Symposium Identifying Optimal Physical Implementations for beyond von Neumann Computing Concepts (SYCC)

jointly organized by
the Magnetism Division (MA),
the Low Temperature Physics Division (TT),
the Thin Films Division (DS), and
the Semiconductor Physics Division (HL)

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Emerging ambitious cognitive tasks have triggered the development of new powerful computer architectures that are disruptively different to the traditional von-Neumann computer architecture. Fields of applications include smart manufacturing, autonomous driving, machine learning for robotics, data analytics, diagnostics, efficient sensing or the creation of predictive material property models, the understanding of important brain functionalities, enabling the study of long-term processes such as learning, development, and neuro-degenerative diseases. With Moore's law coming to an end, the speed and energy efficiency of incumbent computing devices is inadequate to cope with the in-time demands for processing big data efficiently. A range of fundamentally different new computing concepts have been devised such as neuromorphic computing, reservoir computing, probabilistic or stochastic computing. To implement this, circuits that achieve reconfigurable three-dimensional connectivity, and the exploitation of new devices that incorporate synaptic or neural functions, or strong nonlinear responses are considered. A key question is the physical realization by different concepts and materials platforms (resistively switching oxides, hybrid organic-inorganic nanoparticle, spintronics) that are currently being explored. It is obvious that different physical realizations optimize the implementation and performance of different computing concepts. This symposium reviews recent progress in physical implementations of complementary computational paradigms with a focus of highlighting the advantages, disadvantages and limitations of the different physical systems.

Overview of Invited Talks and Sessions

(Lecture hall H1)

Invited Talks

SYCC 1.1	Fri	9:30–10:00	H1	**On the Link Between Energy and Information for the Design of Neuromorphic Systems** — •Narayan Srinivasa
SYCC 1.2	Fri	10:00–10:30	H1	**Encoding neural and synaptic functionalities in electron spin: A pathway to efficient neuromorphic computing** — •Kaushik Roy
SYCC 1.3	Fri	10:30–11:00	H1	**Neuromorphic computing with spintronic nano-oscillators** — •Philippe Talatchian, Miguel Romera, Sumito Tsunegi, Flavio Abreu Araujo, Vincent Cros, Paolo Bortolotti, Juan Trastoy, Kay Yakushiji, Akio Fukushima, Hitoshi Kubota, Shinji Yuasa, Maxence Ernoult, Damir Vodenicarevic, Tifenn Hirtzlin, Nicolas Locatelli, Damien Querlioz, Julie Grollier
SYCC 1.4	Fri	11:15–11:45	H1	**Artifcial Intelligence and beyond von Neumann architectures, a mutual opportunity** — •Mirko Prezioso, Farnood Merrikh Bayat, Dmitri Strukov
SYCC 1.5	Fri	11:45–12:15	H1	**Brain-inspired approaches in ultrafast magnetism** — •Johan H. Mentink

Sessions

SYCC 1.1–1.5	Fri	9:30–12:15	H1	**Identifying optimal physical implementations of non-conventional computing**

SYCC 1: Identifying optimal physical implementations of non-conventional computing

Time: Friday 9:30–12:15 Location: H1

Invited Talk SYCC 1.1 Fri 9:30 H1

On the Link Between Energy and Information for the Design of Neuromorphic Systems — •Narayan Srinivasa — Eta Compute, USA

Recent understanding of our nervous system reveals that sensory organs are optimized for efficient uptake of information from the environment to the brain. While bulk of the energy consumed in this process is to generate asynchronous action potentials for signal communication, evolutionary pressure has further optimized on this mode of communication within the brain for efficient representation and processing of information. We will explore this link between energy and information to reveal some of the mechanisms, circuits and energy efficient codes in the brain. The implications of this link point to considerations for the physical implementation of neuromorphic systems of the future.

Invited Talk SYCC 1.2 Fri 10:00 H1

Encoding neural and synaptic functionalities in electron spin: A pathway to efficient neuromorphic computing — •Kaushik Roy — ECE, 465 Northwestern Ave., Purdue University, WL, IN 47906, USA

Present day computers expend orders of magnitude more computational resources to perform various cognitive and perception related tasks that humans routinely perform every day. This has recently resulted in a seismic shift in the field of computation where research efforts are being directed to develop neurocomputers that attempt to mimic the human brain by nanoelectronic components and thereby harness its efficiency in recognition problems. Bridging the gap between neuroscience and nanoelectronics, I will review recent developments in the field of spintronic device based neuromorphic computing. Description of various spin-transfer torque mechanisms that can be potentially utilized for realizing device structures mimicking neural and synaptic functionalities will be presented. A cross-layer perspective extending from the device to the circuit and system level is presented to envision the design of an All-Spin neuromorphic processor enabled with on-chip learning functionalities. Device-circuit-algorithm co-simulation framework calibrated to experimental results suggest that such All-Spin neuromorphic systems can potentially achieve almost two orders of magnitude energy improvement in comparison to state-of-the-art CMOS implementations.

Invited Talk SYCC 1.3 Fri 10:30 H1

Neuromorphic computing with spintronic nano-oscillators — •Philippe Talatchian[1], Miguel Romera[1], Sumito Tsunegi[2], Flavio Abreu Araujo[1], Vincent Cros[1], Paolo Bortolotti[1], Juan Trastoy[1], Kay Yakushiji[2], Akio Fukushima[2], Hitoshi Kubota[2], Shinji Yuasa[2], Maxence Ernoult[1,3], Damir Vodenicarevic[3], Tifenn Hirtzlin[3], Nicolas Locatelli[3], Damien Querlioz[3], and Julie Grollier[1] — [1]Unité Mixte de Physique, CNRS, Thales, Université Paris-Sud, Palaiseau, France — [2]Spintronics Research Center (AIST), Tsukuba, Ibaraki, Japan — [3]C2N, CNRS, Université Paris-Sud, Orsay, France

Biological neurons emit periodic electrical spikes and can synchronize their rhythmic activity. Inspired from these features, it would be attractive to implement oscillatory neural networks for computing in hardware, with nanoscale oscillators capable of synchronization. However, despite numerous proposals, there is today no demonstration of brain-inspired computing with coupled nano-oscillators. One difficulty is that training these networks requires tuning the coupling between oscillators. Here we show experimentally that through their high frequency tunability, spintronic nano-oscillators can learn to perform pattern recognition. We train a network of four coupled spin-torque nano-oscillators to recognize spoken vowels with an experimental recognition rate of 88 percents [1]. These results open new paths towards highly energy efficient bio-inspired computing on-chip based on non-linear nano-devices.

[1] M. Romera, P. Talatchian et al, Nature. Vol 563, p.230-234, 2018.

15 min. break

Invited Talk SYCC 1.4 Fri 11:15 H1

Artifcial Intelligence and beyond von Neumann architectures, a mutual opportunity — •Mirko Prezioso[1,2], Farnood Merrikh Bayat[1,2], and Dmitri Strukov[2] — [1]Mentium Technologies Inc, 3448 Elings Hall, University of California at Santa Barbara, Santa Barbara, California, 92106, USA — [2]Department of Electrical and Computer Engineering, University of California at Santa Barbara, Santa Barbara, California, 93106, USA

The revolution in artificial intelligence was triggered not by any significant algorithm breakthrough, but by the availability of more powerful GPU hardware. Since then, more powerful dedicated digital systems have been developed but their speed and energy efficiency are still insufficient for more ambitious cognitive tasks. The main reason is that the use of conventional paradigm based on von Neumann architectures and digital mode operations for the implementation of neuromorphic networks, with their high parallelism and noise/variability tolerance, is inherently unnatural. Conversely, the performances can be dramatically improved using in-memory computing architectures based on analog computation. In this way, the key operation, the vector-by-matrix multiplication, is implemented on the physical level by utilization of the fundamental Ohm and Kirchhoff laws. I will discuss the recent progress of UC Santa Barbara group for the development of such analog and mixed-signal neuromorphic networks based on metal-oxide memristors. Additionally, I will discuss a more near-term solutions based on floating gate memory devices, which are being developed at Mentium Technologies, a spin-off of UCSB.

Invited Talk SYCC 1.5 Fri 11:45 H1

Brain-inspired approaches in ultrafast magnetism — •Johan H. Mentink — Radboud University, Nijmegen, Netherlands

The explosive growth of digital data and its related energy consumption is pushing the need to develop fundamentally new physical principles for faster and more energy-efficient control of materials. Magnetic materials are already at the center of computing today, due to their ability to store information within the direction of magnetic moments in a non-volatile and rewritable way. In recent years, tremendous progress has been made in controlling magnetism with femtosecond optical pulses, including demonstrations of record-breaking fast write-read events [1], operation in technologically relevant materials such as CoPt [2] and enabling magnetic recording that is not only much faster but also exhibits a projected heat load of only 22 aJ per magnetic bit [3]. Here we present our recent progress focused on (i) experimental demonstration of supervised learning of an opto-magnetic neural network that exploits the optical control of magnetization of Co/Pt films as artificial synapses [4] and (ii) using machine learning to simulate ultrafast quantum spin dynamics in antiferromagnets triggered by ultrafast control of the exchange interaction [5]. [1] K. Vahaplar et al., PRL 103, 117201 (2009), [2] C.H. Lambert et al., Science 345, 1337 (2014), [3] A. Stupakiewicz et al., Nature 542, 71 (2017). [4] A. Chakravarty, et al. preprint arXiv:1811.01375, 2018, [5] J.H. Mentink, J. Phys.: Condens. Matter. 29, 453001 (2017).