SYBT 1: Beyond Transistors: Material-Based Edge Computing Paradigms

Time: Wednesday 9:30–12:15 Location: HSZ/AUDI

Invited Talk SYBT 1.1 Wed 9:30 HSZ/AUDI

Finding Neuromorphic Advantage with Magnetism — •Johan Mentink — Radboud University, Nijmegen, Netherlands

Neuromorphic computing promises much faster and much more energy-efficient computations with applications domains spanning the whole compute continuum. Nevertheless, rather little is known about applications of neuromorphic computing in computational physics such as the simulation of magnetic materials. In this talk we present our results on exploring and benchmarking neuromorphic computing for probabilistic simulations of quantum magnetism. Our explorations include hardware paradigms such as in-memory computing [1], probabilistic bits [2,3] and large-scale simulations with spiking-based systems electronic systems. We find that the massively parallel nature of neuromorphic hardware offers important scaling advantages over existing digital hardware and enables orders of magnitude faster and more energy-efficient variational quantum Monte Carlo simulations. Moreover, beyond existing neuromorphic paradigms, we show that even better scaling is in reach by adopting new magnetic device concepts, such as those harnessing Brownian skyrmion dynamics [4]. Our results open a path to find neuromorphic computational advantage in probabilistic quantum simulation and suggest high potential to break existing computational barriers for selected computational problems in general.

[1] D. J. Kösters, et al. APL ML 1, 016101 (2023) [2] R.J.L.F. Berns et al., arXiv:2504.18359 (2025) [3] S. Chowdhury, Nat Commun 16, 9193 (2025) [4] Th. Winkler et al., arXiv:2508.19623 (2025)

Invited Talk SYBT 1.2 Wed 10:00 HSZ/AUDI

Accelerating Neural Networks Computation with Ferroelectric Oxides — •Laura Bégon-Lours, Nikhil Garg, Alexandre Baigol, Anwesha Panda, Nathan Savoia, and Alexander Flasby — Integrated Systems Laboratory, D-ITET, ETH Zürich

On conventional computers, the performance of AI models is limited by the data transfer between the memory and the processor. Compute-in-Memory architectures offer a new paradigm: Vector-Matrix Multiplications may be performed by a voltage drop through a matrix of programmable resistances, the *synaptic weights*. Ferroelectric materials are excellent candidates for their realization: the conductance is programmed by controlling the configuration of the ferroelectric domains. The mechanisms governing the resistive switching in WOx / HZO-SL (5 nm) bilayers are discussed. The effect of the programming pulse duration and amplitude on the polarization switching are investigated, from milliseconds to nanoseconds timescales. Devices of different sizes and shapes are measured down to 500 nm in dimension. For an device size of 1 micrometer square, an On/Off ratio as high as 4 is obtained for 20 ns pulses, a 4-fold improvement compared to 40 um devices. The relatively low crystallization temperature of polycrystalline hafnium oxide / zirconium oxide superlattices (HZO-SL) is compatible with the Back-End-Of-Line (BEOL) of CMOS transistors. These results not only demonstrate the functionalization of the BEOL with synaptic weights, but also pave the way for the integration of ferroelectric field-effect transistors with Beyond CMOS semiconductors.

Invited Talk SYBT 1.3 Wed 10:30 HSZ/AUDI

a photonic approach to probabilistic computing — •Wolfram Pernice — Heidelberg University, Kirchhoff-Institute for Physics, Heidelberg, Germany

Unlike artificial neural networks (ANNs), which focus on maximizing accuracy, biological systems excel at handling uncertainty. This ability is believed to be essential for adaptability and efficiency, yet traditional ANNs, implemented on deterministic hardware, struggle with capturing the full probabilistic nature of inference. To address this limitation, Bayesian neural networks (BNNs) replace deterministic parameters with probability distributions, allowing us to distinguish between epistemic uncertainty (due to limited data) and aleatoric uncertainty (arising from noise). By incorporating Bayesian inference, BNNs enable uncertainty quantification and allow for out-of-distribution detection in cases of incomplete data. However, processing probabilistic models remains a challenge for conventional digital hardware, which relies on deterministic von Neumann architectures that separate memory from computation. In electronic crossbar arrays, memristors exhibit inherent stochasticity, making them suitable for probabilistic inference. Yet, sequential sampling and variability in memristive materials present obstacles. To address these challenges, I will outline recent progress in photonic computing architectures that harness hardware noise as a computational resource rather than a constraint.

15 min break

Invited Talk SYBT 1.4 Wed 11:15 HSZ/AUDI

Tackling Reliability and Scalability in Neuromorphic Computing via Noise-aware Learning — •Eleni Vasilaki — Computer Science, The University of Sheffield, 211 Portobello, Sheffield, S1 4DP, UK

Neuromorphic computing has evolved into a broad label covering technologies ranging from biologically inspired systems to machine-learning-style architectures. Computing with materials is often promoted as a potentially energy-efficient alternative to conventional hardware, but some of these claims lack robust empirical support. In this talk I will outline key challenges in the field, with a focus on variability and scalability. I will present concrete examples from my recent work showing how noise-aware learning in systems with stochastic, device-level behaviour can help mitigate variability and improve robustness. These results suggest that while variability poses real constraints, it can be addressed through appropriate learning strategies.

Invited Talk SYBT 1.5 Wed 11:45 HSZ/AUDI

Bayesian nanodevices for trustworthy artificial intelligence — •Damien Querlioz — Univ Paris-Saclay, CNRS, Palaiseau, France.

Artificial intelligence (AI) increasingly powers safety-critical systems that demand robust, energy-efficient computation, often under conditions of data scarcity and uncertainty. Traditional AI approaches are limited in their ability to quantify confidence, leaving them vulnerable to unreliable predictions. In this talk, we introduce Bayesian electronics, which harnesses the intrinsic randomness of emerging nanodevices for on-device Bayesian computations. By encoding probability distributions at the hardware level, these devices naturally estimate uncertainty and reduce overhead compared with purely deterministic designs. We examine how Bayesian networks and Bayesian neural networks can be implemented in this framework to enhance sensor fusion and out-of-distribution detection. We also describe how hardware training via Markov chain Monte Carlo or Langevin dynamics yields energy-frugal sampling-based learning. Finally, we draw parallels with biological systems that are hypothesized to similarly exploit noise for probabilistic computation. By integrating device physics, algorithmic design and system-level optimization, Bayesian electronics offers a path towards more trustworthy and adaptive AI hardware.