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► **To cite this version:**

Antoine Bonneau, Frédéric Le Mouël, Fabien Mieleville. Ultra Low Power Ambient Artificial Intelligence. Journées sur la recherche en apprentissage frugal (JRAF), Grenoble INP; Inria; EcoInfo, Nov 2022, Grenoble, France. hal-03986104

HAL Id: hal-03986104

<https://hal.science/hal-03986104v1>

Submitted on 13 Feb 2023

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Ultra Low Power Ambient Artificial Intelligence

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JRAF - Grenoble - Nov. 2022

1 Use Cases & Context

- Ampere's active control platform
- CITI's Cortex Lab
- Ambient / Frugal AI
- Thesis Subject

2 Research key points / State of the art (SoA)

- On-Device Learning
- Intermittent Learning
- Federated Learning

3 Work plan

Ampère's active control platform

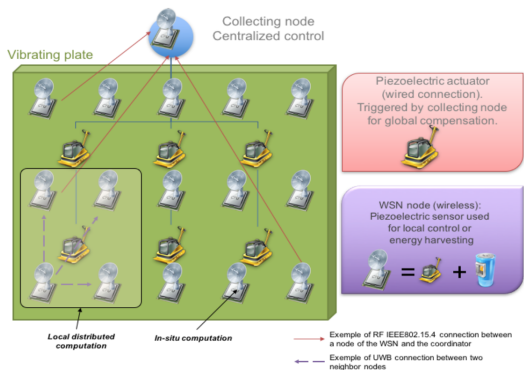


Figure 1: Ampère's vibrating bench

► Issues

- Vibration Reduction
- Energy Harvesting

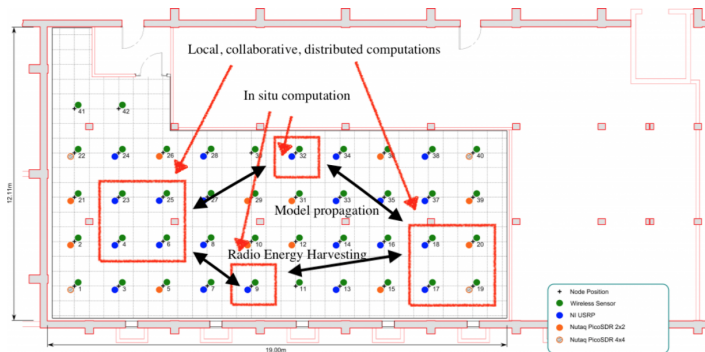


Figure 2: Nodes and activation example in Cortex Lab platform

► Issues

- reallocate / power off antennas
- max covering / bandwidth / homogeneity
- min interferences

- ▶ Ambient Intelligence (Aml)¹
 - ▶ embedded
 - ▶ context-aware
 - ▶ adaptive
 - ▶ anticipatory

- ▶ Frugal Artificial Intelligence (Frugal AI)²
 - ▶ input : less data
 - ▶ learning process : less computational resources
 - ▶ model : less memory
 - ★ reduced energy consumption

¹E. Aarts [Jan. 2004]. “Ambient intelligence: a multimedia perspective”. In: *IEEE Multimedia*. DOI: [10.1109/MMUL.2004.1261101](https://doi.org/10.1109/MMUL.2004.1261101).

²Mikhail Evchenko et al. [Nov. 2021]. *Frugal Machine Learning*. DOI: [10.48550/arXiv.2111.03731](https://doi.org/10.48550/arXiv.2111.03731).

- ▶ Started last month : \sim 20 papers selected
- ▶ Goals
 - ▶ Deployment of a WSN as a monitoring and adaptive action solution
 - ▶ Minimal footprint energy aiming for autonomy
 - ▶ Exploiting networking AI to improve and maintain itself
- ★ Energy efficiency as a cross-cutting topic
- ▶ Focus on Time Series data (reduced feature set and samples)

Outline : State of the Art

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SoA On-Device Learning : Resources constrained learning

- ▶ Target : WSN Nodes \rightarrow IoT low-end devices [Ojo et al. 2018]

MCU Arch	Clock speed	On-Board Storage	RAM	Current
16 or 32 bit	≤ 50 MHz	≤ 512 KB	≤ 64 KB	≤ 10 mA

- ▶ Memory constraints \rightarrow Compressed Models [Profentzas et al. 2022]
 - ▶ Pruning
 - ▶ Quantization
 - ▶ Encoding
- ▶ Computation constraints \rightarrow Preprocessed Models [Lin et al. 2022]
 - ▶ Transfer Learning
 - ▶ Fine Tuning

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- ▶ Quantization
- ▶ Encoding

Use 2-3 \times more RAM

- ▶ Computation constraints \rightarrow Preprocessed Models [Lin et al. 2022]

- ▶ Transfer Learning
- ▶ Fine Tuning

Tested on IoT middle-end device
No energy consumption evaluation

SoA Intermittent Learning : Duty cycling

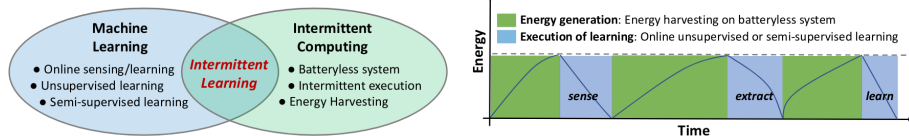


Figure 3: Intermittent Learner duty [Lee et al. 2019]

- ▶ Energy Harvesting → Extreme power scarcity
 - ▶ checkpointing approaches
 - ▶ task-based approaches [Lee et al. 2019]
- ▶ Changes in energy availability → Energy-aware reconfiguration [Bakar et al. 2021]
 - ▶ peripheral selection / sensor sampling
 - ▶ communication pattern

SoA Intermittent Learning : Duty cycling

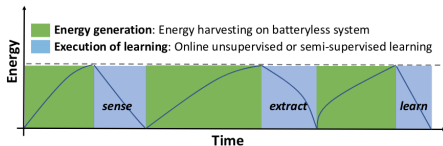
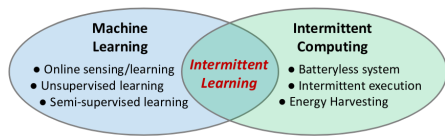


Figure 3: Intermittent Learner duty [Lee et al. 2019]

- ▶ Energy Harvesting → Extreme power scarcity
 - ▶ checkpointing approaches
 - ▶ task-based approaches [Lee et al. 2019]
- Do not consider powering off by itself**
- ▶ Changes in energy availability → Energy-aware reconfiguration [Bakar et al. 2021]
 - ▶ peripheral selection / sensor sampling
 - ▶ communication pattern
- Use tiny machine learning model instead of heuristics**

SoA Federated Learning : Bypass computational weaknesses

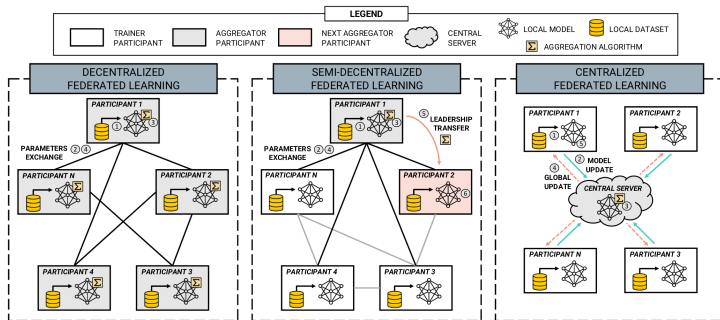


Figure 4: DFL architectures [Beltrán et al. 2022]

- ▶ Learning in a spatially correlated group → Adaptive Neighbor Matching [Z. Li et al. 2022]
- ▶ Costly communication → reduce shared weights [C. Li et al. 2021]

SoA Federated Learning : Bypass computational weaknesses

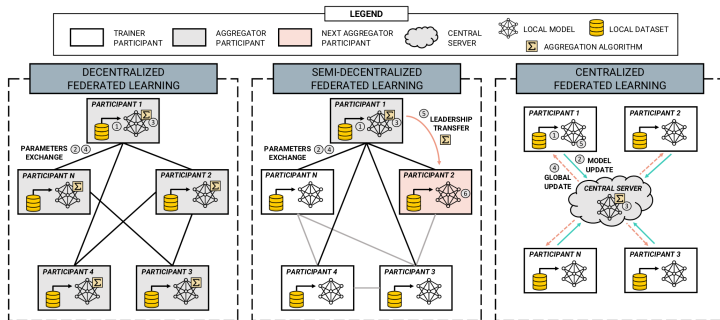


Figure 4: DFL architectures [Beltrán et al. 2022]

Do not evolve with changes & resource-consuming

- ▶ Learning in a spatially correlated group → Adaptive Neighbor Matching [Z. Li et al. 2022]
 - ▶ Costly communication → reduce shared weights [C. Li et al. 2021]
- Use a centralized FL Algorithm

1 Use Cases & Context

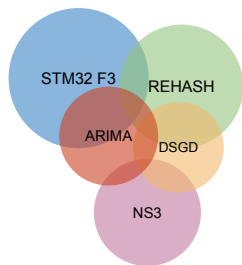
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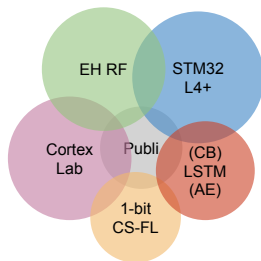
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- Federated Learning

3 Work plan

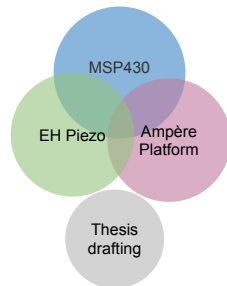
Work plan ... will most likely age poorly



Year 1



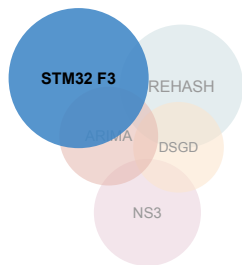
Year 2



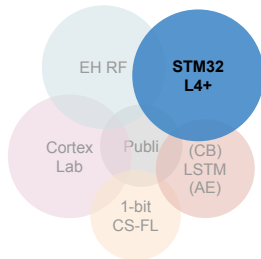
Year 3



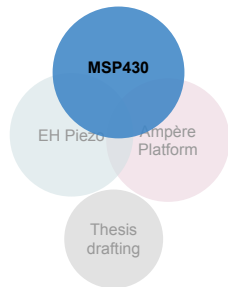
Work plan ... will most likely age poorly



Year 1



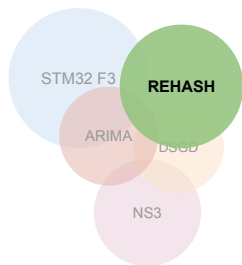
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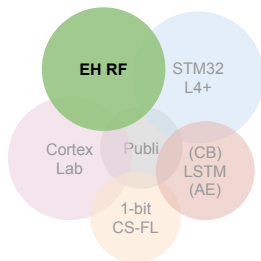
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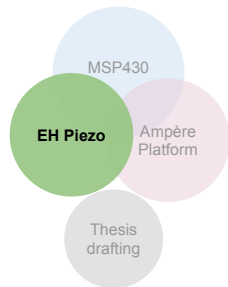
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Year 1



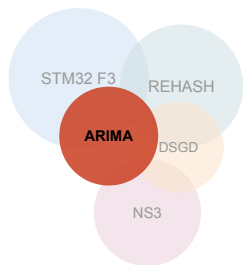
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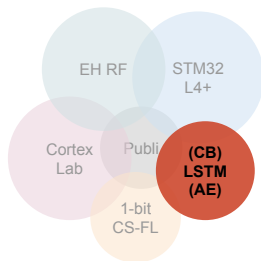
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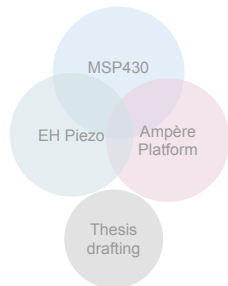
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Year 1



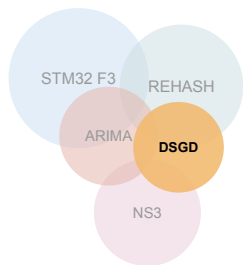
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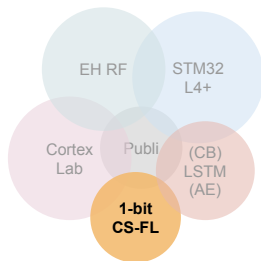
Year 3



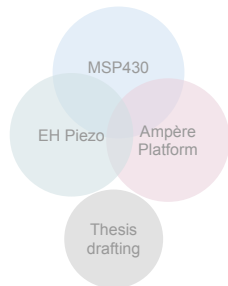
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Year 1



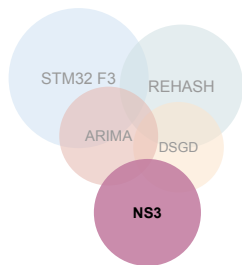
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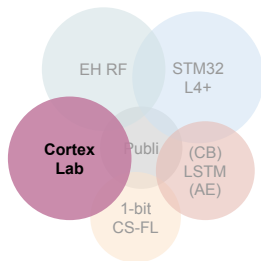
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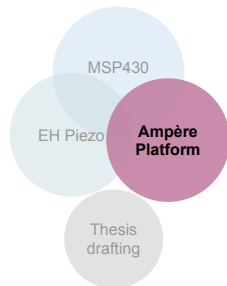
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Year 2



Year 3



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