Machine Learning on Edge in Sensor Systems (SenSys-ML 2024)

Poonam Yadav
University of York, UK
poonam.yadav@york.ac.uk

Edith C.H. Ngai
University of Hong Kong, Hong Kong
chngai@eee.hku.hk

Manik Gupta
BITS, Pilani, India
manik@hyderabad.bits-pilani.ac.in

Shaswot Shresthamali
Keio University, Tokyo, Japan
shaswot@acsl.ics.keio.ac.jp

Alok Ranjan
Bosch India
alok_ranjan@ieee.org

***Abstract*—The explosion of sensors in smartphones and the Internet of Things (IoT) is generating a massive amount of data. This has the potential to revolutionise fields like healthcare, environmental management, and city planning. However, to unlock this potential, we need machine learning (ML) to transform raw sensor data into actionable insights. Machine learning offers a powerful way to turn sensor data into something we can understand and use. However, several challenges stand in the way of bringing these ideas to life: (1) Limited Resources: Devices often have limited computing power, memory, and battery life. (2) Complex Systems: Building ML models for sensor systems can be intricate. (3) Real-World Testing: Designing effective studies and collecting reliable data (ground truth) can be difficult. Sensys-ML 2024 workshop tackles these challenges by providing early feedback on research involving machine learning for sensor systems (TinyML). This workshop focuses on approaches that combine sensor data with ML, especially those that run on devices themselves or leverage edge/fog computing.**

***Index Terms*—Machine Learning, TinyML, UltraML, Sensor Systems**

I. Introduction

Developing and deploying machine learning (ML) models directly on devices and sensors, often referred to as TinyML, presents a distinct set of challenges compared to traditional cloud-based ML [1]. Unlike powerful server farms, these devices have inherent limitations that must be carefully considered. Most devices lack the high-performance CPUs and GPUs found in data centers. This restricts the complexity of ML models that can be deployed, demanding efficient algorithms and careful code optimization. Device memory is often limited, impacting the size and type of data models can store and process. This necessitates techniques like model pruning and quantization to reduce memory footprint. Many devices rely on batteries, and complex ML computations can drain them quickly. Techniques like power-efficient algorithms and duty cycling (turning on/off components when needed) are crucial for continuous operation. Limited bandwidth can hinder communication with cloud servers for training or data transfer. This necessitates storing and processing data locally on the device whenever possible. Sensitive data collected by sensors raises privacy concerns. On-device processing can minimise data transmission, but strong security measures are still needed to protect data stored locally on the device from unauthorised access. These challenges highlighted the need for a dedicated research focus on TinyML. Recognizing this, the idea for a workshop emerged among attendees of the CPS-IoT 2019 conference. This led to the creation of the first Sensys-ML workshop [2] at ACM Sensys 2019, a platform to discuss early-stage research and work-in-progress specifically within the domain of TinyML in Sensor Systems. The success of this initial workshop led to a second edition [3] co-located with CPS-IoT 2020.

II. Sensys-ML 2024

The 3rd Workshop on Machine Learning on Edge in Sensor Systems (Sensys-ML 2024) [4] brings together researchers from diverse backgrounds – sensing, networking, and machine learning – to showcase their cutting-edge work in building intelligent sensor systems. Sensys-ML offers a unique platform for researchers to present Work-In-Progress (WIP) papers focused on TinyML/UltraML for sensor systems. A rigorous review process ensures the selection of only the most promising work for presentation, allowing authors to receive valuable in-depth feedback from the community. This year, four outstanding WIP papers have been chosen for in-depth discussion. In addition to paper presentations, Sensys-ML 2024 features a special tutorial session titled "Towards Robust and Heterogeneous Federated Learning." This session welcomes students, researchers, academics, and industry professionals interested in this powerful machine learning technique.The tutorial dives deep into:

1) Key challenges hindering the implementation of federated learning
2) Robustness and system heterogeneity issues
3) Methods and tools available to address these challenges

The selected papers for Sensys-ML 2024 address some of the most fascinating themes in TinyML research, including:

- FACC: A Flexible and Asynchronous Updating Strategy for Cooperative Edge Caching – This research explores innovative caching techniques for edge computing.
- Harnessing LLMs for High-level Reasoning Over Spatiotemporal Sensor Traces – This paper investigates the

979-8-3503-6336-4/24/$31.00 ©2024 IEEE
DOI 10.1109/SenSys-ML62579.2024.00005

potential of Large Language Models (LLMs) in extracting insights from sensor data.

- Resource-Aware Split Federated Learning for Edge Intelligence – This work explores distributed federated learning approaches to optimise resource usage at the edge.
- Advancements in Machine Learning at the Edge in Sensor Systems: Insights from Sensys-ML and TinyML communities - This position paper explores recent breakthroughs and promising research directions in machine learning for sensor systems at the edge (TinyML). These insights are valuable for researchers, developers, and anyone interested in the work of Sensys-ML and the broader TinyML community.

These innovative papers highlight crucial areas for further exploration: caching, LLMs, and distributed federated learning. The advancements presented at Sensys-ML 2024 are expected to have a significant impact on real-world applications and shape the future direction of TinyML research.

III. Sensys-ML 2024 Organisation

A. Workshop Chairs

Dr Poonam Yadav (University of York, UK)
Prof Edith C.H. Ngai (The University of Hong Kong, Hong Kong)

B. Technical Program Chairs

Dr Poonam Yadav (University of York, UK)
Dr Manik Gupta (BITS Pilani, Hyderabad, India)

C. Publicity Chairs

Dr Shaswot Shresthamali (Keio University, Tokyo, Japan)
Dr Alok Ranjan (Bosch, India)

D. Publication Chairs

Dr Shijia Pan (University of California Merced, USA)

E. Technical Program Committee

Prof Cecilia Mascolo (University of Cambridge, UK)
Dr Alok Ranjan (Bosch, India)
Dr Shaswot Shresthamali (Keio University, Tokyo, Japan)
Dr Man Wu (Keio University,Tokyo, Japan)
Dr Manik Gupta (BITS Pilani, Hyderabad, India)
Prof Nic Lane (University of Cambridge,UK)
Dr Carles Gomez Montenegro (UPC, Spain)
Dr Diana Andreea Popescu (Amazon, UK)
Dr Akshay Nambi (Microsoft Research, India)
Dr Stylianos I. Venieris (Samsung AI, UK)
Dr Shiqiang Wang (IBM Research, NY, USA)
Dr Yuan He (Keio University, Tokyo, Japan)

IV. Acknowledgments

We would like to express our sincere gratitude to all those who provided rigorous reviews and extensive feedback to the authors during the submission process. Your contributions were invaluable.

We are also grateful to the CPS-IoT 2024 [5] organizing committee, especially the General Chairs, Guoliang Xing (The Chinese University of Hong Kong) and Tei-Wei Kuo (Delta Electronics & National Taiwan University, Taiwan). Our thanks extend as well to the Workshop/Tutorial and Competition Chairs: Shahriar Nirjon (University of North Carolina at Chapel Hill, USA), Chris Lu (University College London, UK), and Tian Guo (Worcester Polytechnic Institute, USA).

Their tireless help and support over the past six months were instrumental in the success of the workshop. We would also like to thank everyone who contributed their time, talent, or resources to make this event possible.

This workshop is supported, in part, by EPSRC and DSIT TMF-uplift: CHEDDAR: Communications Hub For Empowering Distributed ClouD Computing Applications And Research (EP/X040518/l), (EP/Y037421/l), EPSRC IAA (EP/X525856/l), and EPSRC REMOTE (EP/Y019229/1).

References

[1] Banbury et al., Benchmarking TinyML Systems: Challenges and Direction, SysML 2020, https://arxiv.org/abs/2003.04821
[2] Github Sensys-ML 2019 website: https://sensysml.github.io/sensysml2019/
[3] Github Sensys-ML 2020 website: https://sensysml.github.io/sensysml2020/
[4] Github Sensys-ML 2024 website: https://sensysml.github.io/sensysml2024/
[5] CPS-IoT Week 2024. https://cps-iot-week2024.ie.cuhk.edu.hk/