MA 29: Neuromorphic Magnetism / Magnetic Logic

Time: Wednesday 11:30–12:45 Location: HSZ 02

MA 29.1 Wed 11:30 HSZ 02

Brownian Computing Realized Using Skyrmions — •Maarten A. Brems[1], Klaus Raab[1], Grischa Beneke[1], Jan Rothörl[1], Peter Virnau[1], Johan H. Mentik[2], and Mathias Kläui[1] — [1]Institut für Physik, Johannes Gutenberg-Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany — [2]Radboud University, Institute for Molecules and Materials, Heyendaalseweg 135, 6525 AJ Nijmegen, The Netherlands

Reservoir computing (RC) has been considered as one of the key computational principles beyond von-Neumann computing. Magnetic skyrmions, topological particle-like spin textures in magnetic films, are particularly promising for implementing RC since they respond strongly nonlinear to external stimuli and feature inherent multiscale dynamics. We propose and experimentally demonstrate a conceptually new approach to skyrmion computing that combines the RC and Brownian computing [1] concepts. By confining the thermal skyrmion motion [2] that can be electrically gated, we find that already a single skyrmion in a confined geometry suffices to realize non-linearly separable functions, which we demonstrate for the XOR gate along with all other Boolean logic gate operations [3]. Our proposed concept ensures low training costs as well as ultra-low power operation and can be readily extended by including more skyrmions in the reservoir, suggesting high potential for scalable and low-energy reservoir computing.
[1] M. A. Brems et al., Appl. Phys. Lett. 119, 132405 (2021). [2] J. Zázvorka et al., Nat. Nanotechnol. 14, 658 (2019). [3] K. Raab, M. A. Brems et al., Nat. Commun. 13, 6982 (2022).

MA 29.2 Wed 11:45 HSZ 02

Superparamagnetic tunnel junctions for neuromorphic computing — •Leo Schnitzspan[1,2], Gerhard Jakob[1,2], and Mathias Kläui[1,2] — [1]Institut für Physik, Johannes Gutenberg Universität Mainz — [2]Max Planck Graduate Center, Mainz

Superparamagnetic tunnel junctions (SMTJ) are promising building blocks in the field of neuromorphic computing. In a SMTJ, the magnetic free layer can switch its magnetic orientation induced by thermal activation, leading to a random two-level resistance fluctuations[1]. We show nanosecond fluctuations with dwell times below 10 ns for our inplane magnetized SMTJs. Their intrinsic stochastic behaviour and additional tunability by external magnetic fields, Spin Transfer Torques (STT) or Spin Orbit Torques (SOT) are prerequisites for low-energy artificial neurons in neural networks. True random number generation is demonstrated and evaluated by the statistical test suite from NIST. The probability of a P- (=0) or AP- (=1) state depends on the energy landscape and can be affected by STT. However, the average fluctuation speed is strongly dependend on the temperature. We demonstrate that Joule heating, induced by a large applied current, leads to significantly shorter dwell times. From dwell time measurements, the contributions of STT and Joule heating are extracted.

[1] Hayakawa, K. et al., Phys. Rev. Lett. 126, 117202 (2021).

MA 29.3 Wed 12:00 HSZ 02

Impact of DMI on magnonic antiferromagnetic leaky integrate-and-fire neuronal networks — •Verena Brehm and Alireza Qaiumzadeh — QuSpin, NTNU Trondheim, Norway

Two shifts of paradigms promise to revolutionize modern day computation: First, neuromorphic computing aims to mimic the human brain, which is a fundamentally different approach compared to the state-of-the-art von Neuman computing architecture. Second, antiferromagnetic magnonics promises to be faster and more energy-efficient compared to conventional electronics through avoidance of Joule heating and high-frequency eigenexcitations. We combine both fields and study a proof-of-principle antiferromagnetic spiking neural network, more specifically a leaky integrate-and-fire model both analytically and numerically [1,2].

[1] Johannes W. Austefjord, Verena Brehm, Serban Lepadatu and Alireza Qaiumzadeh: 'Non-volatile leaky integrate-and-fire neurons with domain walls in antiferromagnetic insulators'. http://arxiv.org/abs/2211.16845 (2022).

[2] Even Tønseth, Verena Brehm, Alireza Qaiumzadeh: 'Effects of DMI on spike propagation in neuromorphic systems', to be submitted.

MA 29.4 Wed 12:15 HSZ 02

Light-controlled nanomagnetic logic circuits — •Naëmi Leo[1,2], Matteo Menniti[2], Pieter Gypens[3], Jonathan Leliaert[3], and Paolo Vavassori[2] — [1]CSIC - INMA, Zaragoza, Spain — [2]CIC nanoGUNE BRTA, Spain — [3]Ghent University, Belgium

Magnetic metamaterials with magnetostatically-coupled elements offer an interesting platform to implement low-power and neuromorphic-inspired data processing, in particular when combined with thermally-driven switching processes. By combining nanomagnetic elements with light-controlled plasmonic heaters, here we demonstrate how to design nanomagnetic Boolean OR or AND gates with nanosecond operation. The reconfigurability logic is achieved either by modifying the field protocol setting the initial state or optically, by changing the polarisation and order of the laser pulses exciting the system. Thermoplasmonic-nanomagnetic metamaterials thus lend themselves for the implementation of future fast (up to GHz), energy-efficient (picojoule), and optically-reconfigurable platform for in-memory computation schemes.

MA 29.5 Wed 12:30 HSZ 02

Antiferromagnet-based neuromorphics using dynamics of topological charges — •Shu Zhang — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

We propose a spintronics-based hardware implementation of neuromorphic computing, specifically, the spiking neural network, using topological winding textures in one-dimensional antiferromagnets. The consistency of such a network is emphasized in light of the conservation of topological charges, and the natural spatiotemporal interconversions of magnetic winding. We discuss the realization of the leaky integrate-and-fire behavior of neurons and the spike-timing-dependent plasticity of synapses. Our proposal opens the possibility for an all-spin neuromorphic platform based on antiferromagnetic insulators.