tinyML® Research Symposium

Enabling Ultra-low Power Machine Learning at the Edge

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TINY ML

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1

Comparing classic ML techniques with DL for tiny ML human activity recognition

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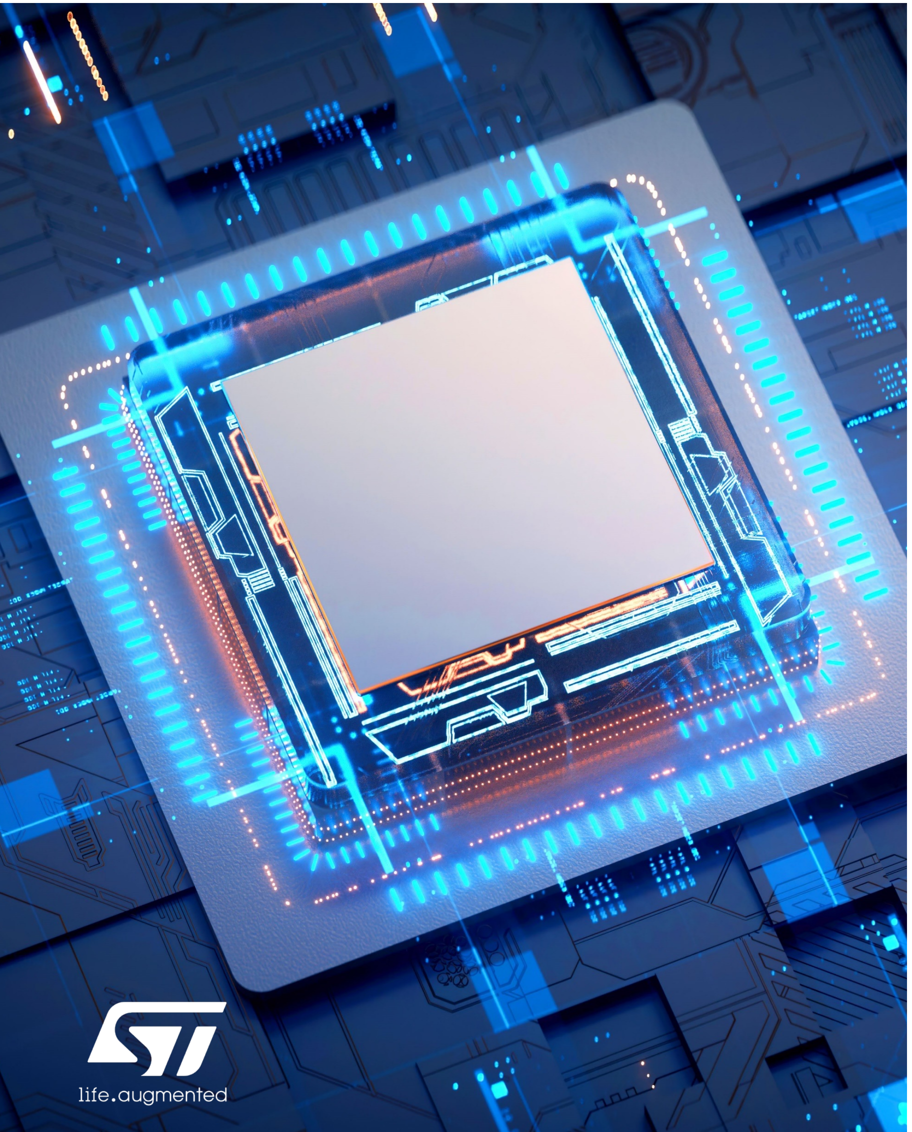
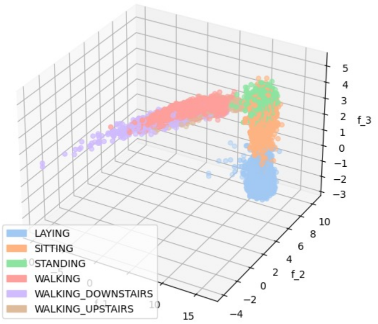
Introduction



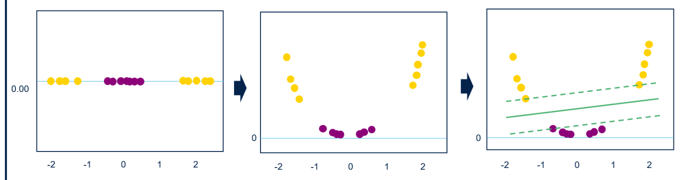
- Analysis and classification of Human Activity Recognition (HAR) on MCUs using inercial sensors
  - running, walking, climbing up and down stairs
- Compare the inference time, memory density and power consumption when using:
  - Classic ML Algorithms
  - DL
  - Add PCA before the ML and DL
- Expected Benefits:
  - Lower complexity
  - Lower memory cost
  - Faster inference

Main ML and DL algorithms

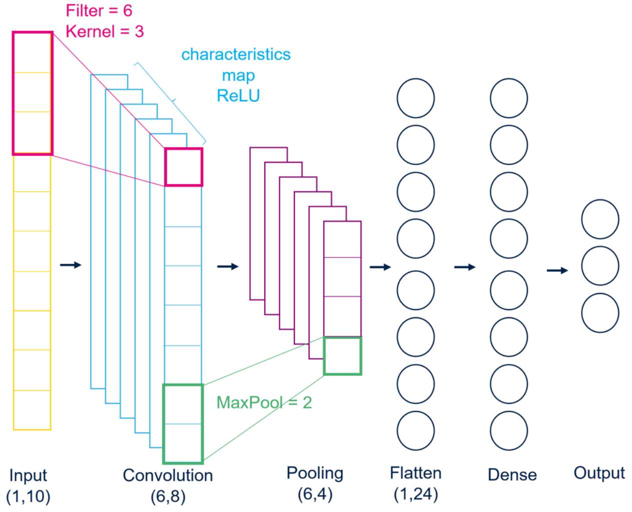
Principal Component Analysis



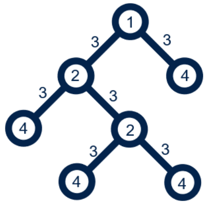
Support Vector Machine



1 Dimensional Convolution Neural Network

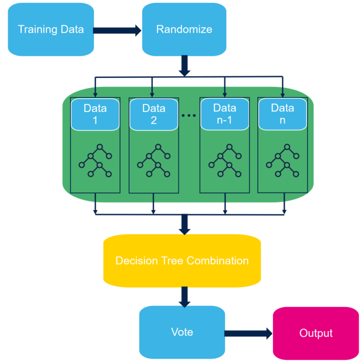


Decision Tree Regressor



1. Root Node
2. Chance Node
3. Branch
4. Leaf Node

Random Forest



All images created by the author

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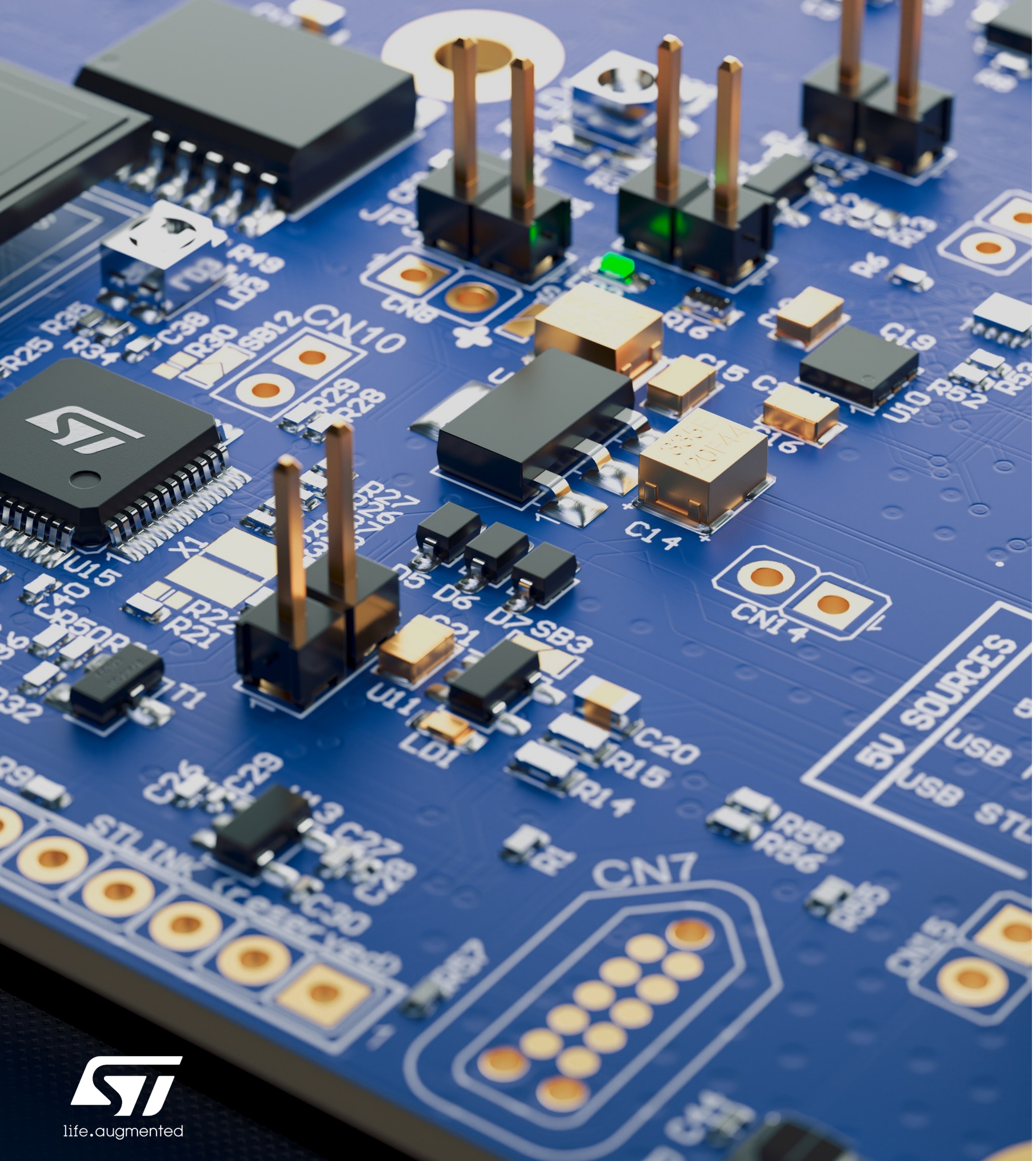

Resources

- Open data sets used:
  - UCI HAPT
  - STMicroelectronics HAR

- Software and framework:
  - Python:
    - Scikit-Learn / Keras / TensorFlowLite
  - Model export
    TFLite / ONNX / MicroML (raw C)
  - Embedded C
    - STM32CubeIDE + X-CUBE-AI

- Hardware:
  - B-U585I-IOT02A
  - X-NUCLEO-LPM01A

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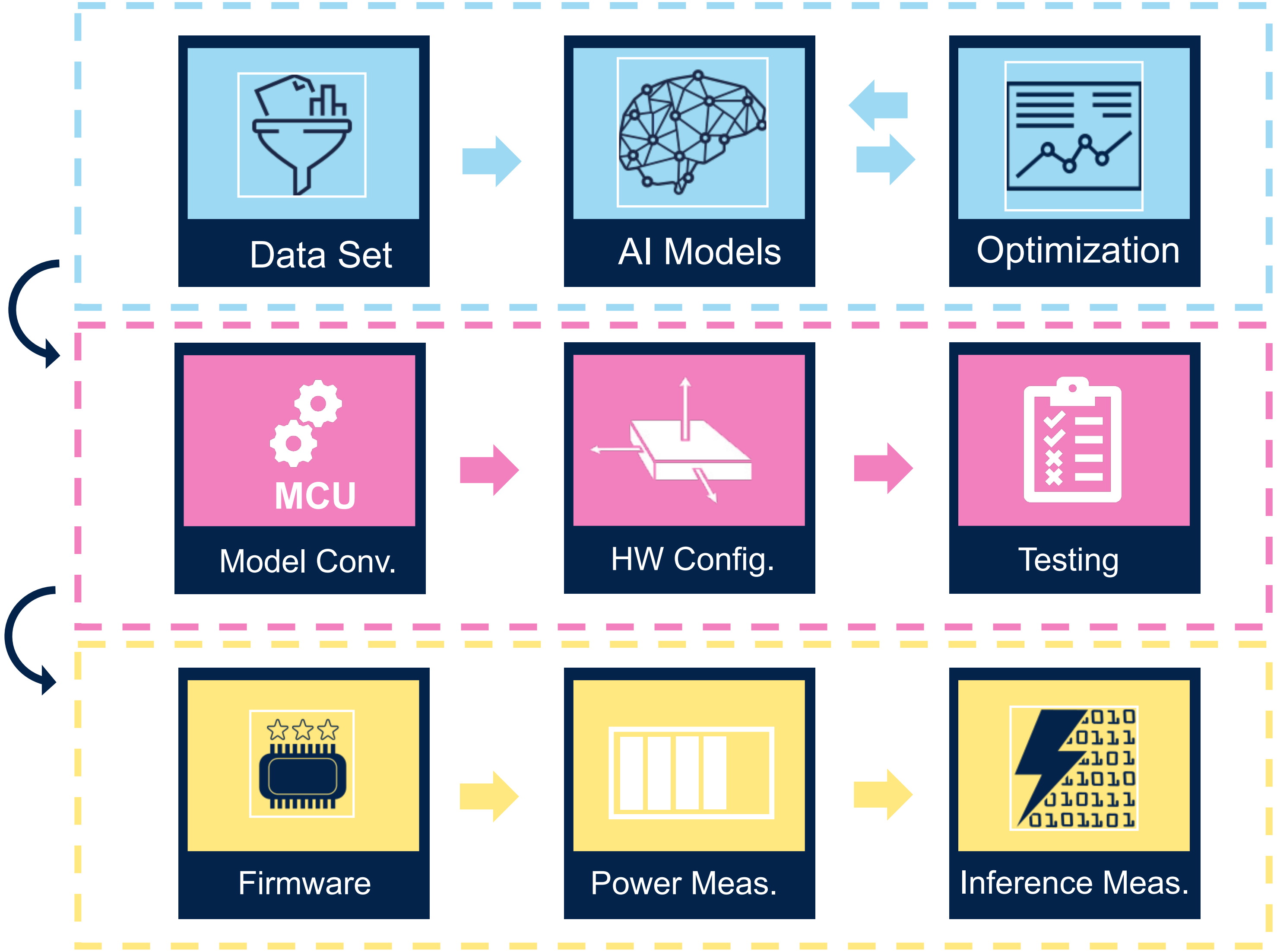
Methodology – from design to test



Model creation, adjustments and evaluation

Model conversion and Hardware setup

Firmware deployment and measurements

Experiments and results

- Inference time and memory for all evaluated models running on the ARM Cortex M33
  - Balanced memory optimization
  - 8bit Quantization (PTQ)

- Model evaluation
  - Accuracy and confusion matrix

- Power consumption
  - MCU was placed in STOP2 mode when not executing the model with full RAM retention

Basic Information and Characteristics		
Microcontroller	STM32U575 @ 160Mhz	
Run Mode	Typ. 7.15 mA @ 44.7uA/MHz	
Low Power Mode	106uA for the entire board / MCU 19.5uA	
External Memories	512-Mbit NOR / 64-Mbit PSRAM	
Internal Memories	2MB FLASH / 786 KB SRAM	
MEMS Settings	ODR = 50Hz	ODR = 26Hz
Datasets	UCI HAPT	STMicroelectronics
Input Size	(561,1)	(26,3)
PCA Cost (FLASH/RAM)	217.51 KB 4.51 KB	23.42 KB 0.17 KB
AI Models Explored	DTR, RF, SVM and 1DCNN	

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Avg Results

UCI HAPT

UCI HAPT			
Model	**FLASH (KB)**	**RAM (KB)**	**Inference (ms)**
DTR	13.34	3.72	0.023
PCA+DTR	217.51+23.19	4.51+3.72	15.4+0.054
RF	49.36	3.72	0.149
PCA+RF	217.51+112.18	4.51+3.72	15.4+0.328
SVM	13575.70	52.23	178
PCA+SVM	217.51+296.27	4.51+28.62	15.4+2.66
CNN	1131.22	55.00	28.4
PCA+CNN	217.51+41.22	4.51+3.91	15.4+0.7

ST

ST			
Model	**FLASH (KB)**	**RAM (KB)**	**Inference (ms)**
DTR	12.09	1.63	0.023
PCA+DTR	23.42+12.93	0.17+1.59	2.08+0.027
RF	47.53	1.63	0.148
PCA+RF	23.42+38.06	0.17+1.59	2.08+0.138
SVM	658.57	30.52	15.48
PCA+SVM	23.42+200.79	0.17+16.24	2.08+10.19
CNN	60.84	4.84	1.34
PCA+CNN	23.42+40.46	0.17+3.91	2.08+0.7

Power consumption

Model	STMICROELECTRONICS	UCI HAPT
	Avg. Current (uA)	Avg. Current (uA)
PCA + DTR	122	214
PCA + RF	123	218
PCA + SVM	191	239
1DCNN	122	352
PCA + 1DCNN	164	226

Accuracy

Model	STMICROELECTRONICS	UCI HAPT
	Accuracy %	Accuracy %
DTR	94.61	98.32
PCA + DTR	98.32	97.63
RF	96.38	95.44
PCA + RF	97.28	94.19
SVM	94.78	94.80
PCA + SVM	94.55	94.37
1DCNN	99.19	99.38
PCA + 1DCNN	97.80	91.65

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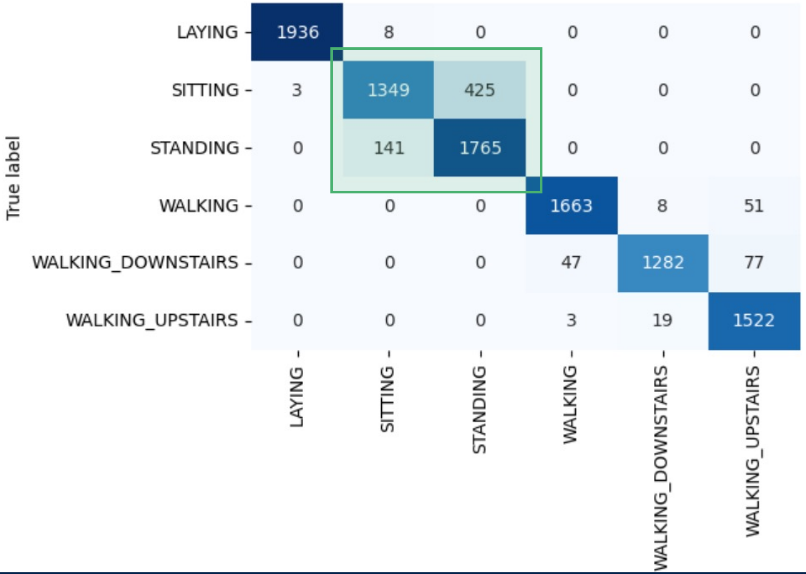
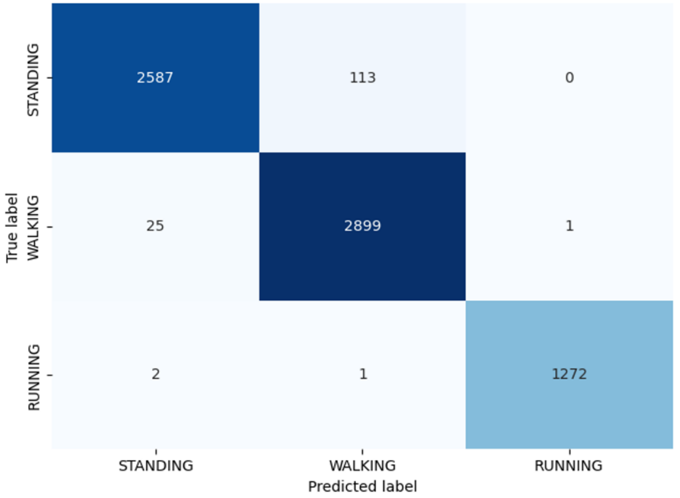
Best Results

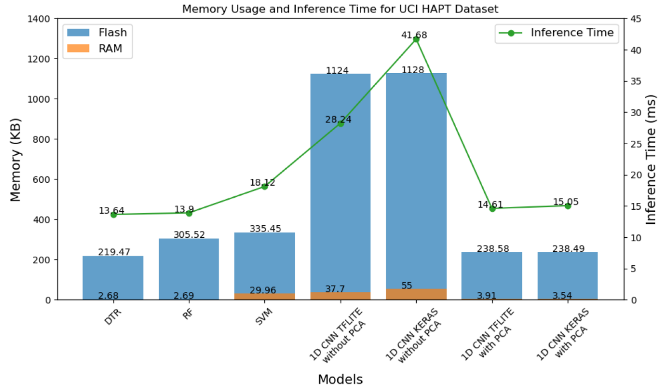
UCI HAPT (PCA+1DCNN)



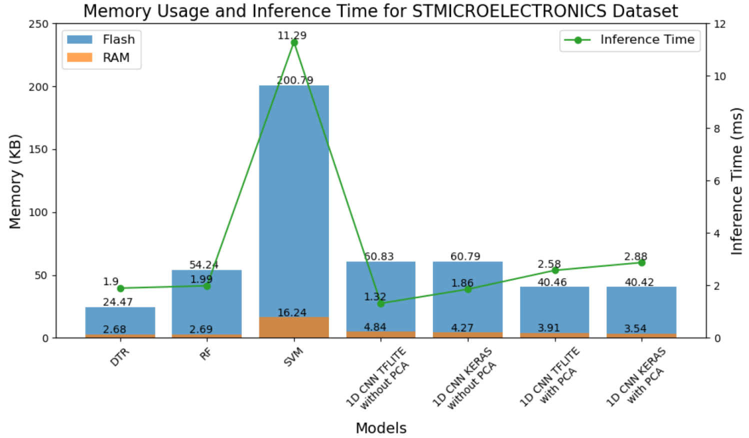
ST (PCA+1DCNN)

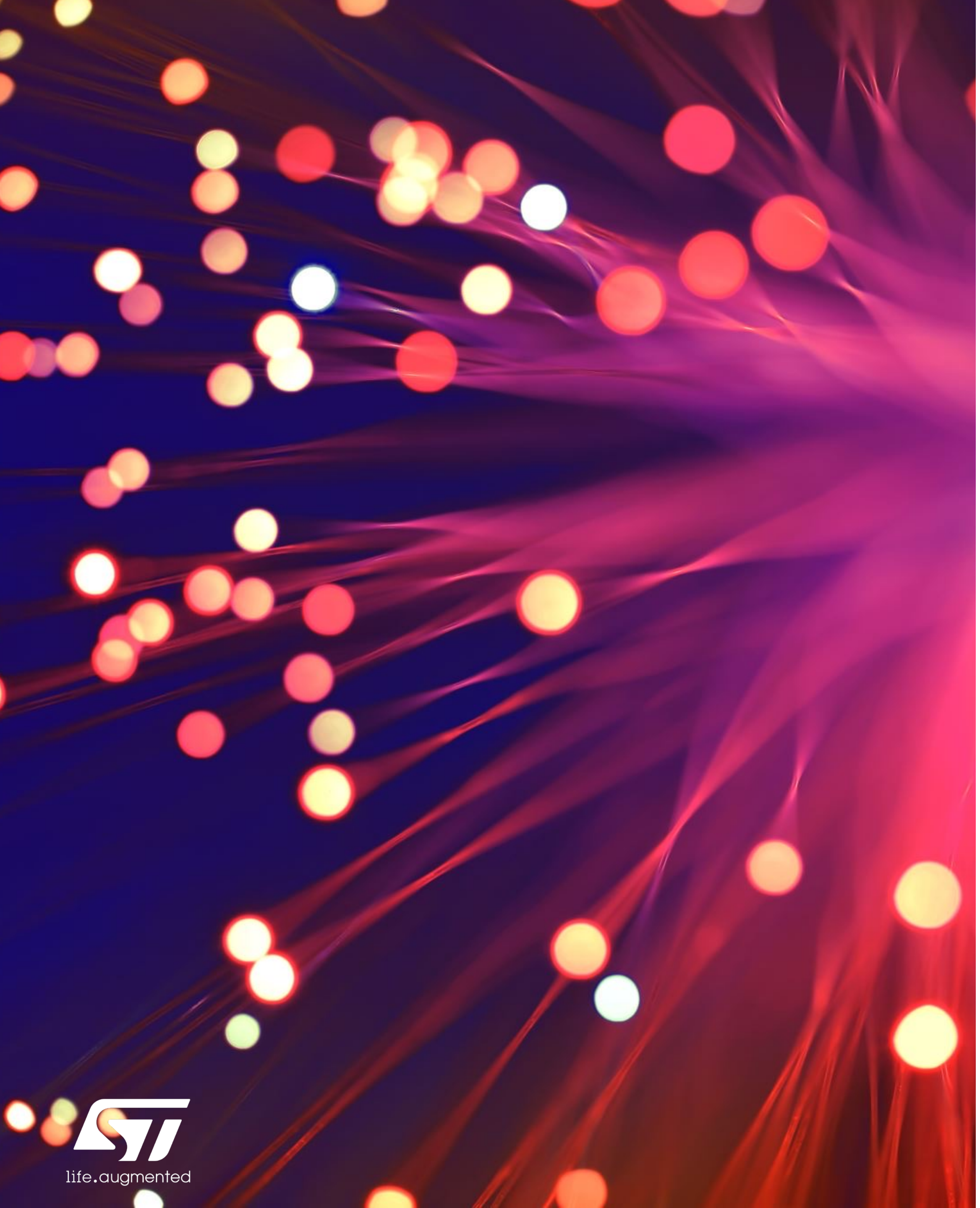


UCI HAPT



ST





Key takeaways

- DTR proved to be an interesting alternative to 1DCNN for the data sets used
- Selective Advantage of PCA: Incorporating it can lead performance improvements
- Benefits of PCA are not uniform across all algorithms and must be weighed against the increased computational cost for others
- The combination of PCA + 1DCNN provided an equivalent memory and inference time, but with lower complexity
- https://github.com/brunomontanari/TinyMLSymposium2024

Future work

- Evaluate more datasets
  - WISDM
  - PAMP2
  - UniMib
  - SHL

- Exploring various optimization and quantization methods available
  - TFLITE
  - X-CUBE-AI

- Adapting tinyML frameworks to compare classic ML and DL for FL scenarios
  - Benefits of lowering the AI model complexity

Questions?

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