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# Ultra Low Power Ambient Artificial Intelligence

**Antoine Bonneau**<sup>1,2</sup> Frédéric Le Mouël<sup>1</sup> Fabien Meyeville<sup>2</sup>

Contact : [antoine.bonneau@insa-lyon.fr](mailto:antoine.bonneau@insa-lyon.fr)

<sup>1</sup>Univ Lyon, INSA Lyon, Inria, CITI, EA3720, 69621 Villeurbanne, France

<sup>2</sup>Univ Lyon, Université Claude Bernard Lyon 1, INSA Lyon, Ecole Centrale de Lyon, CNRS, Ampère, UMR5005, 69622 Villeurbanne, France

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

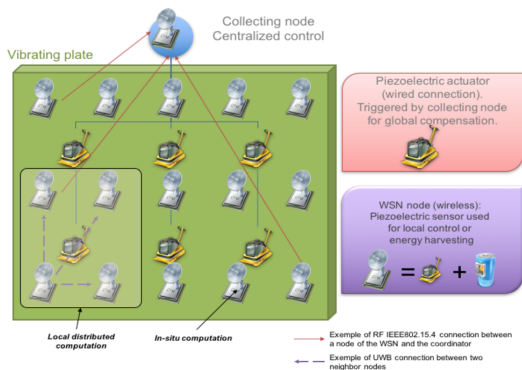


Figure 1: Ampère's vibrating bench

## ► Issues

- Vibration Reduction
- Energy Harvesting

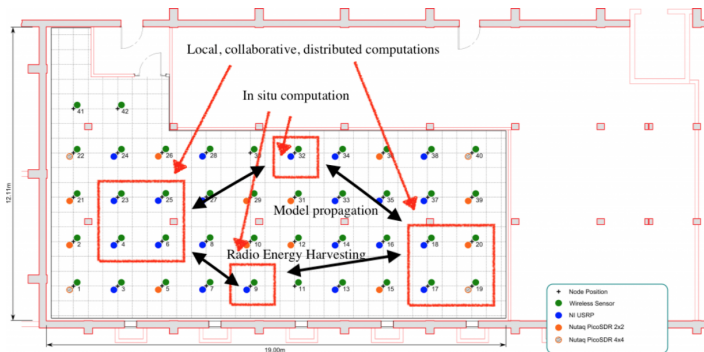


Figure 2: Nodes and activation example in Cortex Lab platform

## ► Issues

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

- ▶ Ambient Intelligence (Aml)<sup>1</sup>
  - ▶ embedded
  - ▶ context-aware
  - ▶ adaptive
  - ▶ anticipatory
  
- ▶ Frugal Artificial Intelligence (Frugal AI)<sup>2</sup>
  - ▶ input : less data
  - ▶ learning process : less computational resources
  - ▶ model : less memory
  - ★ reduced energy consumption

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<sup>1</sup>E. 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).

<sup>2</sup>Mikhail 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	$\leq 50$ MHz	$\leq 512$ KB	$\leq 64$ KB	$\leq 10$ 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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- ▶ Pruning
- ▶ Quantization
- ▶ Encoding

Use 2-3 × more RAM

- ▶ Computation constraints → 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

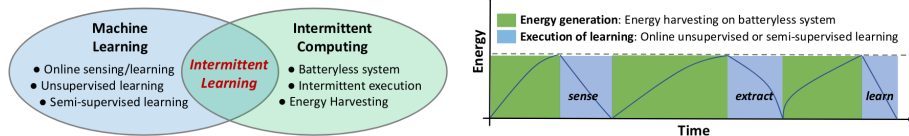


Figure 3: Intermittent Learner duty [Lee et al. 2019]

- ▶ 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

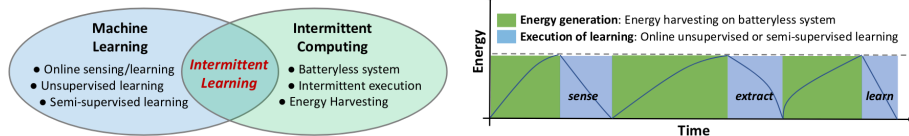


Figure 3: Intermittent Learner duty [Lee et al. 2019]

- ▶ 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

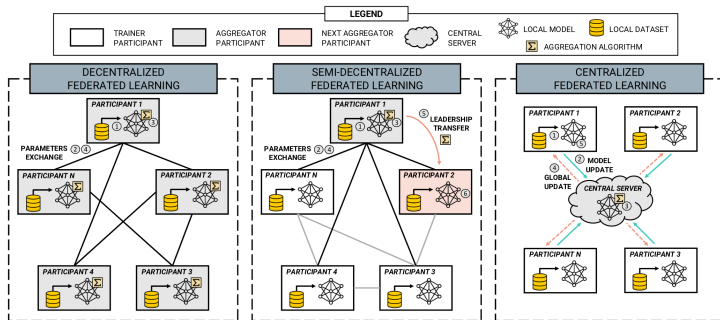


Figure 4: DFL architectures [Beltrán et al. 2022]

- ▶ 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

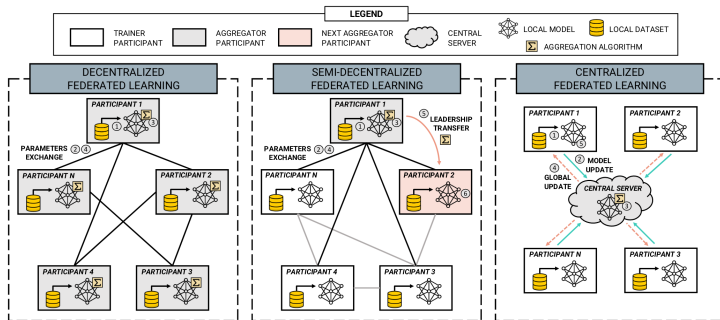


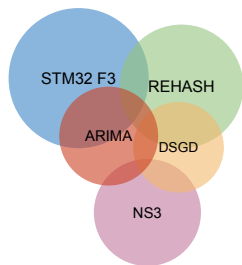
Figure 4: DFL architectures [Beltrán et al. 2022]

Do not evolve with changes & resource-consuming

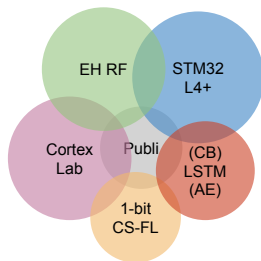
- ▶ Learning in a spatially correlated group → Adaptive Neighbor Matching [Z. Li et al. 2022]
  - ▶ Costly communication → reduce shared weights [C. Li et al. 2021]
- Use a centralized FL Algorithm

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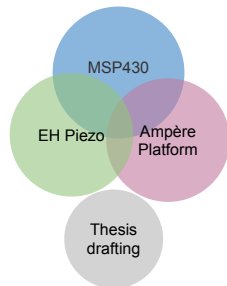
# Work plan ... will most likely age poorly



Year 1



Year 2

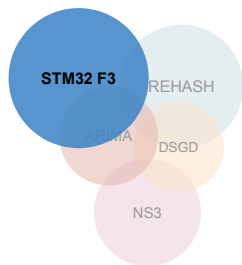


Year 3

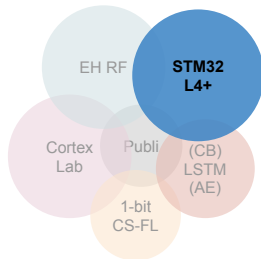




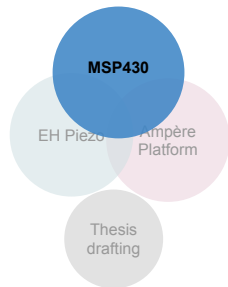
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Year 1



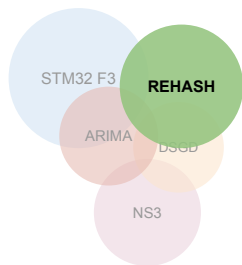
Year 2



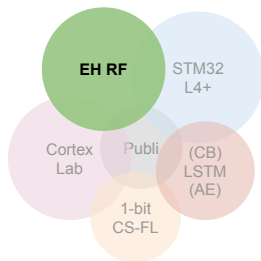
Year 3



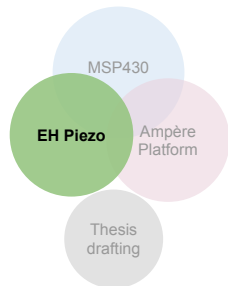
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Year 1



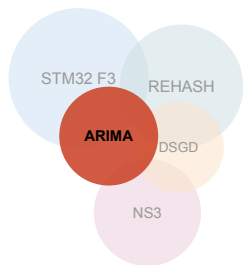
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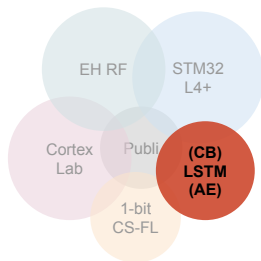
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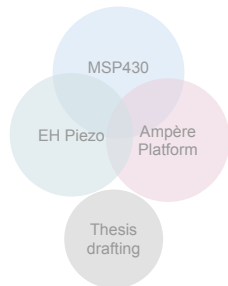
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Year 1



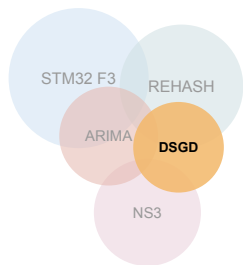
Year 2



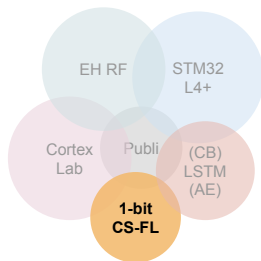
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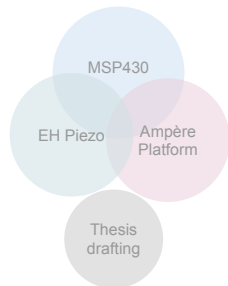
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Year 1



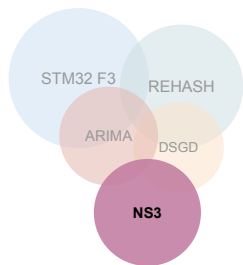
Year 2



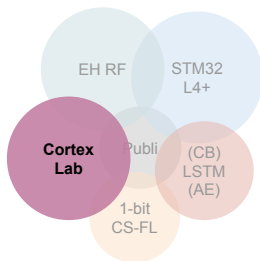
Year 3



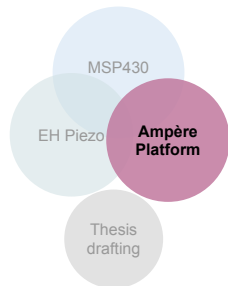
# Work plan ... will most likely age poorly



Year 1



Year 2



Year 3



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