

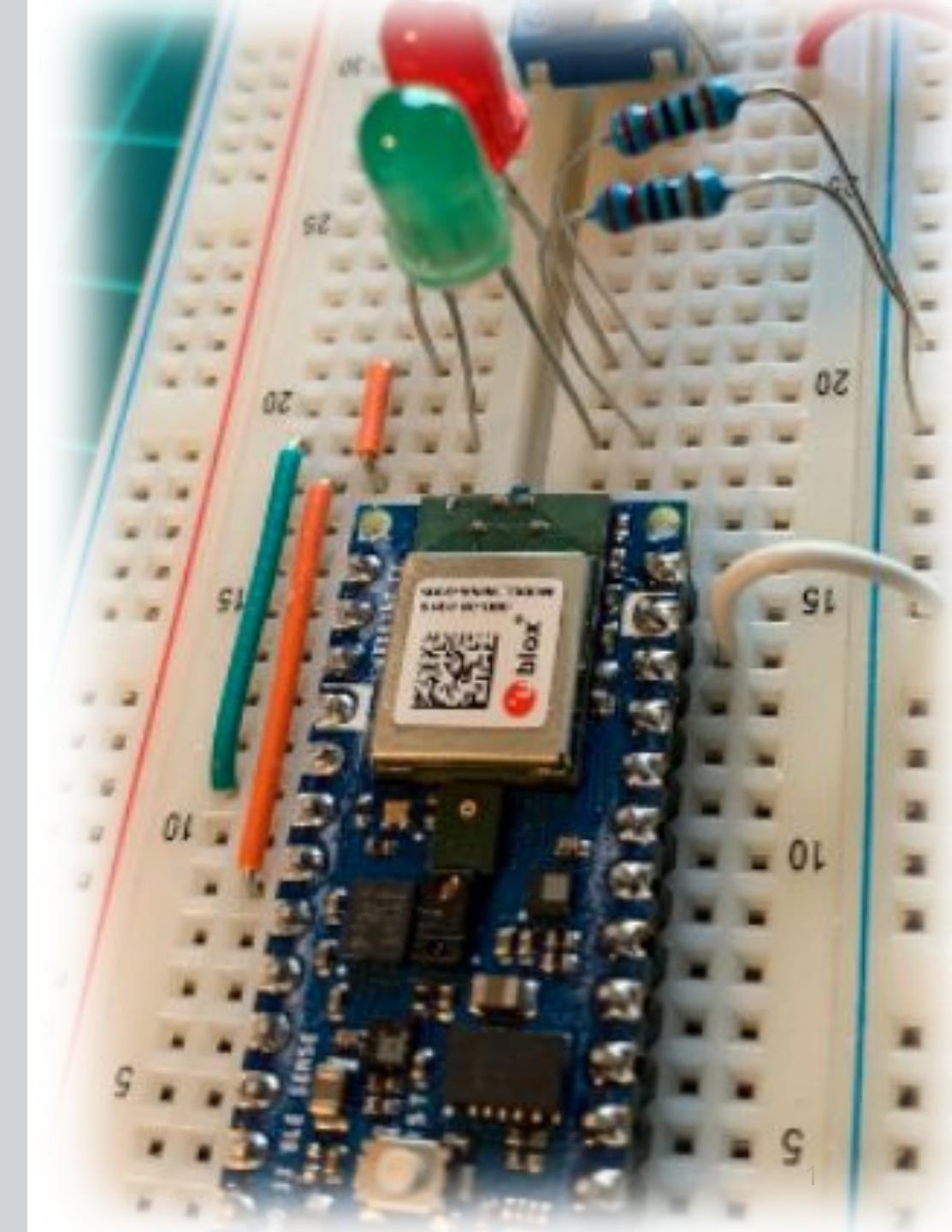
# IESTI01 – TinyML

## Embedded Machine Learning

### 1. About the Course & Syllabus



Prof. Marcelo Rovai  
UNIFEI



Dear students,

Welcome to the first class of the IESTI01 (TinyML) EAD course. I am Professor Marcelo Rovai, a former student here at UNIFEI, and I am pleased to be with you this semester.

IESTI01 is a discipline that mixes Machine Learning (part of Artificial Intelligence) with small devices, such as microcontrollers and sensors, whose main characteristics are ultra-low power consumption, usually 32-bit CPUs, and a few kilobytes of memory.

We understand that the explosive growth of the Machine Learning field, the ease of use of software development platforms such as TensorFlow (TF), based on the Python language, and the current generation of powerful microcontrollers, make TinyML an indispensable topic of study for Engineering students in the areas of Electronics, as well as Computing and Control & Automation.

This mix of expertise and the pioneering nature of this discipline (We were the second university worldwide to have this type of course, Harvard School of Engineering being the first) leads us to significant challenges concerning the necessary basis for the minimum understanding of the matter. Thus, the time we have available for the course is short. So, We must commit ourselves to following the weekly classes and doing complementary activities such as readings, laboratories, and assignments. You can count on me to clarify doubts and to review the necessary concepts for a good understanding of the course (For that, use the FORUM, available in each class).

*Greetings from the south of the world!*

Prof. Marcelo Rovai

# Who I am

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



**Marcelo Rovai**

# What is TinyML?

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

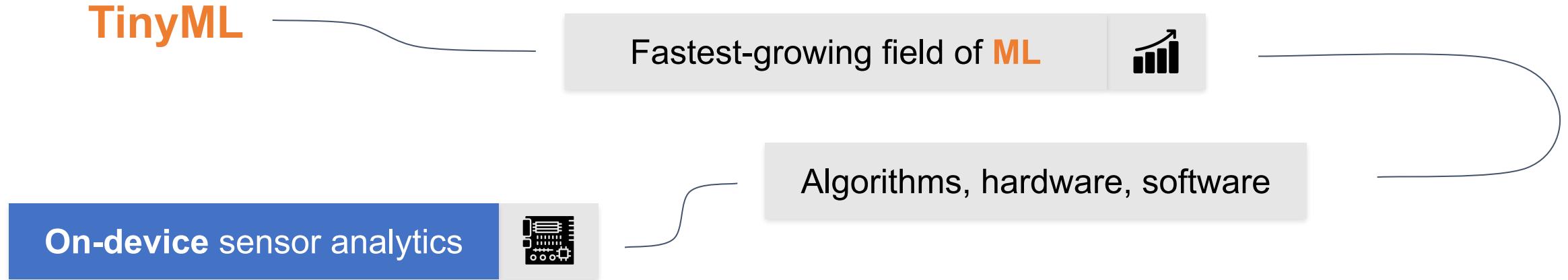
**TinyML**

Fastest-growing field of **ML**

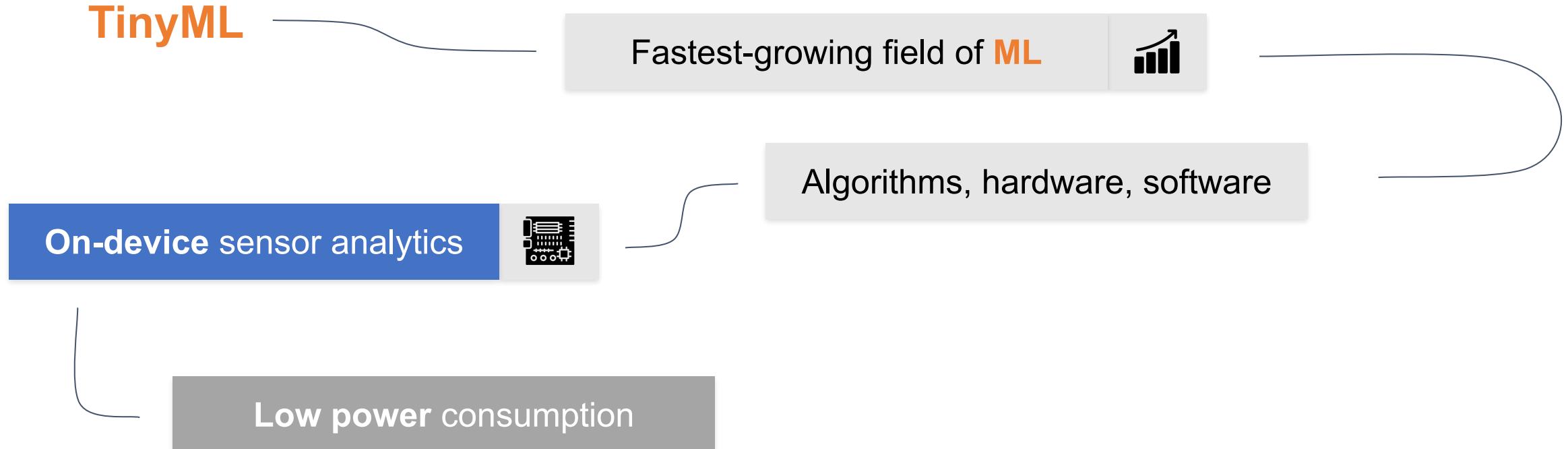


Algorithms, hardware, software

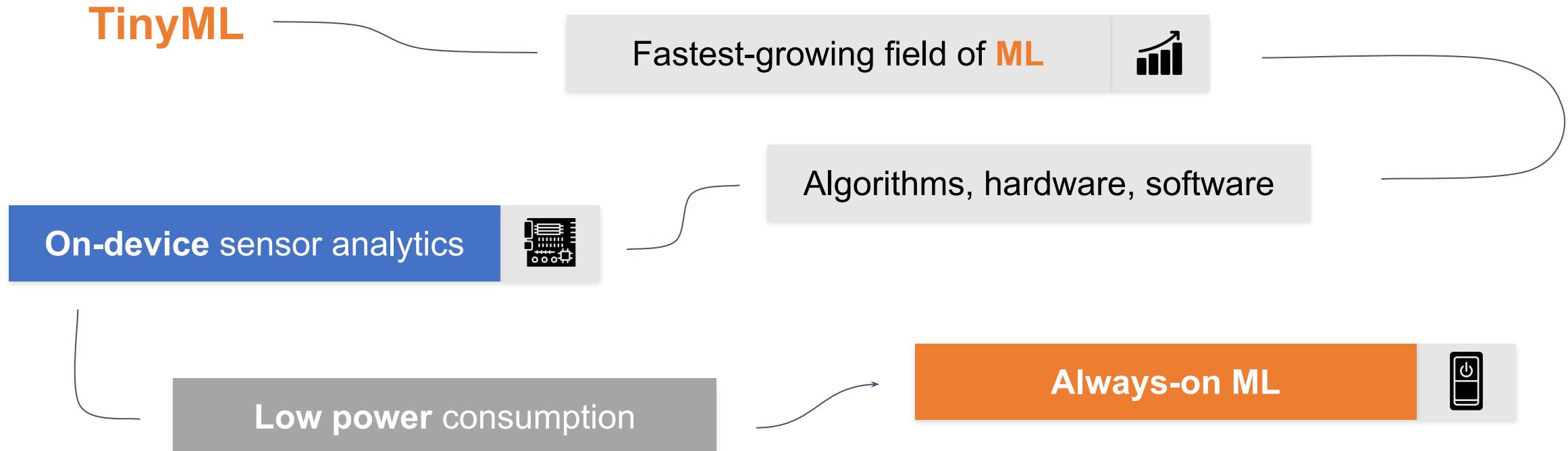
# What is Tiny Machine Learning (**TinyML**)?



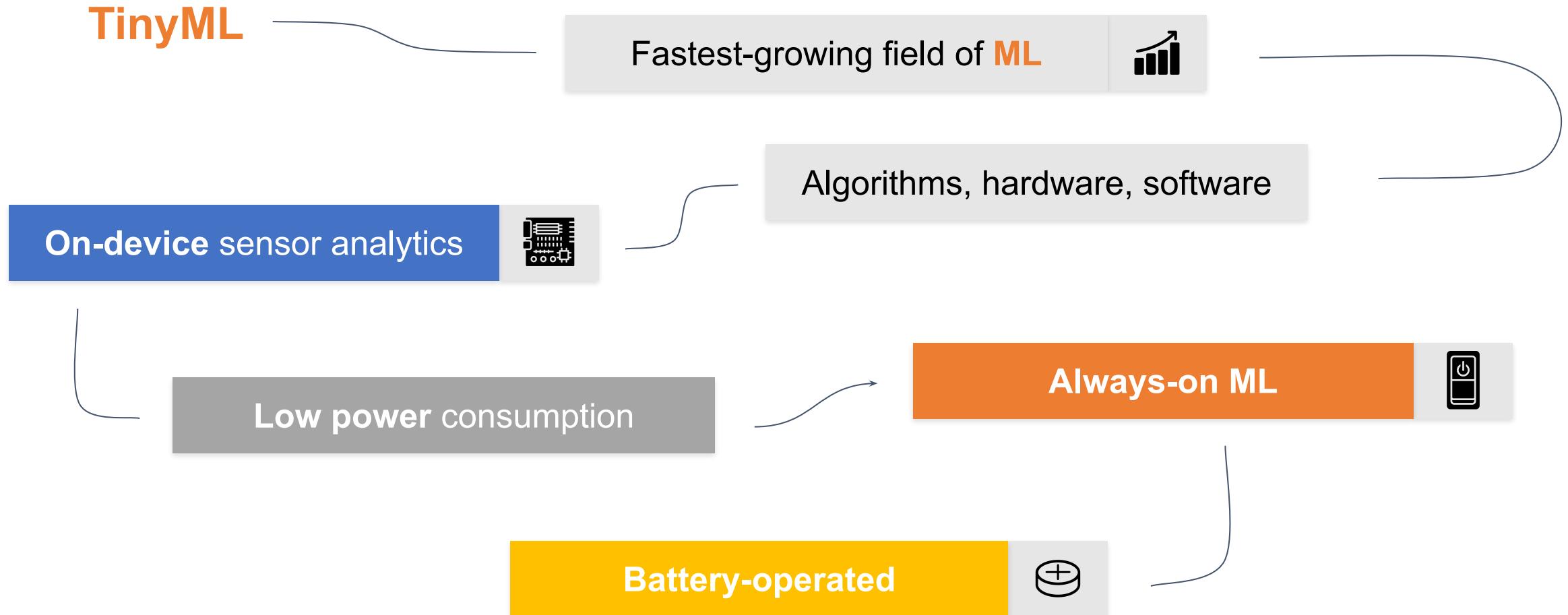
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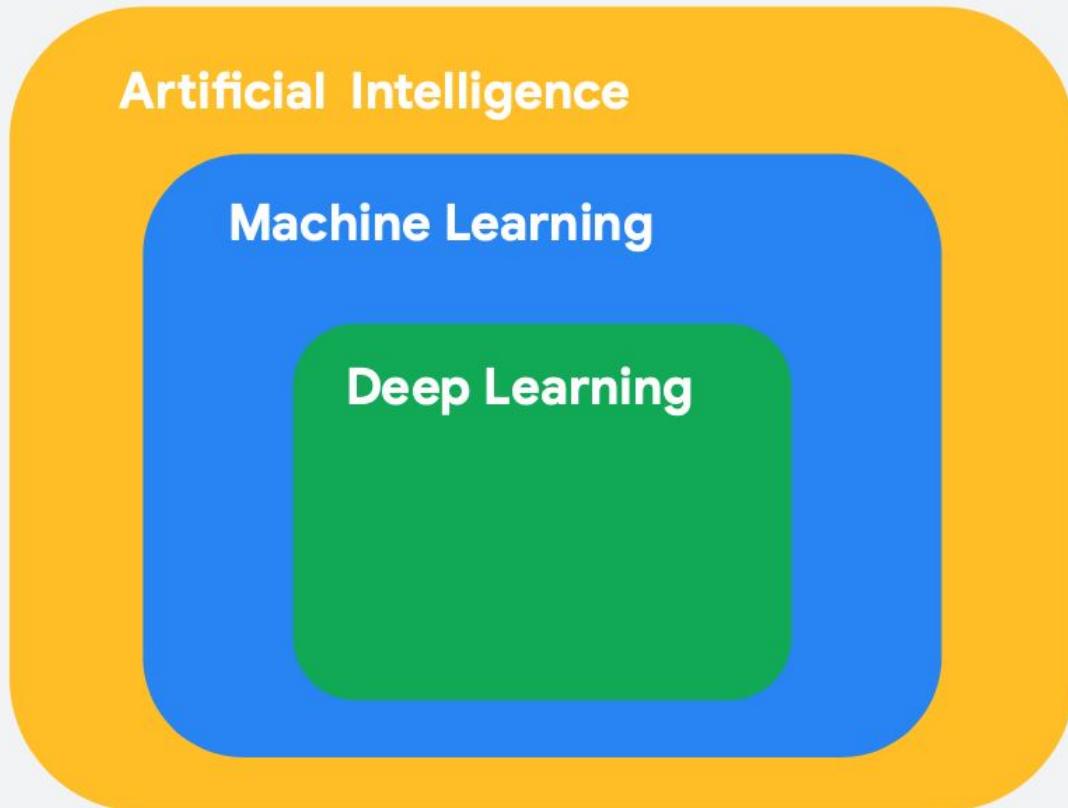


# What is Tiny Machine Learning (**TinyML**)?



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





**AI:** Any technique that enables computers to mimic human behavior

**ML:** Ability to learn without explicitly being programmed

**DL:** Extract patterns from data using neural networks

## EdgeAI/ML

### TinyML

**Edge AI (or Edge ML)** is the processing of Artificial Intelligence algorithms on edge, that is, on users' devices. The concept derives from **Edge Computing**, which starts from the same premise: data is stored, processed, and managed directly at the Internet of Things (IoT) endpoints.

**TinyML** is a subset of **EdgeML**, where sensors are generating data with ultra-low power consumption (batteries), so that we can ultimately deploy machine learning continuously ("always on devices")

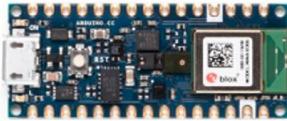
# Hardware



Anomaly Detection  
Sensor Classification  
20 KB



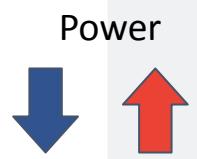
Rpi-Pico  
(Cortex-M0+)



Arduino Nano  
(Cortex-M4)



Arduino Pro  
(Cortex-M7)



EdgeML

TinyML

Image  
Classification  
250 KB+

KeyWord Spotting  
Audio Classification  
50 KB



Object Detection  
Complex Voice  
Processing  
1 MB+



RaspberryPi  
(Cortex-A)



SmartPhone  
(Cortex-A)



Jetson Nano  
(Cortex-A + GPU)

Video  
Classification  
2 MB+

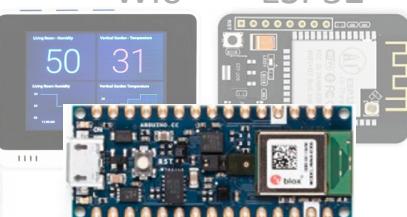
# Hardware



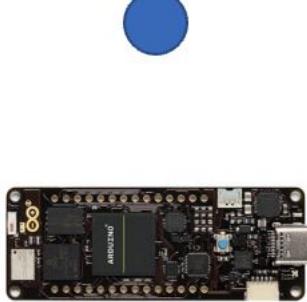
Anomaly Detection  
Sensor Classification  
20 KB



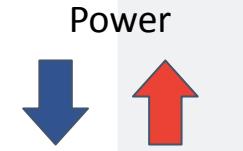
Rpi-Pico  
(Cortex-M0+)



Arduino Nano  
(Cortex-M4)



Arduino Pro  
(Cortex-M7)



## EdgeML

## TinyML

Image  
Classification  
250 KB+

KeyWord Spotting  
Audio Classification  
50 KB



Object Detection  
Complex Voice  
Processing  
1 MB+



Video  
Classification  
2 MB+



RaspberryPi  
(Cortex-A)  
SmartPhone  
(Cortex-A)  
Jetson Nano  
(Cortex-A + GPU)

# TinyML Application Examples

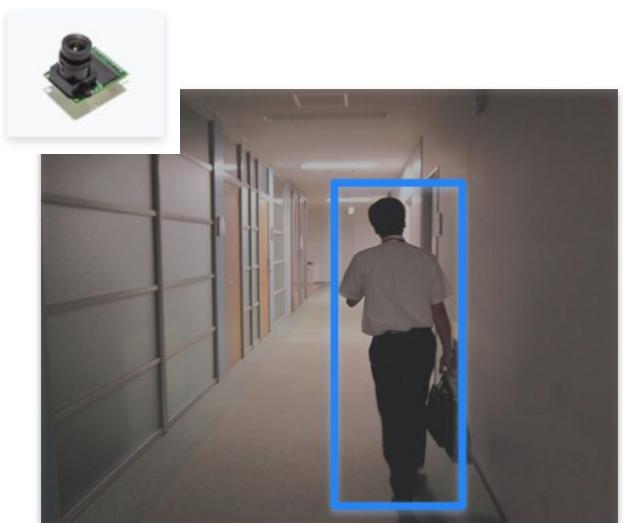
# Sound



# Vibration



# Vision



## 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
- Agriculture

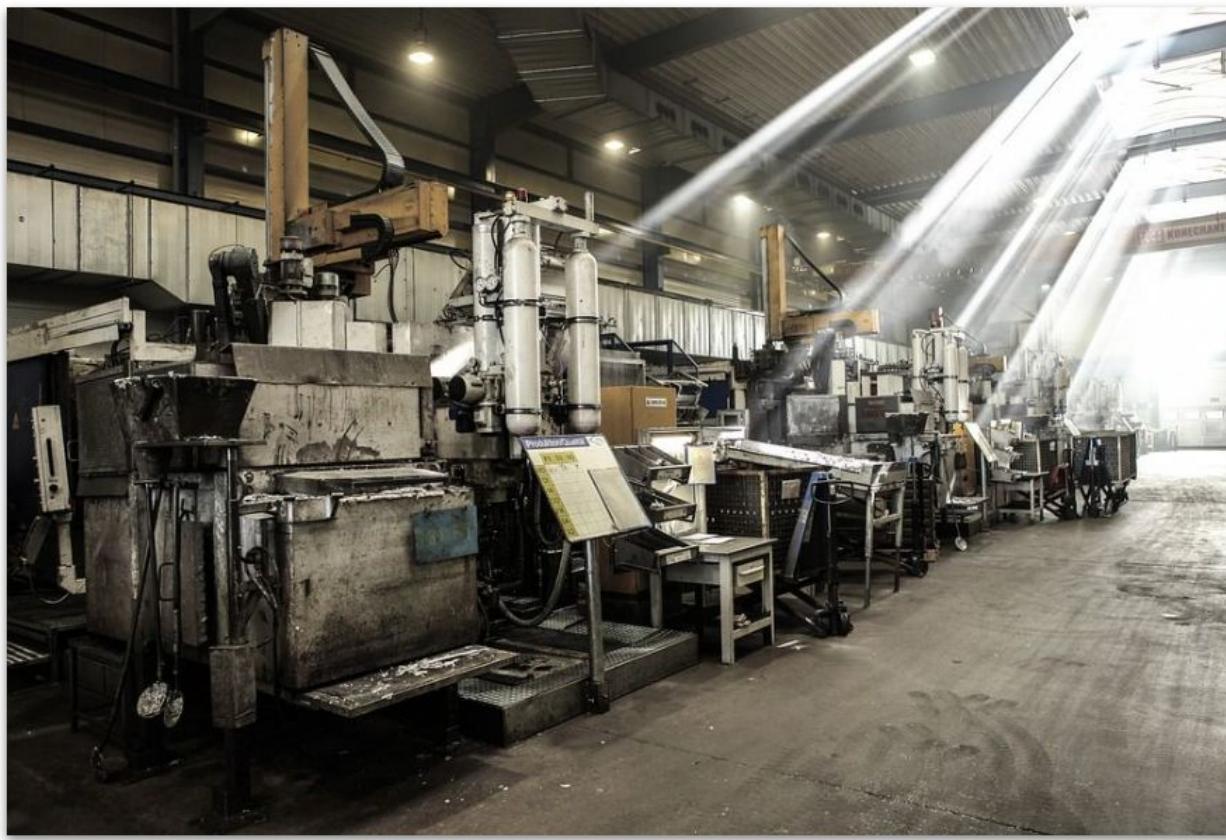
## Human & Animal Sensing



Motion, radar, audio, PPG, ECG

- Health
- Consumer
- Industrial

# Application: Factory machinery

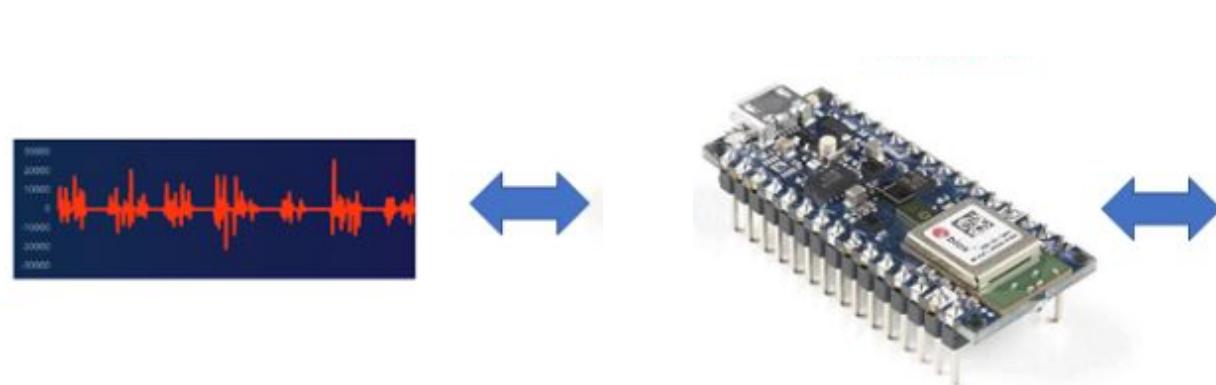
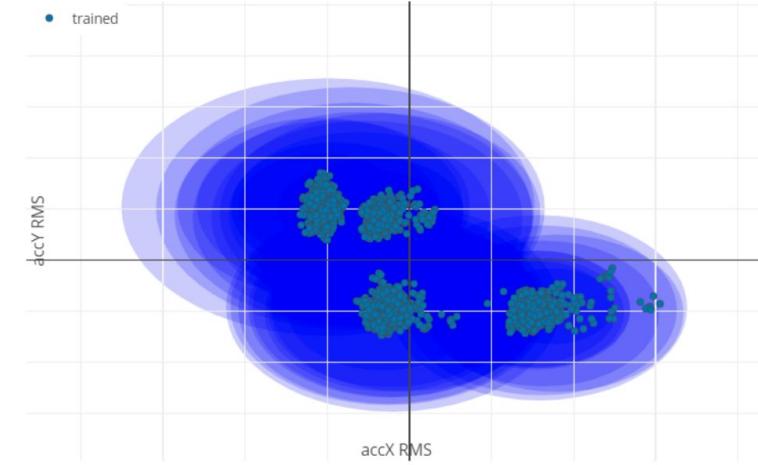


Ball Bearings



Accelerometer

# Industry – Anomaly Detection



IESTI01 2021.2 - Final Group Project: Bearing Failure Detection

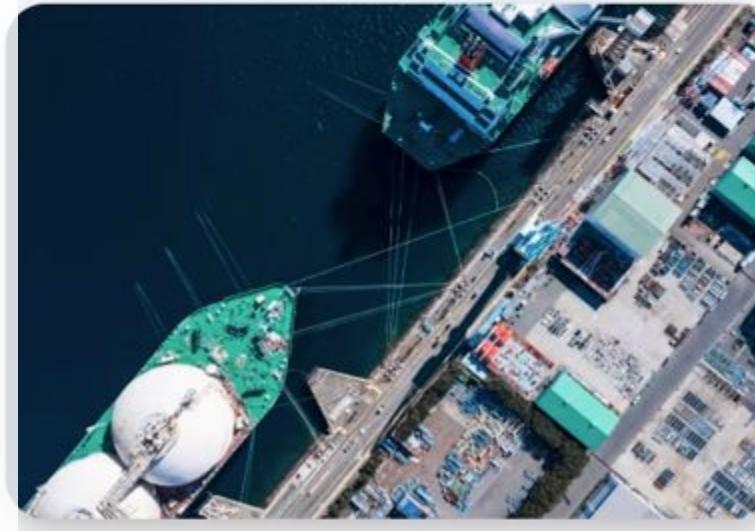
## Predictive Maintenance



Motion, current, audio and camera

- Industrial
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- Infrastructure
- Automotive

## Asset Tracking & Monitoring



Motion, temp, humidity, position, audio and camera

- Logistics
- Infrastructure
- Buildings
- **Agriculture**

 **EDGE IMPULSE**

## Human & Animal Sensing



Motion, radar, audio, PPG, ECG

- Health
- Consumer
- Industrial

# Cow Monitoring

## Using the Internet of Things for Agricultural Monitoring

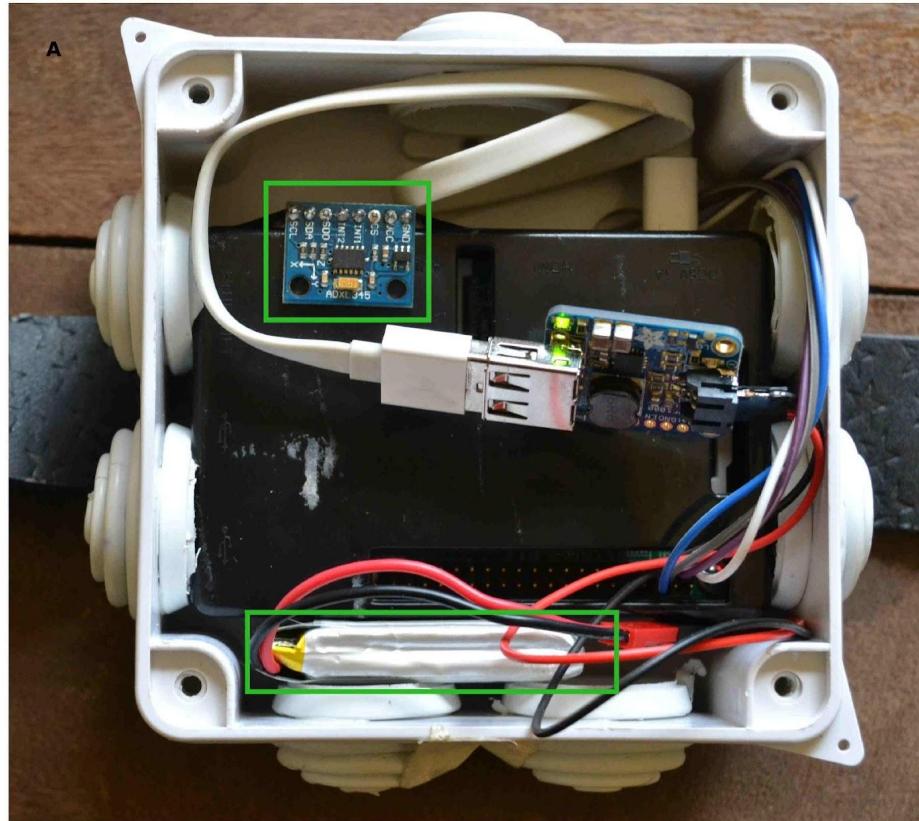
"We aim to deploy a variety of sensors for agricultural monitoring. One of the projects involves using **accelerometer sensors** to monitor activity levels in dairy cows with a view to determining when the cows are on heat or when they are sick."



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>



# Coffee Disease Classification



<https://www.hackster.io/Yukio/coffee-disease-classification-with-ml-b0a3fc>

**Introdução**

O Brasil é responsável por 50% do café exportado globalmente, o que é uma atividade importante para o país; geralmente a análise e classificação de doenças em plantas é feita manualmente, que não são acessíveis para pequenos produtores.

Com o aumento do poder de processamento das placas-mãe microcontroladas e processadores dedicados ao machine learning, a tarefa de embarcar todos morais tem-se tornado possível em diversas áreas.



**João Vitor Yukio Bordin Yamashita**  
Graduando em Engenharia Eletrônica pela UNIFEI

# Forest Fire Detection



[TinyML Aerial Forest Fire Detection](#)



[IESTI01 - Forest Fire Detection – Proof of Concept](#)

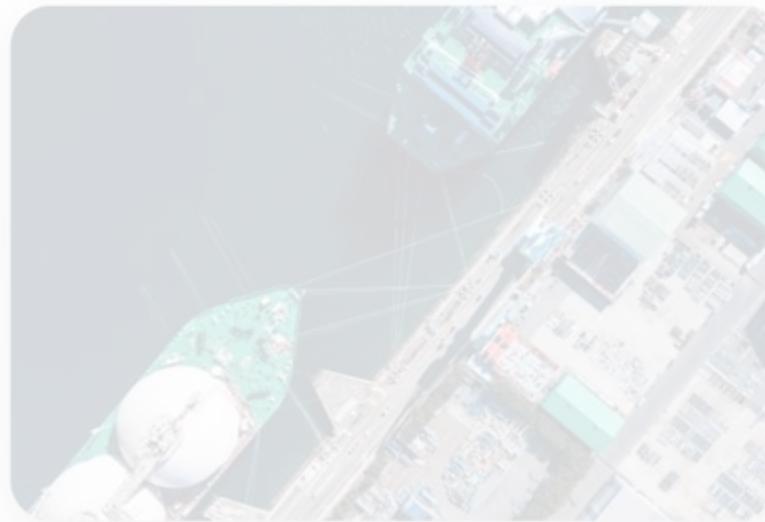
## Predictive Maintenance



Motion, current, audio and camera

- Industrial
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## Asset Tracking & Monitoring



Motion, temp, humidity, position, audio and camera

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- Agriculture

## Human & Animal Sensing



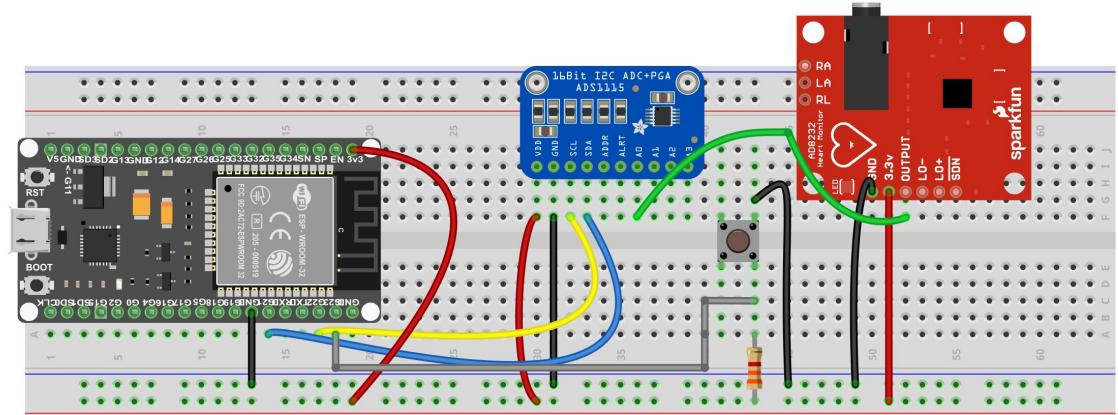
Motion, radar, audio, PPG, ECG

- **Health**
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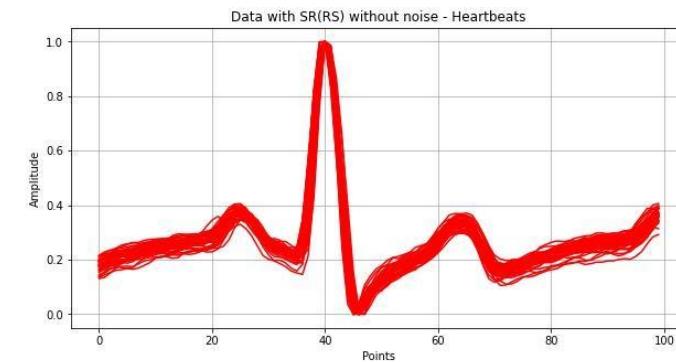
# Health - Human Sensing



[Atrial Fibrillation Detection on ECG using TinyML](#)  
Silva et al. UNIFEI 2021



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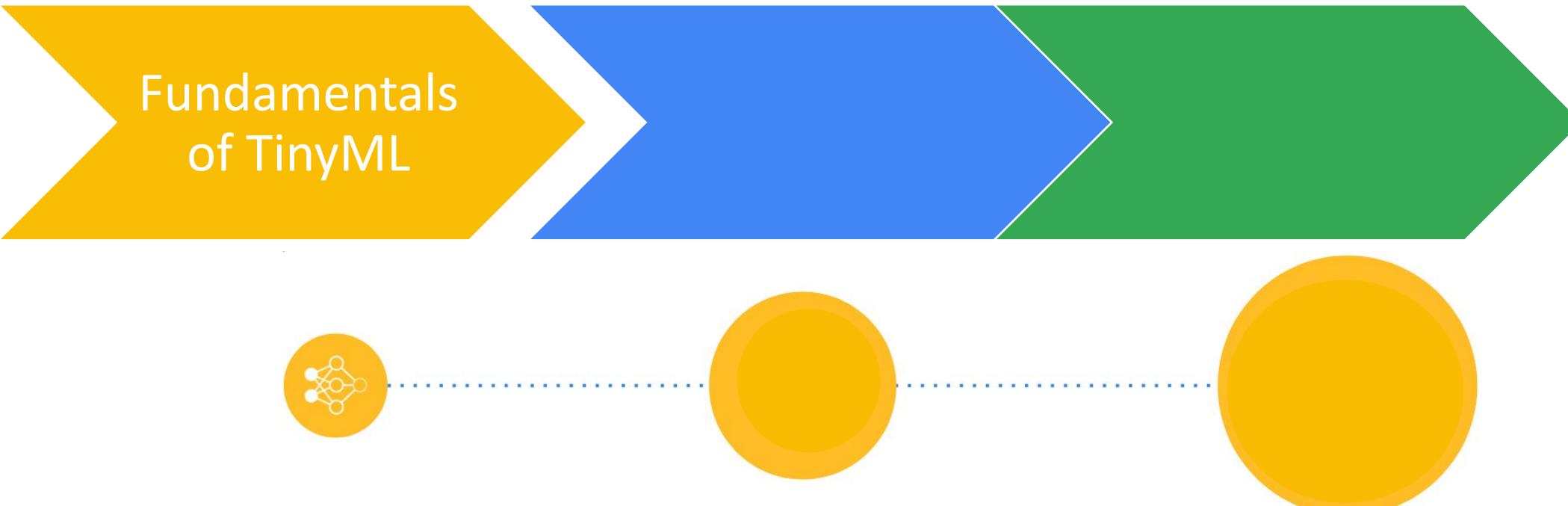


**Guilherme Silva**  
Engenheiro - UNIFEI

# What will We learn?

# What will We learn?

## Part 1



Fundamentals  
of TinyML

Part 1 is all about talking about what is the language of machine learning

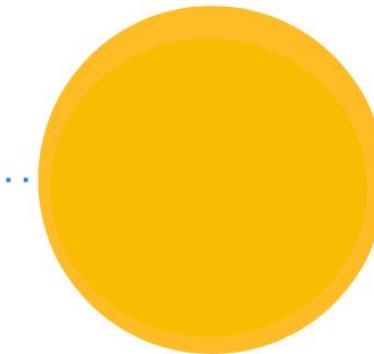
# What we will learn?

## Part 1

Fundamentals  
of TinyML

## Part 2

Applications  
of TinyML



In Part 2, we will get a sneak peek into the variety of different TinyML applications, as keyword spotting (“Alexa”), gesture recognition, understand how to leverage the sensors, and so forth.

# What we will learn?

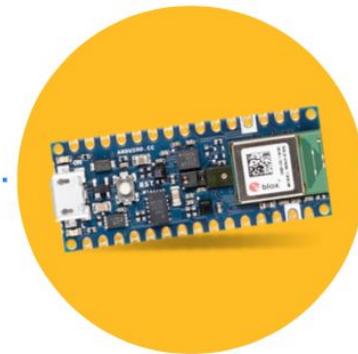
## Part 1

Fundamentals  
of TinyML

## Part 2

Applications  
of TinyML

Deploying  
TinyML



In Part 2, we will **also** learn how to deploy models on a real microcontroller. Along the way we will explore the challenges unique to and amplified by TinyML (e.g., preprocessing, post-processing, dealing with resource constraints).

# Background Requirements



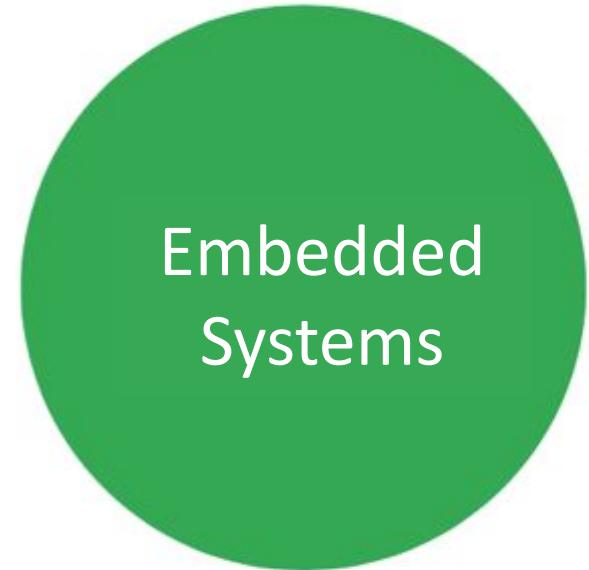
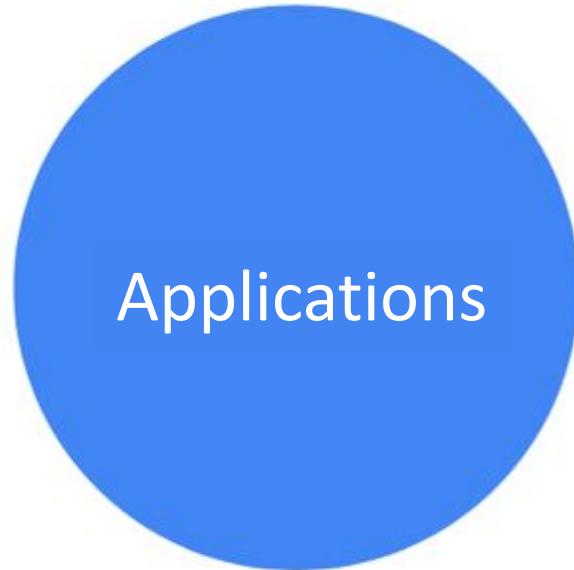
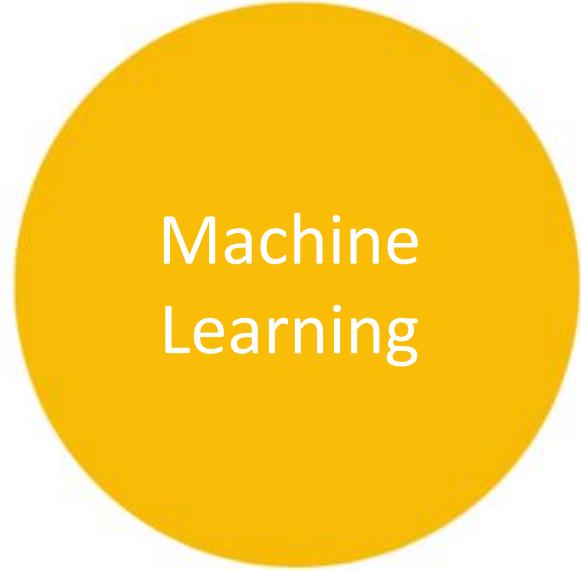
- Python
- TensorFlow
- Google Colab
- Jupyter Notebook

- Python
- TensorFlow ([Lite](#))
- Google Colab
- Edge Impulse Studio

- Python
- TensorFlow ([Lite-Micro](#))
- Google Colab
- Edge Impulse Studio
- IDE ([as Arduino](#))
- C/C++

This course combines **computer science** with **engineering** to feature real-world application case studies that examine the challenges facing **TinyML deployments**.

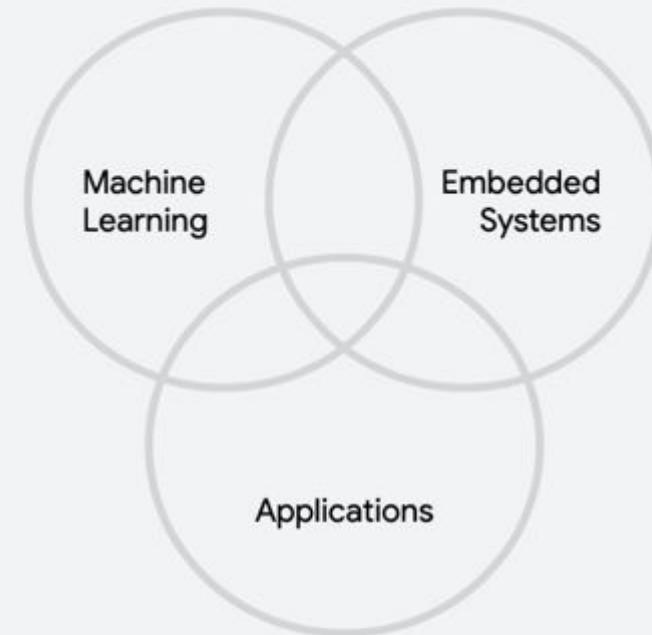
# What areas we will learn?



We will learn the **fundamentals of each of these areas**, just enough to focus on the goal of being able to build **TinyML applications**.

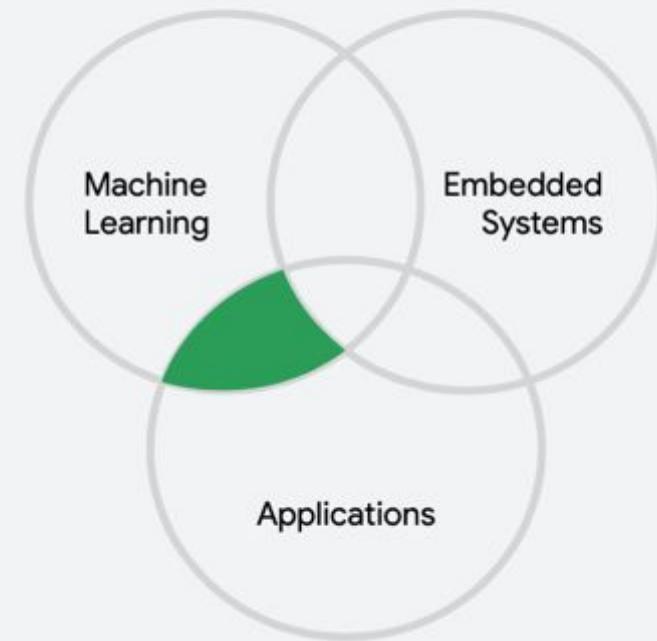
# Interactions

In addition, we will bring these diverse topics together to reveal the interesting learnings at the various **intersections**



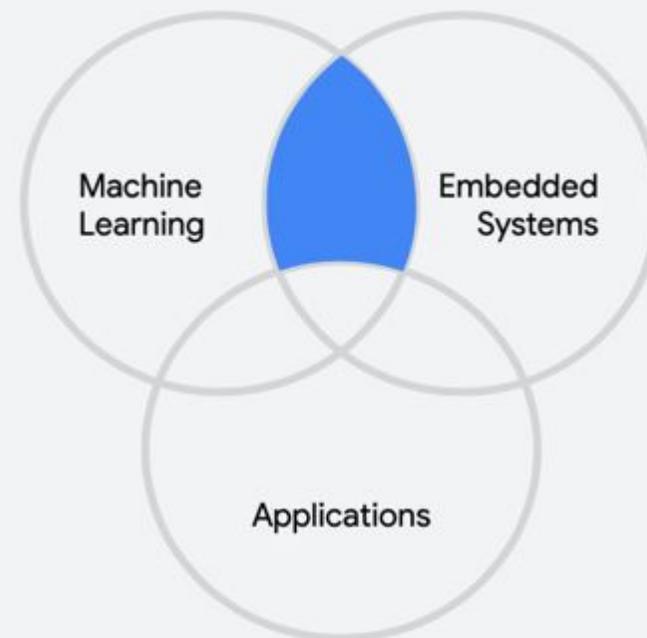
# Interactions

How machine learning can  
enable new and interesting  
**TinyML applications?**



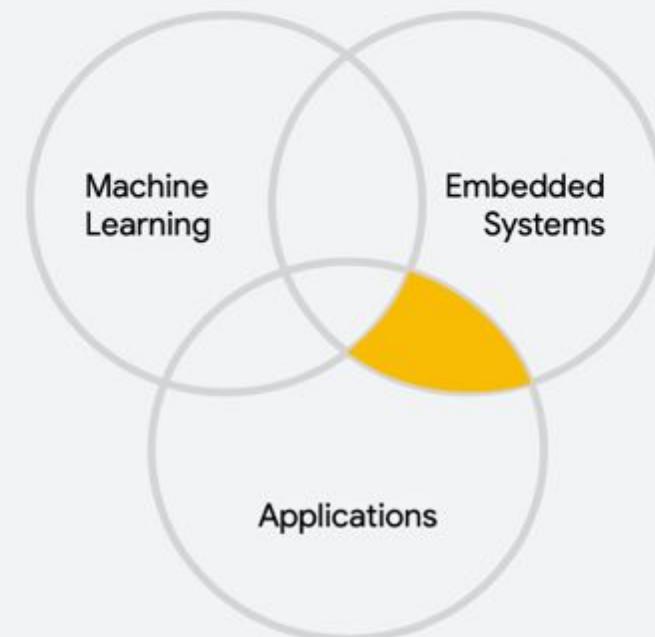
# Interactions

What are the **challenges** with  
enabling **machine learning**  
on **tiny**, resource-constrained  
**embedded devices**?

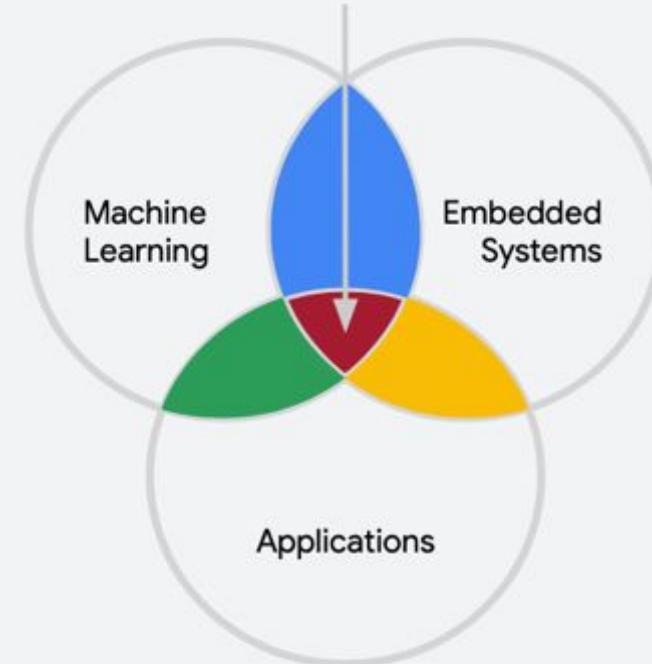


# Interactions

What type of new **use cases** can we possibly enable on **embedded systems** that we could not otherwise do before?



## Applying TinyML



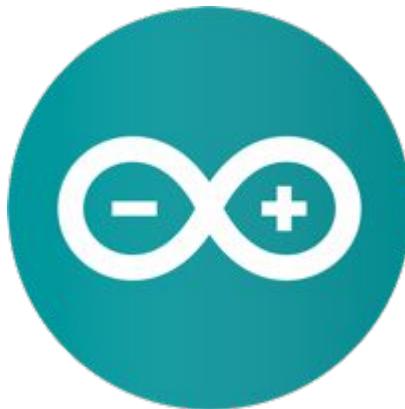
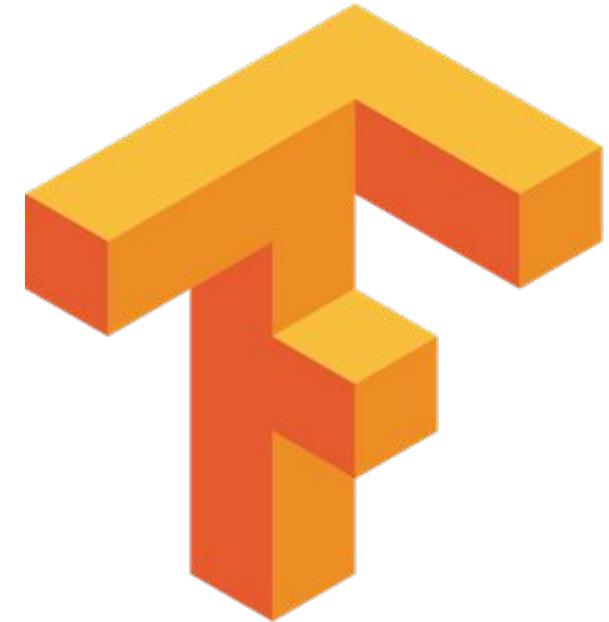
# At the End of the Day

Given your understanding of things at these various intersections, you will have a deep understanding for **how to apply TinyML**

How are we going to get there?

# Hands-on Learning

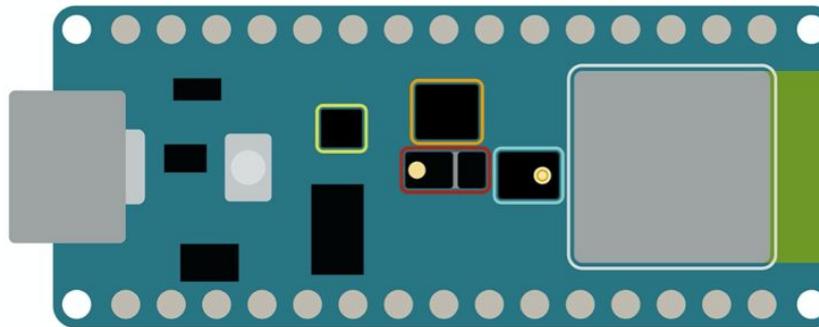
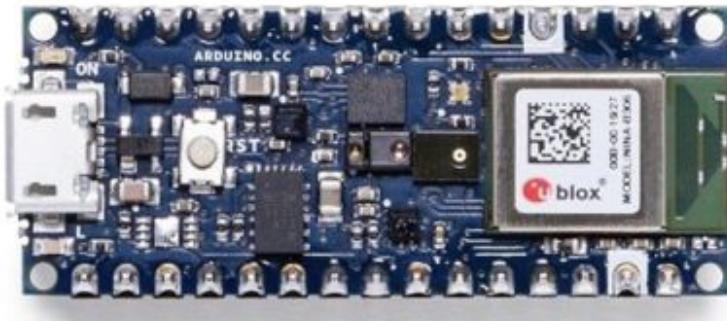
- Software
  - Machine Learning (TensorFlow)
  - Programming environments (Google Colab or Jupyter)
  - Edge Impulse Studio
- Hardware
  - Arduino Nano 33 BLE Sense
  - Sensors



# TinyML Kit



# Nano 33 BLE SENSE & OV7675 Camera



- ◆ Color, brightness, proximity and gesture sensor
- ◆ Digital microphone
- ◆ Motion, vibration and orientation sensor
- ◆ Temperature, humidity and pressure sensor
- ◆ Arm Cortex-M4 microcontroller and BLE module

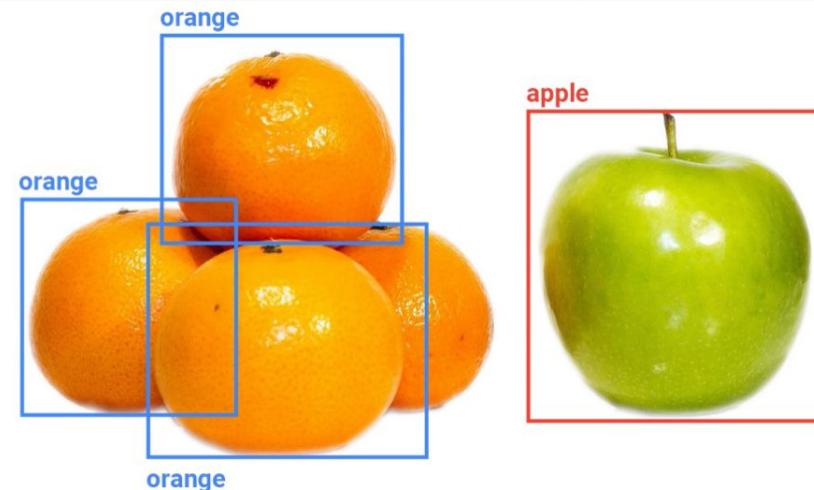
# Hands-on Activities

## Speech

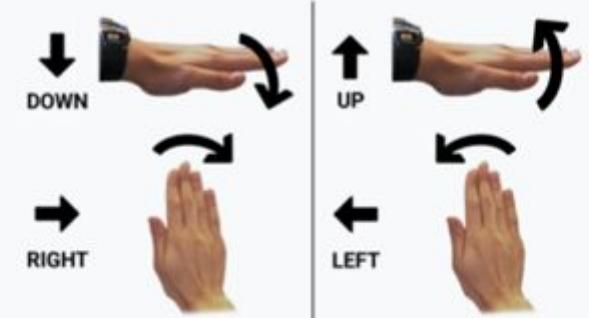


Okay, Google.

## Vision



## IMU



+



+



+

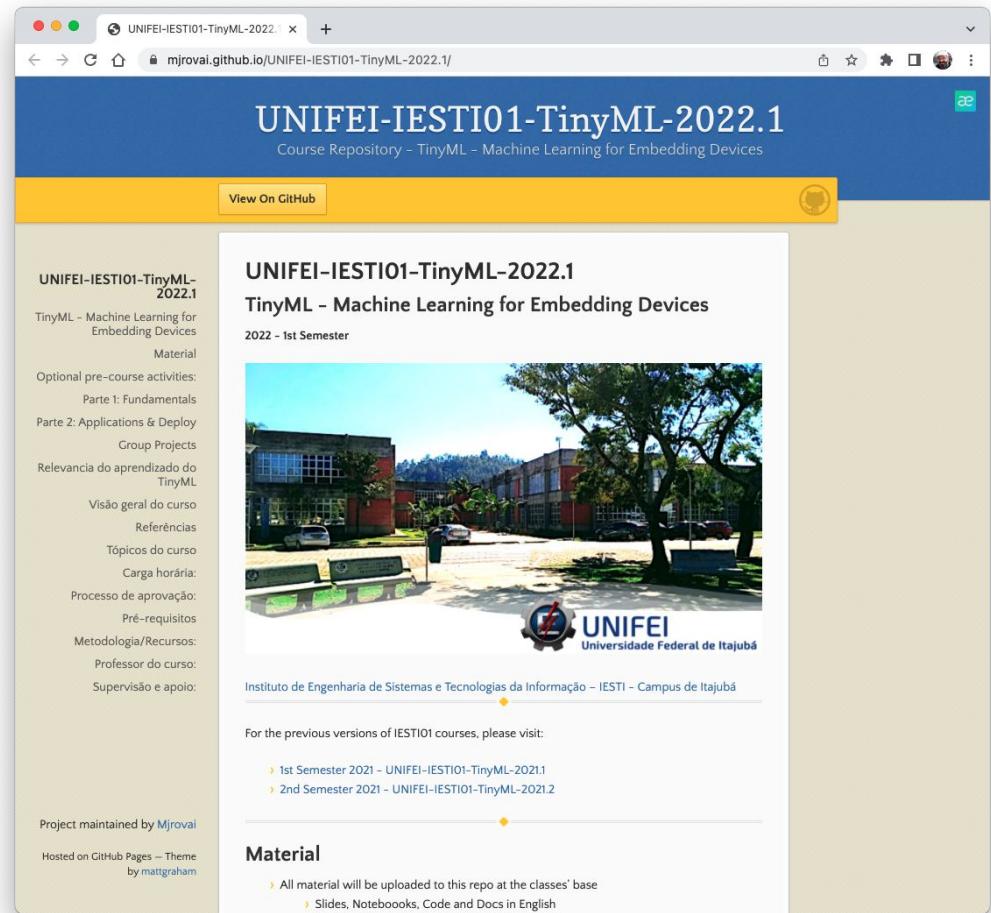


# How is the course structured?

# Course Structure

- Weekly video-recorded lectures (15 weeks)
  - Slides
  - Hands-on coding (by teacher & students)
- Weekly Additional Readings
- Possible Guest Lecturer (previous \*)
- Assignments
  - Quizzes (Weekly)
  - Notebooks with codes (4)
  - Hands-on lab reports (4)
- Final Project (Groups of 3 or 4 students)
  - Report
  - Presentation

(\*) IESTI01 2021.1 -> Daniel Situnayaki, Edge Impulse - US  
IESTI01 2021.2 -> Dr. Marco Zennaro, ICTP - Italy



[Previous IESTI01 Courses available for consultation](#)

# Class planning and approval process

- Minimal suggested Workload (4 hours per week):
  - 30 hours (Weekly recorded classes of about 2h, for 15 weeks)
  - 15 hours of assignments/coding/labs
  - 15 hours in research, individual studies, and final project (in a group)
- Approval process:
  - 1<sup>st</sup> Evaluation:
    - Individual **Quizzes**: 10%
    - Individual **Exercise Lists** (Notebooks): 25%
    - Group **Project Proposal**: 15%
  - 2<sup>nd</sup> Evaluation
    - Individual **Quizzes**: 10%
    - Individual **Practical Projects** (Lab reports): 25%
    - Group **Project Presentation (\*)** and Final Report: 15%

[\(\\*\) Examples: Harvard CS249r – TinyML - Final Projects](#)

[UNIFEI IESTI01 2021.1 – Final Projects](#)

[UNIFEI IESTI01 2021.2 – Final Projects](#)

[UNIFEI IESTI01 2022.1 – Final Projects](#)

# 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/Edge Impulse](#)
- [Computer Vision with Embedded Machine Learning - Coursera/Edge Impulse](#)
- Fundamentals textbook: [“Deep Learning with Python” by François Chollet](#)
- Applications & Deploy textbook: [“TinyML” by Pete Warden, Daniel Situnayake](#)
- Deploy textbook [“TinyML Cookbook” by Gian Marco Iodice](#)

I want to thank **Shawn Hymel** and **Edge Impulse**, **Pete Warden** and **Laurence Moroney** from Google, Professor **Vijay Janapa Reddi** and **Brian Plancher** from Harvard, and the rest of the **TinyMLEdu** team 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



UNIFEI