EE P 596: TinyML

Spring 2024

Dept. of Electrical and Computer Engineering

University of Washington

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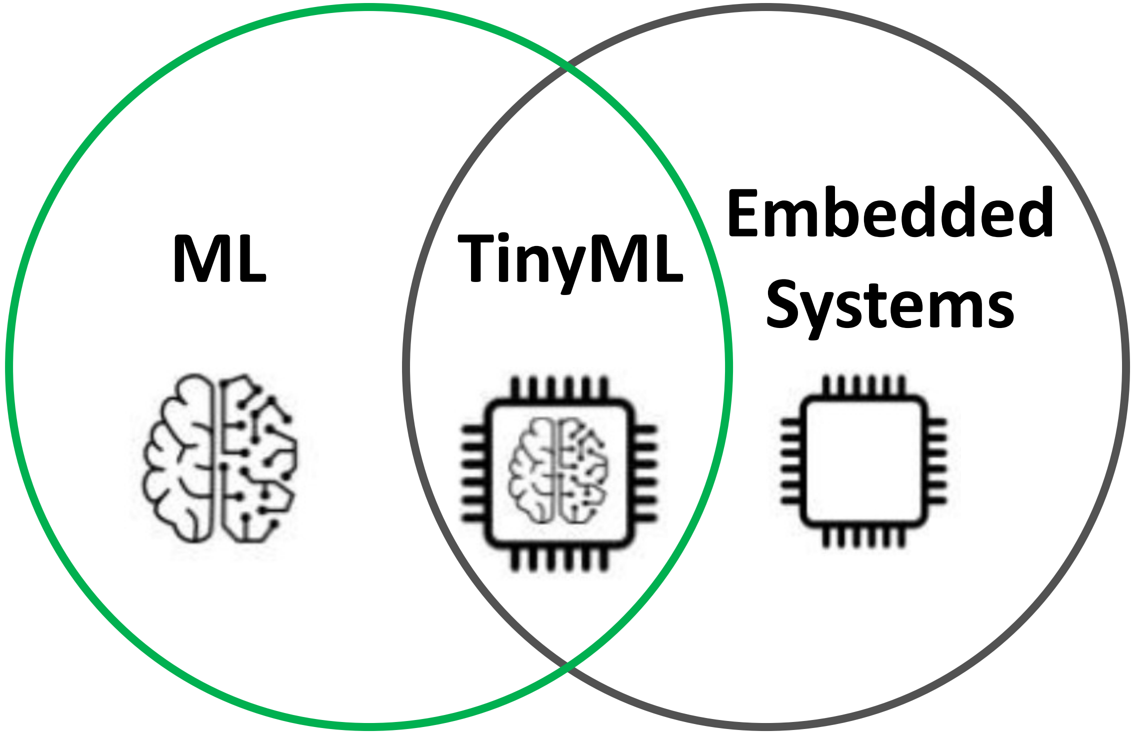
ELECTRICAL & COMPUTER ENGINEERING

UNIVERSITY of WASHINGTON

Foundations and Applications of TinyML

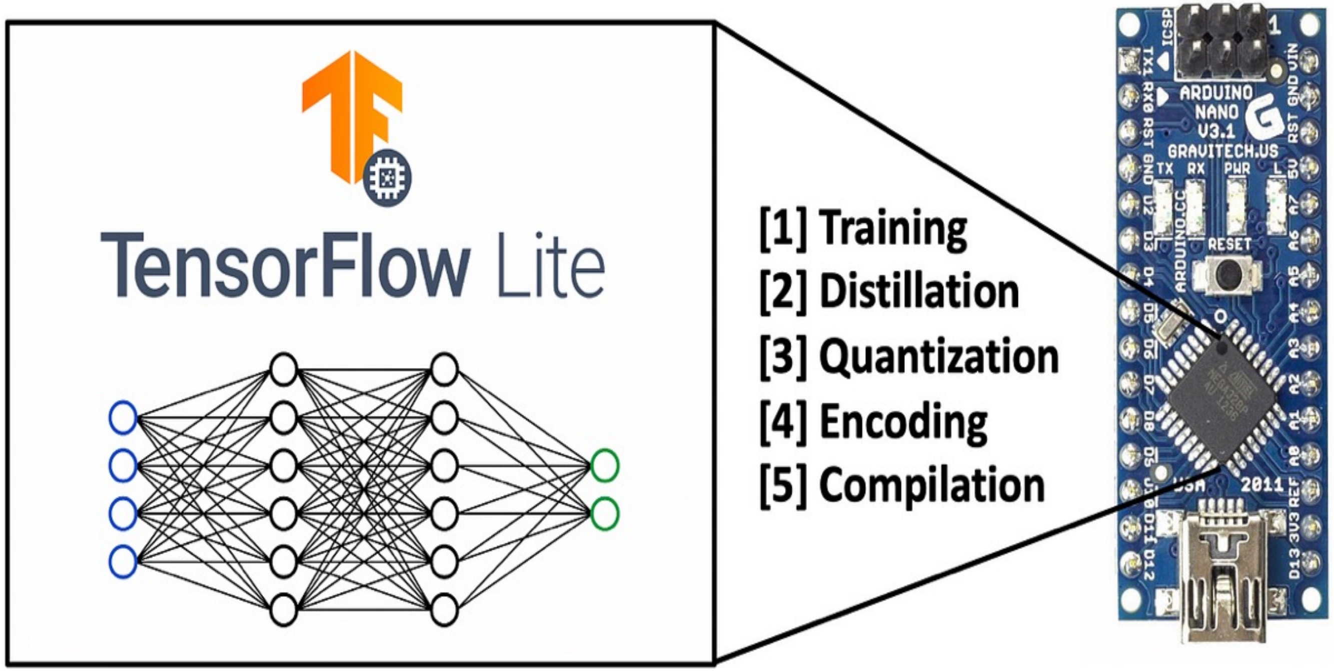
- **TinyML:** Emerging area where **ultra large powerful ML models are converted into executables for embedded systems** that are battery operated and mostly well beyond the operation capacity of the smart phones (e.g., microcontrollers)



ML

TinyML

Embedded Systems

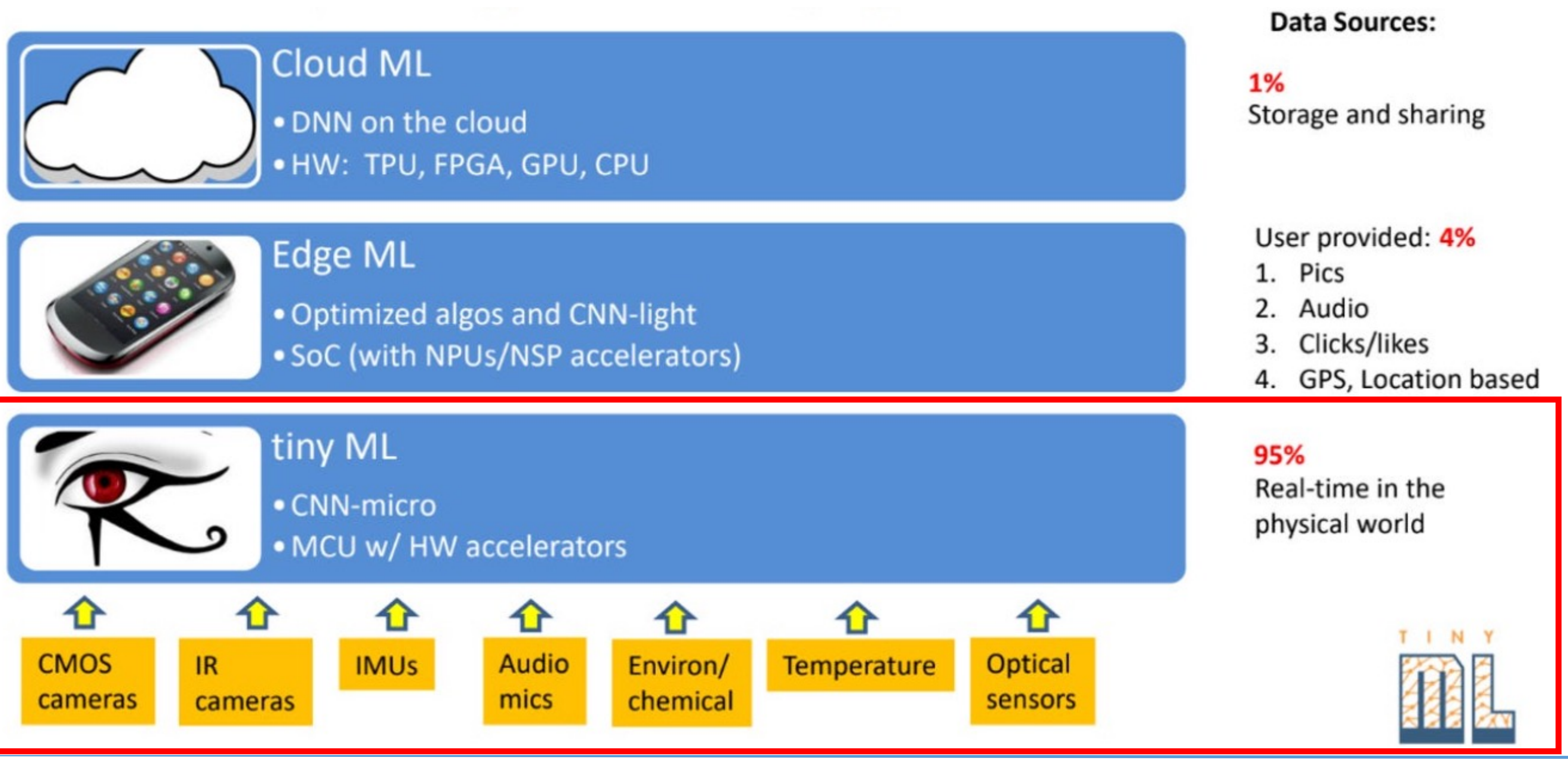


[1] Training
[2] Distillation
[3] Quantization
[4] Encoding
[5] Compilation

Source: https://towardsdatascience.com/tiny-machine-learning-the-next-ai-revolution-495c26463868

Foundations and Applications of TinyML

- TinyML is **real-time processing of time-series data that comes directly from sensors**



Data Sources:

Cloud ML
- DNN on the cloud
- HW: TPU, FPGA, GPU, CPU

1%
Storage and sharing

Edge ML
- Optimized algos and CNN-light
- SoC (with NPUs/NSP accelerators)

User provided: **4%**
1. Pics
2. Audio
3. Clicks/likes
4. GPS, Location based

tiny ML
- CNN-micro
- MCU w/ HW accelerators

95%
Real-time in the physical world

CMOS cameras | IR cameras | IMUs | Audio mics | Environ/ chemical | Temperature | Optical sensors

Source: https://www.tinyml.org/about/

Foundations and Applications of TinyML

- TinyML has **applications in agriculture, health, retail, energy industry**, and more…

Plant disease classification with TensorFlow Lite on Android

Source: https://yannicksergeobam.medium.com/plant-disease-classification-with-tensorflow-lite-on-android-part-2-c2d47371cea3

Solar Scare Mosquito: A solar-operated device that sits on stagnant water to create air bubbles at regular intervals to avoid the breeding of mosquitoes

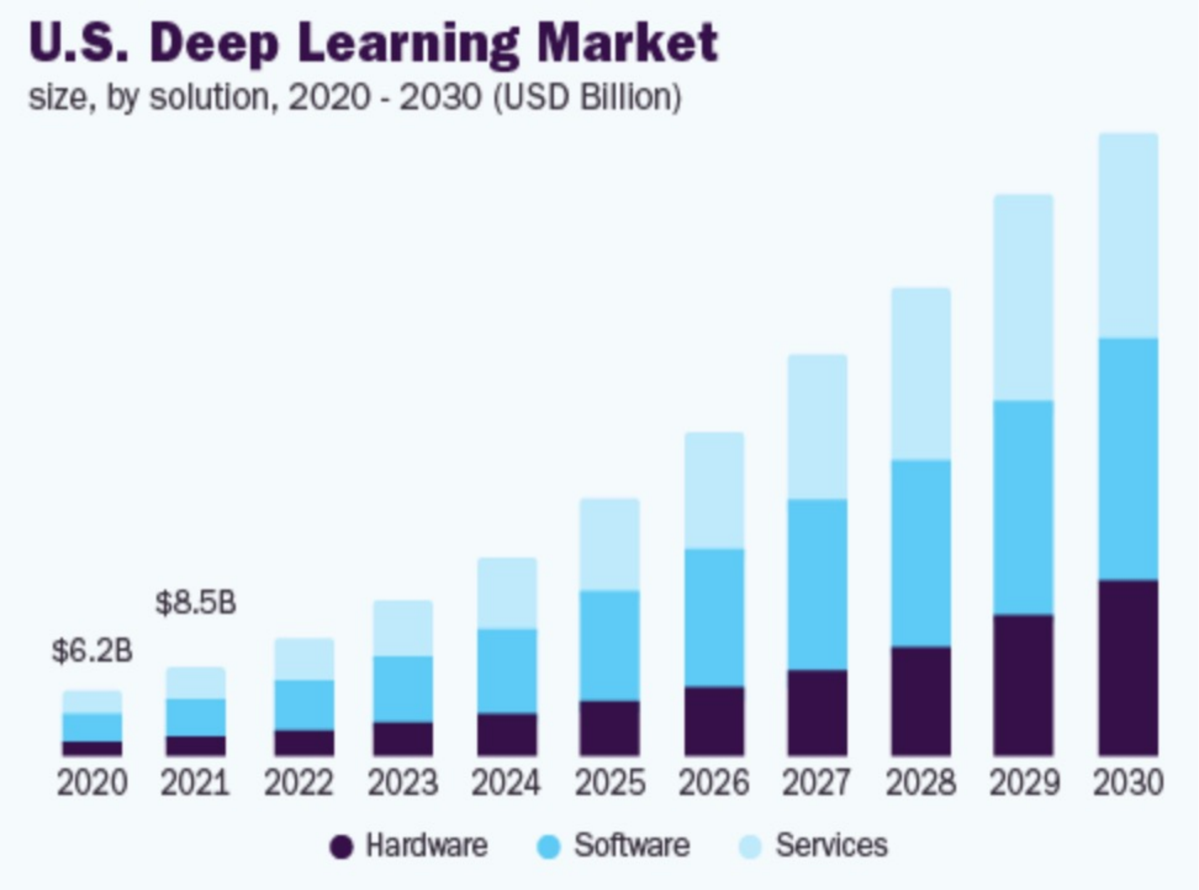
Source: https://theindexproject.org/award/nominees/6558

TinyML for keeping an eye on the inventory of goods on the shelf in retail establishments and sending out warnings when it runs low

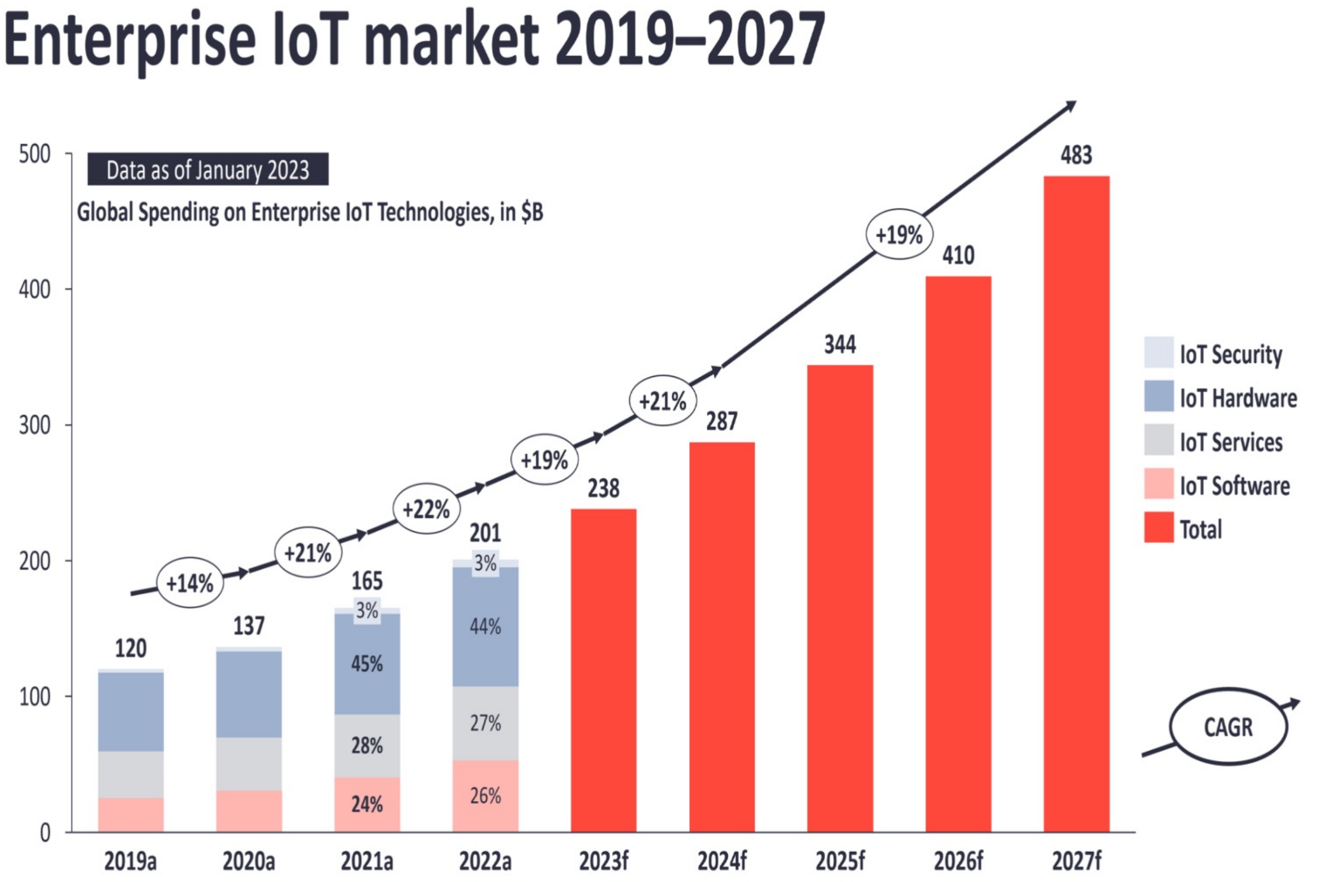
Source: https://www.supermarketnews.com/store-design-construction/amazon-go-goes-smaller

Foundations and Applications of TinyML

- Trend in ML and IoT (TinyML) market

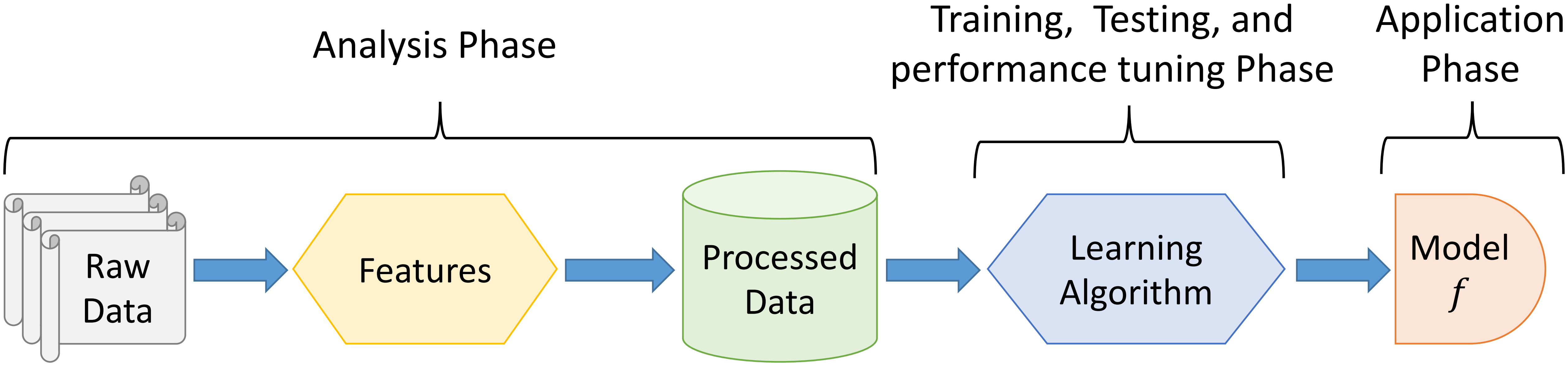


Source: https://www.grandviewresearch.com/industry-analysis/deep-learning-market

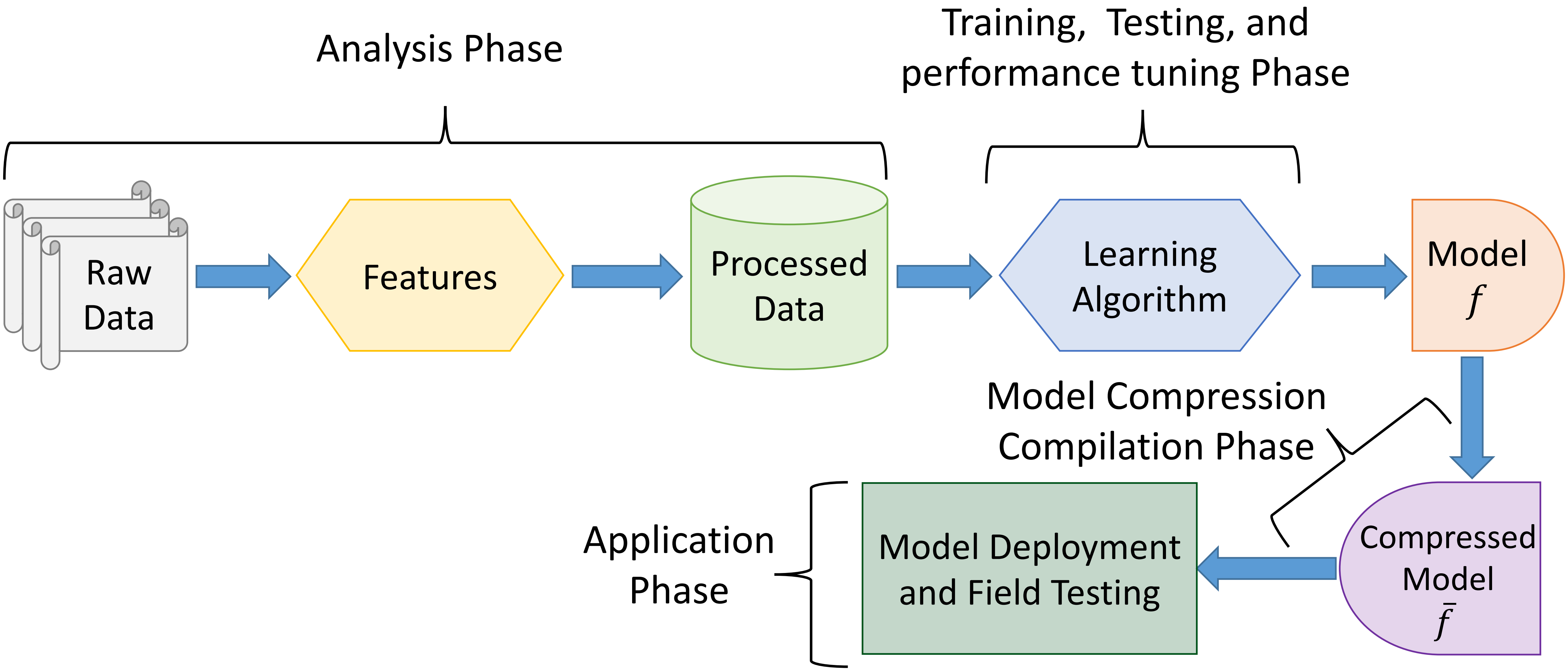


Source: https://h9e3r9w2.rocketcdn.me/wp/wp-content/uploads/2023/02/IoT-market-size-2019-2027.png

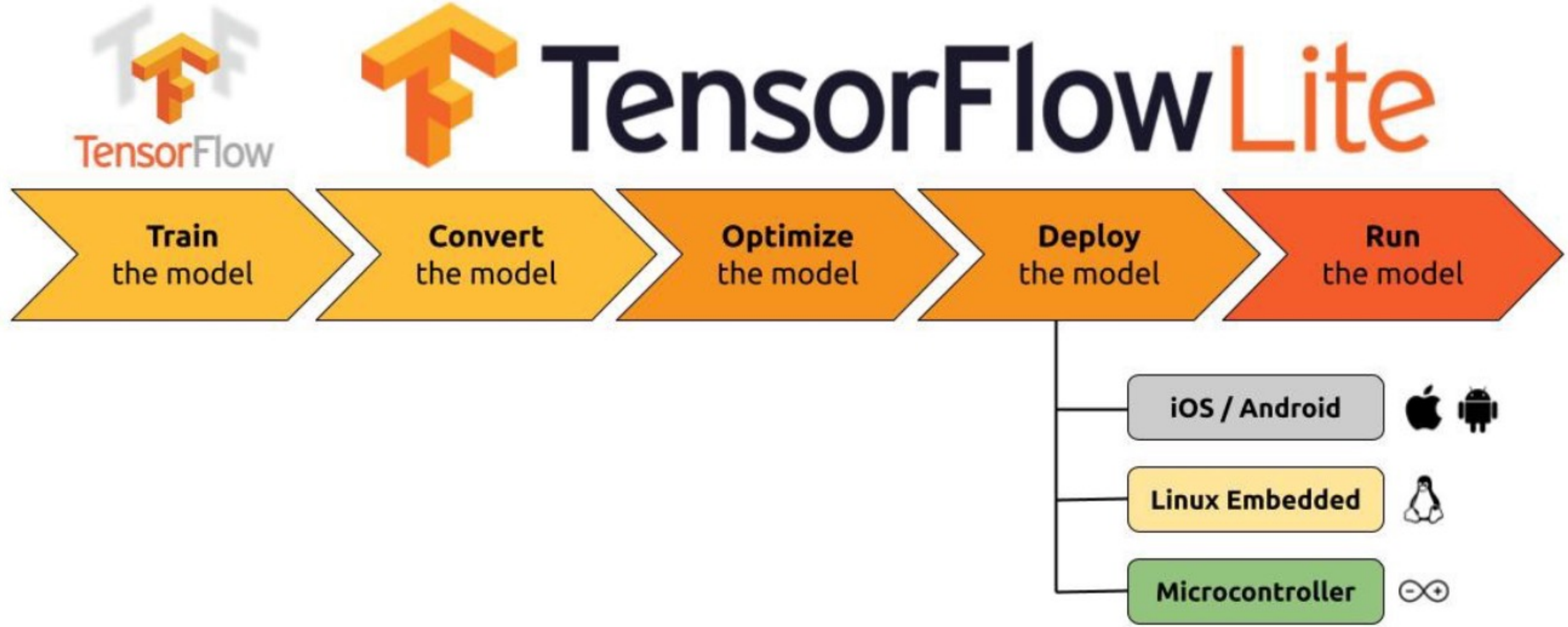
A Schematic View of ML and Its Phases



A Schematic View of TinyML and Its Phases


Analysis Phase
Training, Testing, and performance tuning Phase
Raw Data
Features
Processed Data
Learning Algorithm
Model f
Model Compression Compilation Phase
Compressed Model $\bar{f}$
Model Deployment and Field Testing
Application Phase

TensorFlow (TF) and TFLite Workflow for TinyML



Source: https://leonardocavagnis.medium.com/tinyml-machine-learning-for-embedded-system-part-i-92a34529e899

Foundations and Applications of TinyML

- **One of the first courses to bring ML, embedded systems, and IoT together**
- First two weeks of classes will cover **Fundamentals of ML/TinyML**
- From week 3 – week 9, we will study **one real-word TinyML application per class**. Each problem will have a real-world dataset to work on
- From week 3 – week 9, **first half** of each class will focus on the **needed background of the real-world application** to be studied that week. The **second half** is on learning to **train ML model, deploy TinyML model, and test the performance**
- All labs use **Python and C for coding**, and **we will provide needed modules** and also **work with the students during the labs**

Prerequisites

- Familiarity with Python programming: This will be beneficial as Python is a commonly used language in machine learning and deep learning applications
- Basic understanding of C or C++: Familiarity with one of these programming languages is beneficial, especially for deploying compressed machine/deep learning models onto Arduino, which is a key component of the TinyML course
- No prior coursework in machine/deep learning is necessary: We will introduce and cover the essential basics of machine/deep learning in the first two weeks. Additionally, we will explore these concepts in greater depth with respect to various applications studied from week 3 to week 9

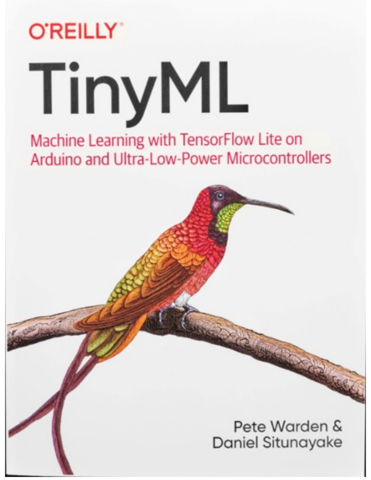
What You Will Learn

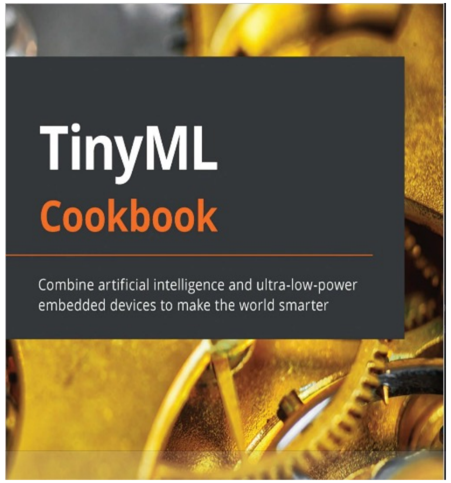
- How to **deploy TinyML models on power and performance-constraint devices to solve real-word problems**
- How to **implement machine learning algorithms** such as k-means clustering, regression, classification, and ensemble learning methods
- How to **use Python libraries** - NumPy, Pandas, Seaborn, and Scikit-learn
- Using **TensorFlow for deep learning** and **TensorFlow Lite (TFLite) for TinyML**
- Using **C language for deploying TinyML on Embedded Systems**
- How to **measure the performance** of the deployed TinyML models
- How to efficiently and effectively run TinyML

- **Course Grade will be based upon homework/projects (45%) and a final project (55%))**

Resources

- **Textbooks**:
  - **TinyML: Machine Learning with TensorFlow Lite on Arduino and Ultra-Low-Power Microcontrollers** 1st Edition by Pete Warden and Daniel Situnayake
  - **TinyML Cookbook** by Gian Marco Lodice


O'REILLY
TinyML
Machine Learning with TensorFlow Lite on Arduino and Ultra-Low-Power Microcontrollers
Pete Warden & Daniel Situnayake


TinyML
Cookbook
Combine artificial intelligence and ultra-low-power embedded devices to make the world smarter

- **Free Online Material**:
  - **TinyML Foundation**: https://www.tinyml.org
  - **Cainvas Platform**: https://cainvas.ai-tech.systems/gallery/

TINY ML

Cainvas

- **Software and Hardware**:
  - **TensorFlow Lite:** https://www.tensorflow.org/lite
  - Tiny Machine Learning Kit Arduino (~$60)

TensorFlow Lite

Course Summary: Topics Covered

- **Week 1: Introduction to TinyML**
  - TinyML Landscape and Related Statistics
  - TinyML Applications
  - TinyML Challenges
  - Introduction to Software and Hardware Used in the Course
- **Week 2: Fundamentals of ML and TinyML**
  - Background on ML: Curve Fitting, Prediction, Overfitting vs. Underfitting
  - Background on Neural Networks: DNNs, CNNs, Dataset Split (Train, Test, and Validation)
  - TinyML Lifecycle and Workflow
  - Quantization Aware Training (QAT) and Post Training Quantization (PTQ)
  - Tiny Deep Learning
  - TensorFlow Lite (TFLite) for TinyML

Course Summary: Topics Covered

- **Week 3: TinyML for Keyword Spotting**
  - Background on Keyword Spotting and Streaming Audio
  - Challenges and Constraints in Keyword Spotting
  - Keyword Spotting Architecture and Data Collection
  - Model Training, Evaluation Metrics, and Deployment

- **Week 4: TinyML for Visual Wake Words**
  - Introduction to Visual Wake Words and Its Challenges
  - Visual Wake Words Dataset
  - MobileNets
  - Transfer Learning for Visual Wake Words
  - Model Training, Evaluation Metrics, and Deployment

Course Summary: Topics Covered

- **Week 5: TinyML for Anomaly Detection**
  - Background on Anomaly Detection and Signal Processing
  - Real and Synthetic Datasets
  - Unsupervised Learning (K-Means Clustering and Autoencorders)
  - Threshold Choice
  - Model Training, Evaluation Metrics, and Deployment

- **Week 6: Robust navigation with TinyCNN**
  - Background on robust low power autonomous driving and challenges
  - Closed loop learning system via Imitation Learning
  - TinyML Approach to replace conventional CVA by CNN
  - Data collection and modeling
  - Model Training, Evaluation Metrics, and Deployment

Course Summary: Topics Covered

- **Week 7: TinyML for Predictive Maintenance**
  - Background on Predictive Maintenance Solutions and Industry Applications
  - Sensors, Sensor Data, and Interface
  - Accelerometer, Gyroscope, Barometer, and Magnetometer
  - TinyML Framework for Predictive Maintenance
  - Model Training, Evaluation Metrics, and Deployment

- **Week 8: TinyML for American Sign Language (ASL) Interpretation**
  - Background on ASL and ASL Interpretation
  - Gesture Motion Datasets and Features
  - Analyzing Gesture Motion Data using Neural Networks
  - TinyML Framework for ASL Interpretation
  - Model Training, Evaluation Metrics, and Deployment

Course Summary: Topics Covered

- **Week 9: Smart Lock Recognition using TinyML**
  - Audio classification for deploying sensitive smart lock model
  - Data processing on audio data
  - Generate, train, and test a TensorFlow model using the SensiML Python SDK
  - Compile and flash the model to the edge device and display the inferred classes in the SensiML Open Gateway user interface

- **Week 10: Final Project Presentations**
  - **Each Group has 12 minutes (Suggested presentation – 9 minutes; Q&A— 3 mins)**
  - **Signup for the presentation order (Same as the project signup)**
- **Final report due on June 7th 11:59pm, 2024**