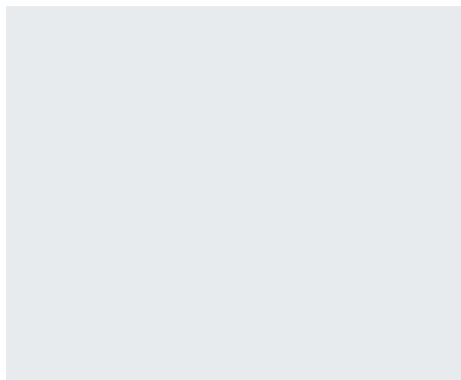


[https://github.com/Mjrovai/UNIFEI-ESTI01-T01-2021.1/blob/main/00\\_Curso\\_Folder/2\\_Applications/Group\\_Projects-Final%20Reports/Projeto\\_final\\_Fire\\_detection/trabalho\\_final\\_Fire\\_Detection.pdf](https://github.com/Mjrovai/UNIFEI-ESTI01-T01-2021.1/blob/main/00_Curso_Folder/2_Applications/Group_Projects-Final%20Reports/Projeto_final_Fire_detection/trabalho_final_Fire_Detection.pdf)

# Person Detection



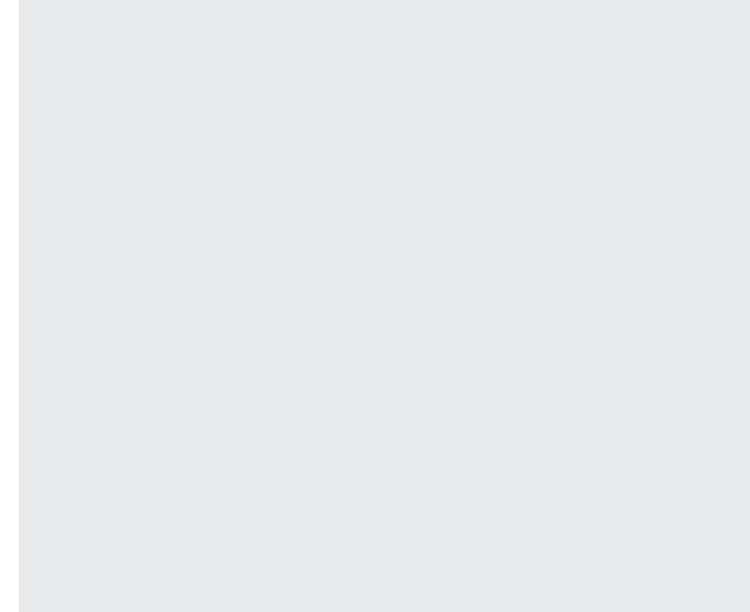
## Person Detection



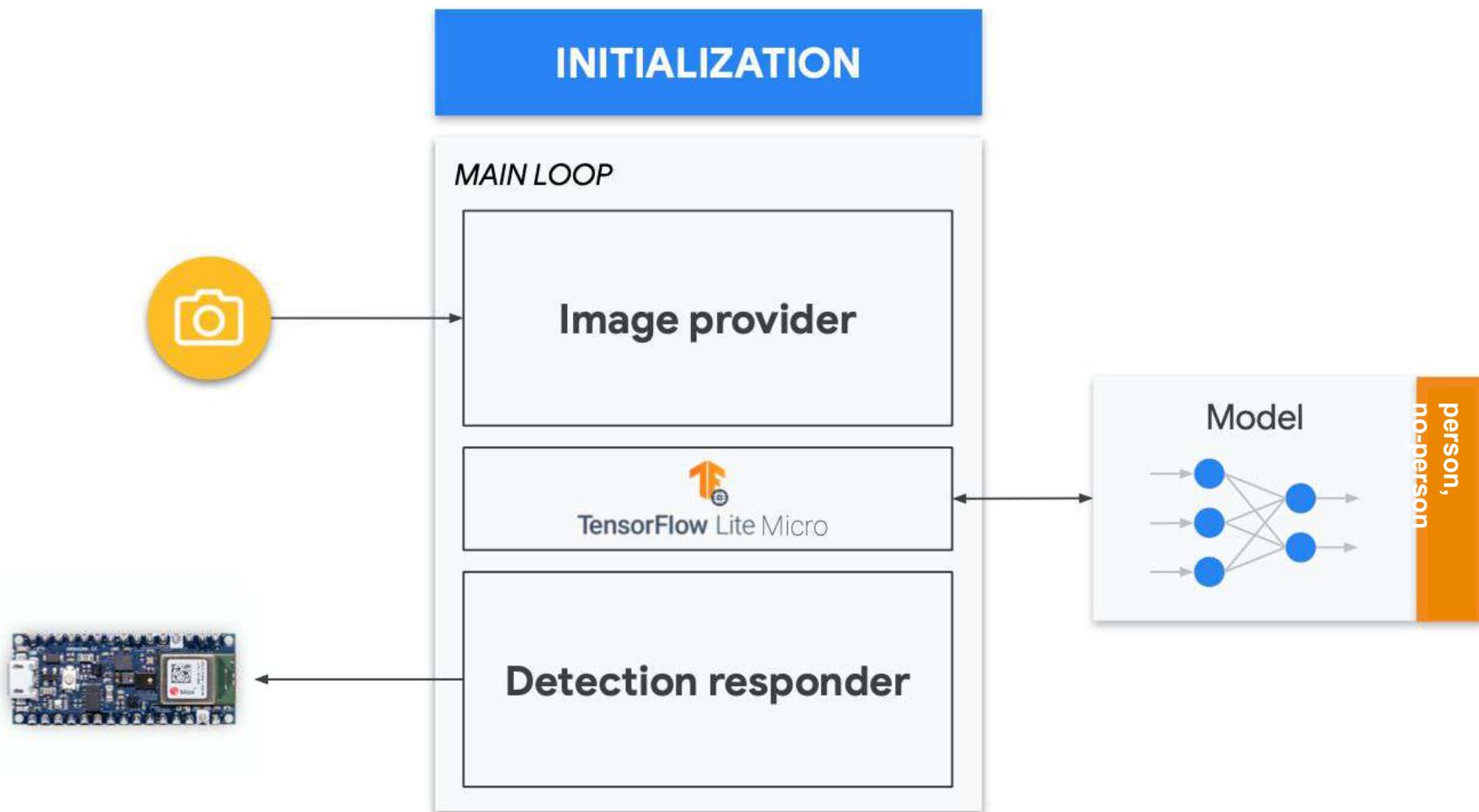
## Mask Detection



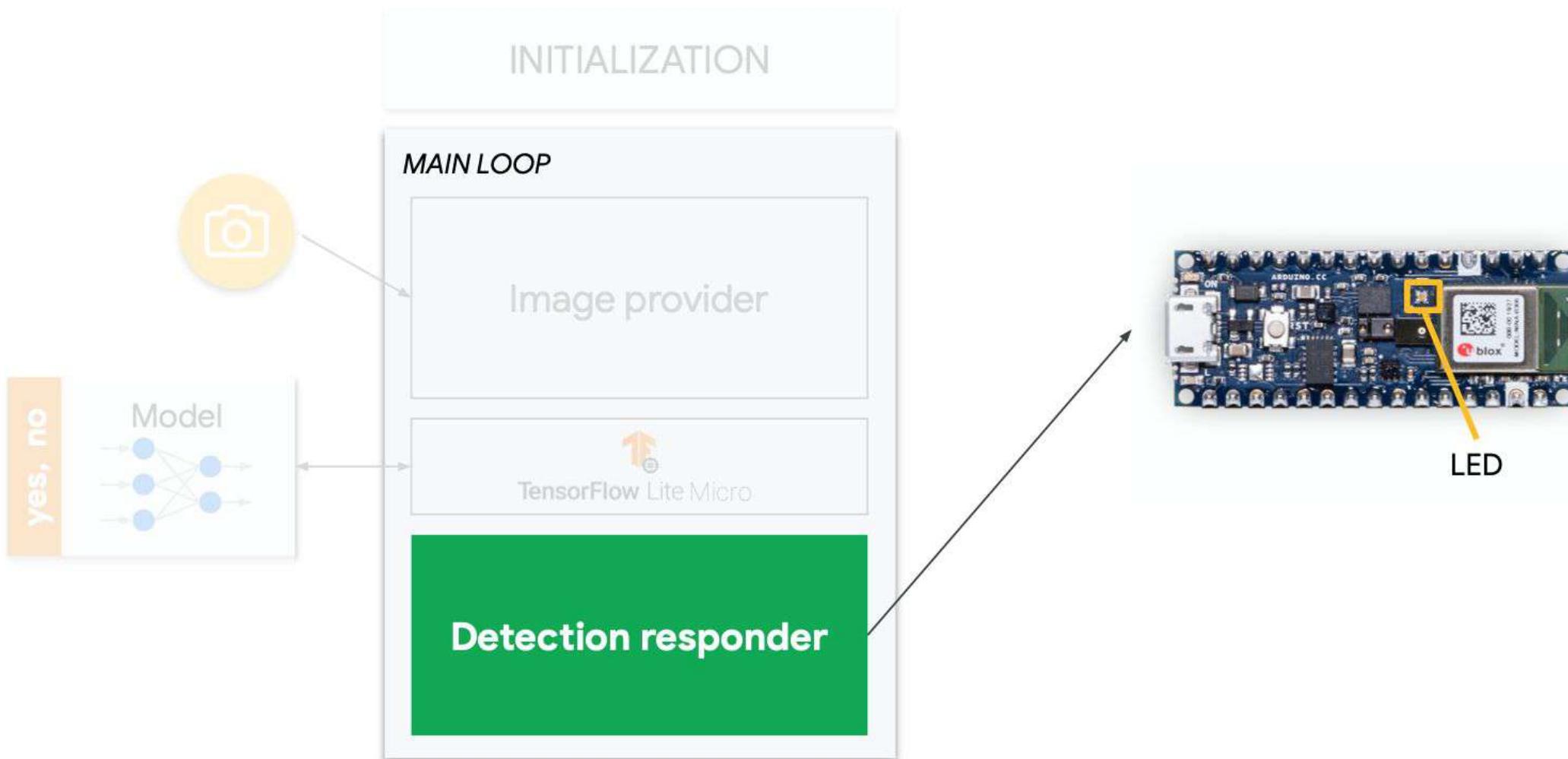
# Person Detection



# Person Detection Components



# Post-processing



# TinyML Projects – UNIFEI / IESTI01

## Vision

- Mask Detection
- Forest Fire Detection

[\[Docs\]](#) [\[Video\]](#)

[\[Docs\]](#) [\[Video\]](#)

## Sound

- Covid Detection (cough)
- Seismic Detection

[\[Docs\]](#) [\[Video\]](#)

[\[Docs\]](#) [\[Video\]](#)

## Vibration

- Personal Trainer

[\[Docs\]](#) [\[Video\]](#)

# TinyML Projects – Select HW examples

## Vision

- Coffee Disease w/ **Seeed Maix Bit** [\[Video\]](#) [\[Docs\]](#)

## Sound

- Listening Temperature w/ **Nano 33** [\[Docs\]](#)

## Vibration

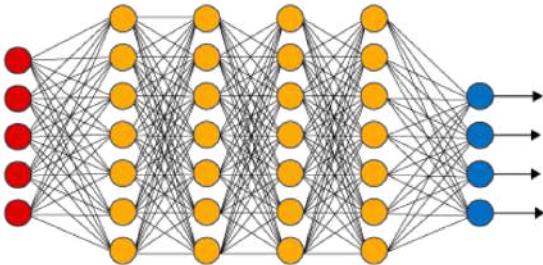
- Motion Recognition w/ **RPi Pico** [\[Docs\]](#)
- Gesture Recognition w/ **Wio Terminal** [\[Docs\]](#)

# How to Train a ML Model?

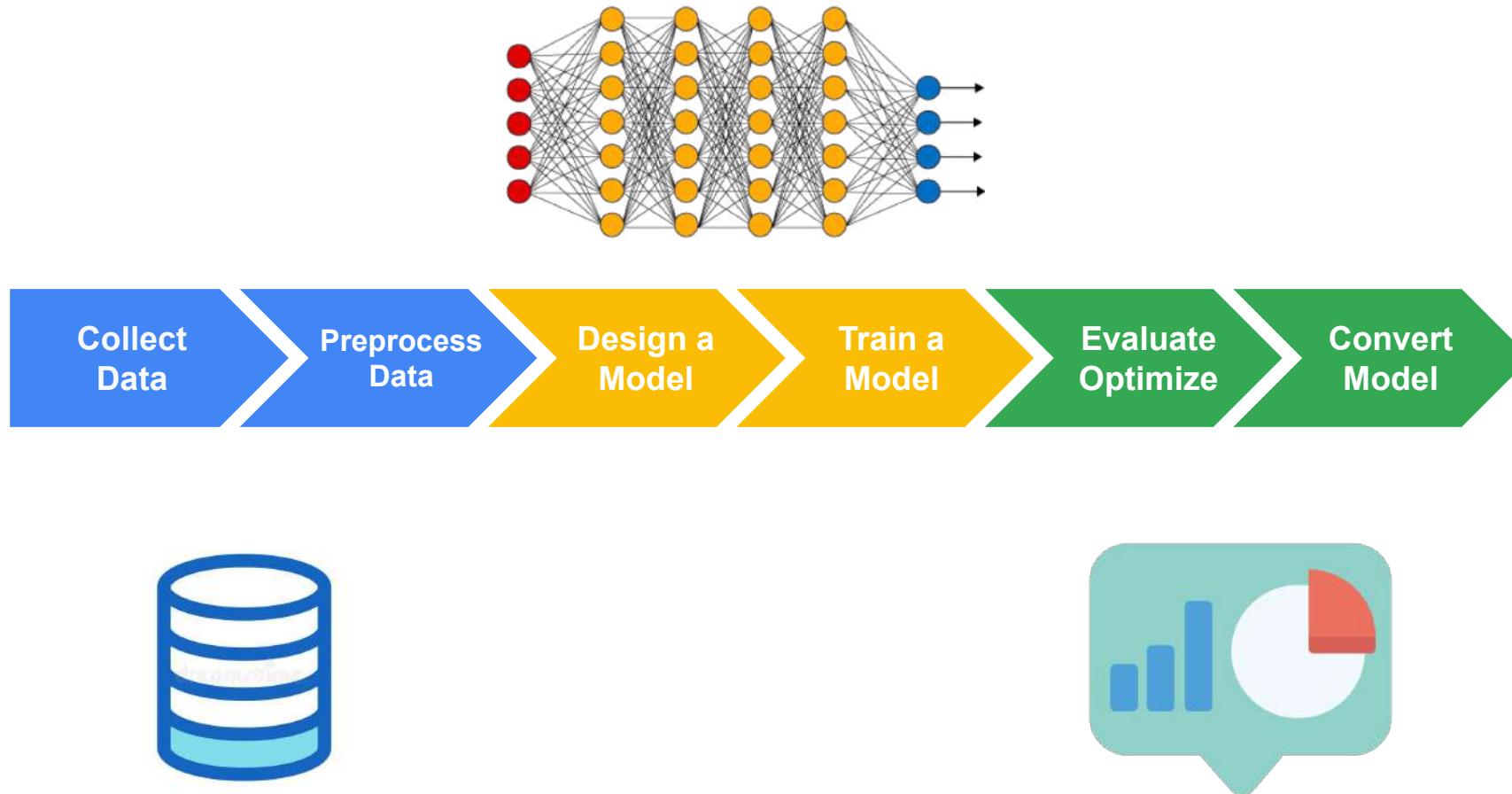
# Machine Learning Workflow



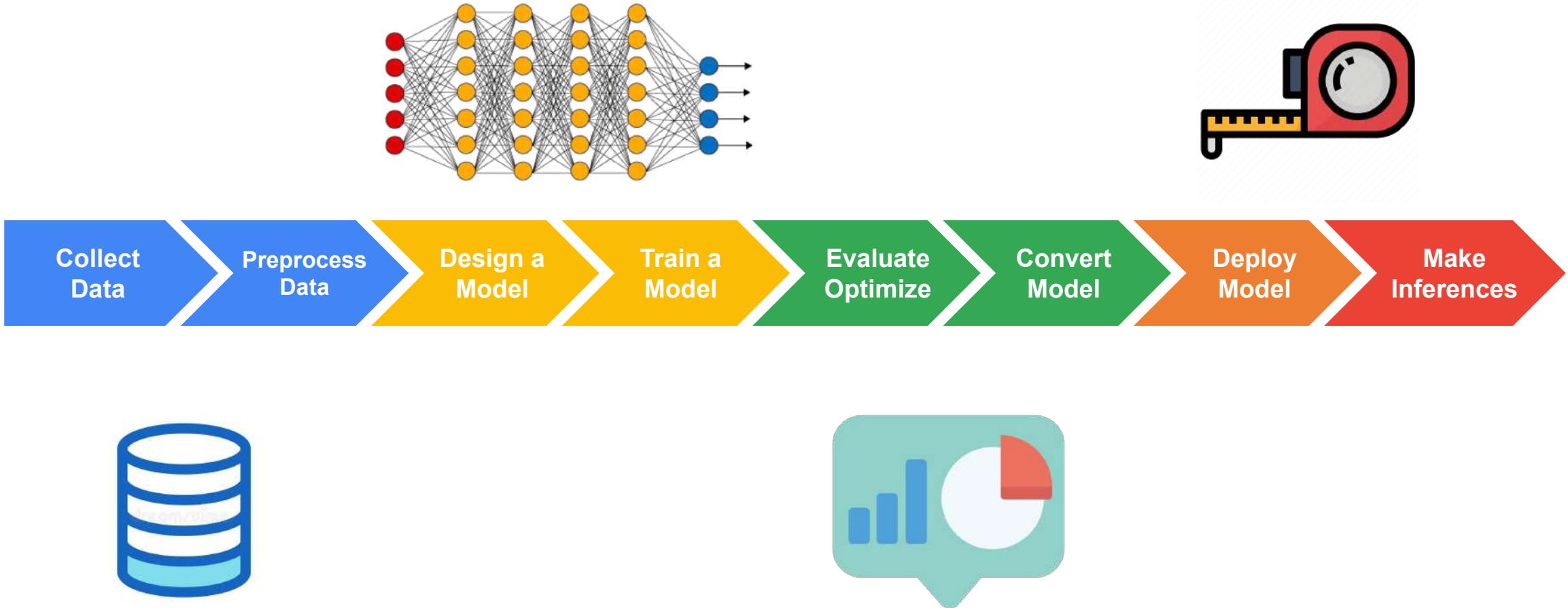
# Machine Learning Workflow



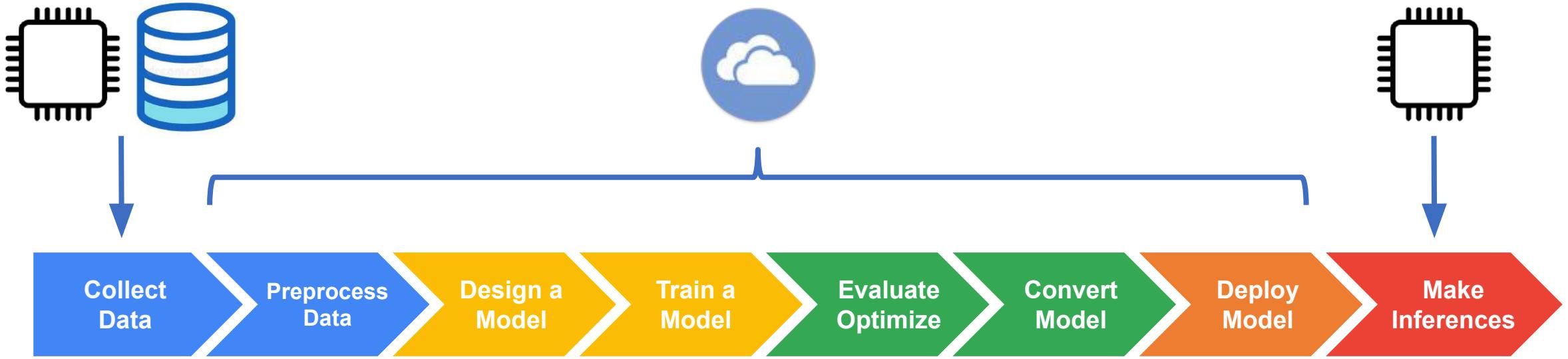
# Machine Learning Workflow



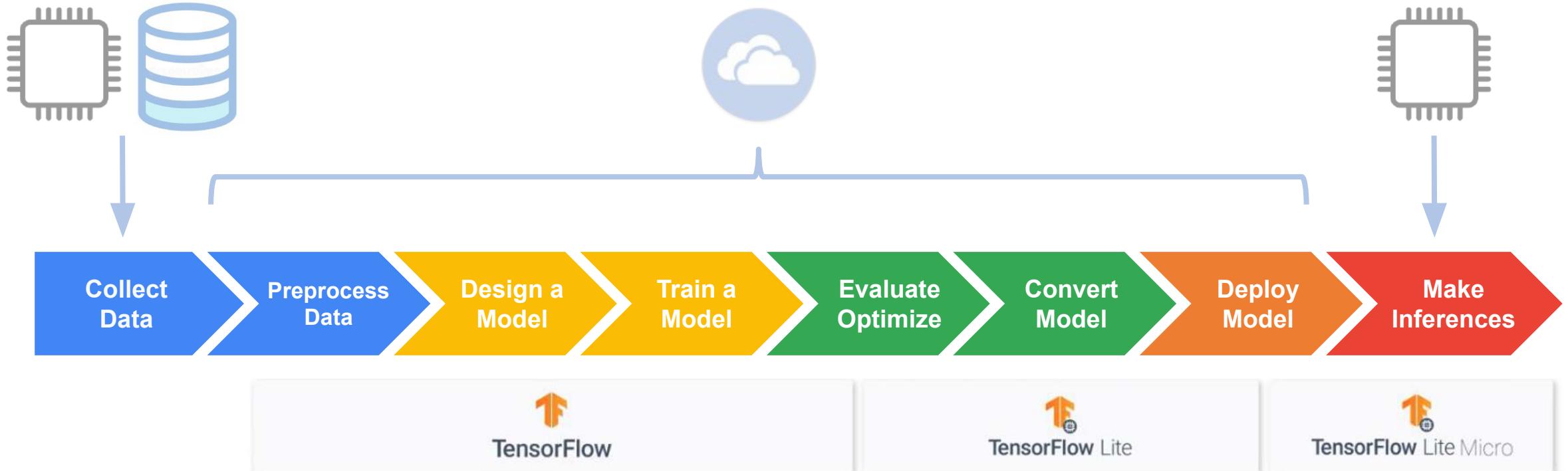
# Machine Learning Workflow (“What”)



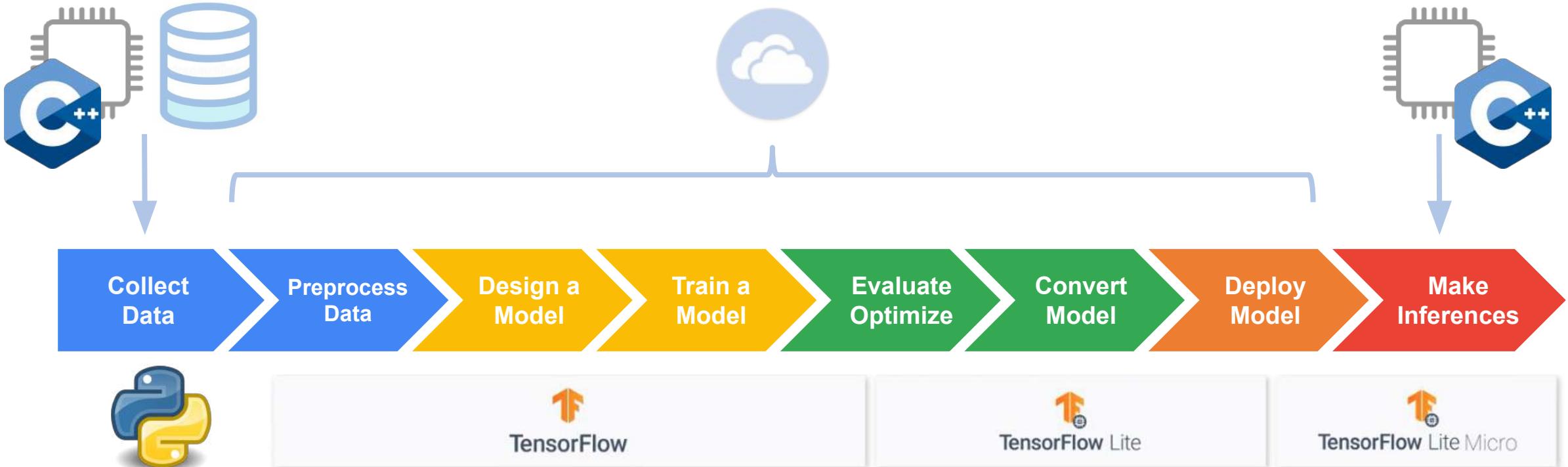
# Machine Learning Workflow (“Where”)



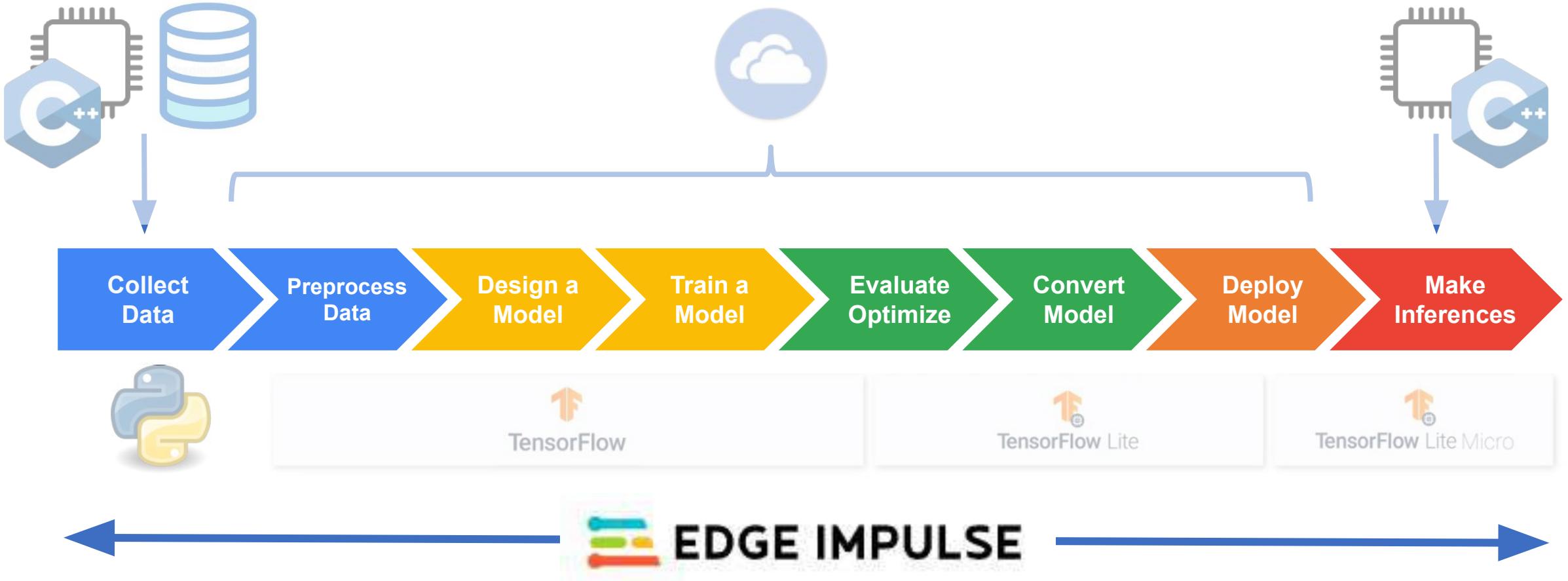
# Machine Learning Workflow (“How”)



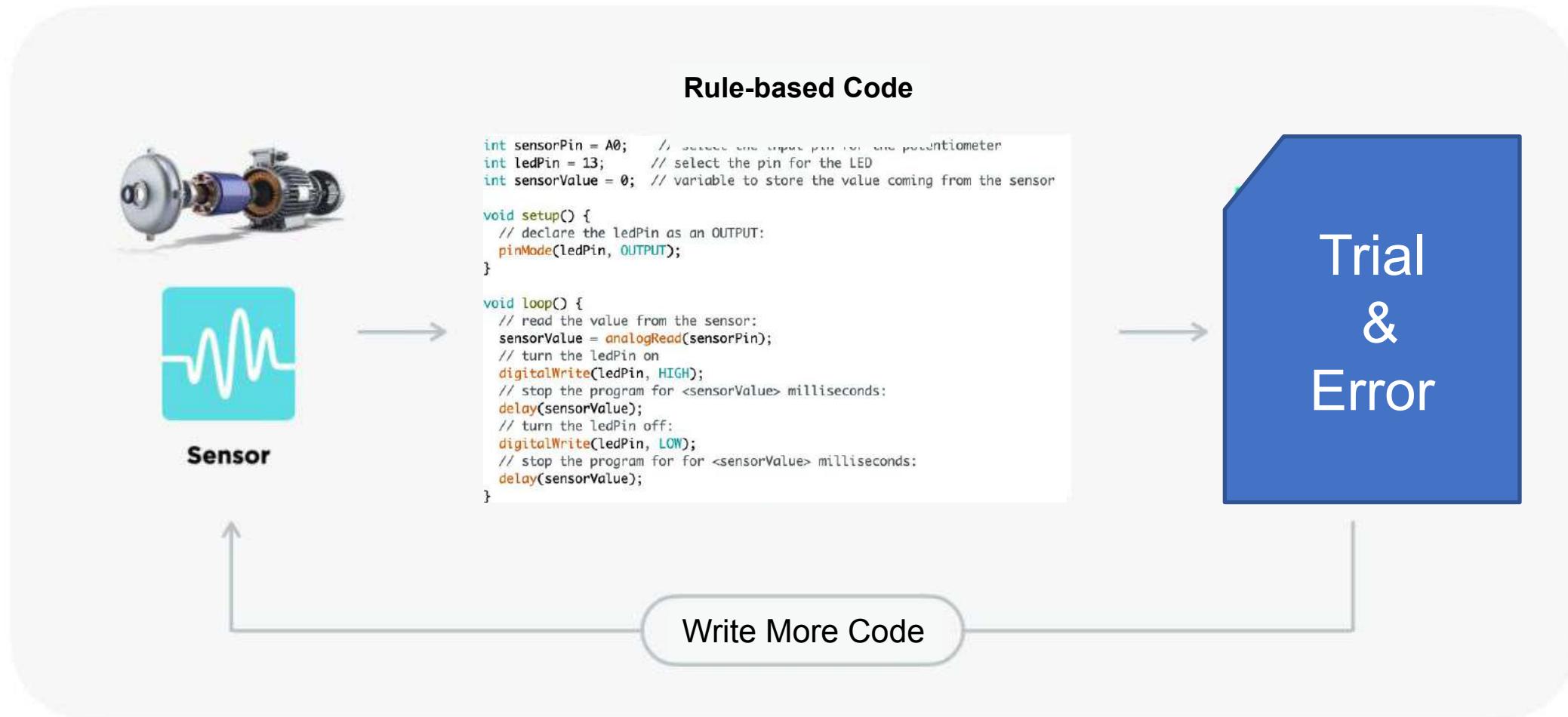
# Machine Learning Workflow (“How”)



# Machine Learning Workflow (“How”)

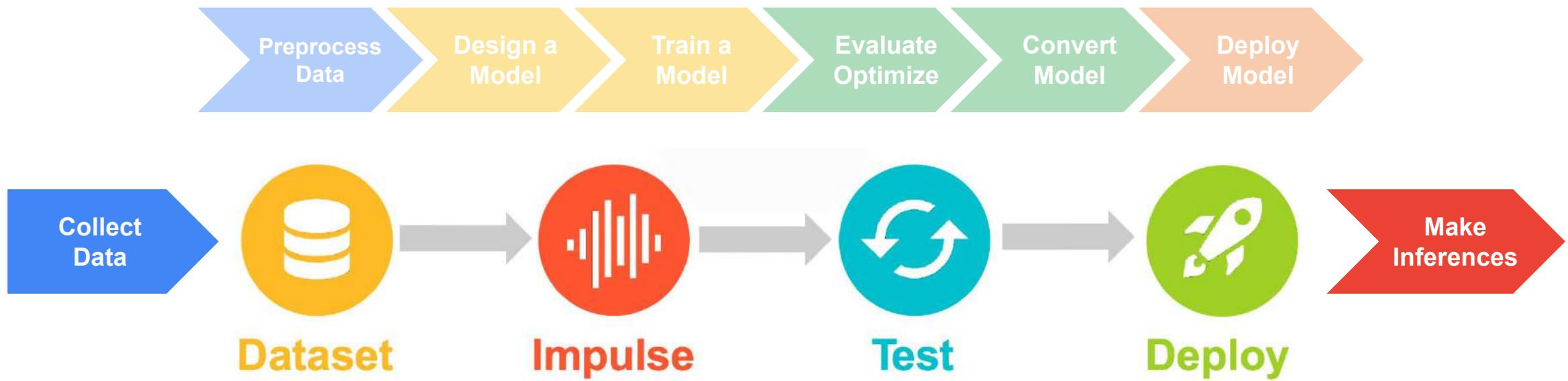


# From rule-based engineering to...

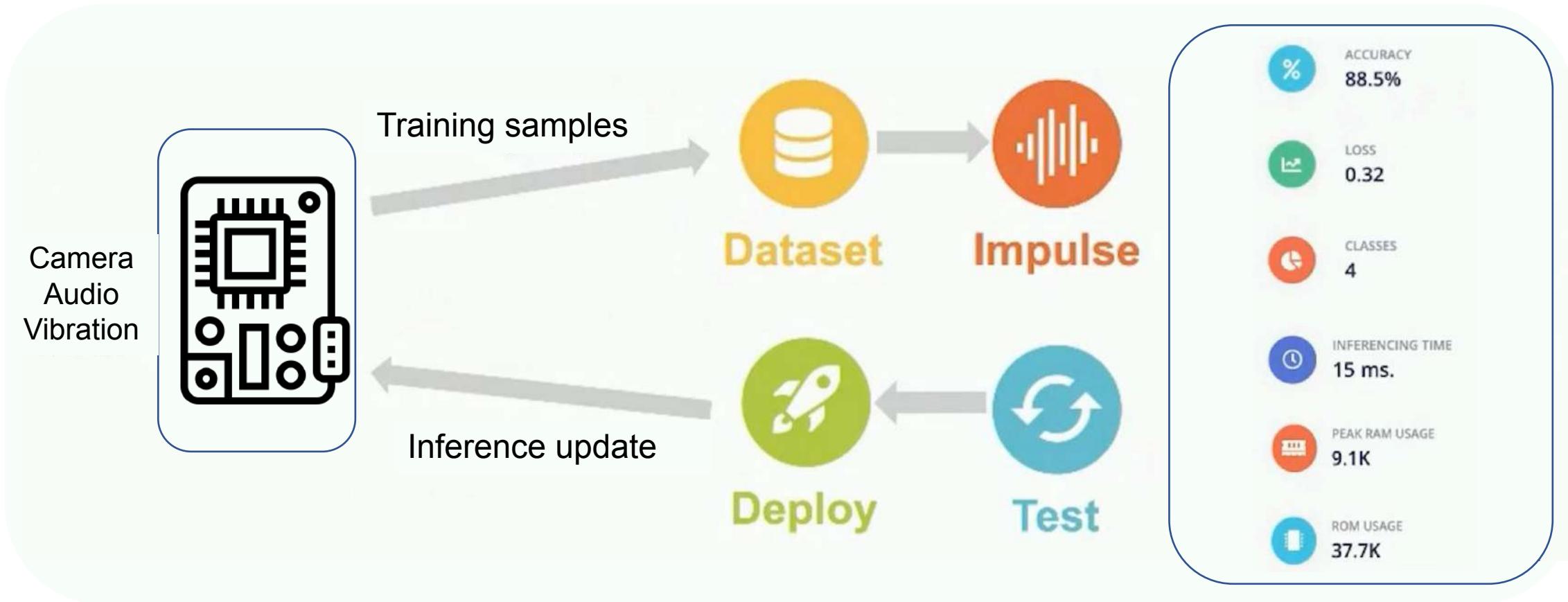


# Data-driven engineering

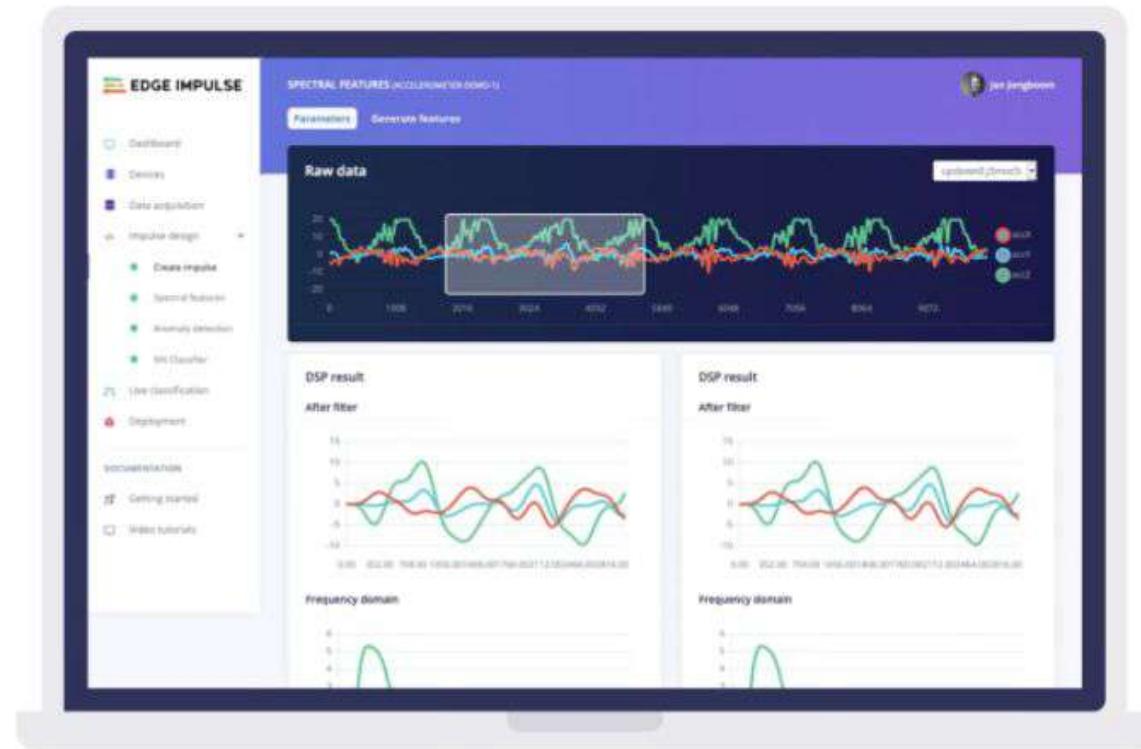
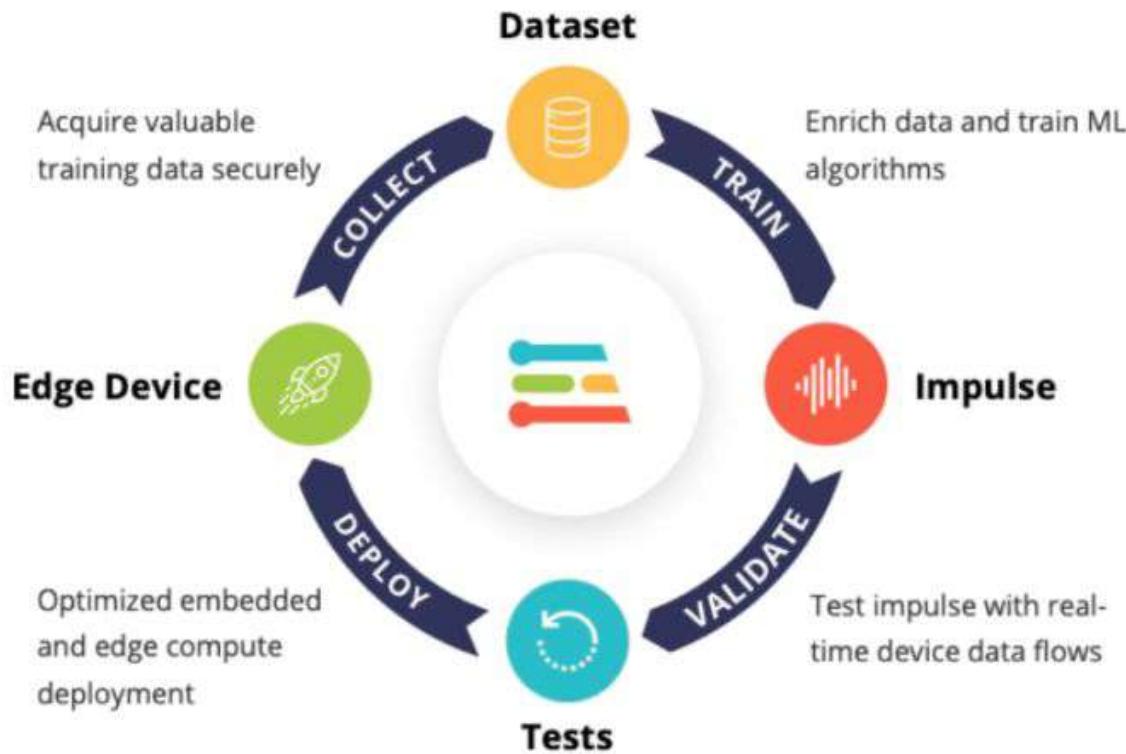




# Data-driven engineering



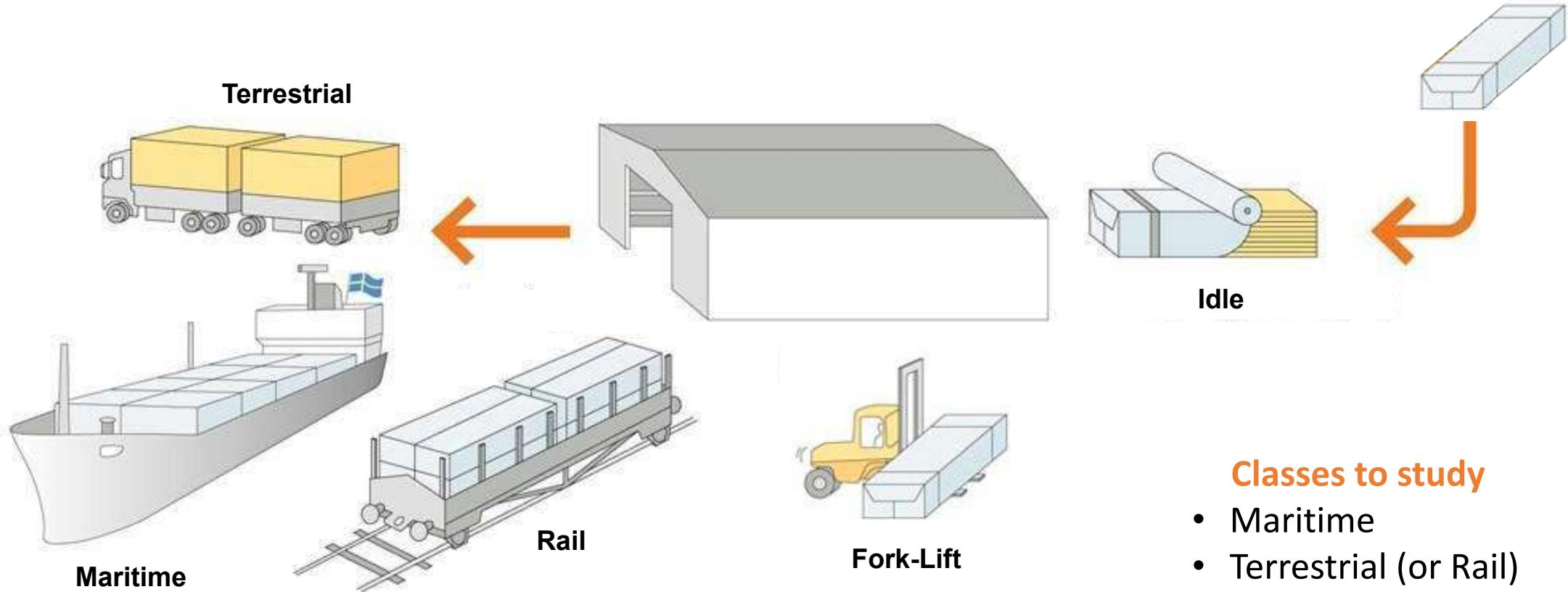
# EI Studio - Embedded ML platform (“AutoML”)



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



# Case Study: Mechanical Stresses in Transport



## Classes to study

- Maritime
- Terrestrial (or Rail)
- Lift
- Idle

# Machine Learning Workflow



Collect  
Data

Preprocess  
Data

Design a  
Model

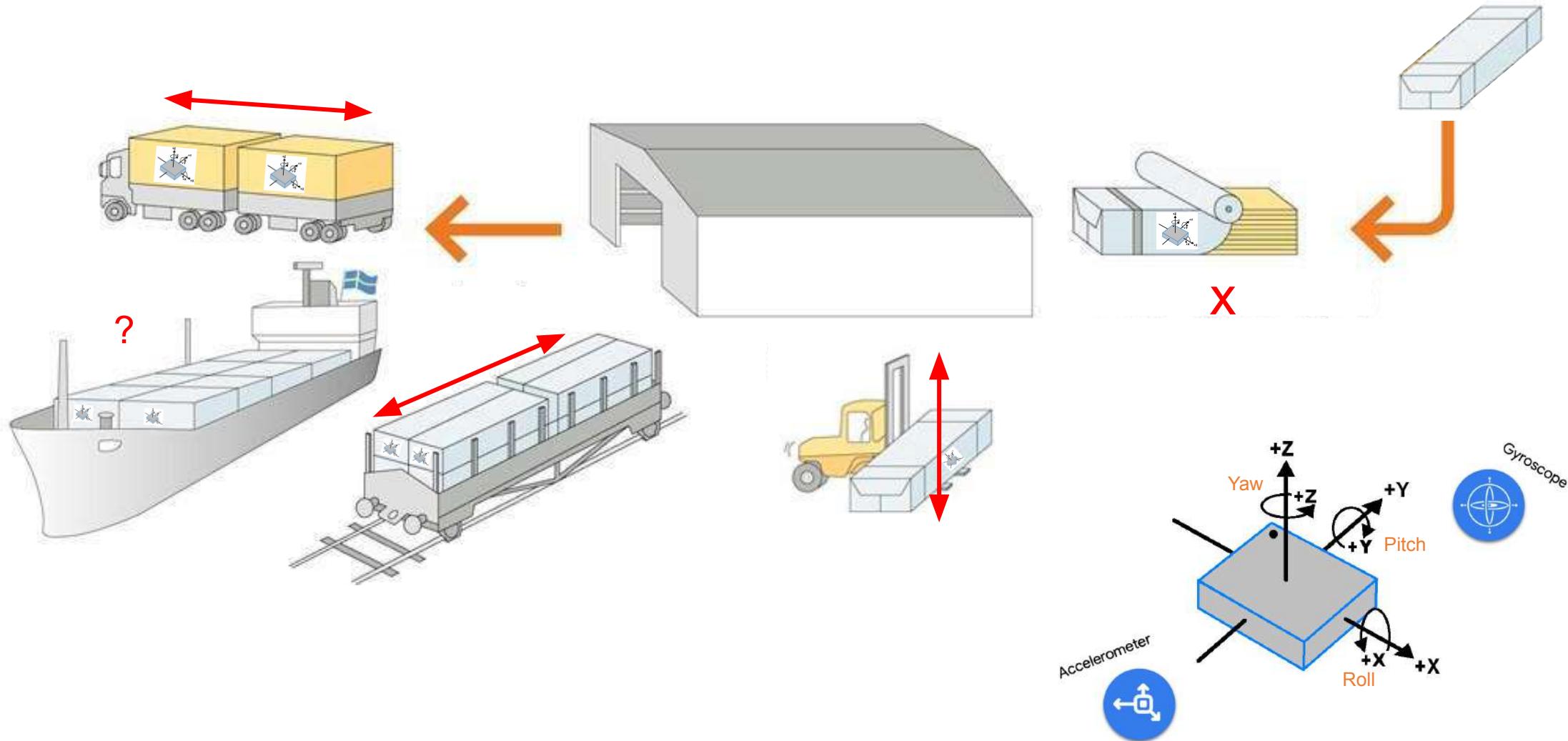
Train a  
Model

Evaluate  
Optimize

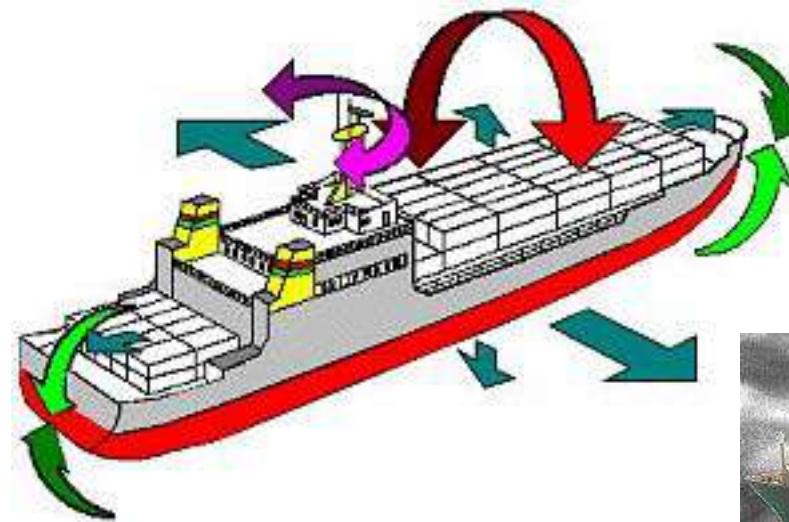
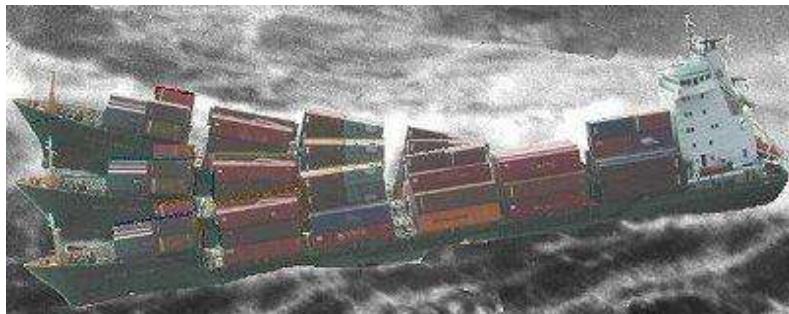
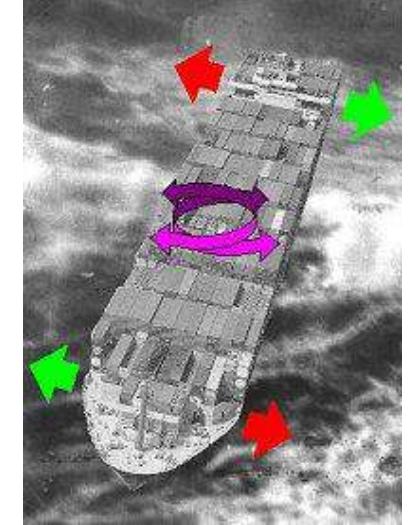
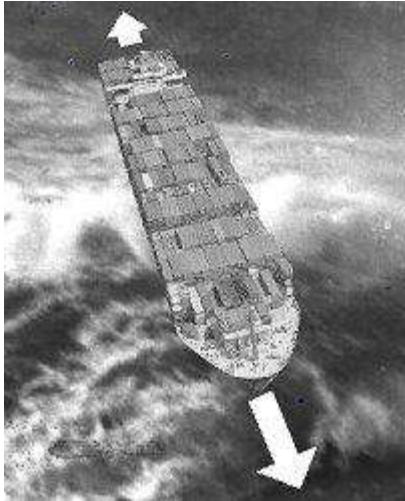
Convert  
Model

Deploy  
Model

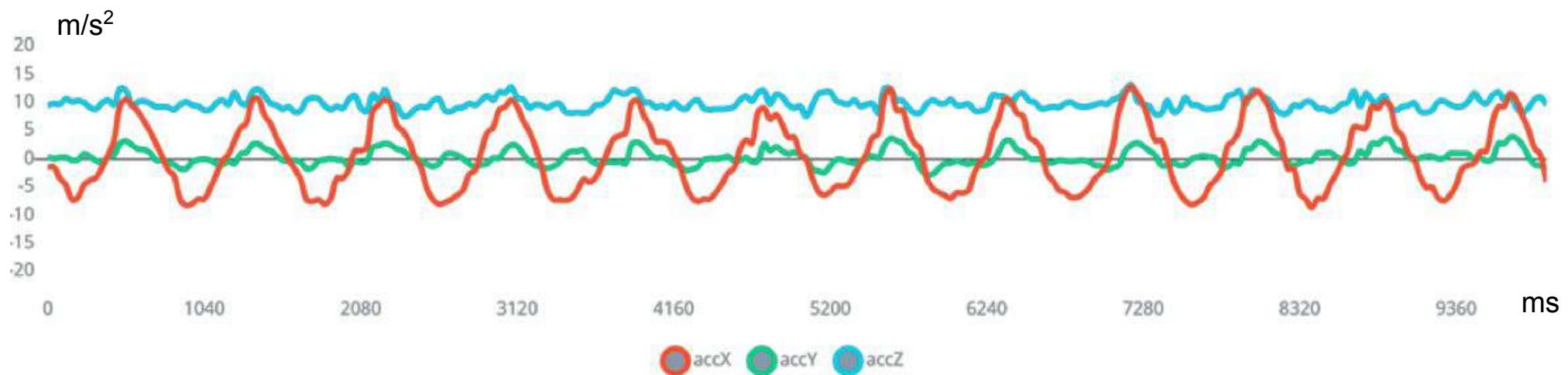
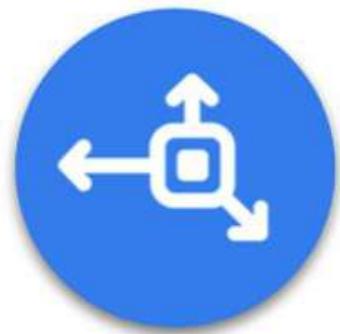
Make  
Inferences

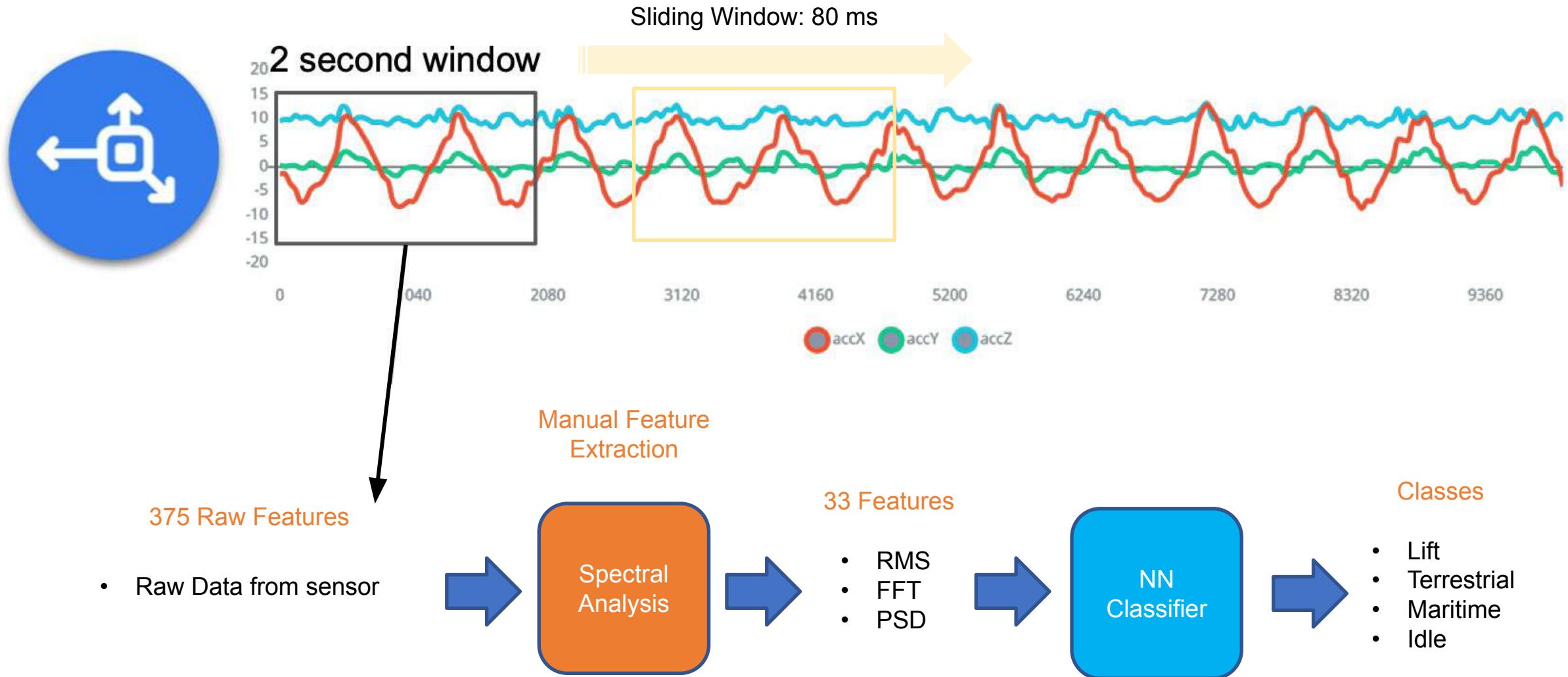


# Mechanical Stresses in Maritime Transport

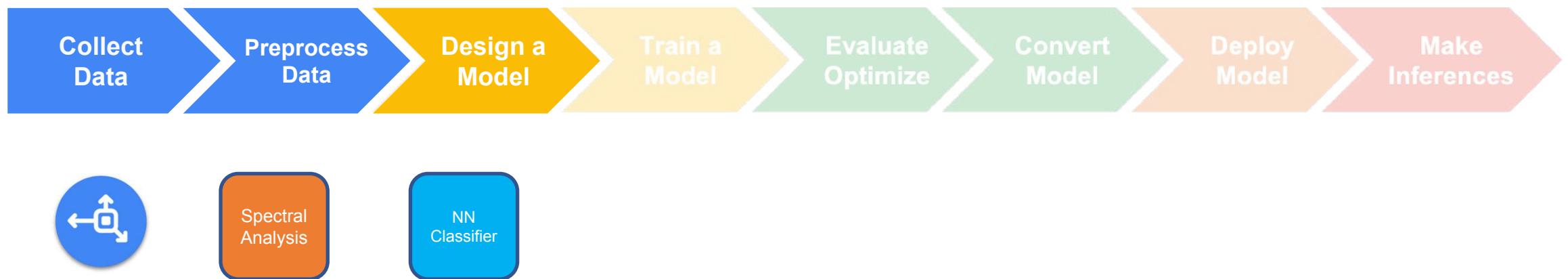


Example: 10 seconds of accelerometer data, captured with a sample rate: 62.5 Hz





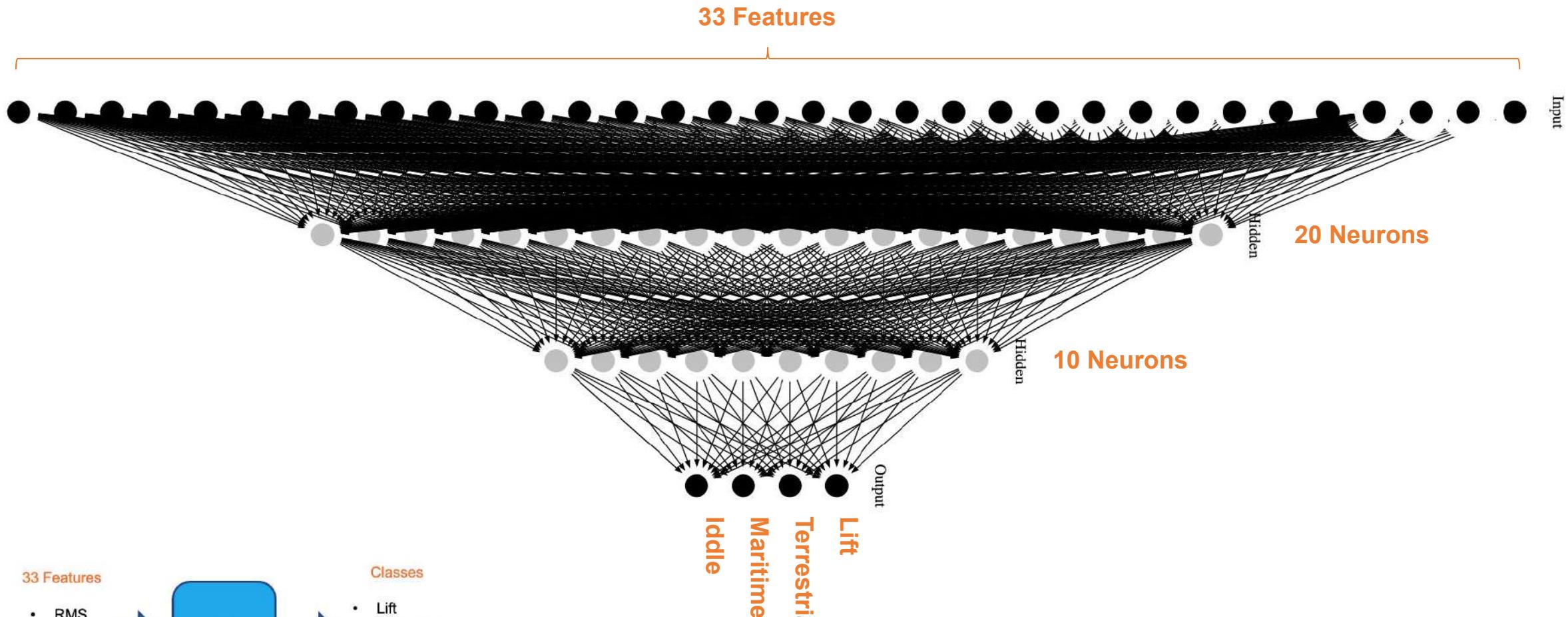
# Model Design (NN Classifier)



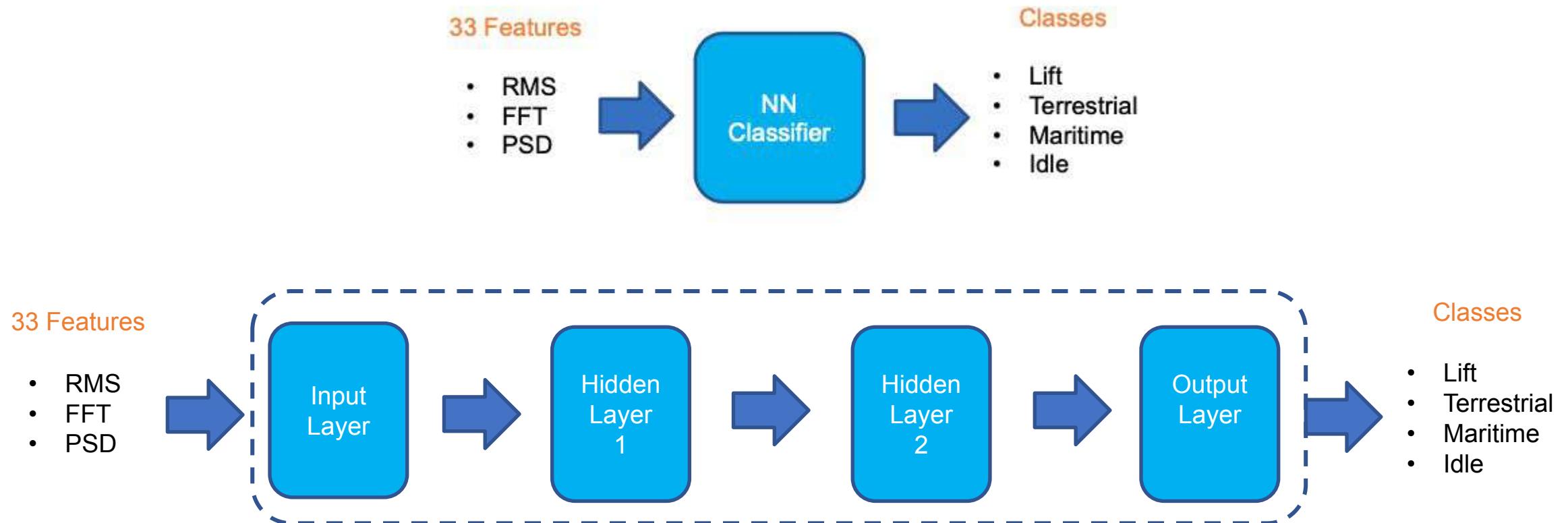
# Model Design (NN Classifier)



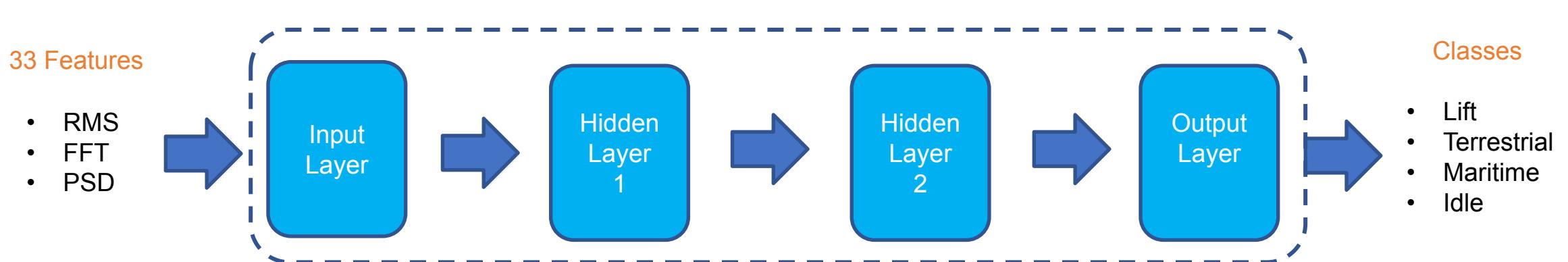
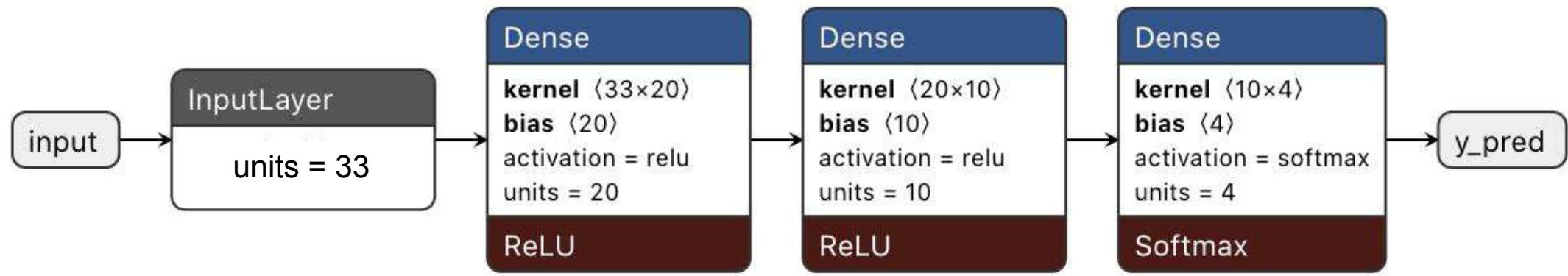
# Model Design (DNN Classifier)



# Model Design (DNN Classifier)



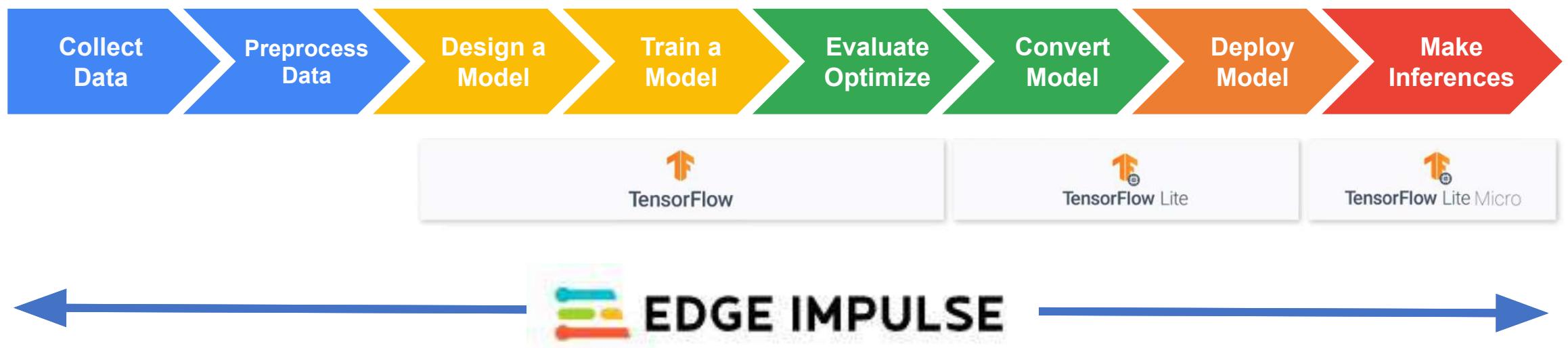
# Model Design (DNN Classifier)



# Train, Evaluate, Convert, Deploy the Model



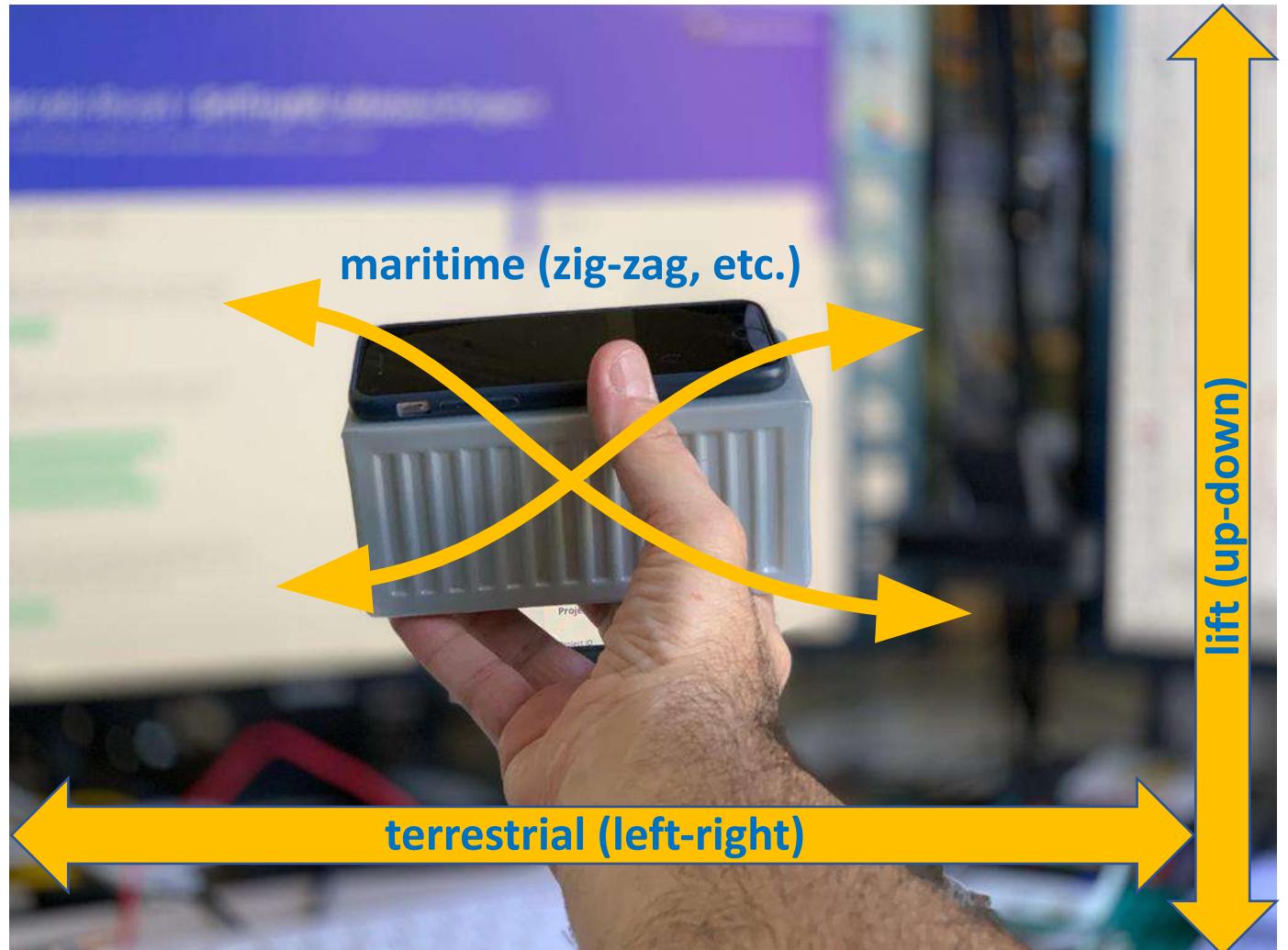
# Train, Evaluate, Convert, Deploy the Model



# Motion Classification

Transportation Classes:

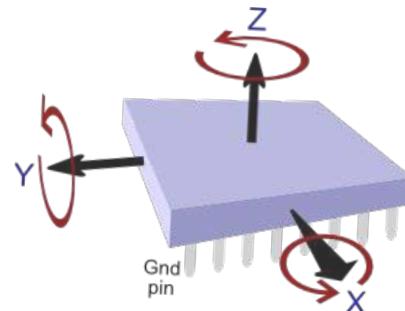
- **lift** (up-down)
- **terrestrial** (left-right)
- **maritime** (zig-zag, etc.)
- **idle**



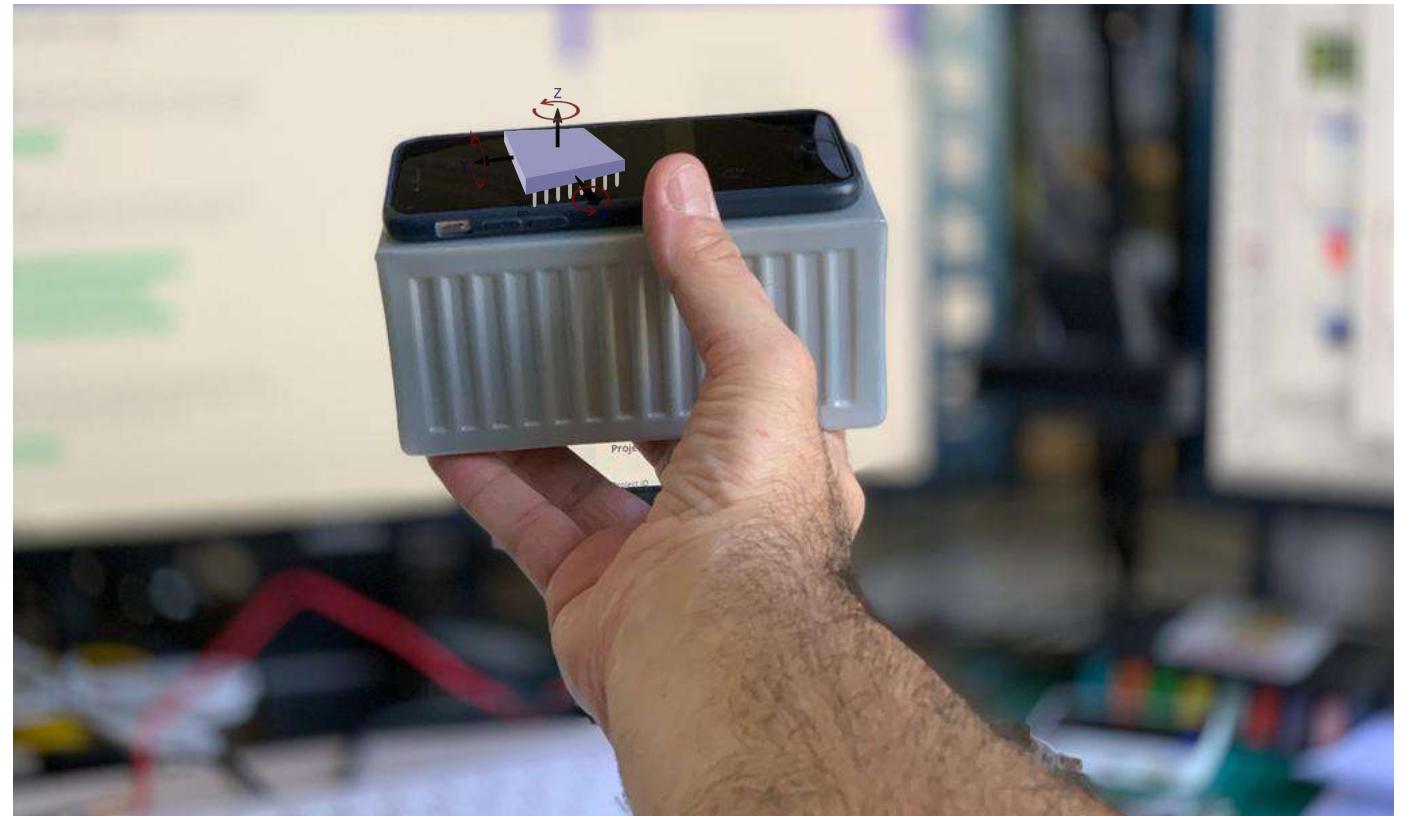
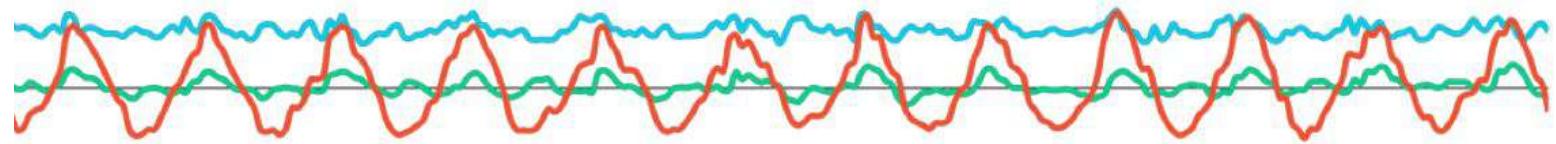
# Motion Classification

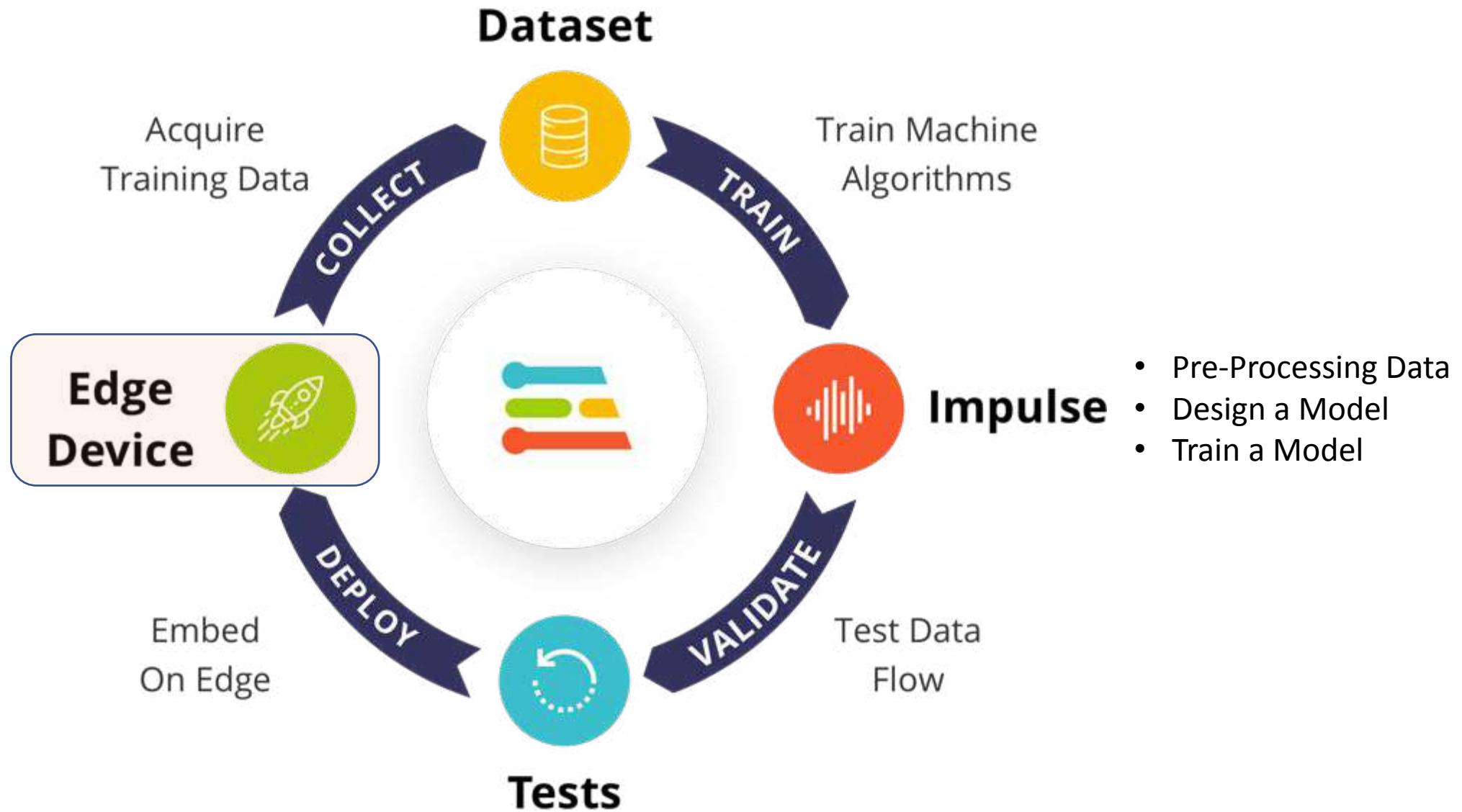
## Transportation Classes

- **lift** (up-down)
- **terrestrial** (left-right)
- **maritime** (zig-zag, etc.)
- **idle**

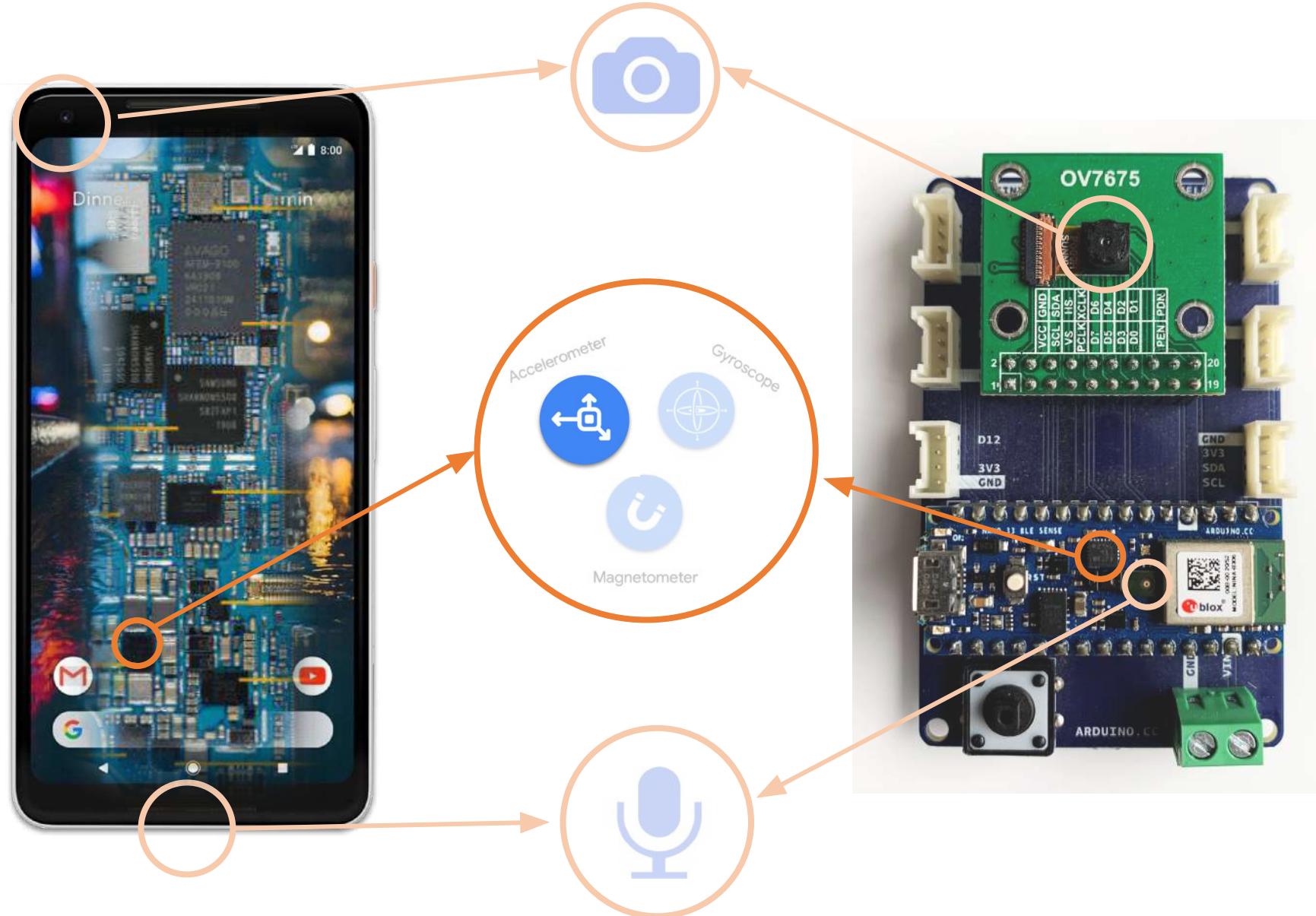


**Data:** collect & test using  
**accelerometer** as sensor





# Sensor - IMU (Inertial Measurement Unit)



Dashboard - SciTinyML-Motion-Project

studio.edgeimpulse.com/studio/51797

EDGE IMPULSE

Project info Keys Export

MJRoBot (Marcelo Rovai)

MJRoBot (Marcelo Rovai) / SciTinyML-Motion-Project

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

Creating your first impulse (100% 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.

DEPLOY YOUR MODEL

Download block output

Sharing

Your project is private.

Make this project public

Summary

DEVICES CONNECTED 1

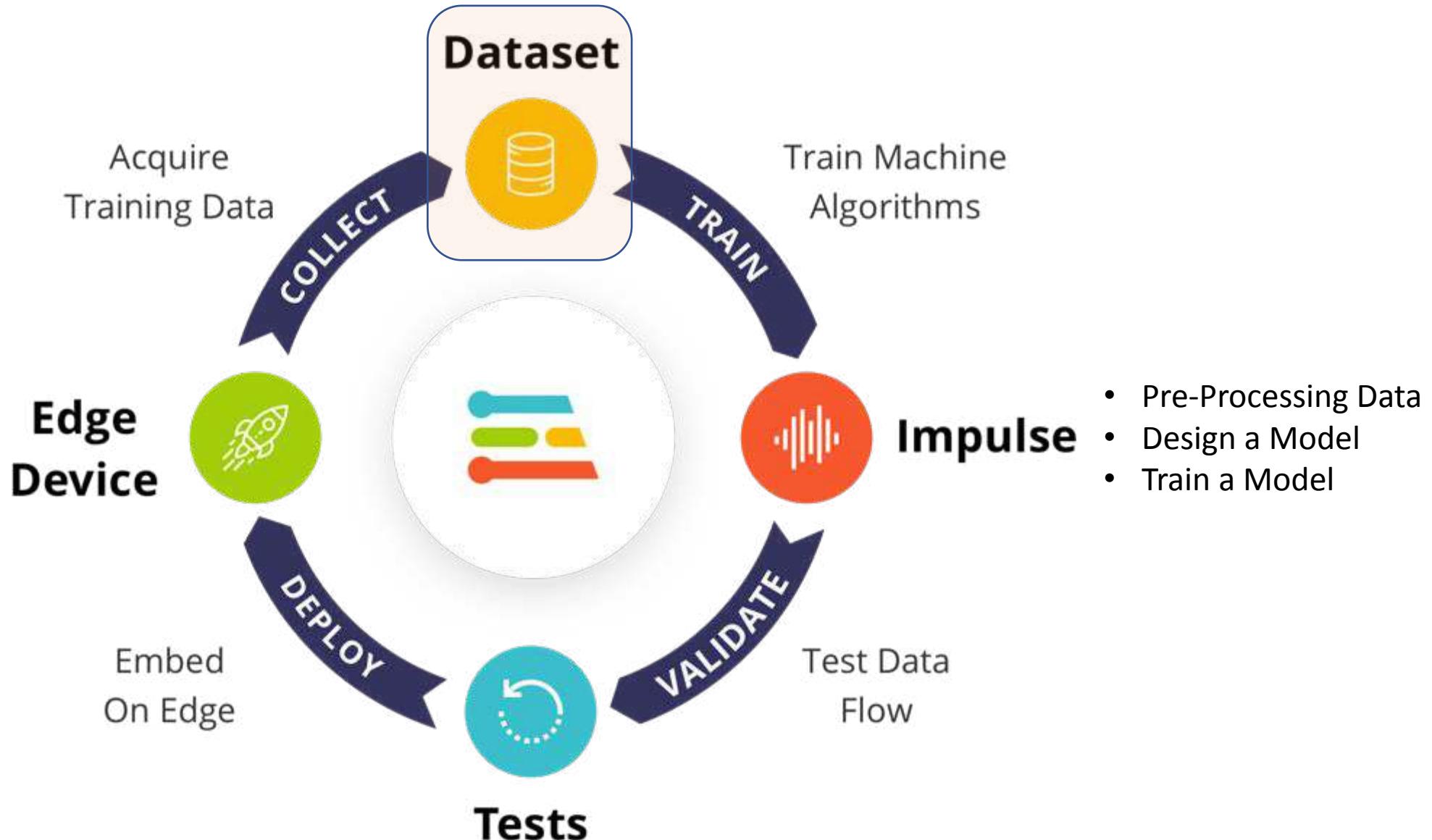
DATA COLLECTED 6m 41s

Collaborators

MJRoBot (Marcelo Rovai) OWNER

Project info

Project ID 51797



**Devices - TinyML4D - Project**

DEVICES (TINYML4D - PROJECT SETUP)

Your devices

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.

**Use your mobile phone**

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

**Show QR code**

**Use your computer**

Capture audio or images from your webcam or microphone, or from an external audio device.

**Collect data**

**Data from any device with the data forwarder**

Capture data from any device or development board over a serial connection, in 10 lines of code.

**Show docs**

**Upload data**

Already have data? You can upload your existing datasets directly in WAV, JPG, PNG, CBOR, CSV or JSON format.

**Go to the uploader**

**Integrate with your cloud**

The enterprise version of Edge Impulse integrates directly with the data stored in your cloud platform.

**Contact us**

Connect a new device

Dashboard

Devices

Data acquisition

Impulse design

Create impulse

Retrain model

Live classification

Model testing

Versioning

Deployment

GETTING STARTED

Documentation

Forums

Marcelo Rovai

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Devices - TinyML4D - Project

studio.edgeimpulse.com/studio/49268/devices

EDGE IMPULSE

DEVICES (TINYML4D - PROJECT SETUP)

Your devices

+ Connect a new device

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

Collect data

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



© 2021 Ed

Devices

Dashboard

Data acquisition

Impulse design

- Create impulse

Retrain model

Live classification

- Model testing
- Versioning
- Deployment

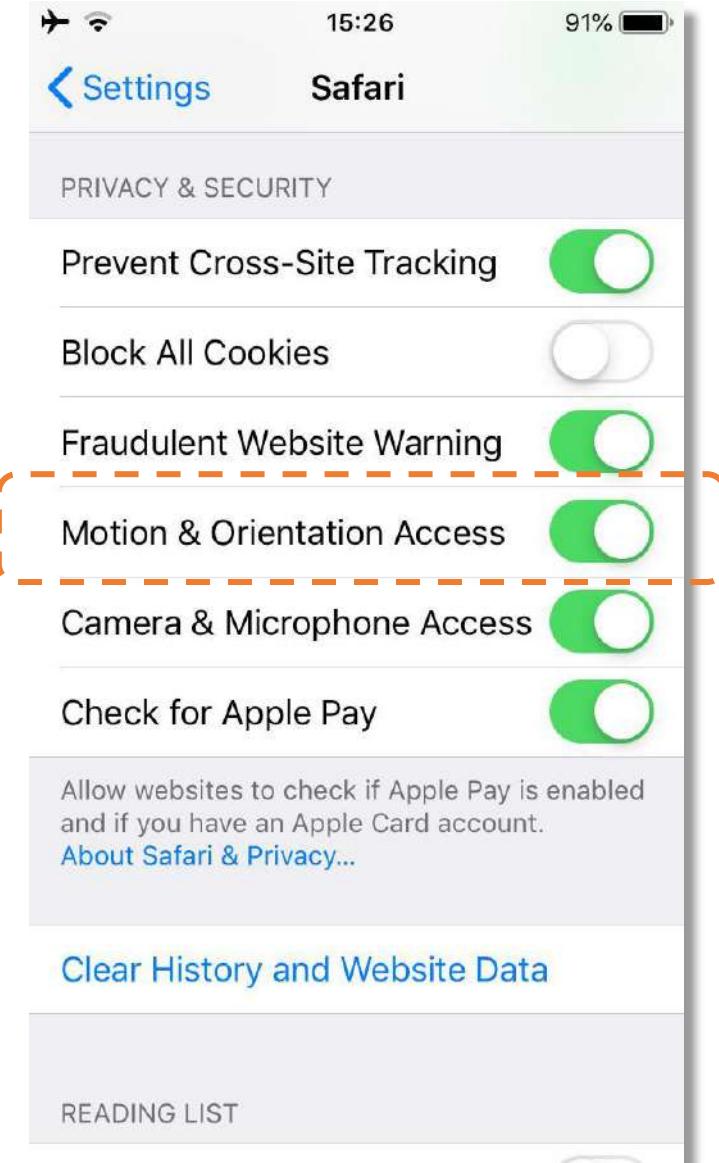
GETTING STARTED

- Documentation
- Forums

Marcelo Rovai

WEBSITE QR CODE  
Open "edgeimpulse.com" in Safari





Devices - TinyML4D - Project

studio.edgeimpulse.com/studio/49268/devices

EDGE IMPULSE

DEVICES (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	REMOTE	LAST SEEN
phone_kq6ray4k	phone_kq6ray4k	MOBILE CLIENT	Accelerometer, Microphone	ONLINE	Today, 12:06:04

Collect data

Device phone\_kq6ray4k is now connected

Get started!

smartphone.edgeimpulse.com 12:07 22% Camera Wi-Fi Data collection

Connected as phone\_kq6ray4k

You can collect data from this

Dashboard

Devices

Data acquisition

Impulse design

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

GETTING STARTED

- Documentation
- Forums

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

© 2021 EdgeImpulse Inc. All rights reserved

Dashboard

Devices (highlighted with a red 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

A screenshot of the Edge Impulse Studio interface showing the 'Devices' page. On the left sidebar, the 'Devices' option is selected and highlighted with a red dashed box. In the main content area, a table lists a single device named 'phone\_kq6ray4k'. A yellow arrow points from the 'Data collection' section on the right towards the 'Connected as' message at the bottom. The bottom right corner shows a mobile device interface with a green checkmark icon and the text 'Connected as phone\_kq6ray4k'.

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 ⓘ 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

A screenshot of the Edge Impulse web studio interface. The left sidebar shows navigation links like Dashboard, Devices, Data acquisition (which is highlighted with a dashed orange border), and Create impulse. The main area is titled 'DATA ACQUISITION (TINYML4D - PROJECT SETUP)' with tabs for 'Training data' and 'Test data'. A prominent message says 'Did you know? You can capture data from any device or development board, or upload your existing datasets - Show options'. Below this is a section for 'DATA COLLECTED' with a red circular icon and 'LABELS 0'. A 'Collected data' section shows 'No data collected yet' with a 'Let's collect some data' button. On the right, there's a 'Record new data' form with fields for 'Device' (showing 'No devices connected'), 'Label' (set to 'up\_down'), and 'Sensor'. A large orange arrow points to the 'Device' field. At the bottom, a dark blue bar says 'RAW DATA Click on a sample to load...'. The top right shows a user profile for 'Marcelo Rovai' and a system status bar with '12:20' and '44%' battery. A large red 'X' icon is overlaid on the right side of the screen, and the text 'Not connected' and 'Refresh this page to reconnect to Edge Impulse' is displayed.

**Collect Data**

The screenshot shows the Edge Impulse Data acquisition interface. On the left, a sidebar menu is open under the 'Data acquisition' section, which is highlighted with a blue arrow pointing from the 'Collect Data' text. The main area displays a table of 'Collected data' with 15 rows, showing sample names like 'idle.2hstvpk2' and 'maritime.2hstpkku3', their labels ('idle' or 'maritime'), addition dates, and lengths (10s). Above the table, it says 'DATA COLLECTED 5m 13s' and 'TRAIN / TEST SPLIT 80% / 20%'. To the right, a 'Record new data' panel is shown with fields for 'Device' (set to 'phone\_kq5ray4k'), 'Label' (set to 'maritime'), 'Sample length (ms.)' (set to '10000'), 'Sensor' (set to 'Accelerometer'), and 'Frequency' (set to '62.5Hz'). A large orange dashed box highlights the 'Label', 'Sensor', and 'Frequency' fields. A yellow arrow points from the 'Start sampling' button towards the bottom right. In the bottom right corner, there's a circular progress bar labeled '4s' and a status bar indicating 'smartphone.edgeimpulse.com' and '12:35 44%'.

DATA ACQUISITION (SCITINYML-MOTION-PROJECT)

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  
5m 13s

TRAIN / TEST SPLIT  
80% / 20%

Record new data

Device: phone\_kq5ray4k

Label: maritime

Sample length (ms.): 10000

Sensor: Accelerometer

Frequency: 62.5Hz

Start sampling

Accelerometer

Microphone

Camera

4s

Recording data

## Collect Data

The screenshot shows the Edge Impulse Data Acquisition interface on a web browser. A large blue arrow on the left points towards the interface with the text "Collect Data".

The interface has a sidebar on the left with the following menu items:

- Dashboard
- Devices
- Data acquisition
- Impulse design
- Create impulse
- Spectral Analysis
- Neural Network (Keras)
- EON Tuner
- Retrain model
- Live classification
- Model testing
- Versioning
- Deployment
- GETTING STARTED
- Documentation
- Forums

The main area is titled "DATA ACQUISITION (SCITINYML-MOTION-PROJECT)". It shows a summary: "DATA COLLECTED 5m 13s" and "TRAIN / TEST SPLIT 80% / 20%".

A table titled "Collected data" lists the following samples:

SAMPLE NAME	LABEL	ADDED	LENGTH
idle.2hstvpk2	idle	Oct 14 2021, 17:54:22	10s
idle.2hstuaut	idle	Oct 14 2021, 17:53:34	10s
idle.2hstt0q3	idle	Oct 14 2021, 17:53:16	10s
idle.2hstt9dk	idle	Oct 14 2021, 17:53:00	10s
idle.2hstsp4a	idle	Oct 14 2021, 17:52:43	10s
idle.2hstrkad	idle	Oct 14 2021, 17:52:06	10s
idle.2hstrkf	idle	Oct 14 2021, 17:51:49	10s
idle.2hstqaj	idle	Oct 14 2021, 17:51:32	10s
maritime.2hstpku3	maritime	Oct 14 2021, 17:51:01	10s
maritime.2hsto9ki	maritime	Oct 14 2021, 17:50:16	10s
maritime.2hstnnqu	maritime	Oct 14 2021, 17:49:58	10s
maritime.2hstn60c	maritime	Oct 14 2021, 17:49:40	10s

To the right, there is a "Record new data" section with fields for "Device" (set to "phone\_kq5ray4k"), "Label" (set to "maritime"), "Sample length (ms.)" (set to 10000), "Sensor" (set to "Accelerometer"), and "Frequency" (set to 62.5Hz). A "Start sampling" button is present.

Below this is a "RAW DATA" plot titled "maritime.2hstpku3" showing three sensor signals: accX (red), accY (green), and accZ (blue) over time.

Collect  
Data

## Original Dataset

## Original Dataset

Collect  
Data

Training Set

Test Set

## Original Dataset

Training Set

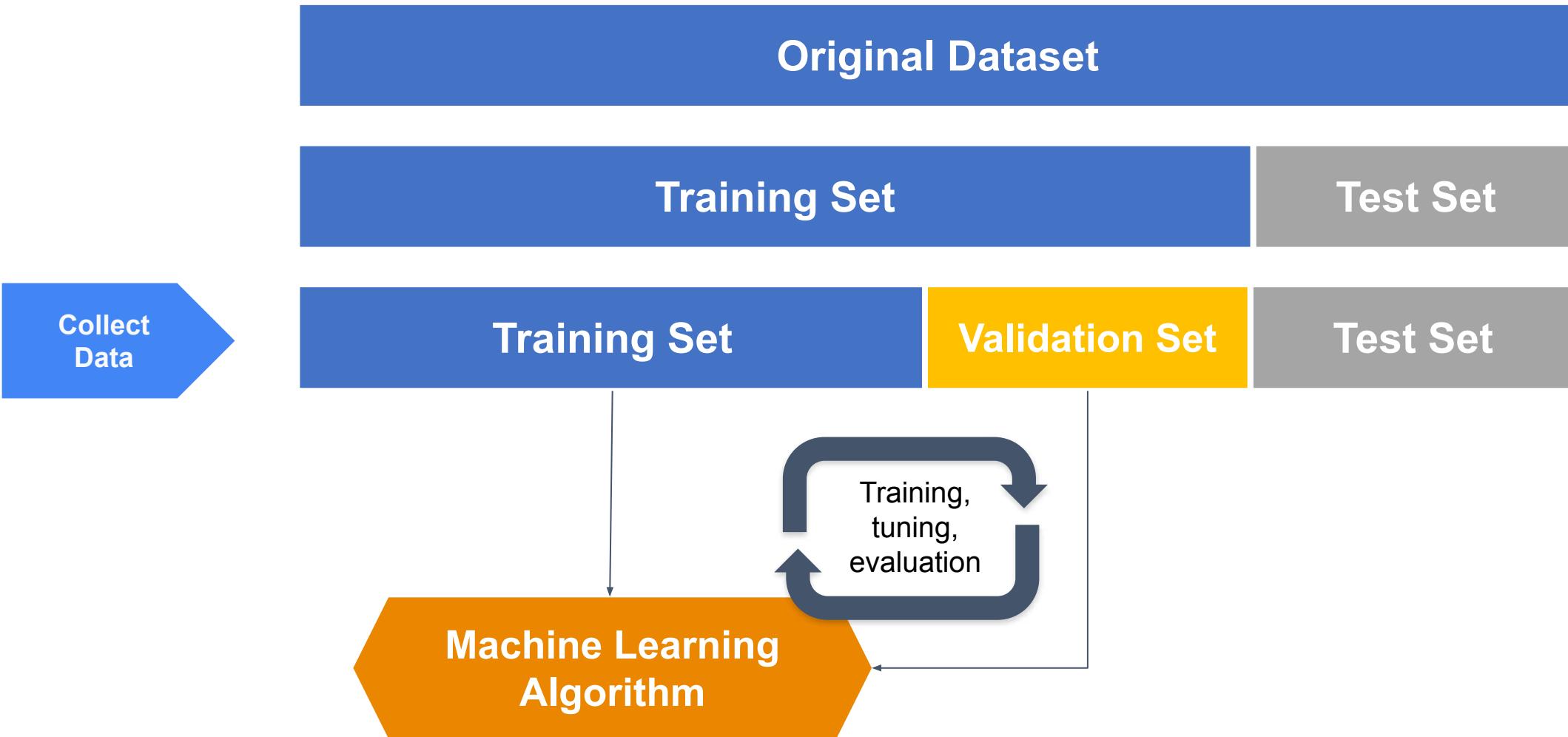
Test Set

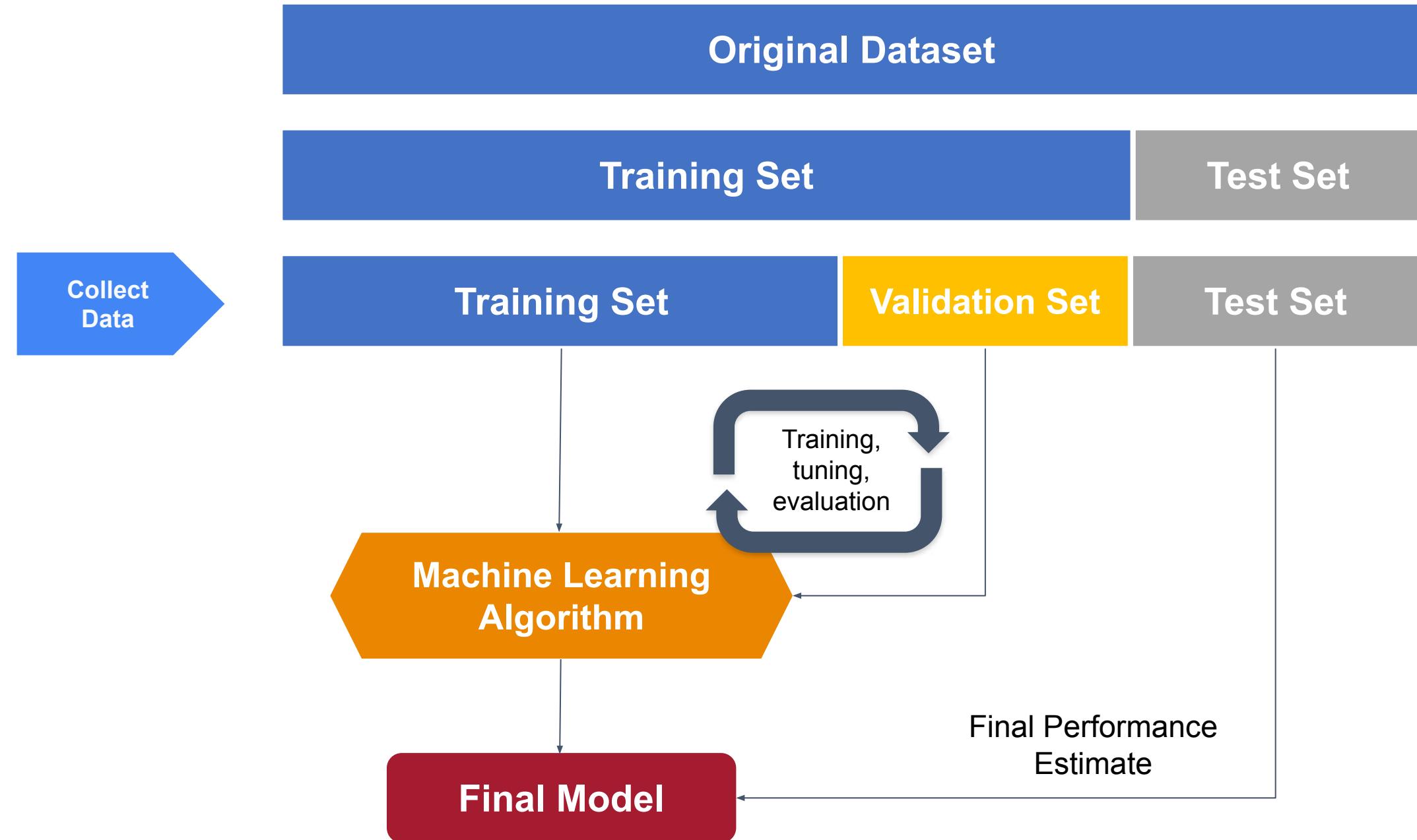
Training Set

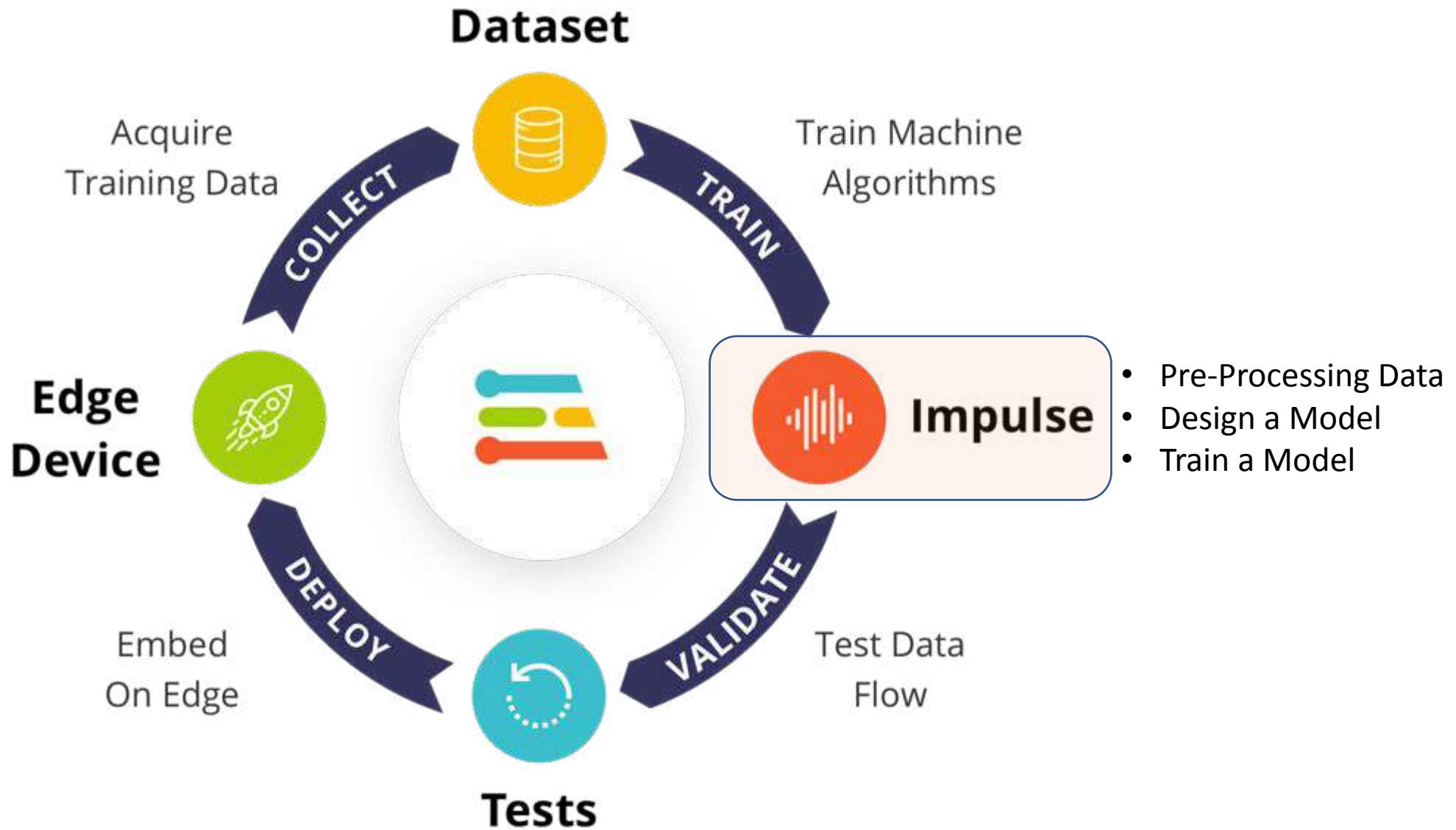
Validation Set

Test Set

Collect  
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 Analysis

Input axes  
 accX  
 accY  
 accZ

**Neural Network (Keras)**

Name  
Neural Network (Keras)

Input features  
 Spectral Analysis

Output features  
4 (idle, lift, maritime, terrestrial)

**Output features**

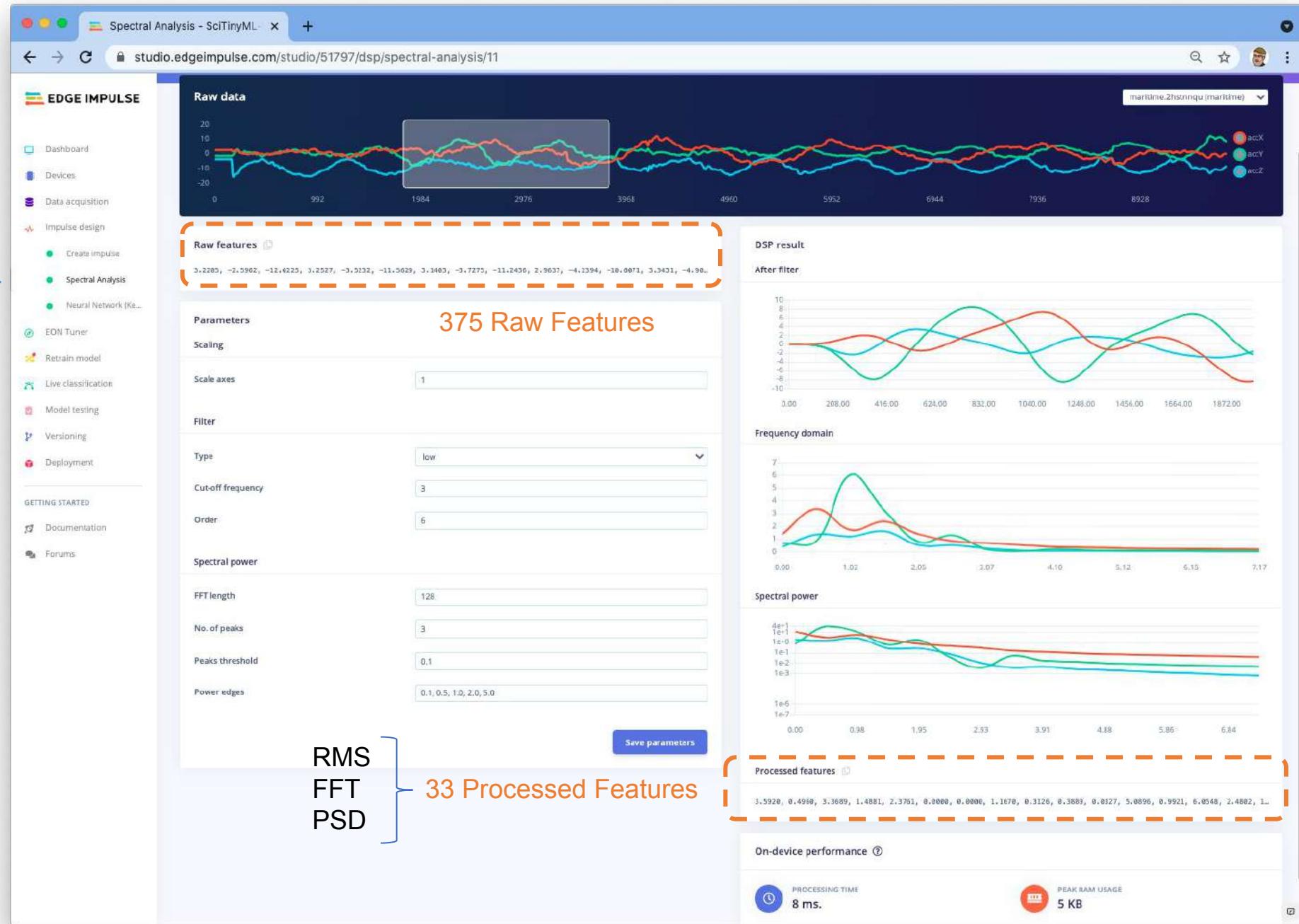
4 (idle, lift, maritime, terrestrial)

**Save Impulse**



### Classes

- Lift
- Terrestrial
- Maritime
- Idle



# Preprocess Data

Preprocess  
Data

Spectral Analysis - SciTinyML x +

studio.edgeimpulse.com/studio/51797/dsp/spectral-analysis/11/generate-features

EDGE IMPULSE

SPECTRAL ANALYSIS (SCITINYML-MOTION-PROJECT)

#1 ▾ EON Tuner Primary

Parameters Generate features

Training set

Data in training set 5m 22s

Classes 4 (idle, lift, maritime, terrestrial)

Window length 2000 ms.

Window increase 80 ms.

Training windows 3,230

Generate features

Feature explorer (3,132 samples)

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

idle lift maritime terrestrial

accX RMS

- ✓ 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

On-device performance

PROCESSING TIME 8 ms. PEAK RAM USAGE 5 KB

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The screenshot shows the Edge Impulse Studio interface for a project titled "SPECTRAL ANALYSIS (SCITINYML-MOTION-PROJECT) #1 EON Tuner Primary". On the left, a sidebar lists various project management and documentation links. The main workspace is divided into sections: "Training set" (listing data details like duration, classes, window length, and training windows), "Feature explorer" (displaying a 3D scatter plot of 3,132 samples across X, Y, and Z axes using RMS and spectral power features, with data points color-coded by class), and "On-device performance" (showing processing time at 8 ms and peak RAM usage at 5 KB). A large blue arrow on the left points towards the "Preprocess Data" section of the interface.

Design a Model

Neural Network (Keras) - SciTI

studio.edgeimpulse.com/studio/51797/learning/keras/12

**EDGE IMPULSE**

**Neural Network settings**

**Training settings**

Number of training cycles ⑦ EPOCHS 30

Learning rate ⑦ 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**

```
graph TD; input --> InputLayer[InputLayer]; InputLayer --> Dense1[Dense<br/>kernel 33x20<br/>bias 20]; Dense1 --> ReLU1[ReLU]; ReLU1 --> Dense2[Dense<br/>kernel 20x10<br/>bias 10]; Dense2 --> ReLU2[ReLU]; ReLU2 --> Softmax[Softmax]; Softmax --> y_pred[y_pred]
```

Train a Model

Neural Network (Keras) - SciTI

studio.edgeimpulse.com/studio/51797/learning/keras/12

### EDGE IMPULSE

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Start training

Training Set Validation Set

Machine Learning Algorithm

Training, tuning, evaluation

### Training output

Model Model version: ② Quantized (int8)

Last training performance (validation set)

ACCURACY 99.7% LOSS 0.01

Confusion matrix (validation set)

	IDLE	LIFT	MARITIME	TERRESTRIAL
IDLE	100%	0%	0%	0%
LIFT	0%	100%	0%	0%
MARITIME	0%	0.6%	99.4%	0%
TERRESTRIAL	0.6%	0%	0%	99.4%
F1 SCORE	1.00	1.00	1.00	1.00

Feature explorer (full training set) ②

accX RMS accY RMS accZ RMS

- idle - correct
- lift - correct
- maritime - correct
- terrestrial - correct
- maritime - incorrect
- terrestrial - incorrect

### On-device performance ②

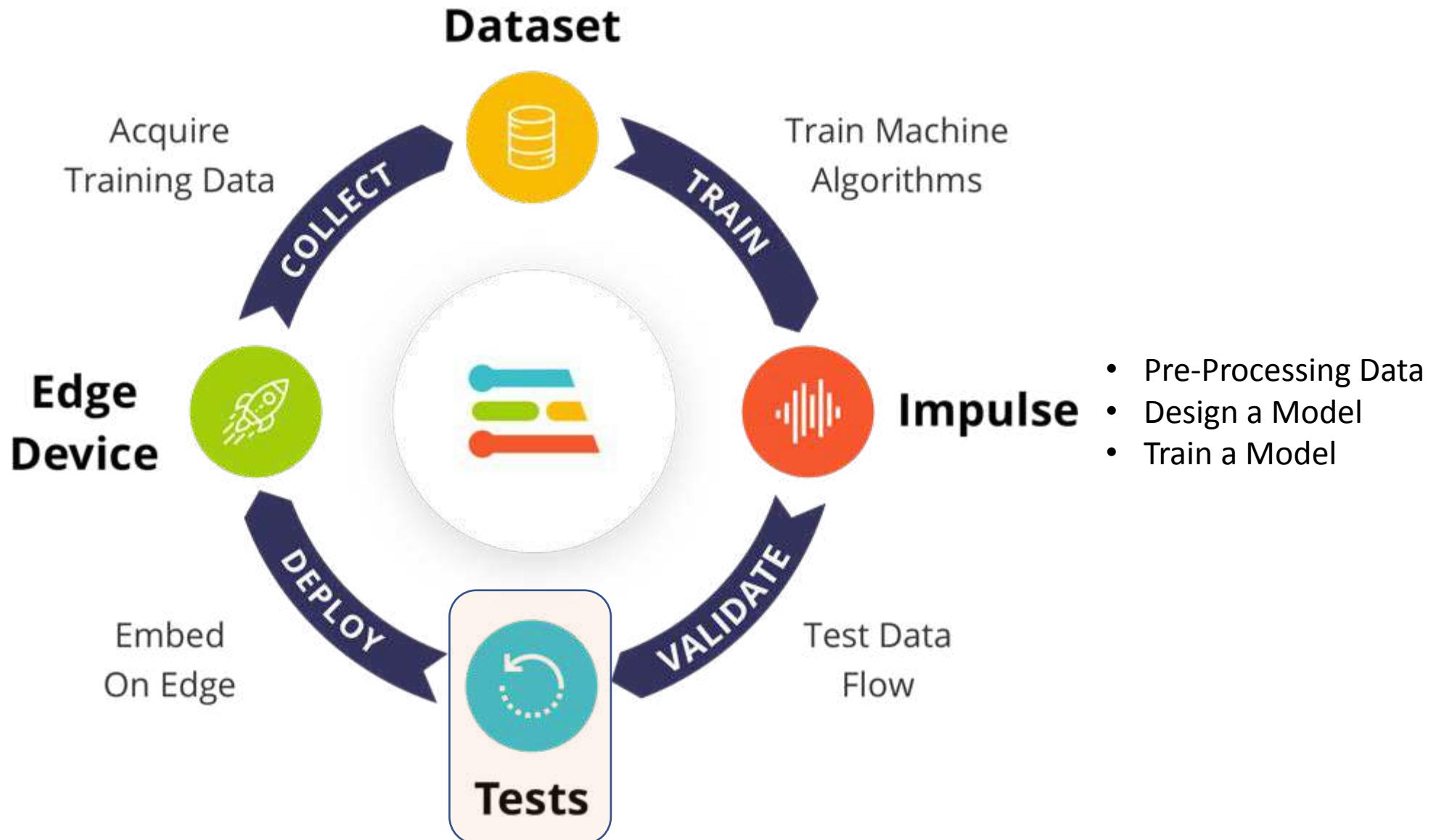
INFERRING TIME 1 ms. PEAK RAM USAGE 1.7K FLASH USAGE 19.0K

**Evaluate Optimize**

The screenshot shows the Edge Impulse web studio interface. On the left, a green arrow points right, labeled "Evaluate Optimize". The main area is divided into two main sections:

- Neural Network settings** (left side):
  - 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). A button "Add an extra layer" is available.
  - Start training** button.
- Training output** (right side):
  - Model**: Model version: Quantized (int8).
  - Last training performance (validation set)**: Accuracy 99.7%, Loss 0.01.
  - Confusion matrix (validation set)**:
 

	IDLE	LIFT	MARITIME	TERRESTRIAL
IDLE	100%	0%	0%	0%
LIFT	0%	100%	0%	0%
MARITIME	0%	0.6%	99.4%	0%
TERRESTRIAL	0.6%	0%	0%	99.4%
F1 SCORE	1.00	1.00	1.00	1.00
  - Feature explorer (full training set)**: Shows scatter plots for accX RMS, accY RMS, and accZ RMS across four categories: idle - correct (green), lift - correct (yellow), maritime - correct (blue), and terrestrial - correct (orange). A legend also shows maritime - incorrect (green) and terrestrial - incorrect (red).
  - On-device performance** (estimated for Arduino Nano):
    - Estimate for Arduino Nano 33 BLE Sense (Cortex-M4F 64MHz), compiled with Edge Impulse EON™ compiler.
    - Performance metrics: INFERENCING TIME 1 ms., PEAK RAM USAGE 1.7K, FLASH USAGE 19.0K.



**Evaluate  
Optimize**

Model testing - SciTinyML-Motion-Project

studio.edgeimpulse.com/studio/51797/validation

EDGE IMPULSE

MODEL TESTING (SCITINYML-MOTION-PROJECT)

MJRoBot (Marcelo Rovai)

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

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.2hvft...	testing	10s		
terrestrial.2...	terrestrial	10s	100%	98 terrestrial
terrestrial.2...	terrestrial	10s	100%	98 terrestrial
lift .2hssi1t6	lift	10s	100%	98 lift
lift .2hst8tvj	lift	10s	100%	98 lift

Training Set      Validation Set      Test Set

Machine Learning Algorithm

Final Model

Final Performance Estimate

Training, tuning, evaluation

Model testing output

Model testing results

ACCURACY 99.74% %

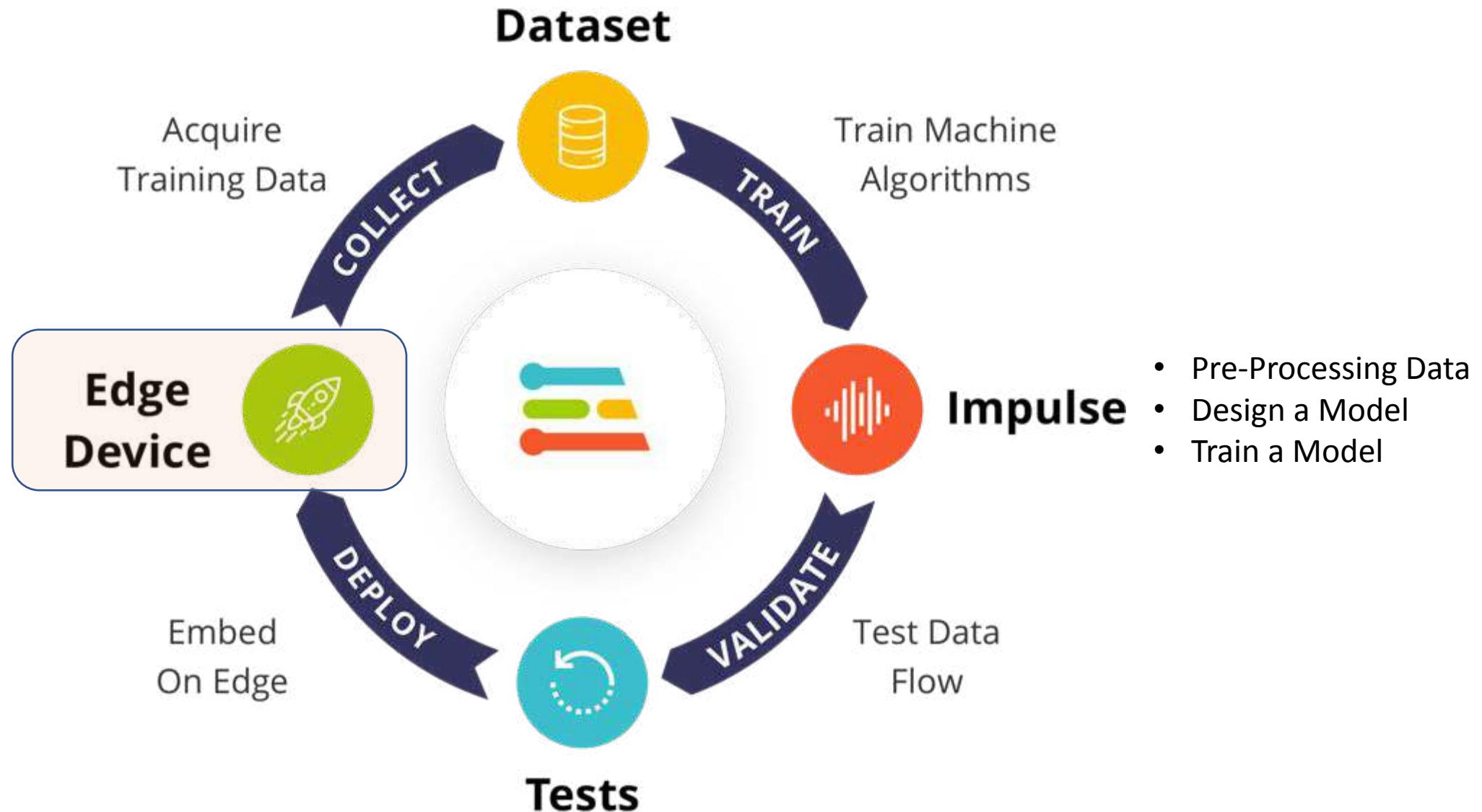
	IDLE	LIFT	MARITIME	TERRESTRIAL	UNCERTAIN
IDLE	99.5%	0.5%	0%	0%	0%
LIFT	0%	100%	0%	0%	0%
MARITIME	0%	0%	99.5%	0%	0.5%
TERRESTRIAL	0%	0%	0%	100%	0%
F1 SCORE	1.00	1.00	1.00	1.00	1.00

Feature explorer

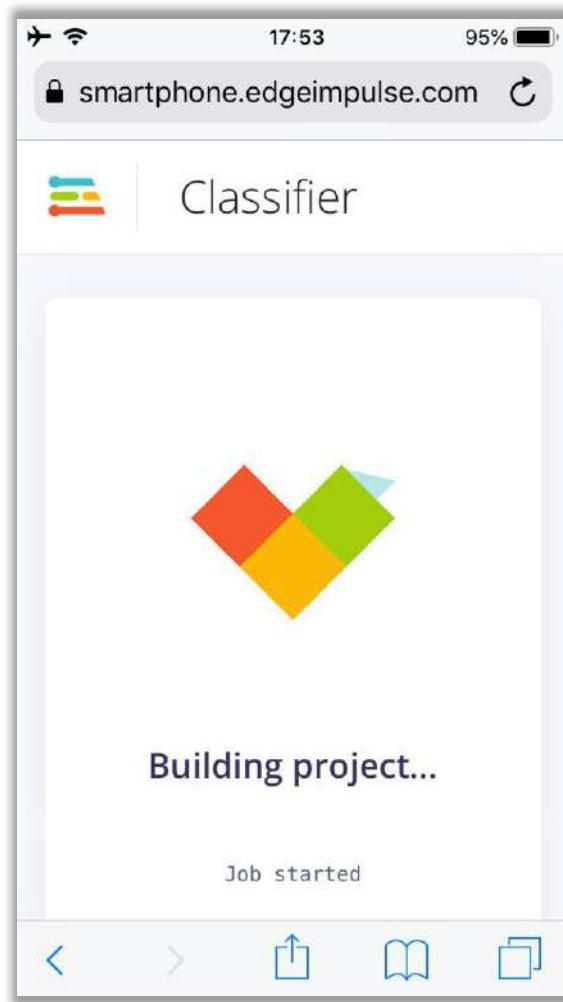
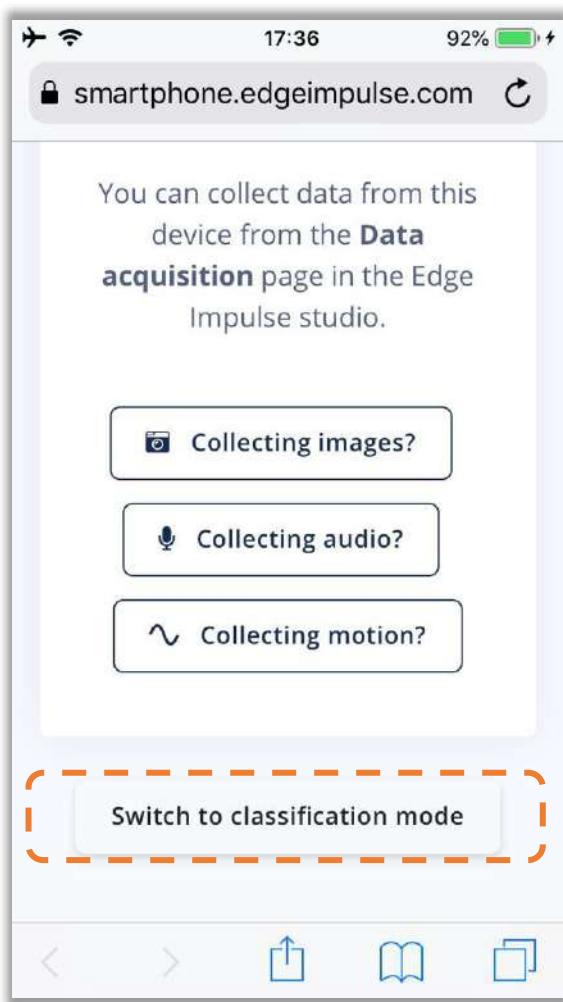
accX RMS accY RMS accZ RMS

idle - correct  
lift - correct  
maritime - correct  
terrestrial - correct  
idle - incorrect  
maritime - incorrect

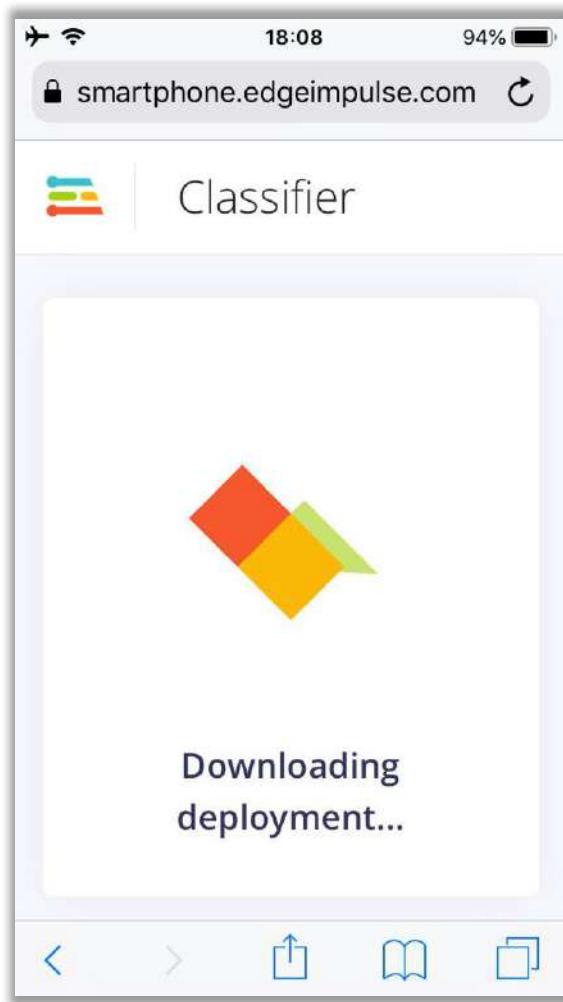
3D Scatter Plot: accX RMS vs accY RMS vs accZ RMS



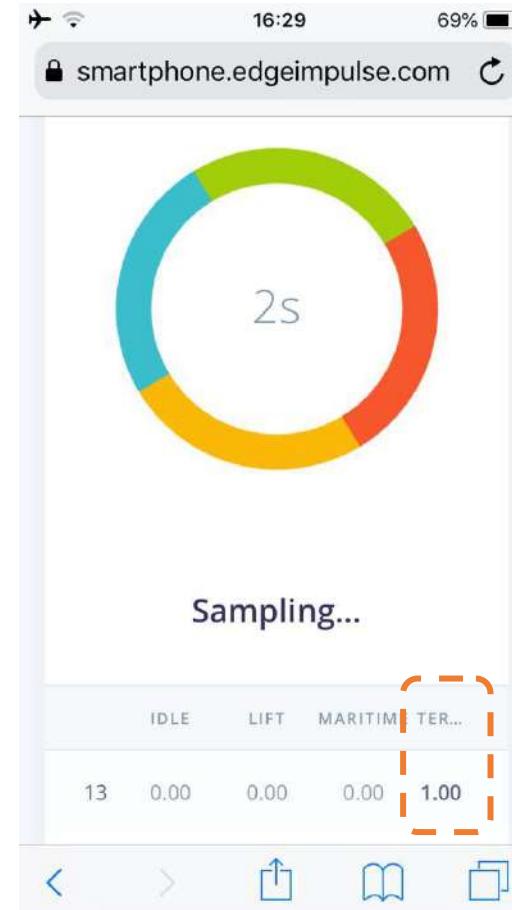
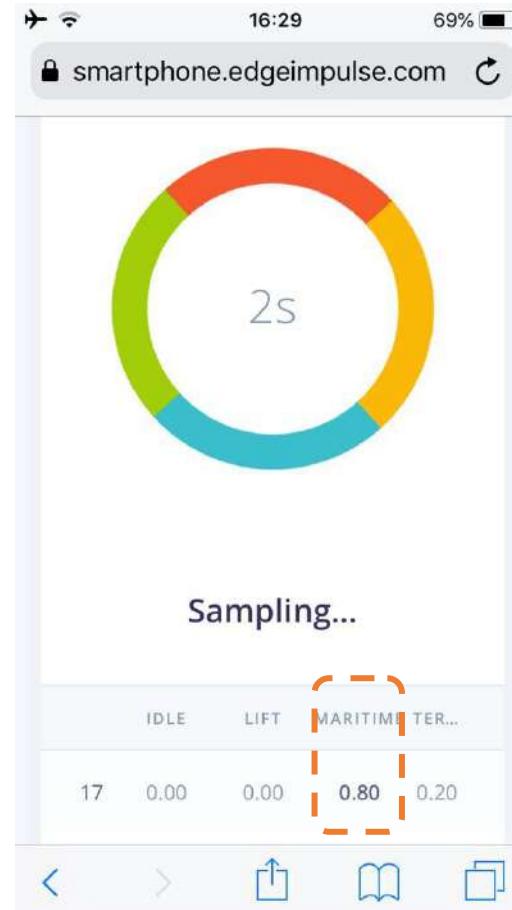
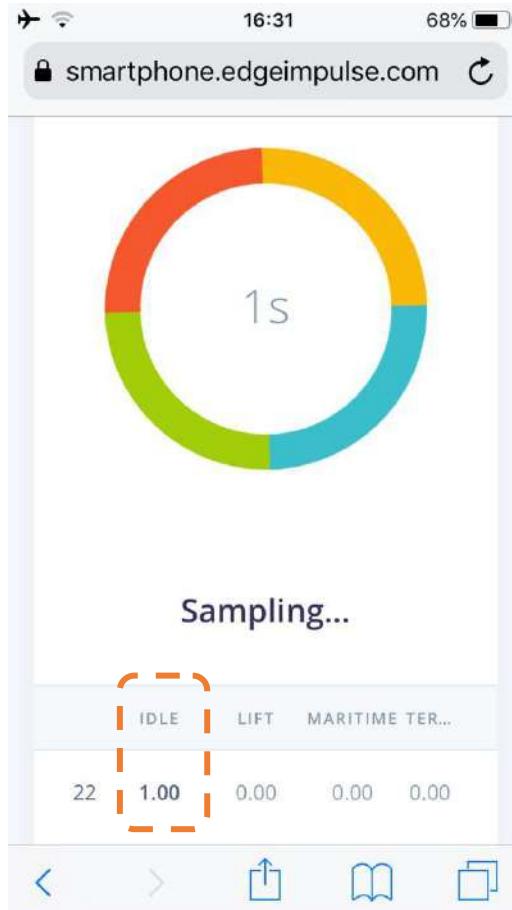
## Convert Model



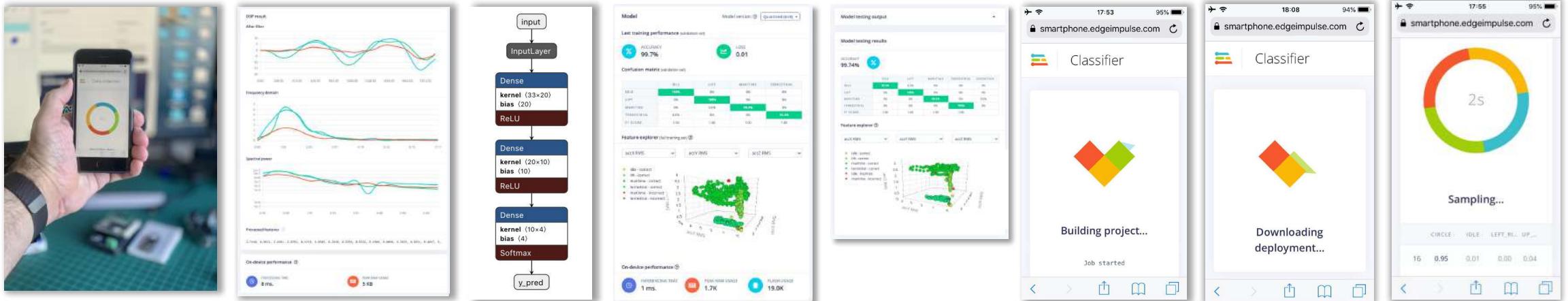
## Deploy Model



## Make Inferences



# Motion Classification - Summary



Spectral Analysis

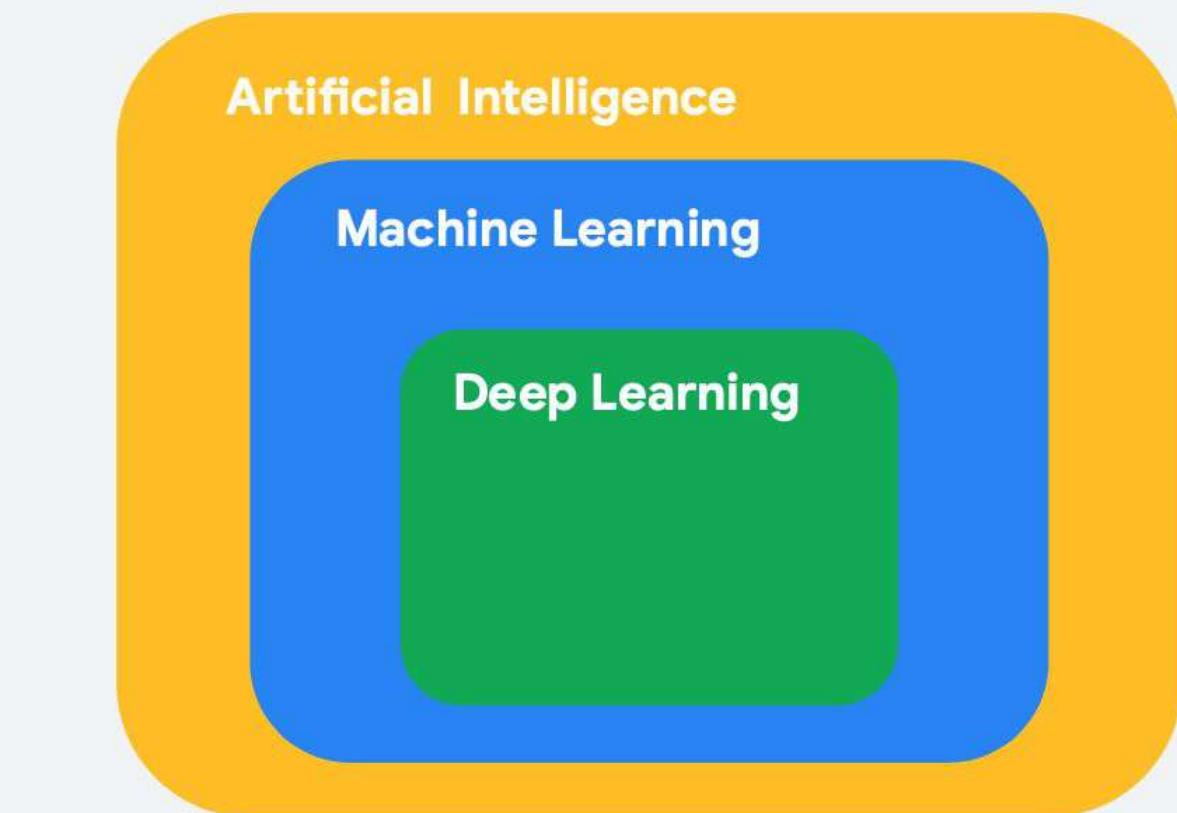
NN Classifier



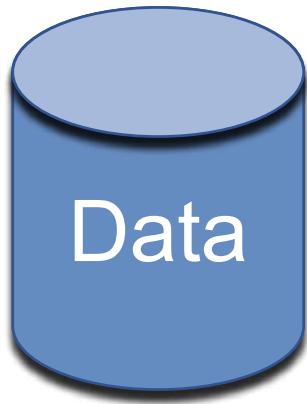
# What AI really is?

# What is (**Deep**) Machine Learning?

1. Machine Learning is a subfield of Artificial Intelligence focused on developing algorithms that learn to solve problems by analyzing data for patterns
2. **Deep Learning** is a type of Machine Learning that leverages **Neural Networks** and **Big Data**



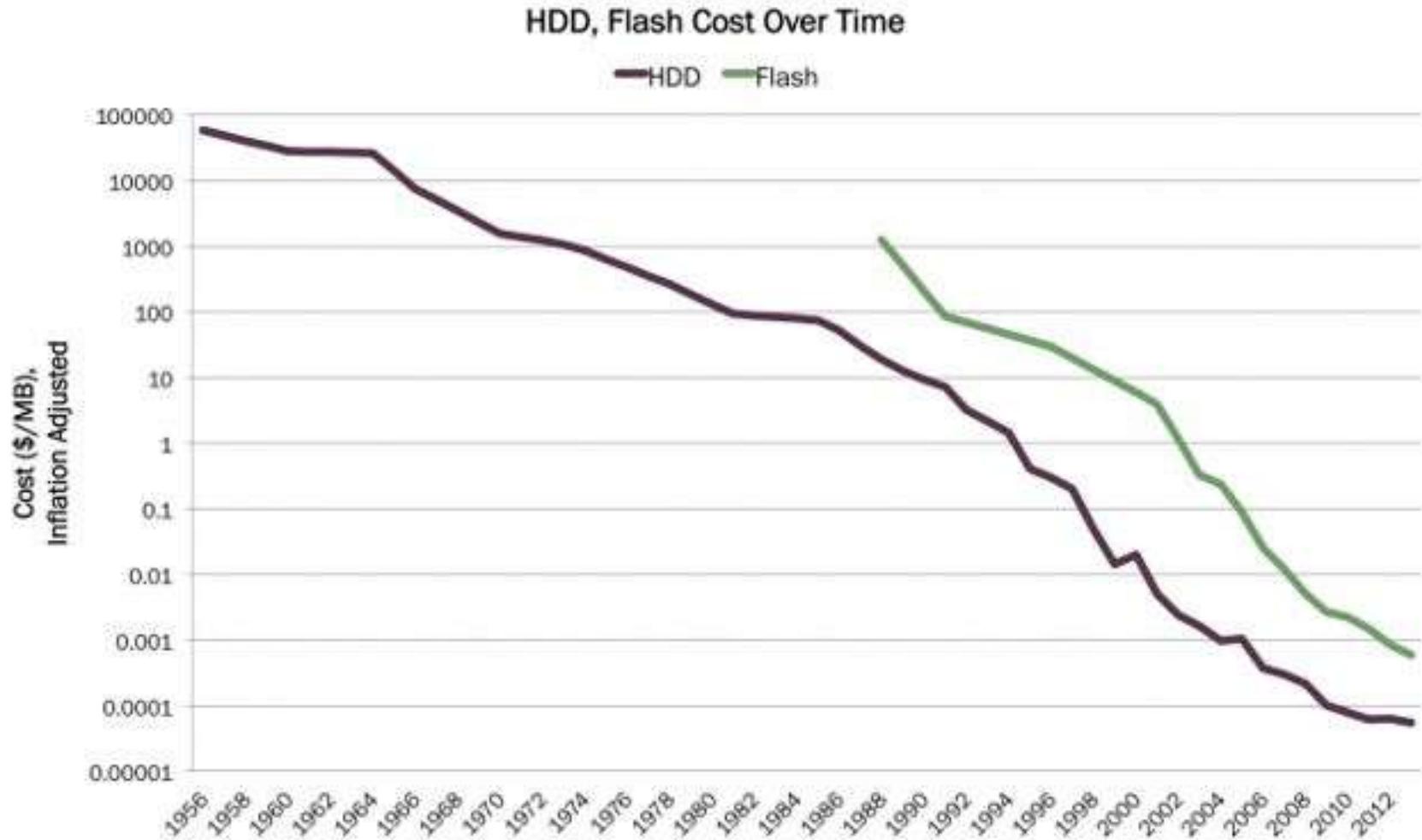
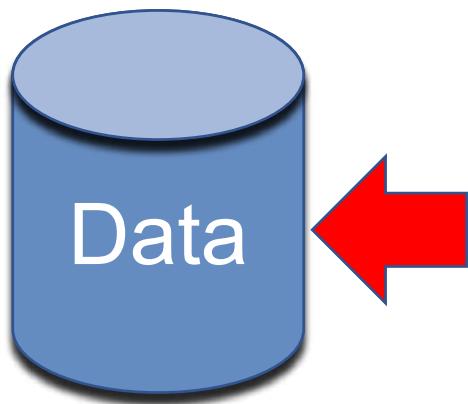
# AI starts with ... Data, lot of data (Big Data)



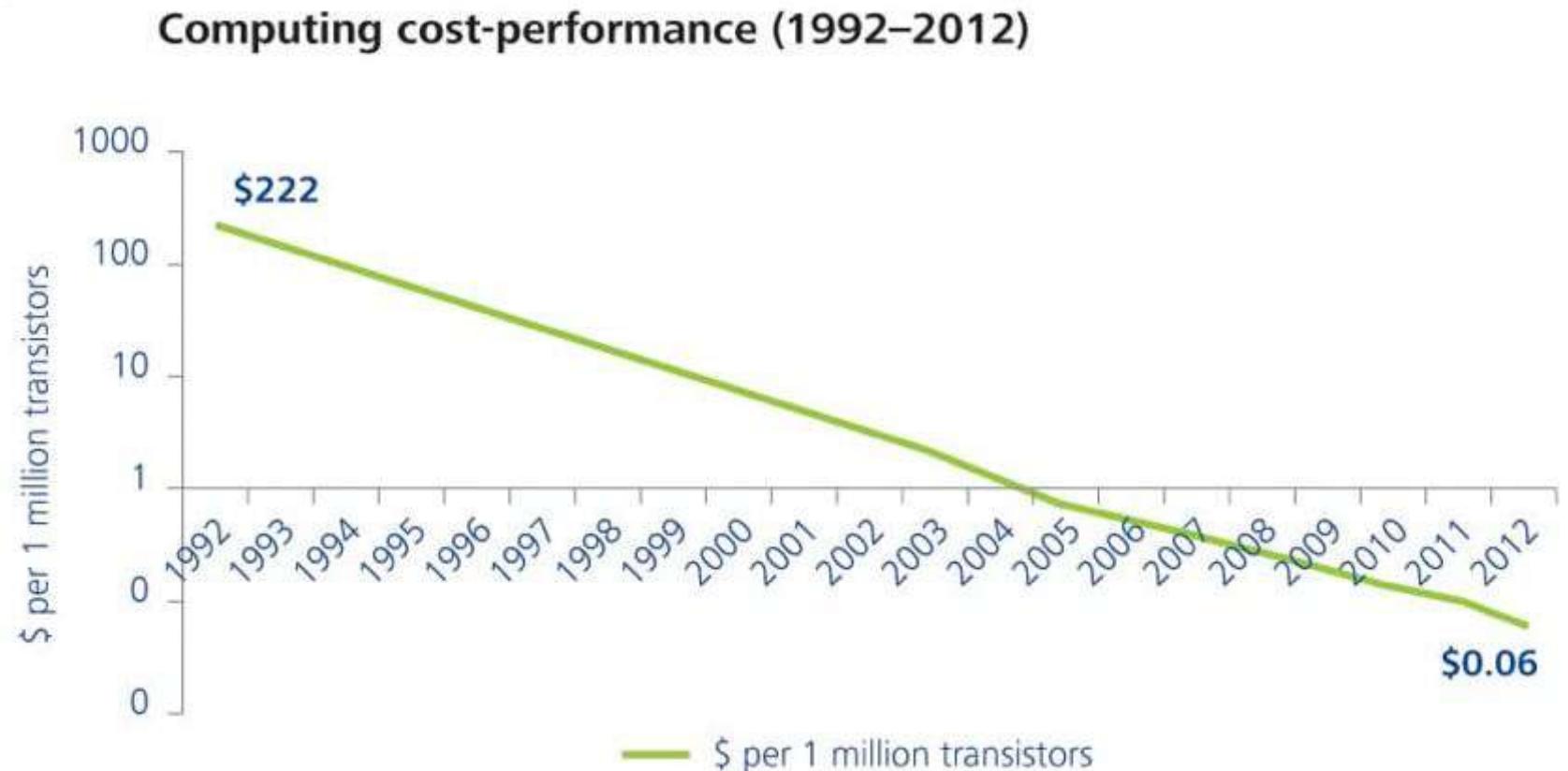
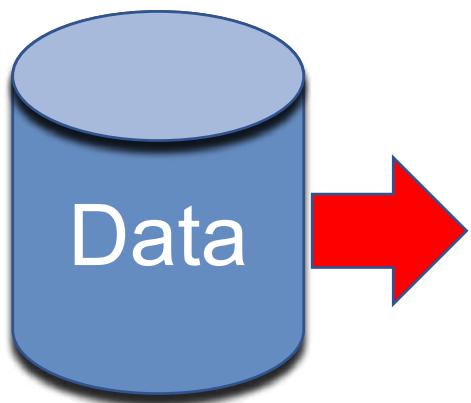
- ✓ Low storage cost & capacity
- ✓ High Performance & Low cost



# Data → Storage

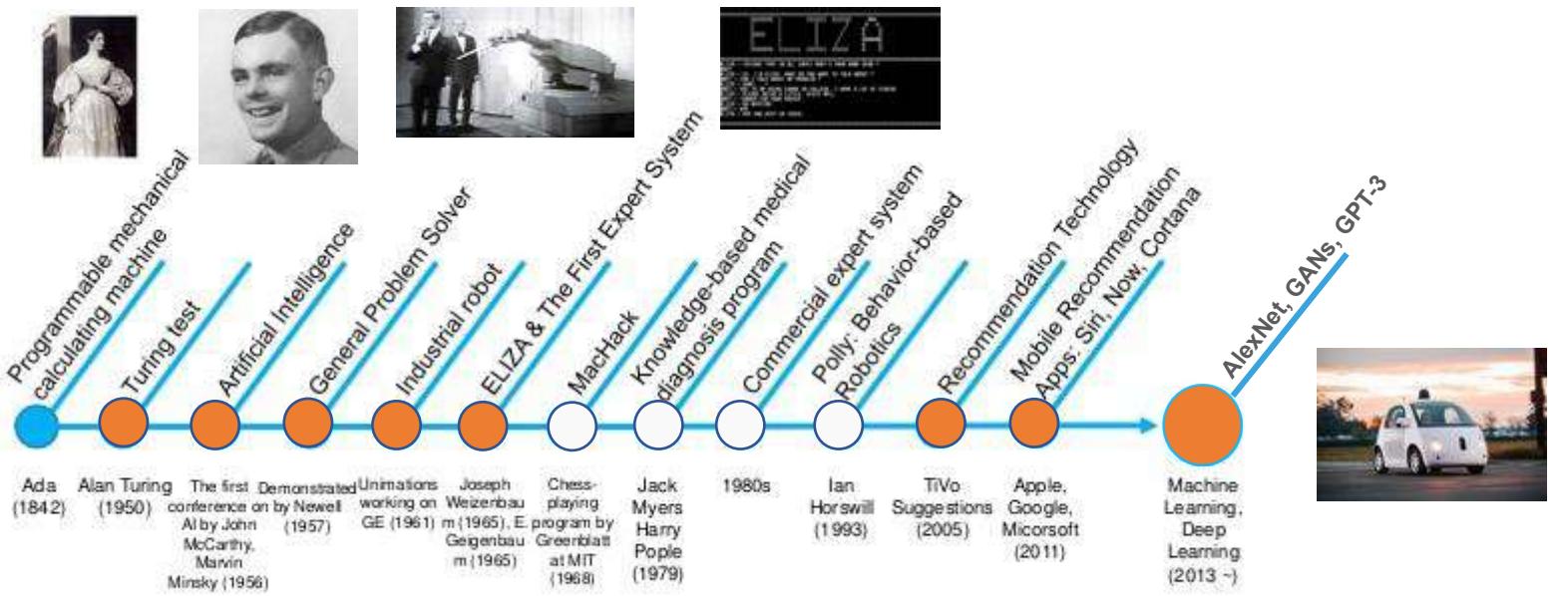
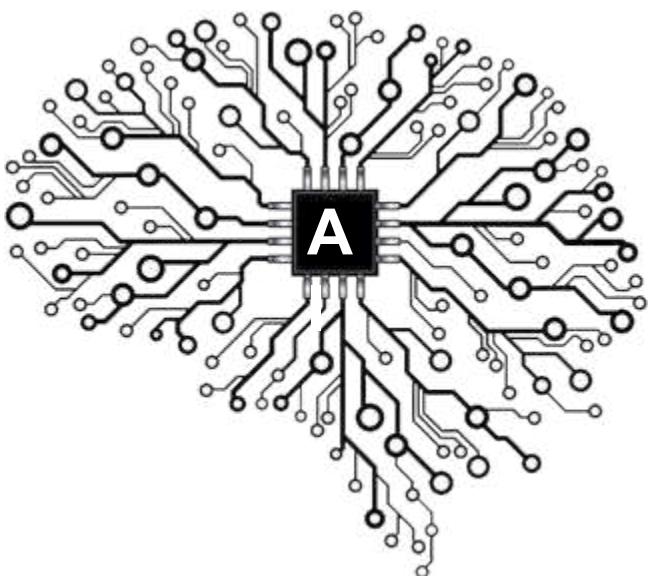


# Data → Processing



Source: Leading technology research vendor

# Artificial Intelligence – AI Timeline



1951: Claude Shannon's maze-solving robots



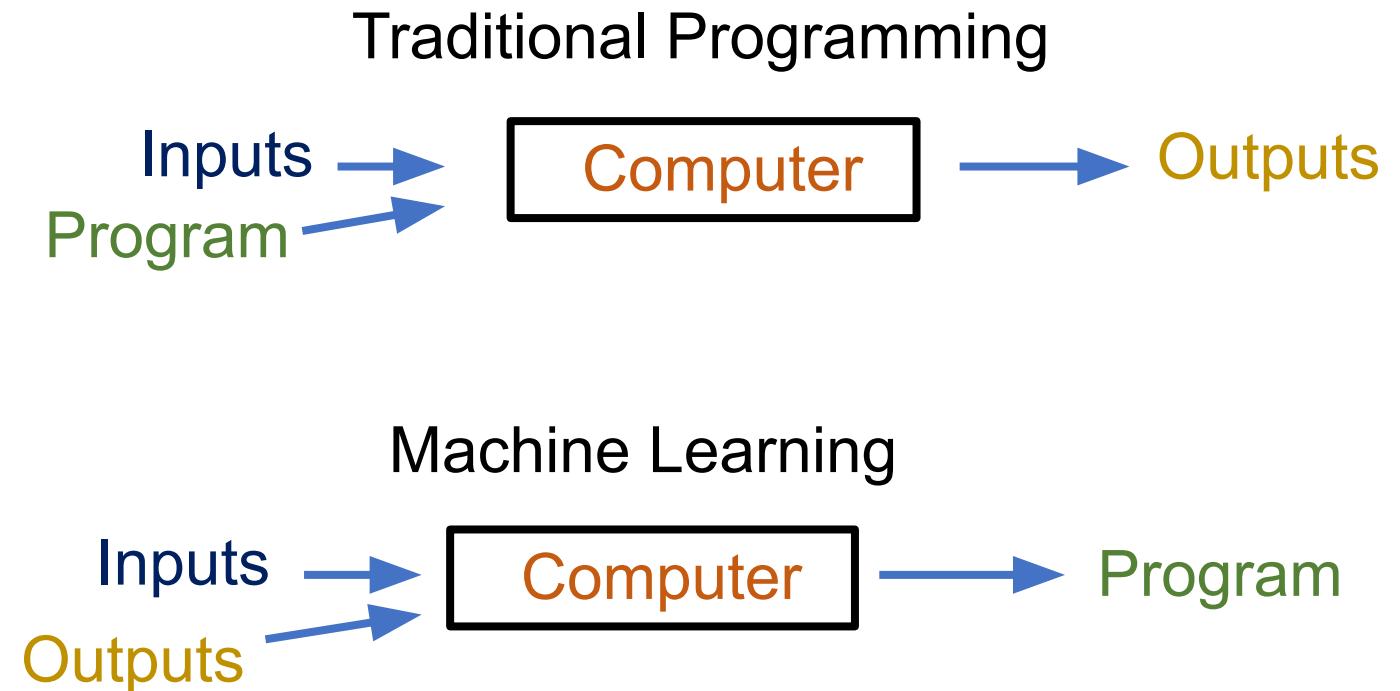
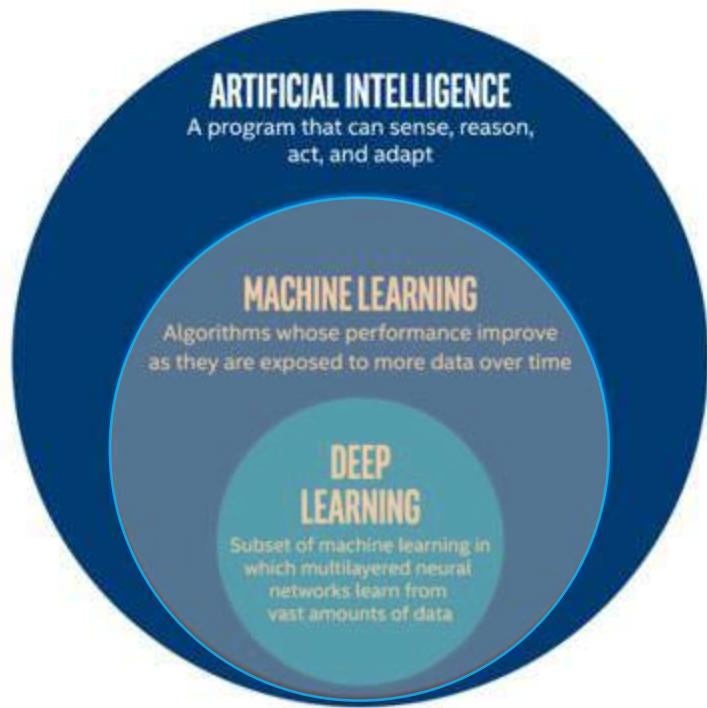
1955: Arthur Samuel's Checkers, the world's first self-learning program



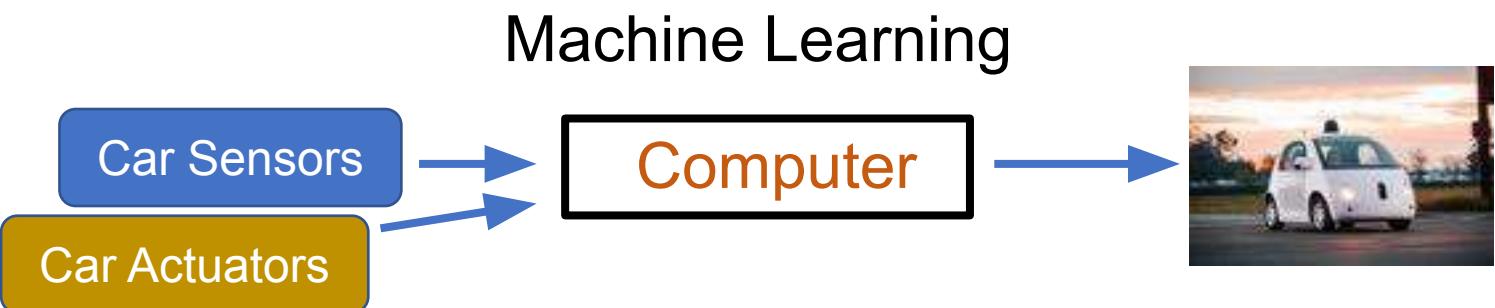
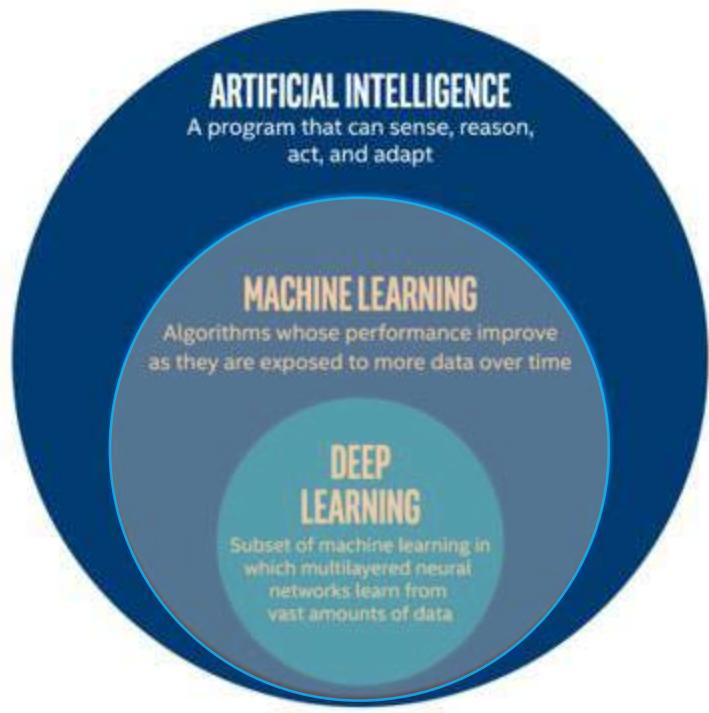
AI Winter  
Many false starts and dead-ends leave AI out in the cold

[https://en.wikipedia.org/wiki/Timeline\\_of\\_artificial\\_intelligence](https://en.wikipedia.org/wiki/Timeline_of_artificial_intelligence)

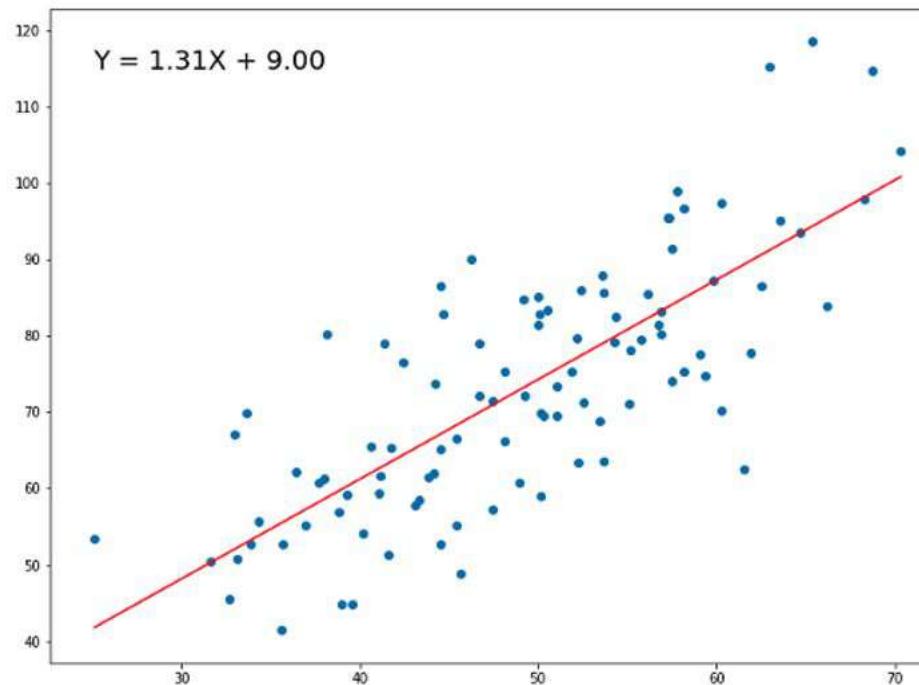
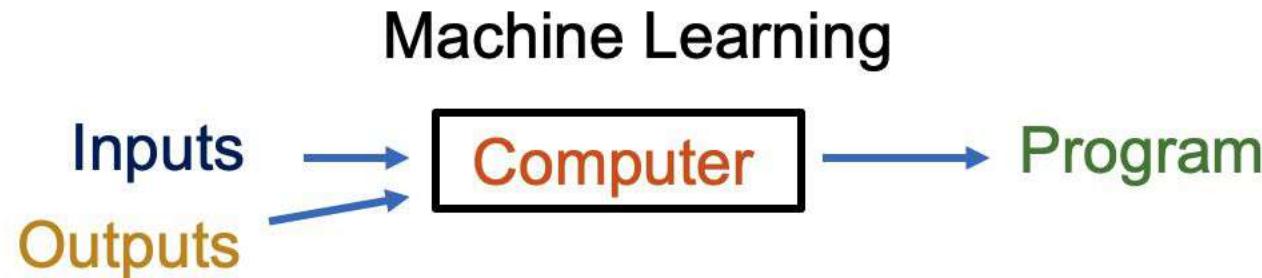
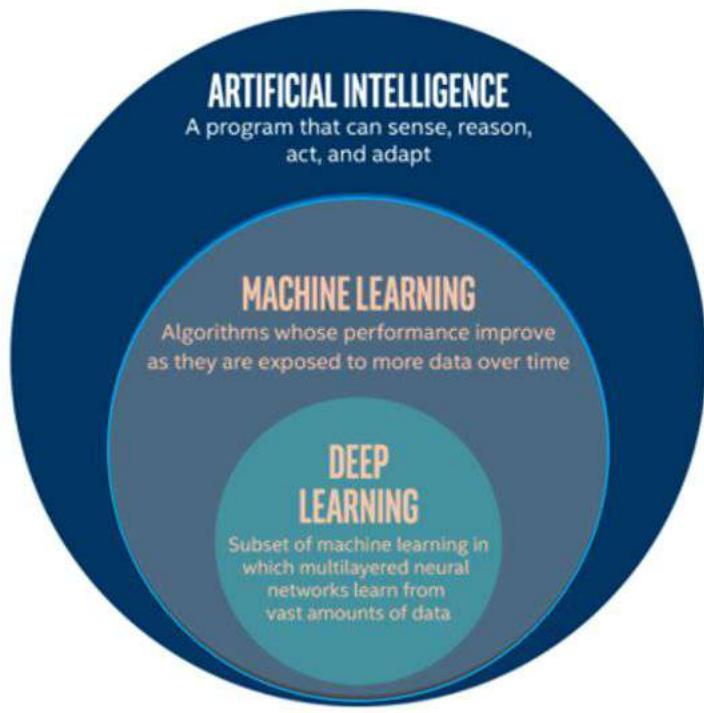
# AI → Machine Learning (ML)



# AI → Machine Learning (ML)



# AI → Machine Learning (ML)



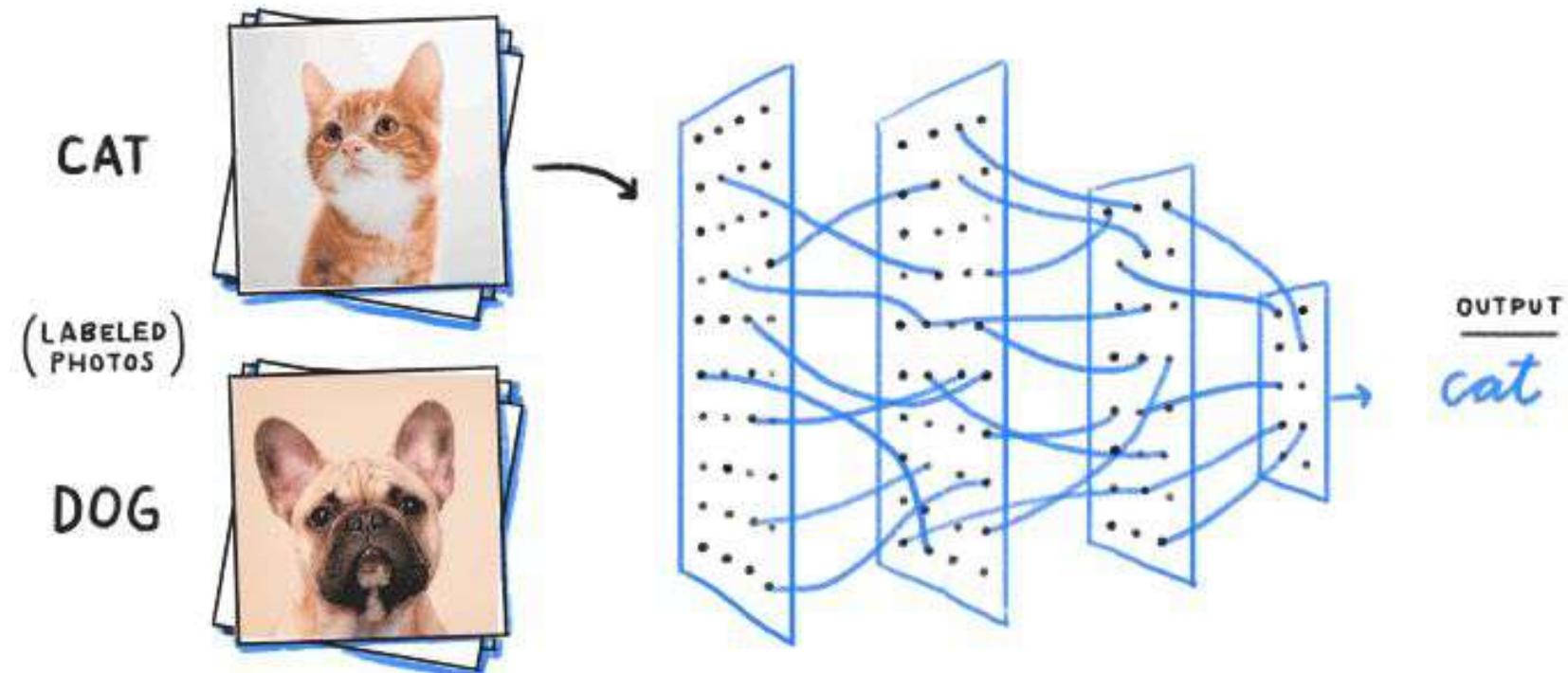
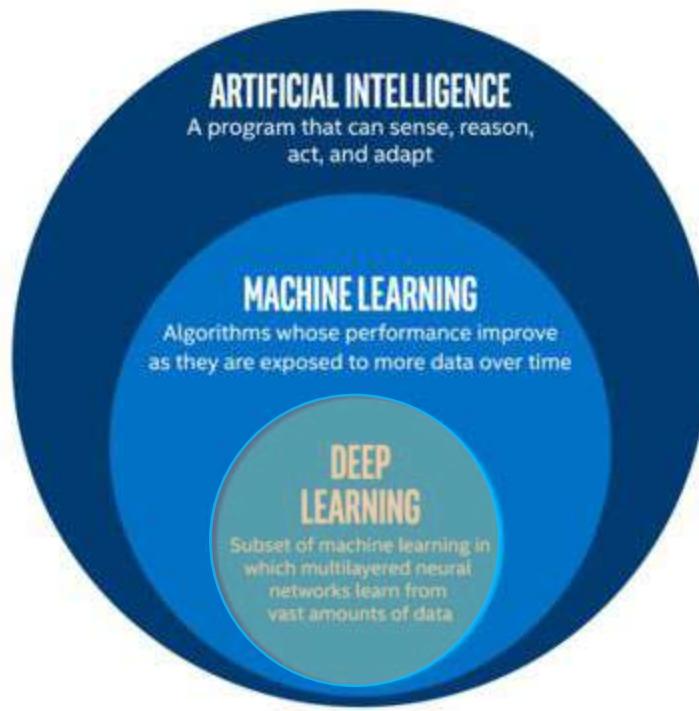
Output ↓      Input ↓

$$Y = w_1 * x_1 + b_0$$

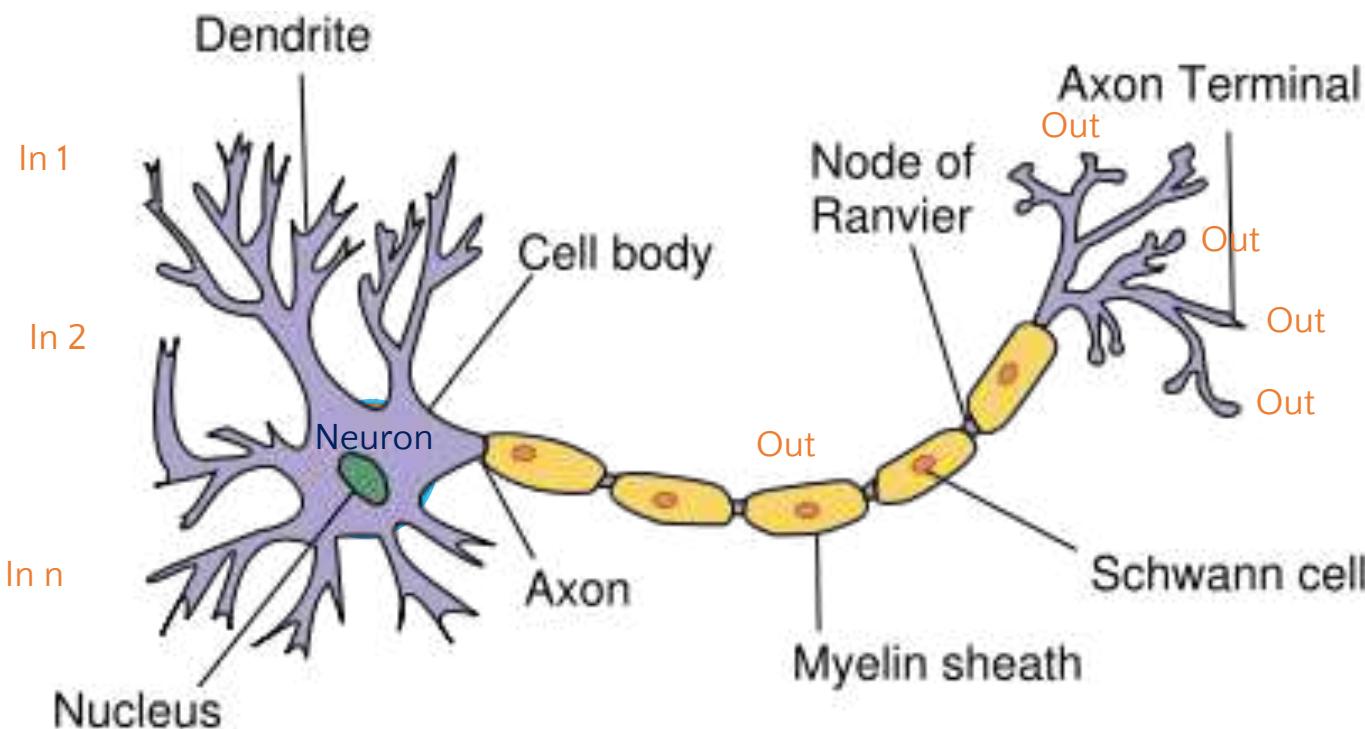
Program (Parameters) ↕

# AI → Deep Learning (DL)

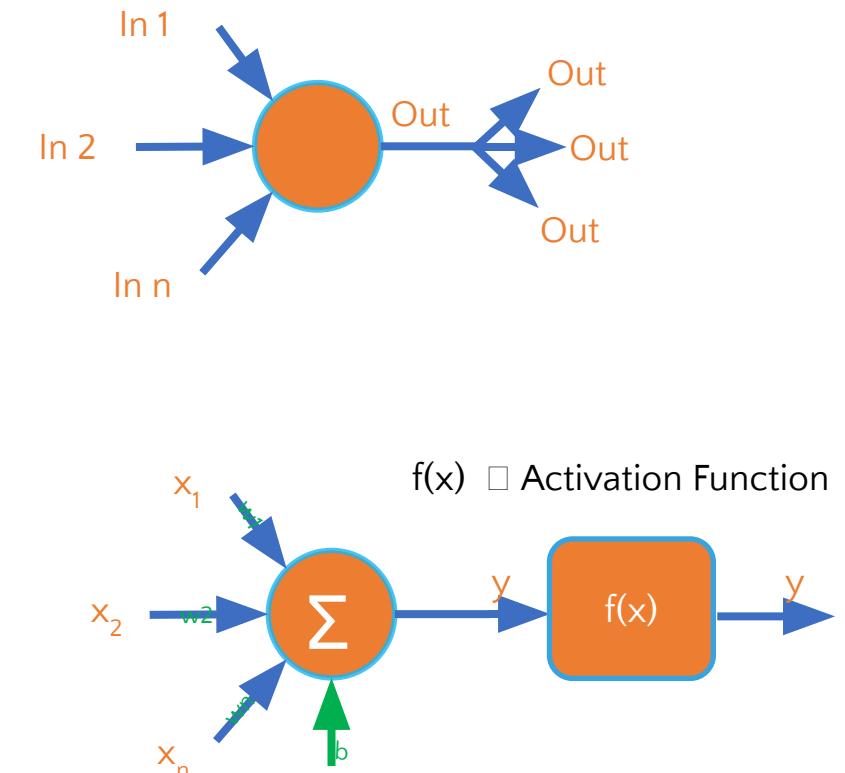
Deep Learning: Subset of Machine Learning in which multilayered neural networks learn from vast amounts of data



# Neuron (Perceptron)

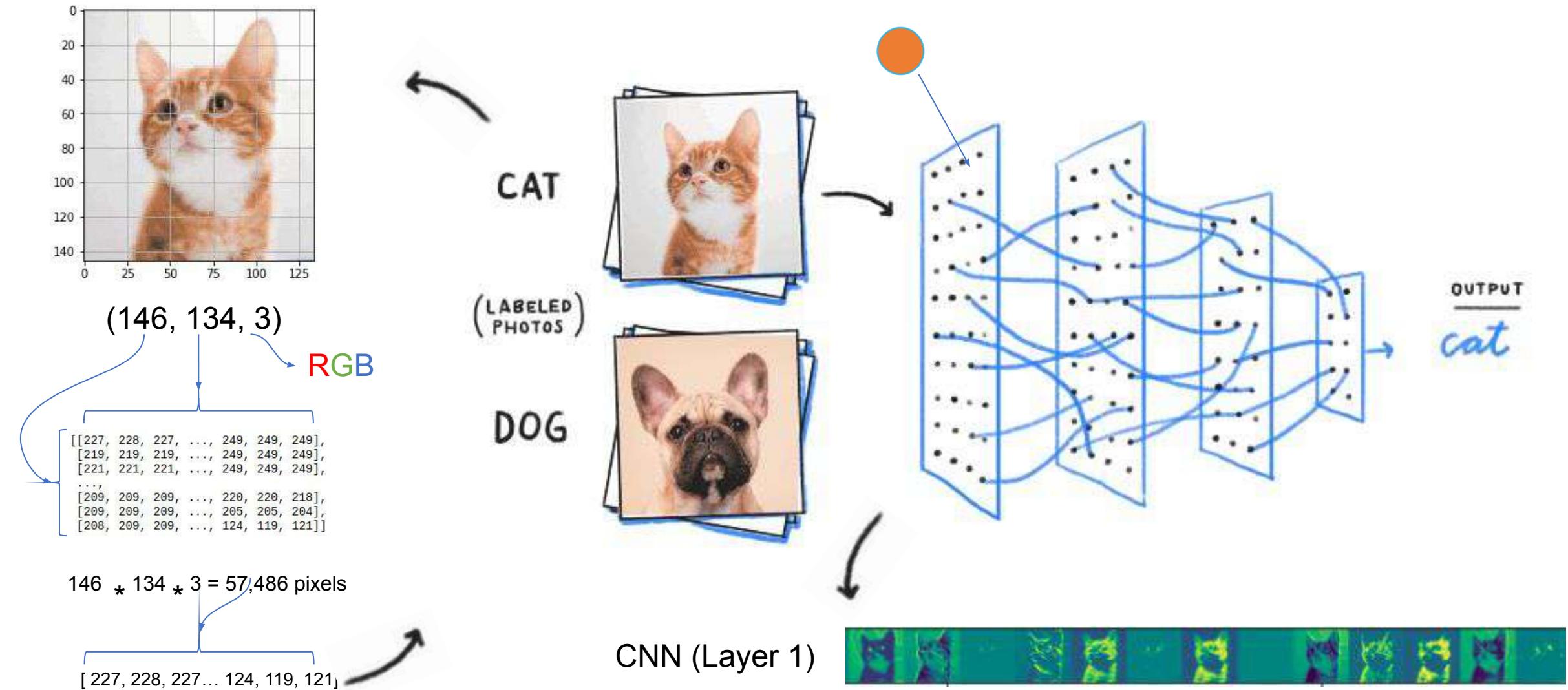


Parameters



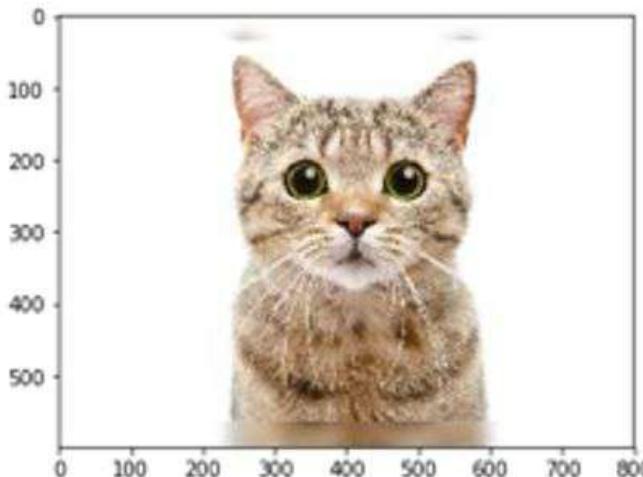
$$y = f\left(\sum_{i=1}^n x_i w_i + b\right)$$

# Artificial Neural Network

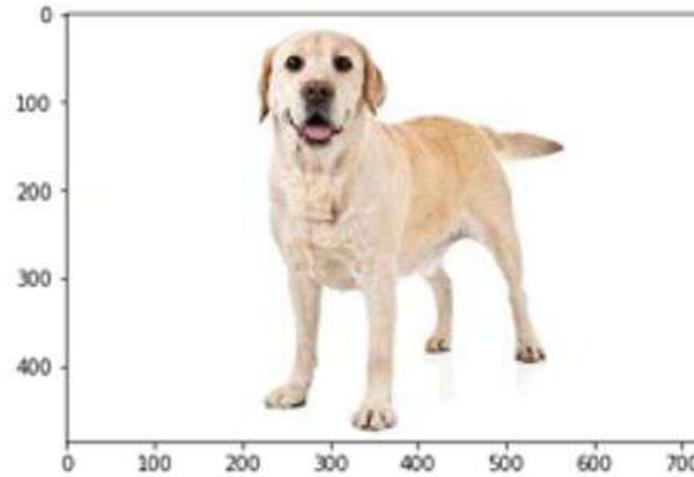


# Image Classification

[PREDICTION]	[Prob]
Egyptian cat	: 64%
tabby	: 14%
bucket	: 3%



[PREDICTION]	[Prob]
Labrador retriever	: 83%
golden retriever	: 13%
bloodhound	: 0%



[PREDICTION]	[Prob]
German shepherd	: 60%
dhole	: 16%
malinois	: 7%



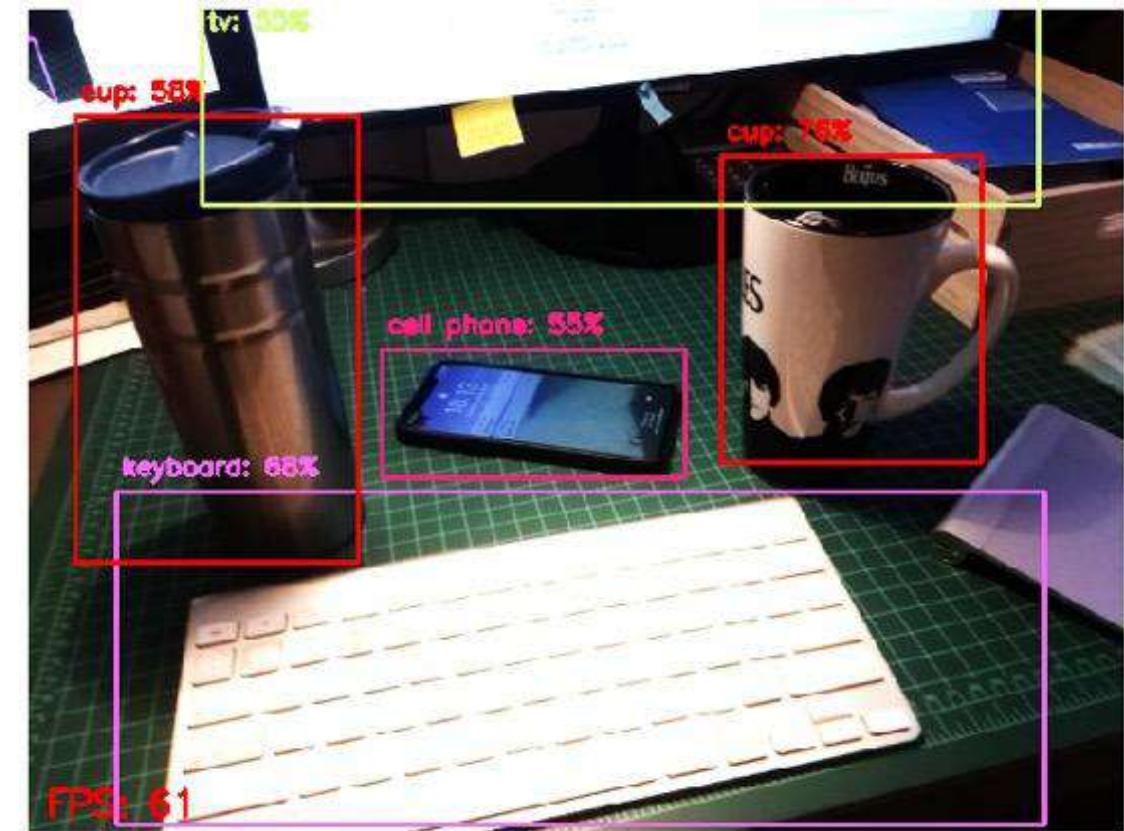
<https://www.hackster.io/mjrobot/exploring-ia-at-the-edge-97588d>

# Object Detection



# Photos

<https://www.hackster.io/mirobot/exploring-ia-at-the-edge-97588d>



# Live Video

# Segmentation



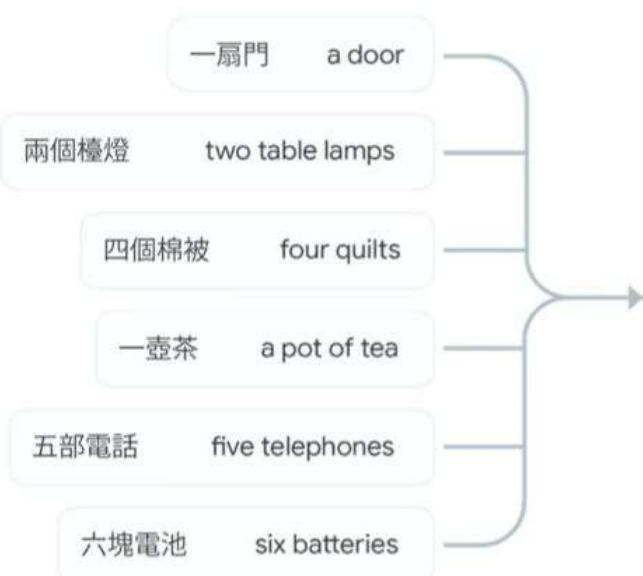
# Pose Estimation



<https://www.hackster.io/mjrobot/exploring-ia-at-the-edge-97588d>

# Machine Translation

1 Upload translated language pairs



2 Train your model



AutoML  
Translation

3 Evaluate



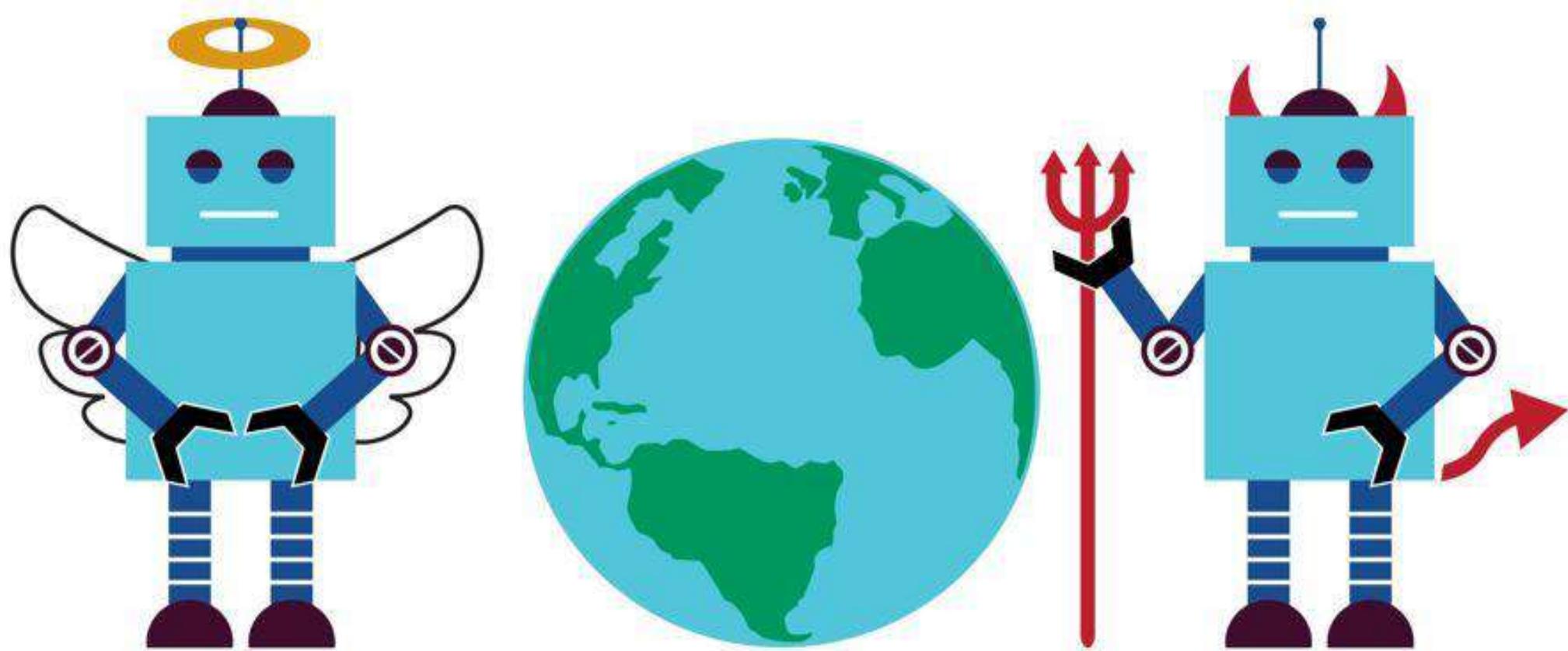
# Recommendations

General AI does not exist (yet)

# Dedicated ML Applications

- Image Classification
- Object Detection
- Pose Estimation
- Voice Recognition
- Gesture Recognition
- Anomaly Detection
- Natural Language Processing (**NLP**)

# Responsible AI



# Learning more about Embedded ML



Twitter: @mjrovai

instructables.com/member/mjrovai

github.com/Mjrovai

hackster.io/mjrobot

medium.com/@rovai

MJRoBot.org

- Deploy machine learning models on mobile and IoT devices:
  - <https://www.tensorflow.org/lite>
- The Embedded Machine Learning Revolution:
  - <https://www.wevolver.com/article/the-embedded-machine-learning-revolution-the-basics-you-need-to-know>
- "Listening Temperature" with TinyML
  - <https://www.hackster.io/mjrobot/listening-temperature-with-tinyml-7e1325>
- Introduction to Embedded Machine Learning (Coursera Course)
  - <https://www.coursera.org/learn/introduction-to-embedded-machine-learning>
- Exploring AI at the Edge!
  - <https://towardsdatascience.com/exploring-ia-at-the-edge-b30a550456db>
- TinyML - Motion Recognition Using Raspberry Pi Pico
  - <https://www.hackster.io/mjrobot/tinyml-motion-recognition-using-raspberry-pi-pico-6b6071>

**Thanks**  
And stay safe!



**UNIFEI**