tinyML® On Device Learning Forum

Enabling Ultra-low Power Machine Learning at the Edge

"Online Learning TinyML for Anomaly Detection Based on Extreme Values Theory"

Eduardo Dos Santos Pereira – Technology Specialist , SENAI

May 16, 2023

TINY ML

www.tinyML.org

The Dawn of On Device Learning in TinyML

The goal of On Device Learning (ODL) is to make edge devices "smarter" and more efficient by observing changes in the data collected and self-adjusting/reconfiguring the device's operating model. Optionally the "knowledge" gained by the device is shared with other deployed devices.

Danilo Pau, Elias Fallon, Evgeni Gousev, Davis Sawyer, Ira Feldman, Christopher B. Rogers

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tinyML On Device Learning Forum 8/31 – 9/1 , 2022 Online

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- Accademia on 8/31/2022
  - On-Device Learning Under 256KB Memory, Song HAN, Assistant Professor, MIT EECS
  - Neural Network ODL for Wireless Sensor Nodes ,Hiroki MATSUTANI, Professor, Keio University
  - Scalable, Heterogeneity-Aware and Trustworthy Federated Learning, Yiran CHEN, Professor, Duke University
  - On-Device Learning For Natural Language Processing with BERT, Warren J. GROSS, Professor, McGill University
  - Is on-device learning the next “big thing” in TinyML? Manuel ROVERI, Associate Professor, Politecnico di Milano
  - ODL Professors Panel
- Industry on 9/1/2022
  - TinyML ODL in industrial IoT, Haoyu REN, PhD Student, Technical University of Munich/Siemens
  - NeuroMem® wearable, hardwired sub milliwatt real time machine learning with wholly parallel access to “neuron memories” fully explainable, Guy PAILLET, Co-founder, General Vision
  - Using Coral Dev Board Micro for ODL innovations, Bill LUAN, Senior Program Manager, Google
  - Platform for Next Generation Analog AI Hardware Acceleration, Kaoutar EL MAGHRAOUI, Principal Research Scientist, IBM T.J Watson Research Center
  - Enabling on-device learning at scale, Joseph SORIAGA, Sr. Director of Technology, Qualcomm
  - Training models on tiny edge devices, Valeria TOMASELLI, Senior Engineer, STMicroelectronics

https://www.tinyml.org/event/on-device-learning/

tinyML EMEA Forum - On Device Learning 9/12 , 2022 Cyprus, In person

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- A framework of algorithms and associated tool for on-device tiny learning, Danilo PAU, Technical Director, IEEE and ST Fellow, STMicroelectronics
- In Sensor and On-device Tiny Learning for Next Generation of Smart Sensors Michele MAGNO, Head of the Project-based learning Center, ETH Zurich, D-ITET
- Continual On-device Learning on Multi- Core RISC-V MicroControllers Manuele RUSCI, Embedded Machine Learning Engineer, Greenwaves
- On-device continuous event-driven deep learning to avoid model drift, Bijan MOHAMMADI, CSO, Bondzai

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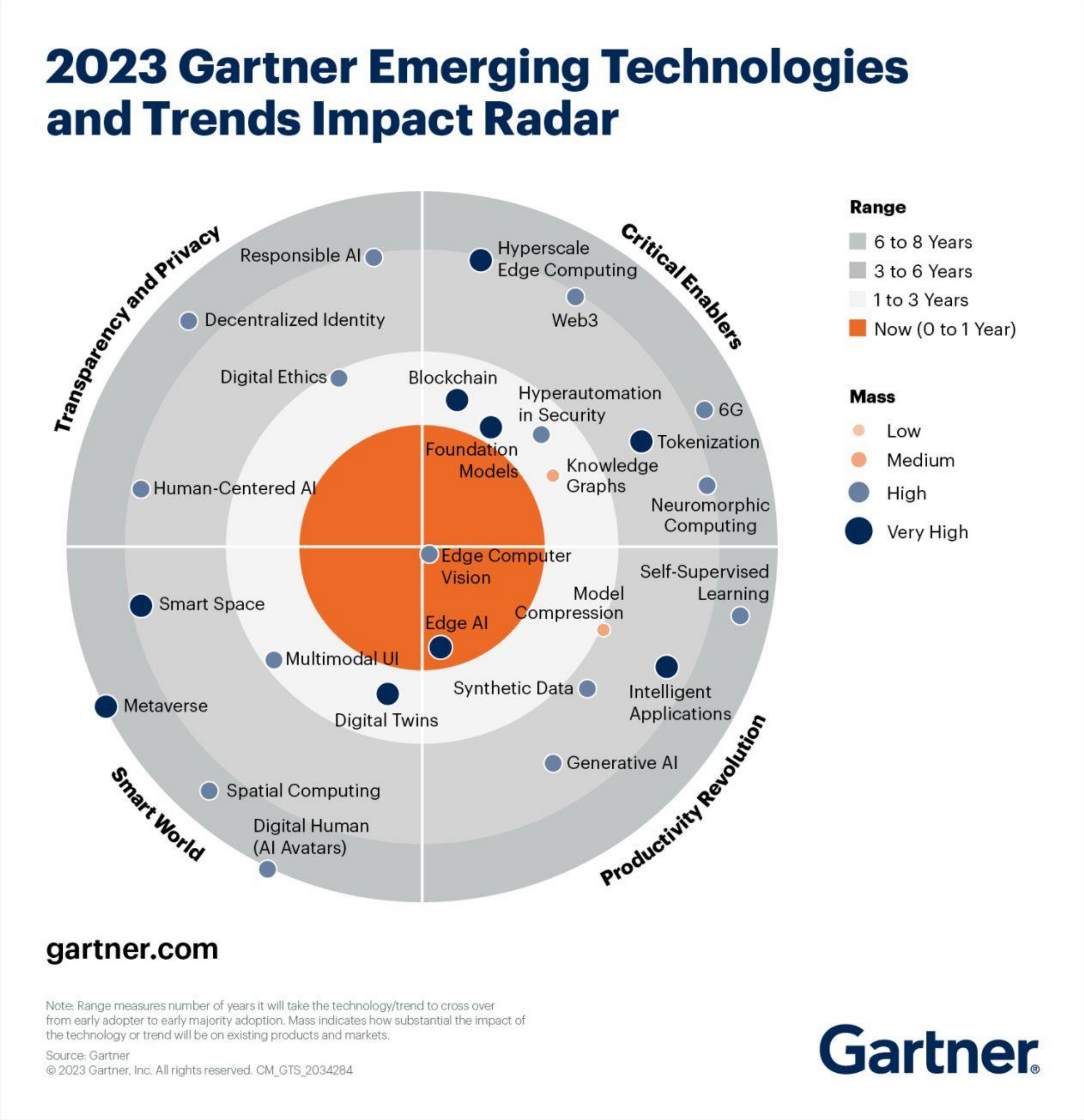

On Device Learning Forum 2023, May 16 2023

- 8:00 - 8:10 Opening remarks by **Danilo Pau**
- 8:10 - 8:40 **Charlotte Frenkel** "Merging insights from artificial and biological neural networks for neuromorphic edge intelligence"
- 8:40 - 9:40 **Giorgia Dellaferrera** "Forward Learning with Top-Down Feedback: Solving the Credit Assignment Problem without a Backward Pass"
- 9:40 - 10:10 **Guy Paillet** "NeuroMem®, Ultra Low Power hardwired incremental learning and parallel pattern recognition"
- 10:10 - 10:40 **Aida Todri-Sanial** "On-Chip Learning and Implementation Challenges with Oscillatory Neural Networks"
- 10:40 - 11:10 **Eduardo S. Pereira** “Online Learning TinyML for Anomaly Detection Based on Extreme Values Theory”
- 11:10 - 11:15 Closing remarks by Danilo Pau

Pacific Time

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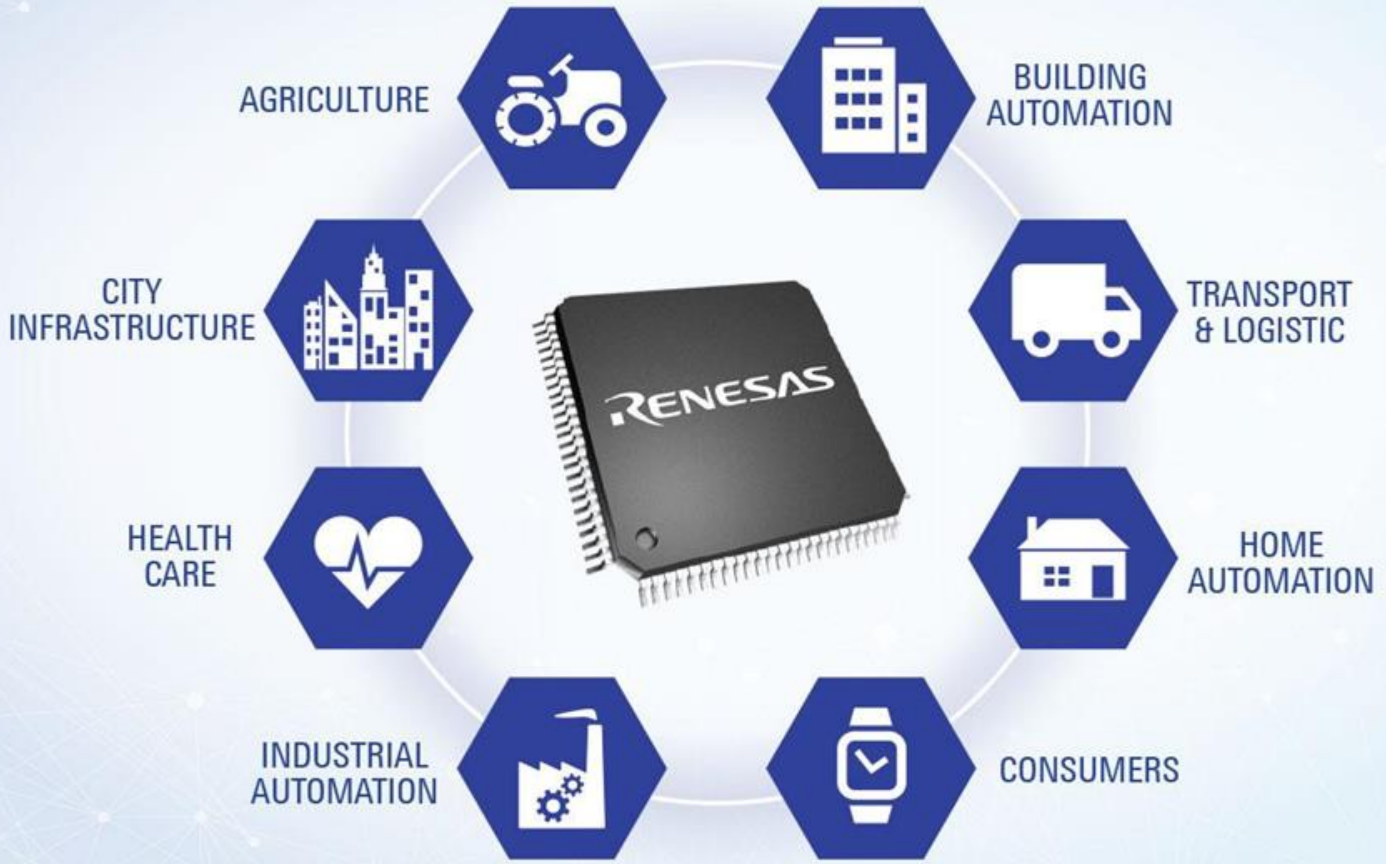

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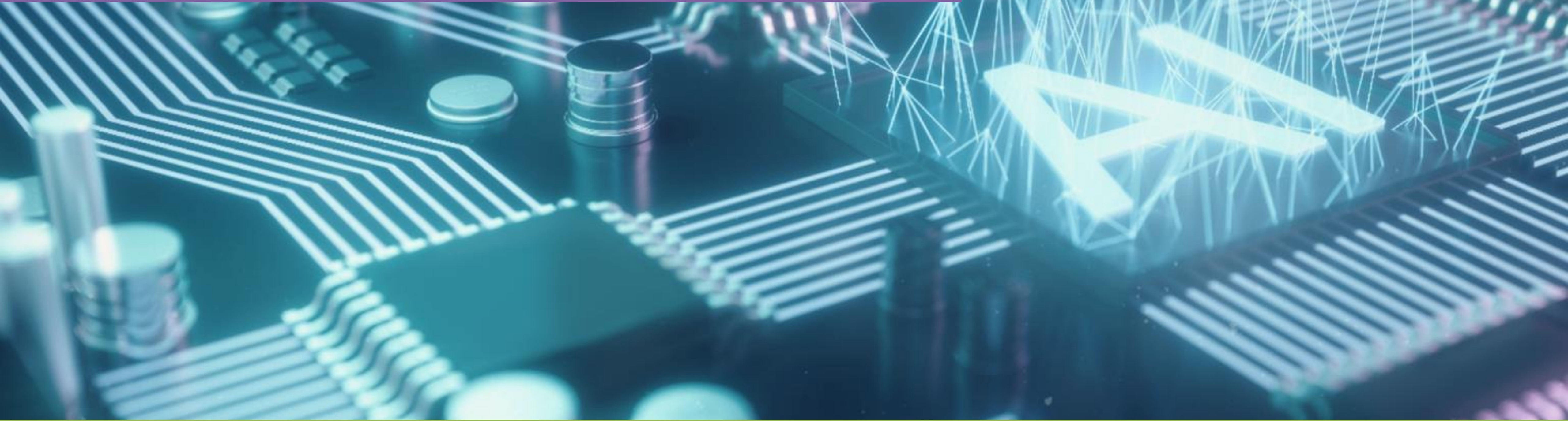
STMicroelectronics provides extensive solutions to make tiny Machine Learning easy



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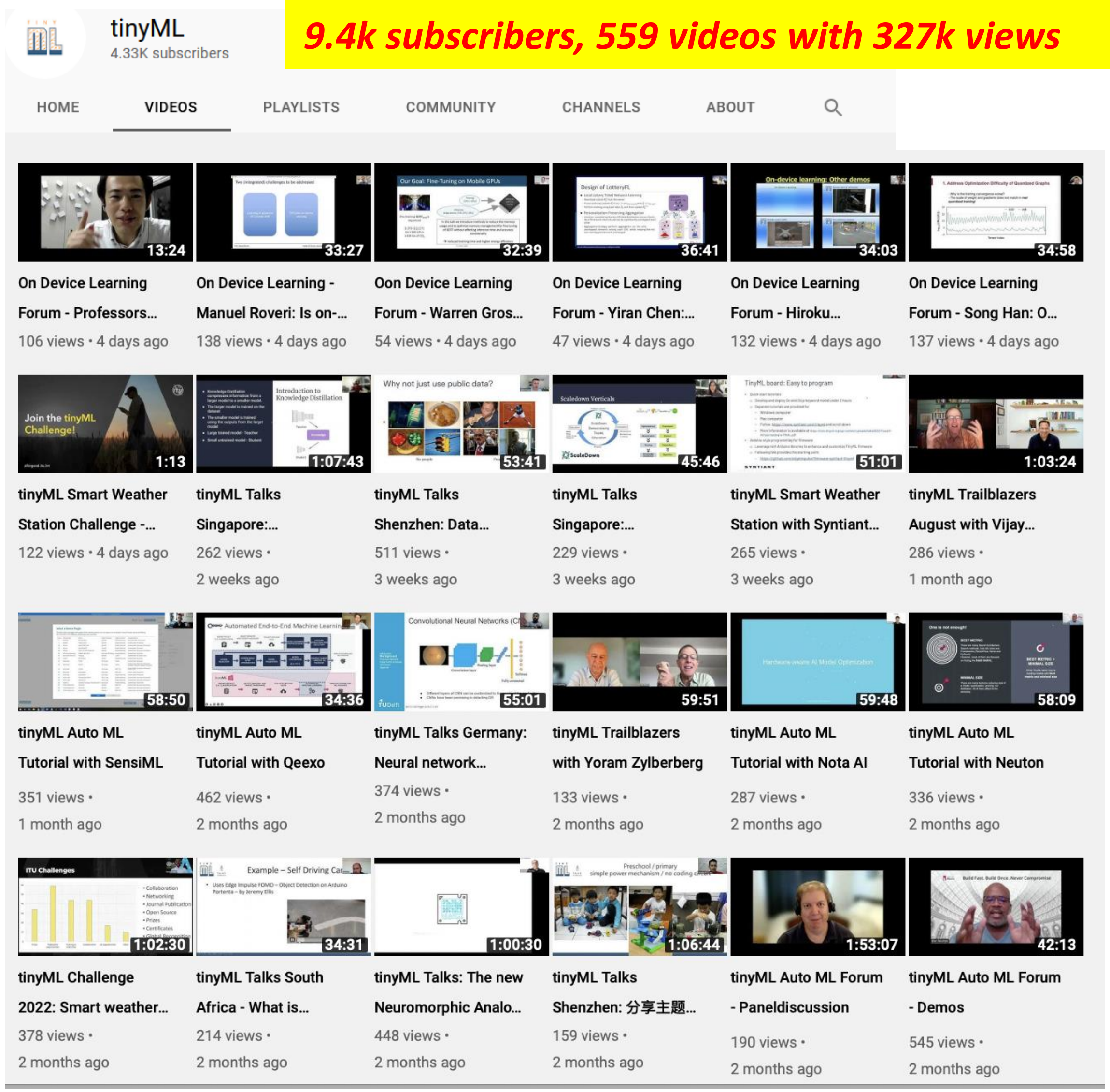

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FOUNDATION

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Reminders

Slides & Videos will be posted tomorrow

tinyml.org/forums youtube.com/tinyml

Please use the Q&A window for your questions

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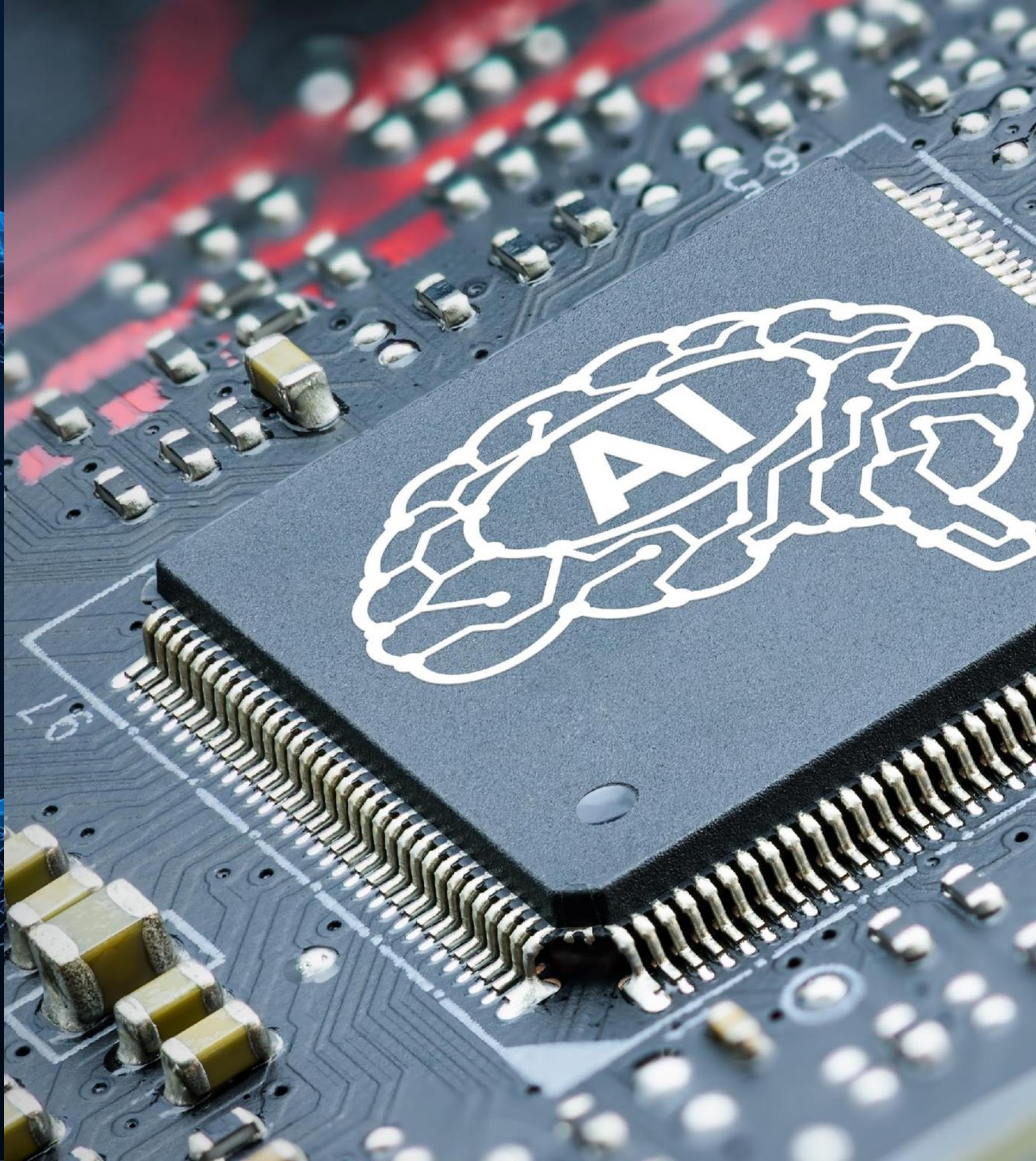
Eduardo Dos Santos Pereira

Eduardo S. Pereira holds a Ph.D. degree in Astrophysics from the Brazilian National Institute for Space Research (INPE). He has completed postdoctoral research in Cosmology (INPE), Computational Astronomy (University of São Paulo USP), and Artificial Intelligence (UNICAMP). He works as a Technology Specialist at SENAI in São José dos Campos, focusing on topics such as Artificial Intelligence, Embedded Systems, Computer Vision, Modeling, and Simulation of physical processes.

Dr. Eduardo dos Santos Pereira

On Device Learning:

TinyML for Anomaly Detection Based on Extreme Values Theory



Eduardo S. Pereira

Ph. D. Artificial Intelligence Specialist

https://www.linkedin.com/in/eduardo-s-pereira-0a036719

Artificial for Tiny Devices

Hardware

	Raspberry Pico (W)	Arduino Nano Sense	ESP 32	Seeed XIAO Sense / ESP32S3	Arduino Pro
32Bits CPU	Dual-core Arm Cortex-M0+	Arm Cortex-M4F	Xtensa LX6 Dual Core	Arm Cortex-M4F (BLE) Xtensa LX7 Dual Core	Dual Core Arm Cortex M7/M4
CLOCK	133MHz	64MHz	240MHz	64 / 240MHz	480/240MHz
RAM	264KB	256KB	520KB (part available)	256KB / 8MB	1MB
ROM	2MB	1MB	2MB	2MB / 8MB	2MB
Radio	(Yes for W)	BLE	BLE/WiFi	BLE / WiFi (ESP32S3)	BLE/WiFi
Sensors	No	Yes	No	Yes (Sense)	Yes (Nicla)
Bat. Power Manag.	No	No	No	Yes	Yes
Price	$	$$$	$	$$	$$$$$

https://media.digikey.com/Resources/Maker/the-original-guide-to-boards-2022.pdf

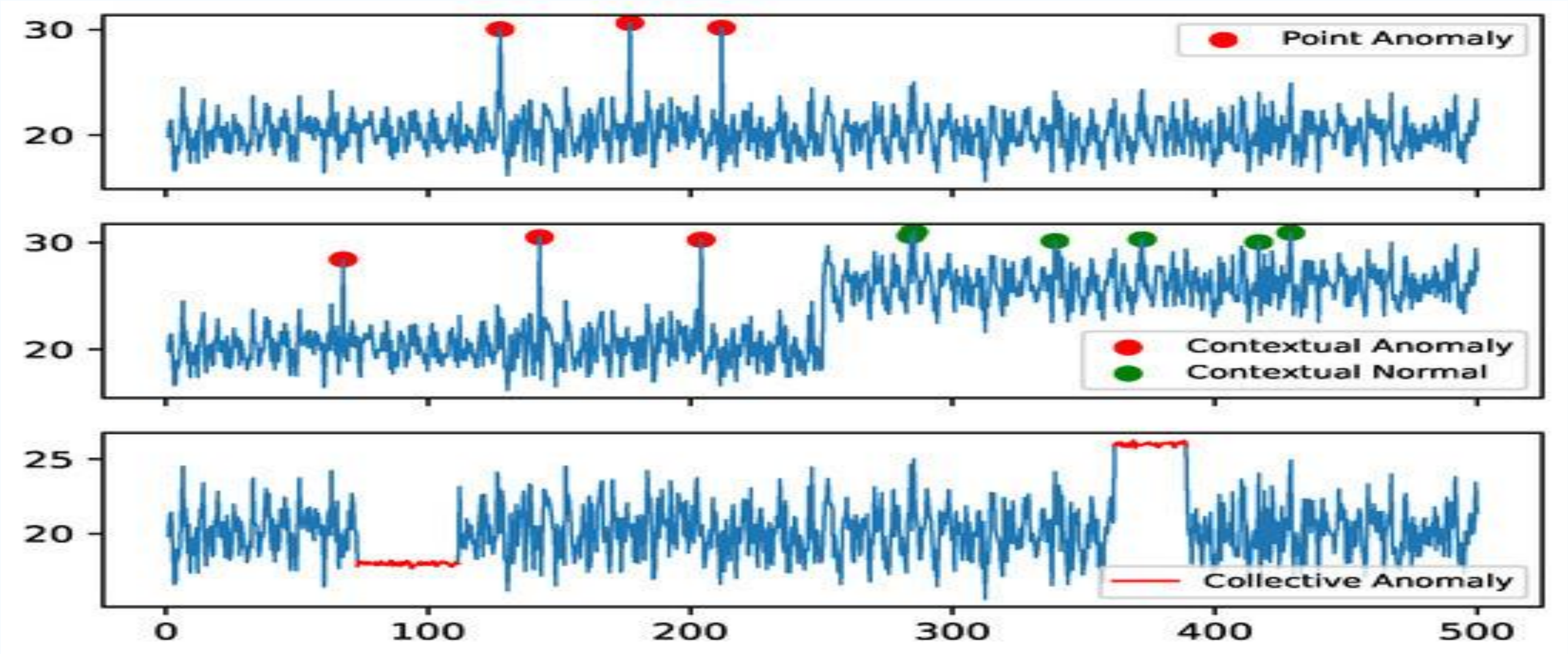
Challenges

The ability to detect anomalies is crucial in many applications:

- Tracking environmental and location parameters based on sensor readings,
- Detecting intrusions
- Identifying credit card fraud

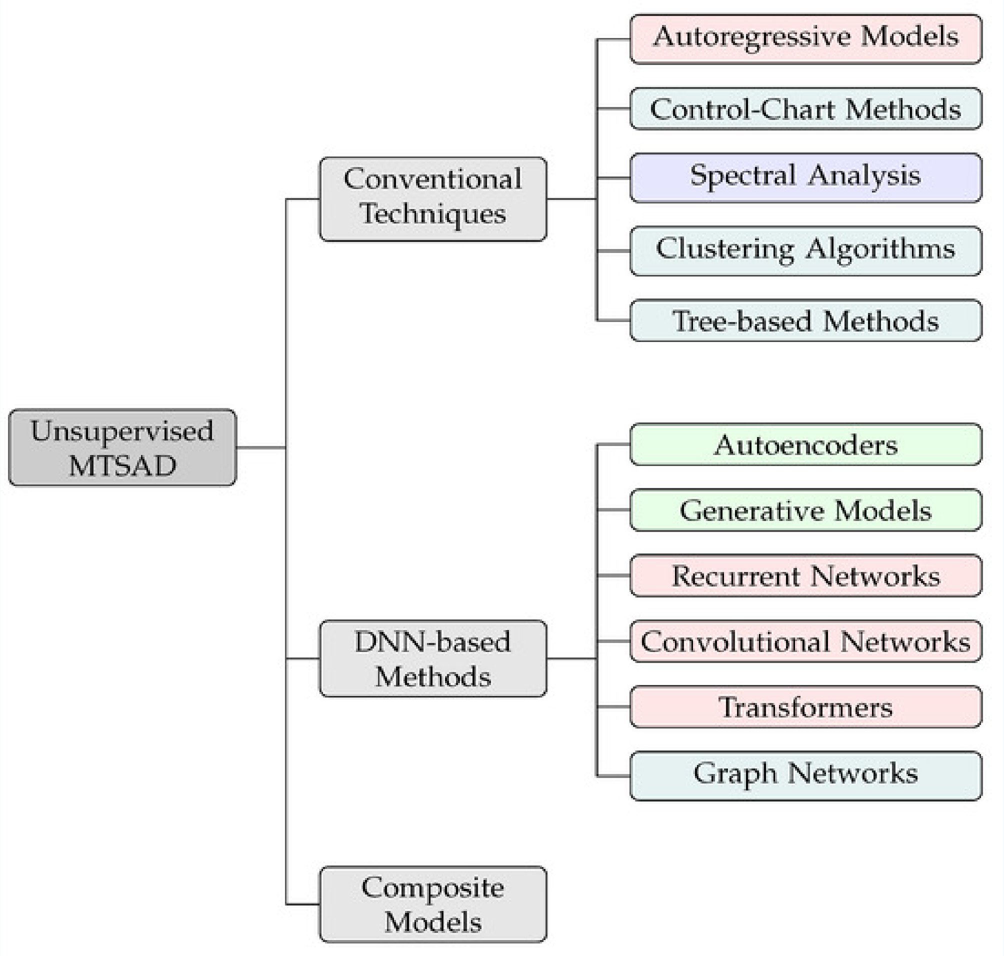
- In all of these scenarios, the data typically has a “**normal**” pattern, and any deviations from this pattern are considered anomalies.

Anomaly in Time Series



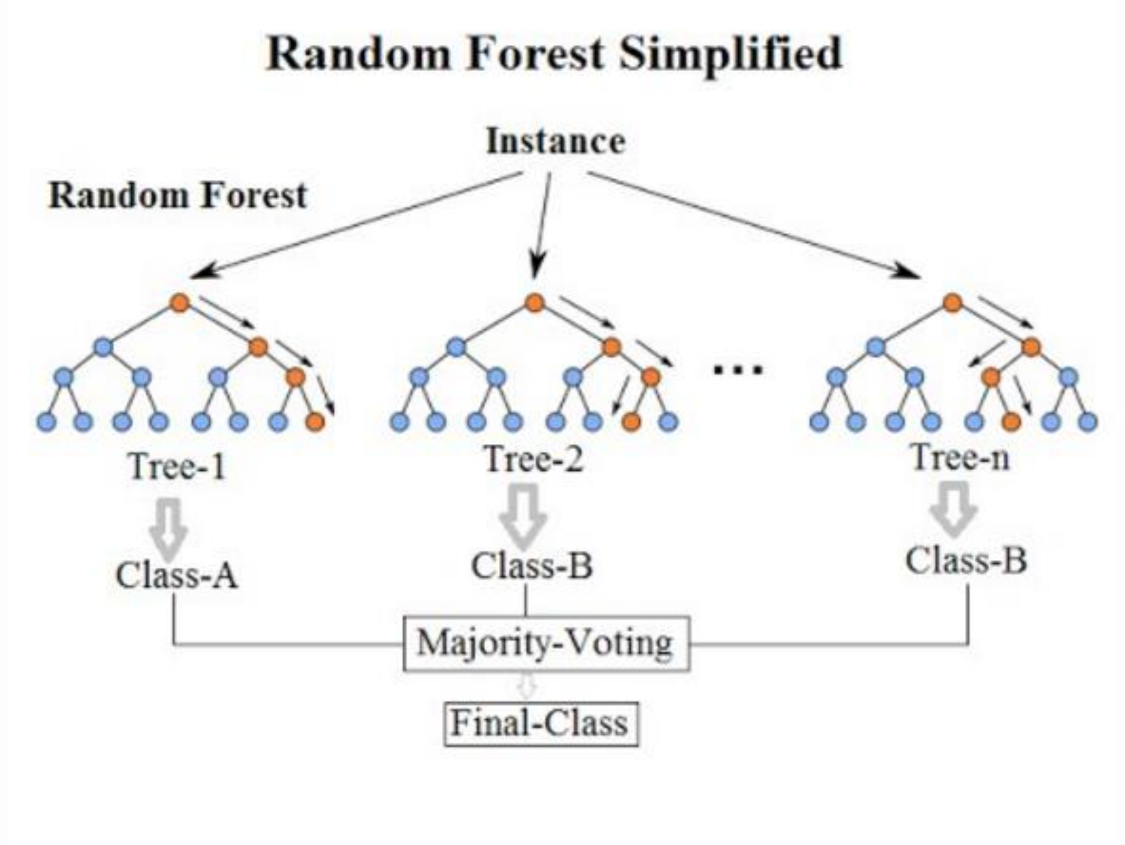
Source: Belay et. al 2023.

Anomaly in Time Series

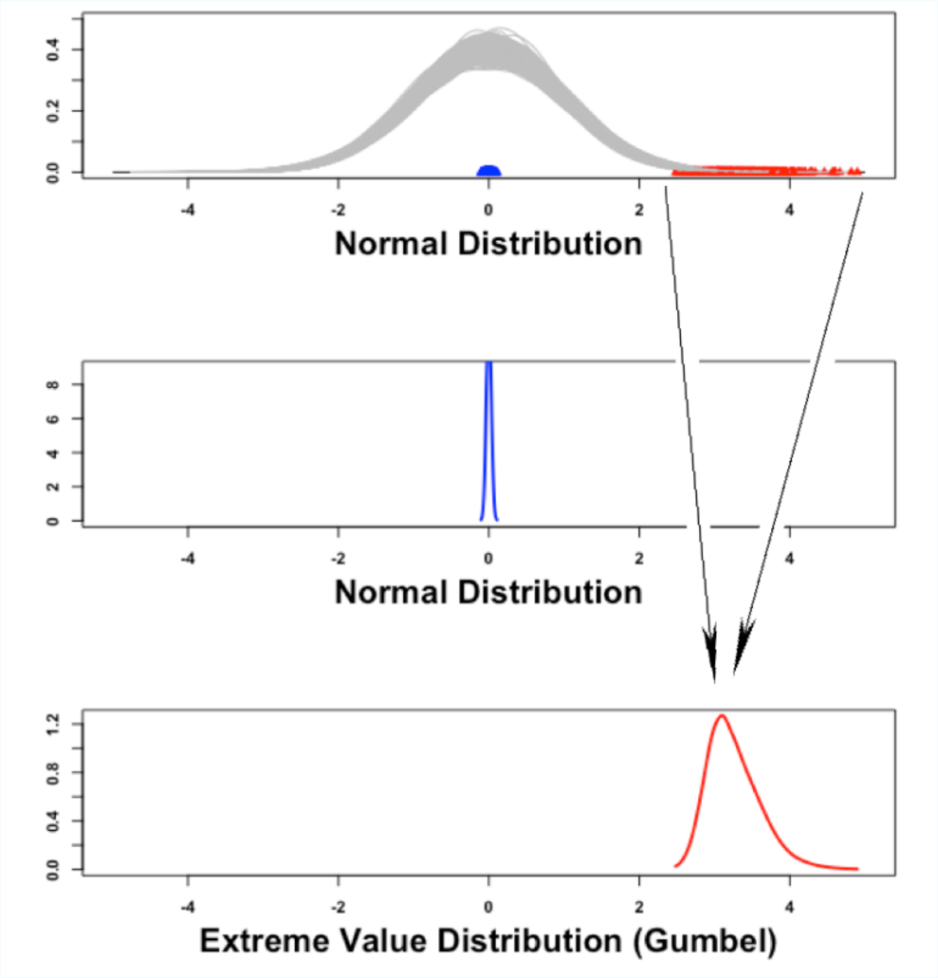


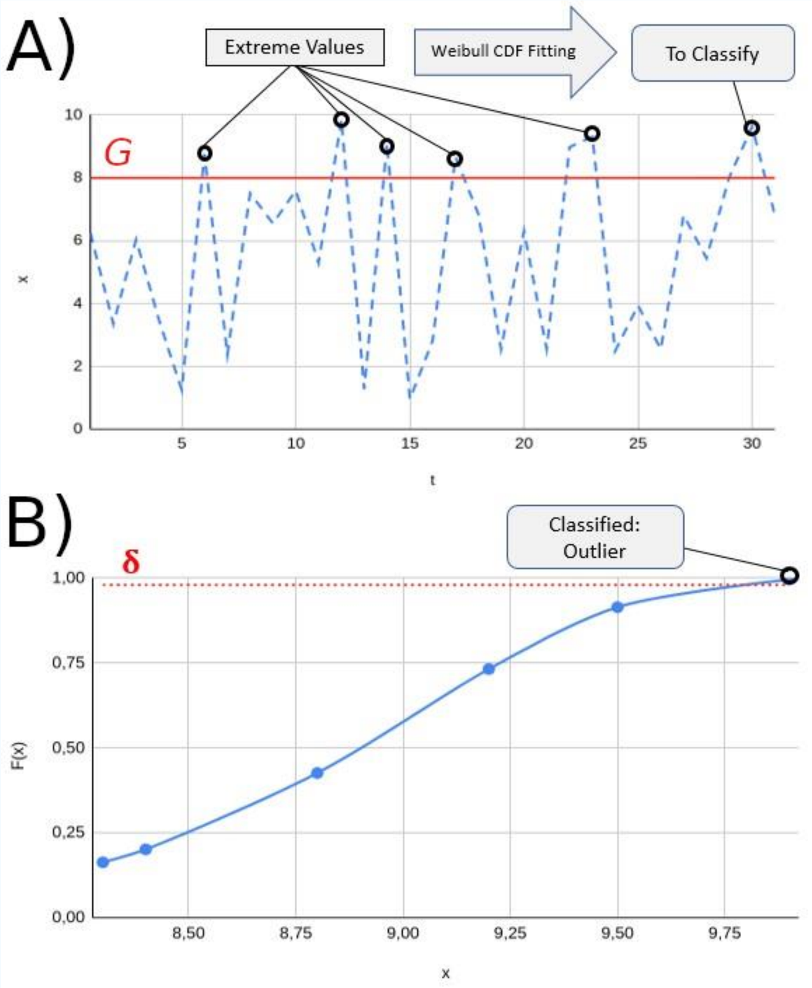
Source: Belay et. al 2023.

Random Forest for Anomaly Classification



Extreme Values Theory





Extreme Values Theory

EVT provides a family of distributions to model extreme values based on data characteristics. A Generalized Extreme Value distribution (GEV) can be expressed as [11]:

$$GEV(x) = \begin{cases} \frac{1}{\lambda} e^{-v^{-\frac{1}{\kappa}}} v^{-(1/\kappa+1)} & \text{if } \kappa \neq 0 \\ \frac{1}{\lambda} e^{-(t+e^{-t})} & \text{if } \kappa = 0 \end{cases} \quad (2)$$

Here, $t = \frac{x-\eta}{\lambda}$ and $v = 1 + \kappa\frac{x-\eta}{\lambda}$, where κ, λ, and η are the shape, scale, and location parameters, respectively. The GEV can represent one of the following distributions: i) Gumbel for $\kappa = 0$; ii) Frechet for $\kappa > 0$; iii) Reversed Wiebull for $\kappa < 0$.

If we assume continuous and bounded (up or down limit) data and a system (or part) with multiple failure modes, failure is best modelled by the Weibull distribution [3].

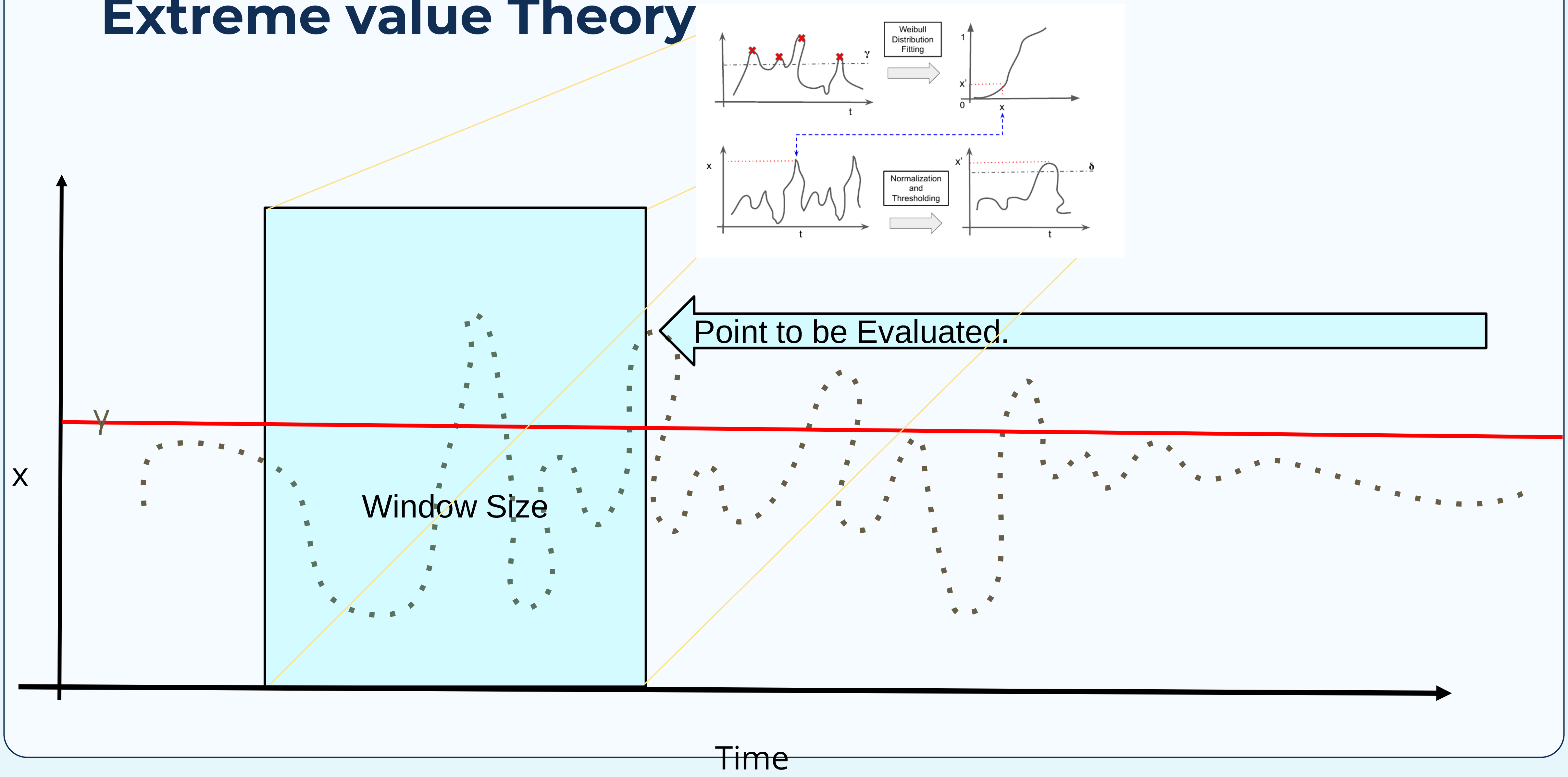
The cumulative distribution function (CDF) of the Weibull distribution can be expressed as [9]:

$$F(x) = 1 - \exp\left[-\left(\frac{x-\eta}{\lambda}\right)^{\kappa}\right], \quad (3)$$

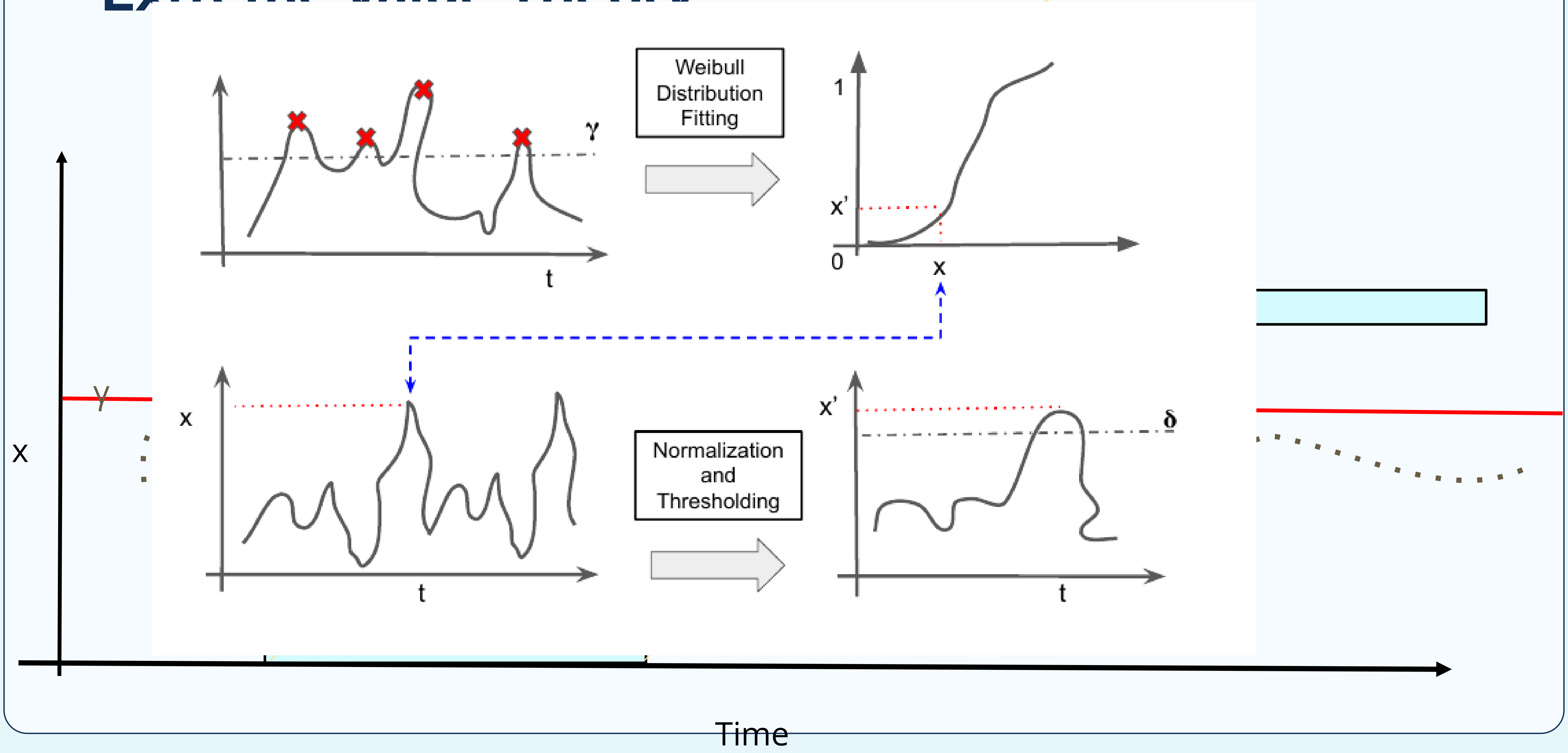
where η is the location parameter.

In the next section, we discuss how to automatically determine parameter Weibull CDF from the data.

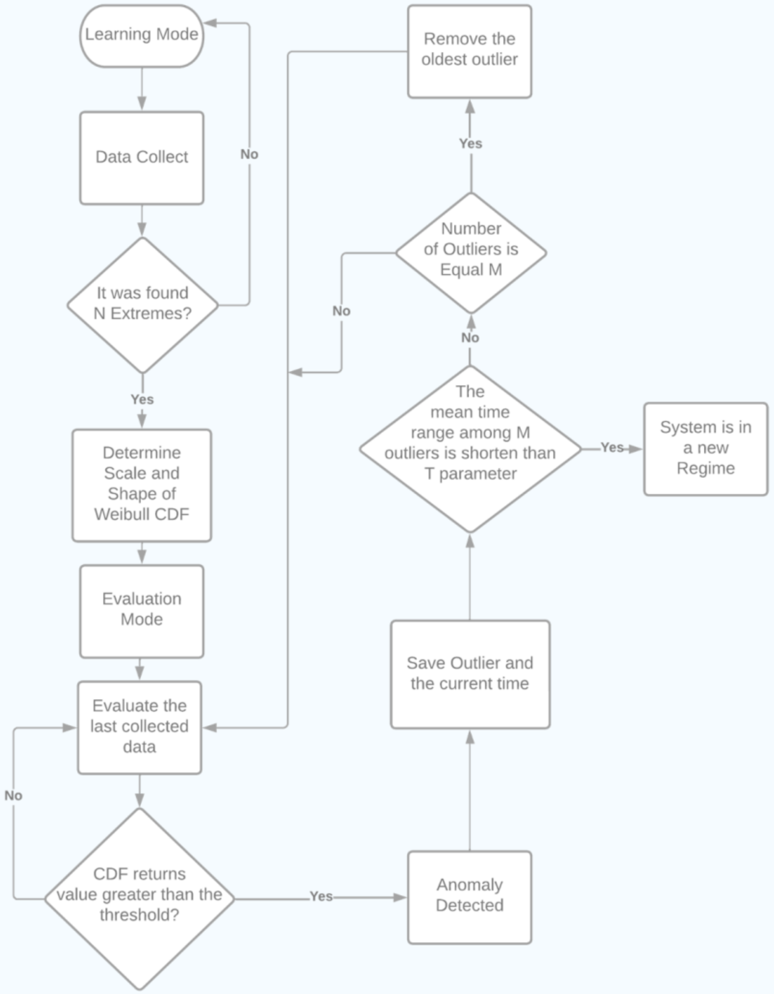
Extreme value Theory



Extreme value Theory



Extreme Values Theory



Extreme Values Theory

TABLE 1. TinyML meta-parameters

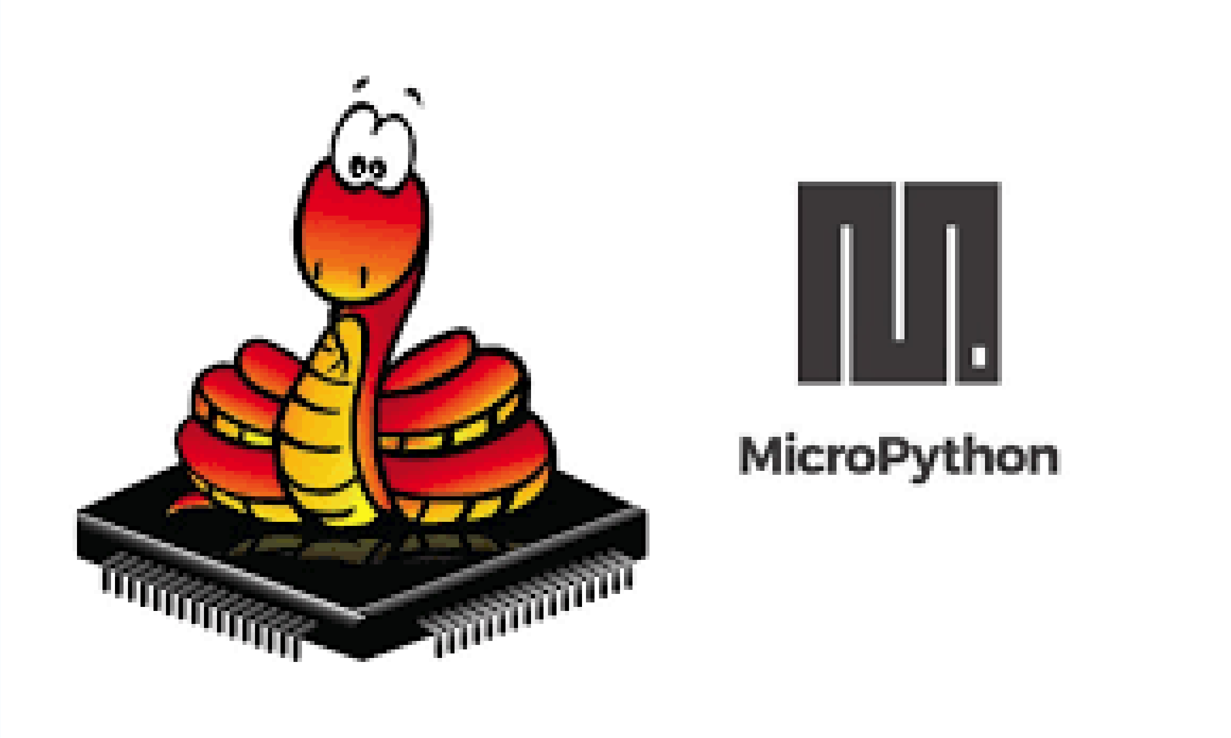
γ	Parameter of bound values function
δ	Threshold of CDF to evaluate if a point is an outlier.
N	Total number of maximum used to find shape and scale parameter of Weibull CDF.
M	Total of outlier, used to classify the nearest outliers as a collective anomaly.
T	Average time range among outliers occurrence necessary to classify outliers as a collective anomaly.
R	The data time sampling ratio.

Extreme Values Theory

TABLE 2. Summary of Experiments.

Experiment	γ	δ	N	M	T (ms)	R (ms)
1	2	0.94	5	5	500	100
2	4	0.94	5	5	500	100
3	2	0.94	10	5	500	100
4	2	0.94	5	10	500	100
5	2	0.94	5	5	1000	100
6	2	0.94	5	5	500	1000

MicroPython



MicroPython and is running on an Arduino RP2040. MicroPython is a lightweight implementation of the Python 3 programming language that is designed to run on MCUs

ulab - Numpy and Scipy to Micropython

https://micropython-ulab.readthedocs.io/en/latest/

ulab - Numpy and Scipy to Micropython

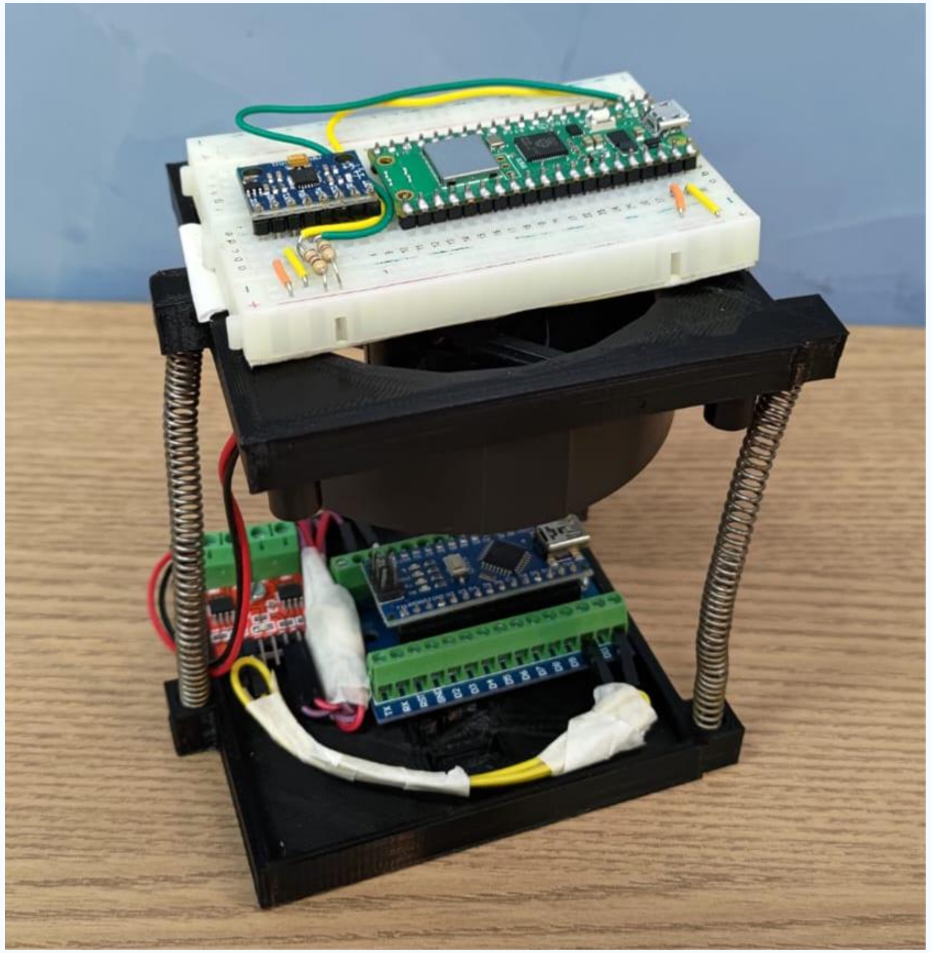
NumPy + MicroPython

info.py [code18-1a.py]

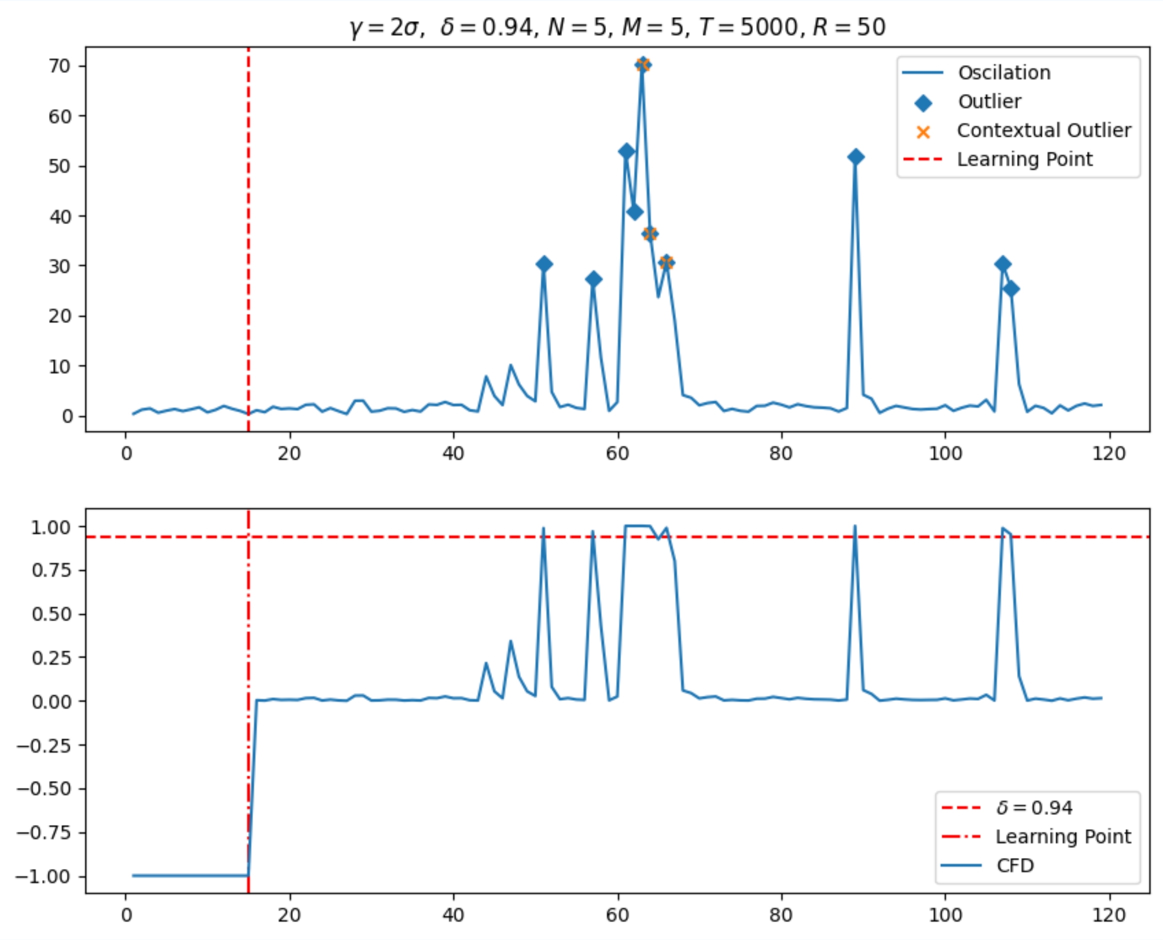
```python
# code18-1
from ulab import numpy as np
a = np.arange(8)
b = np.arange(8,dtype=np.float)
c = np.arange(1,5)
d = np.arange(1,5,2)
e = np.ones((3,3),dtype=np.uint8)
f = np.zeros((3,3))
g = np.eye(3)
h = np.eye(3, dtype=np.int8)
i = np.linspace(10,2,5)
j = np.linspace(-2, 8, 10)
print("{}/{}\n{}/{}".format(a,len(a),b,len(b)))
print("{}/{}\n{}/{}".format(c,len(c),d,len(d)))
print("{}/{}\n{}/{}".format(e,len(e),f,len(f)))
print("{}/{}\n{}/{}".format(g,len(g),h,len(h)))
print("{}/{}\n{}/{}".format(i,len(i),j,len(j)))
```

https://micropython-ulab.readthedocs.io/en/latest/

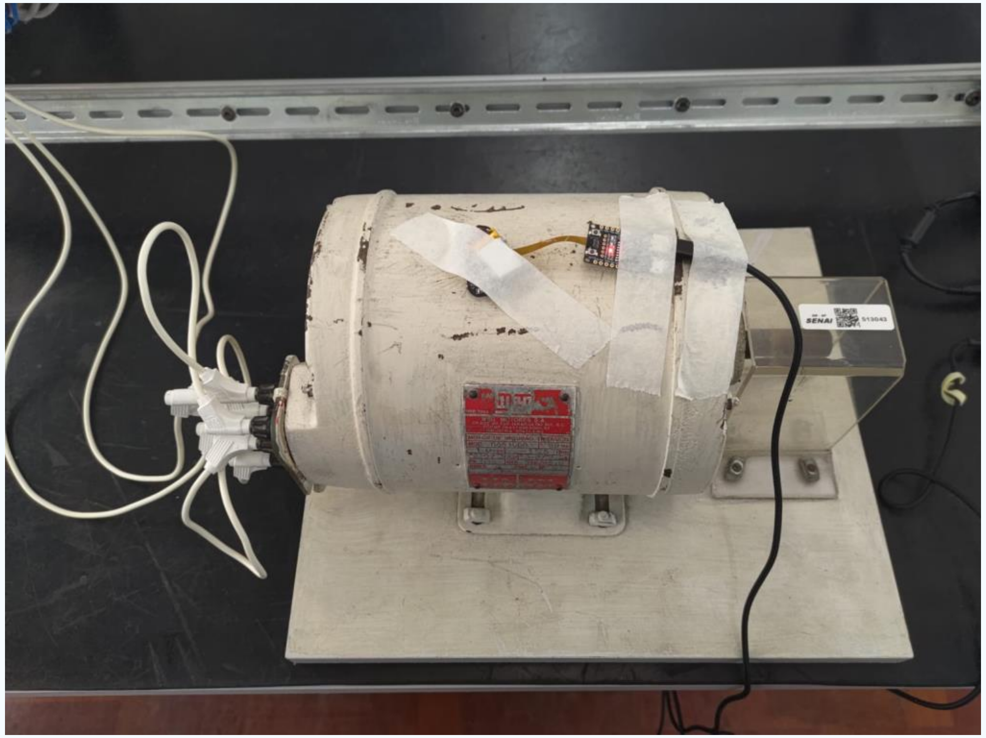
Experimental Results



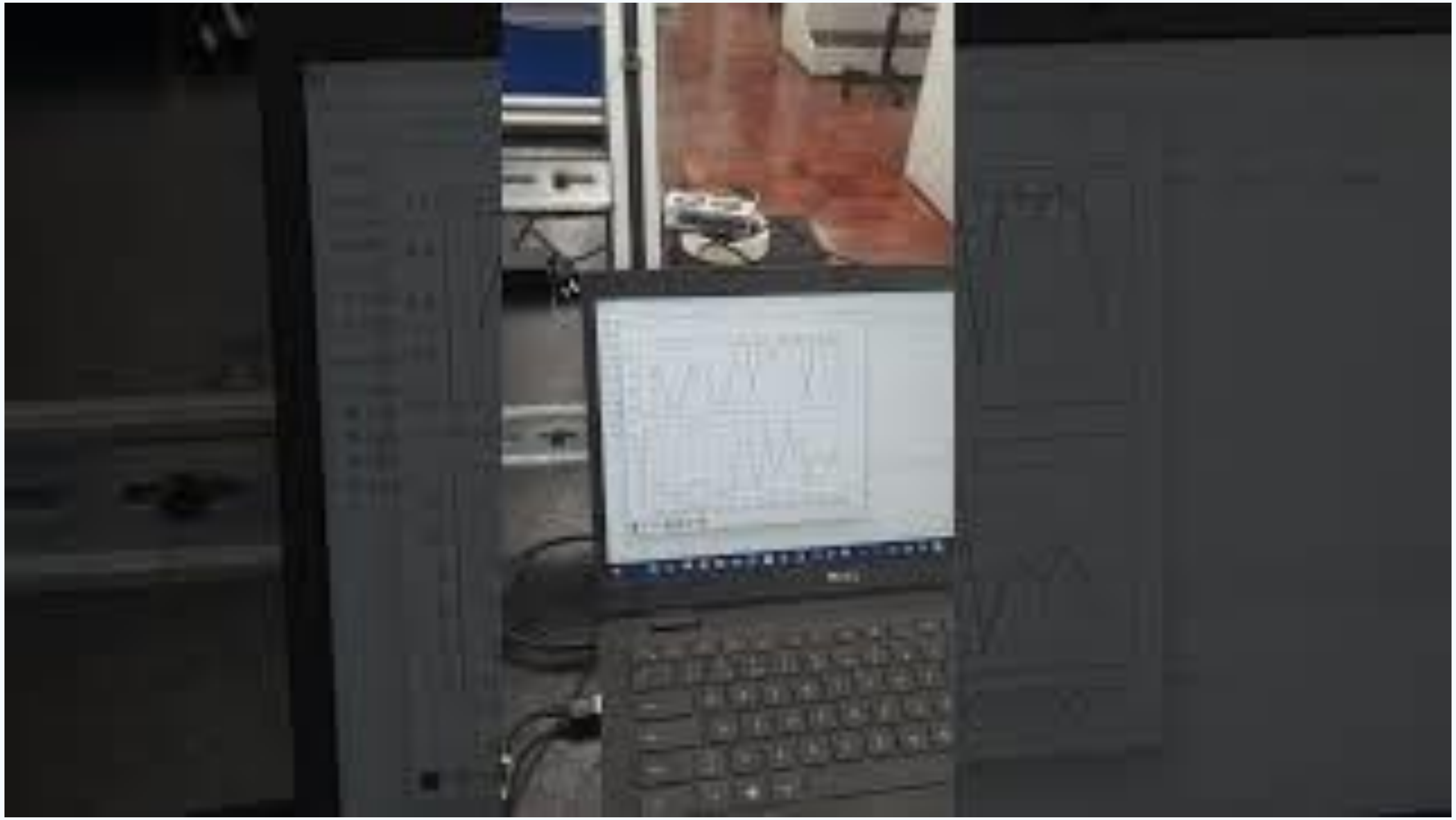
Experimental Results



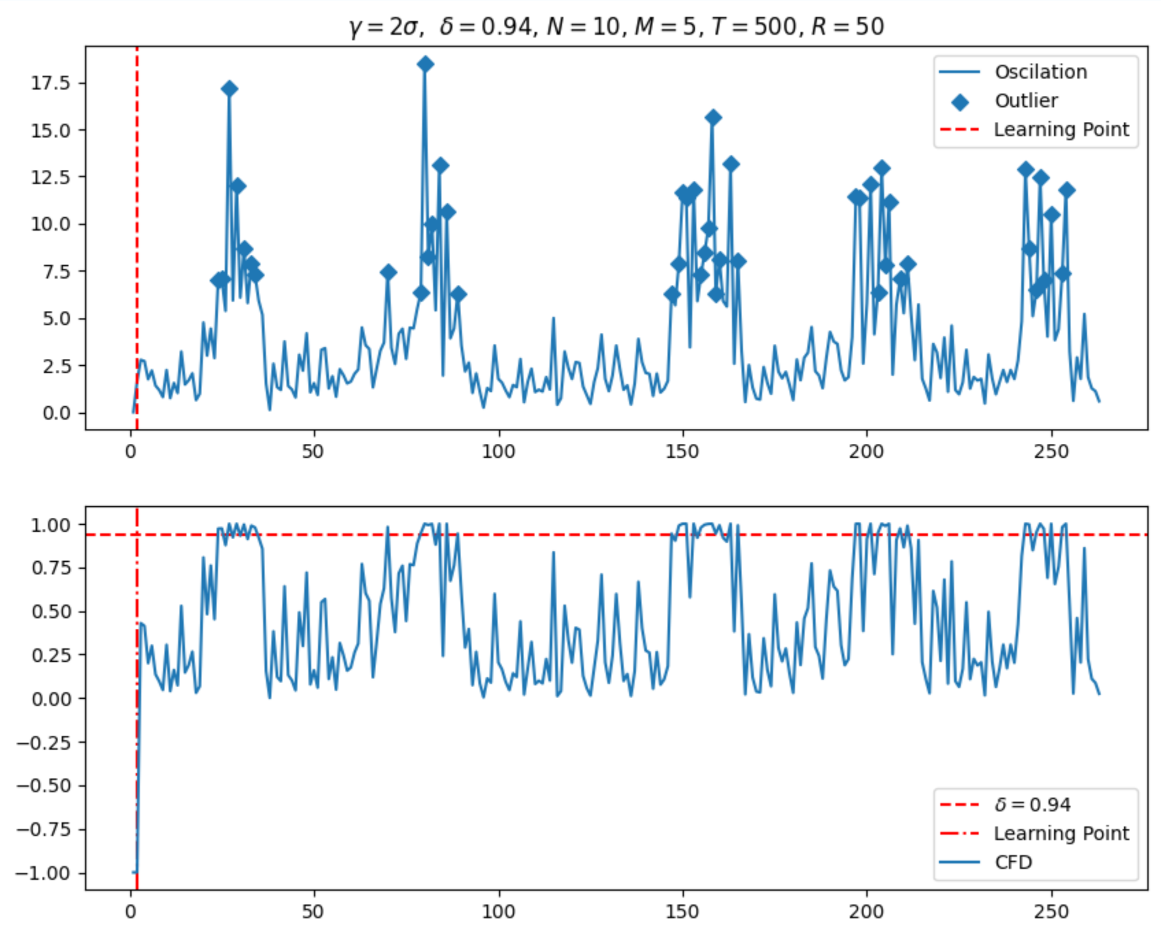
Experimental Results



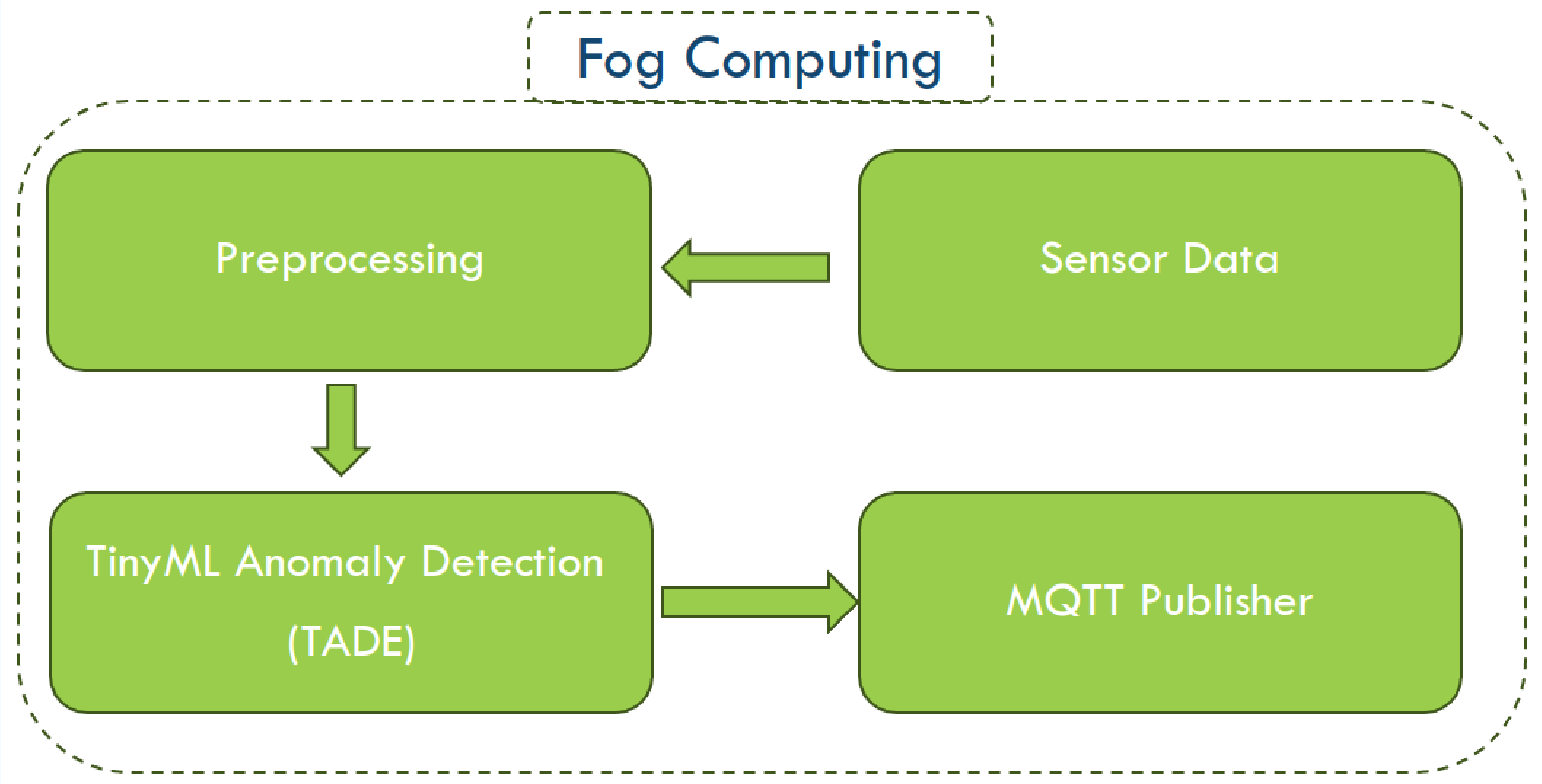
Experimental Results



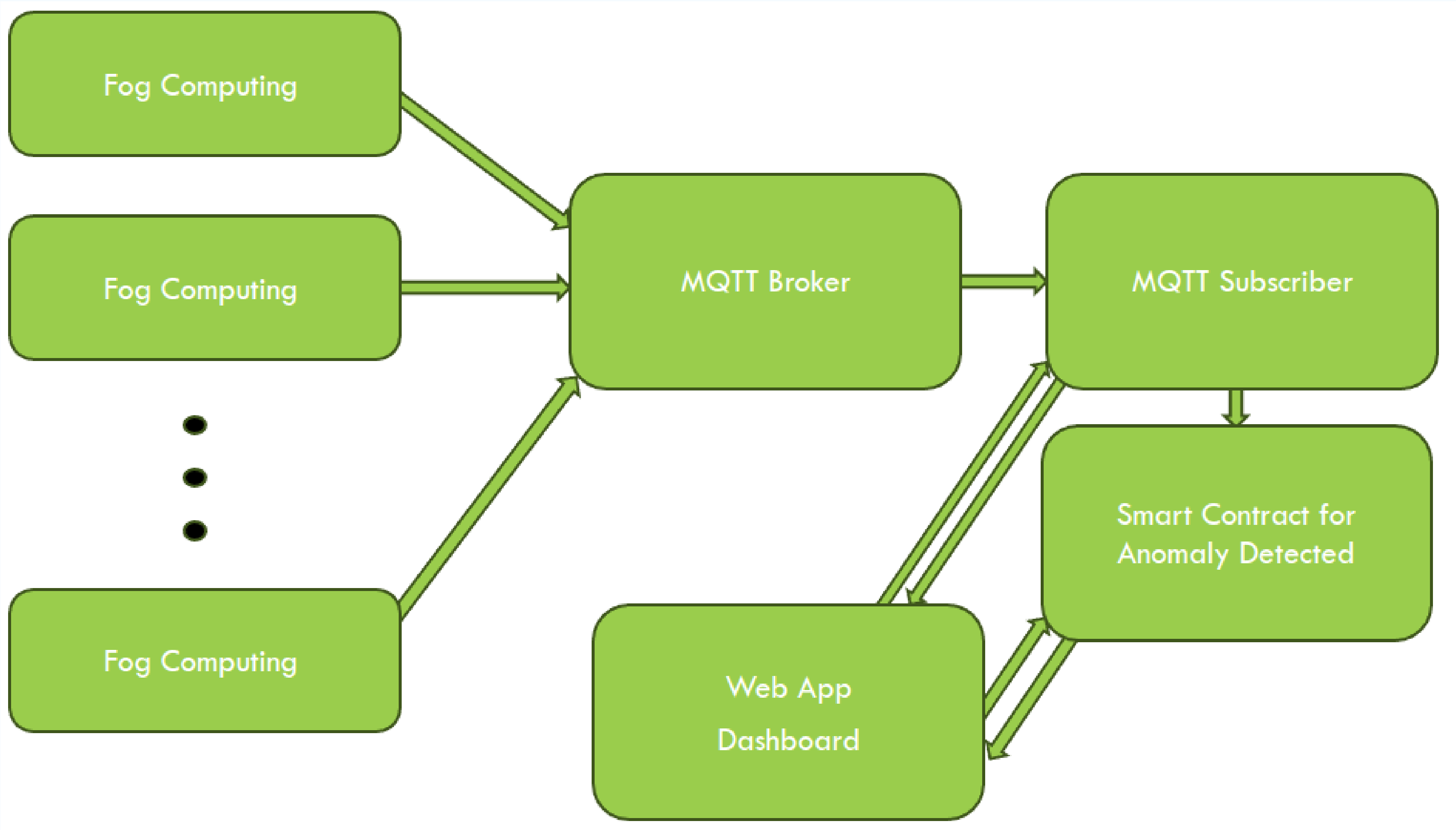
Experimental Results



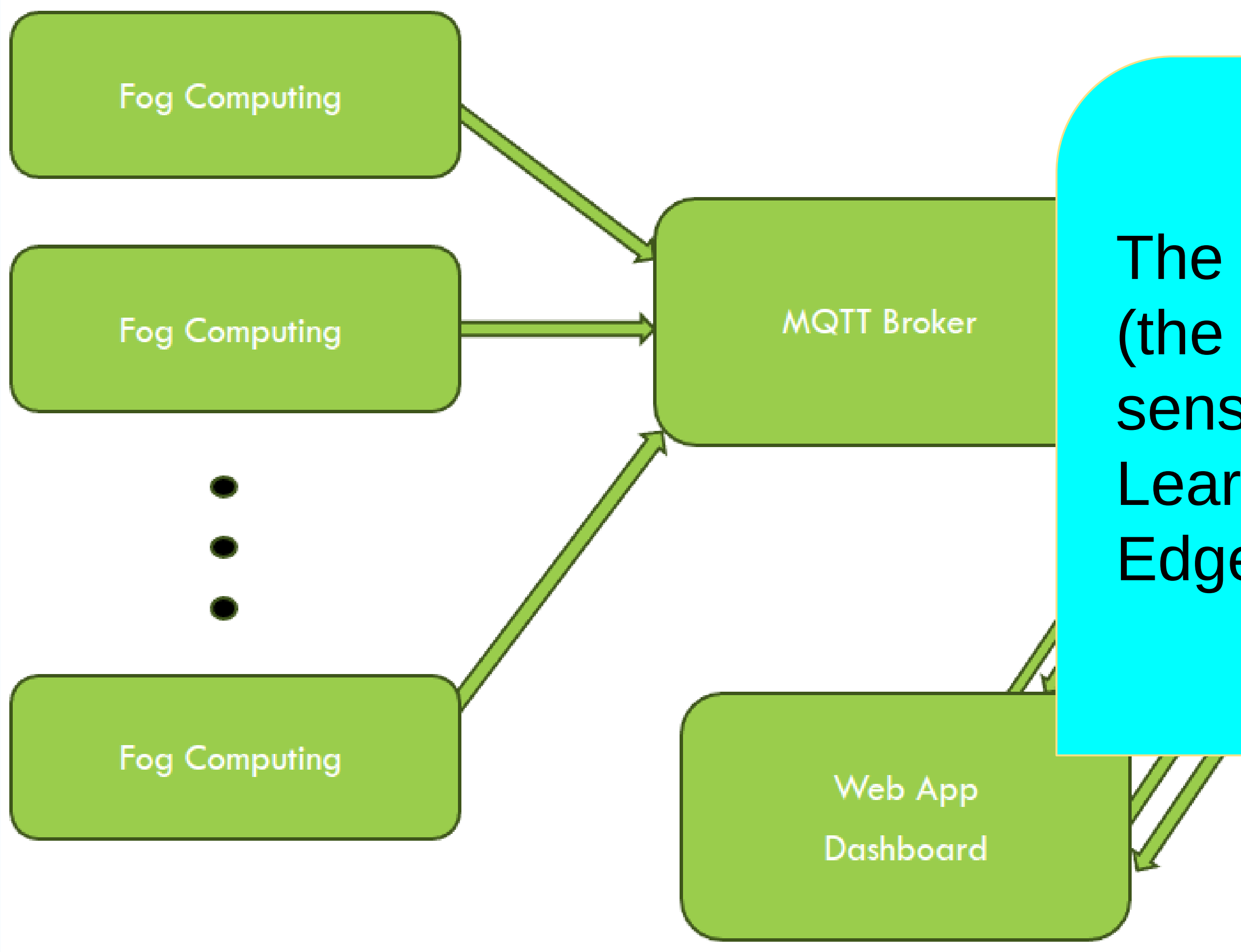
Fog and Edge Computing



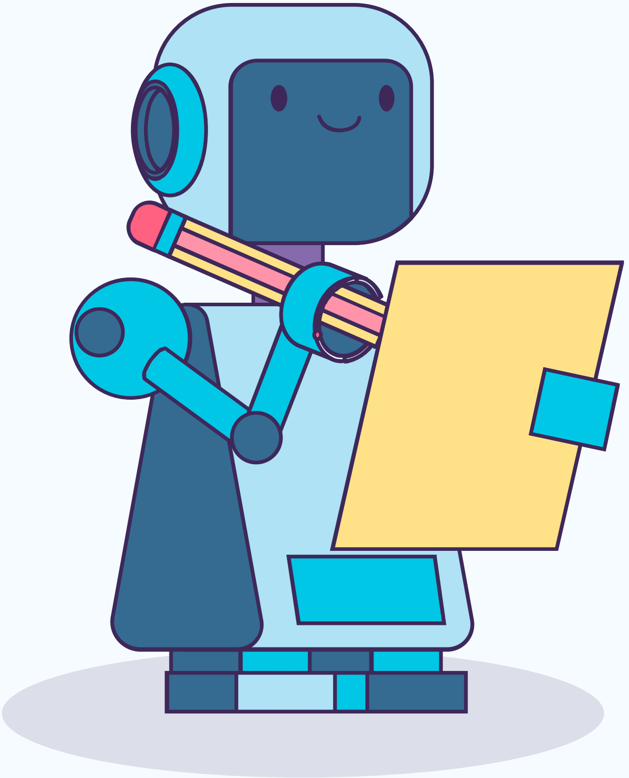
Fog and Edge Computing



Fog and Edge Computing



The individual learning parameters (the same kind of equipment and sensor) can be combined (Ensemble Learning). The final model can run on Edge Device.



Thanks

Questions?

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