Master 2 Research Internship and PhD Proposal

Laboratory: Centre de Nanosciences et de Nanotechnologies (C2N)
Université Paris-Saclay/CNRS, and UMR CNRS/Thales, Palaiseau.
Address: 10 Boulevard Thomas Gobert, 91120 Palaiseau, France
Advisor: Damien Querlioz and Liza Herrera Diez
Website: http://integnano.c2n.u-psud.fr/ https://sites.google.com/site/damienquerlioz/
E-mail: damien.querlioz@c2n.upsaclay.fr, liza.herrera-diez@c2n.upsaclay.fr

Brain-Inspired Systems Employing Multiphysics Spintronic Artificial Synapses

Brain-inspired electronics, or neuromorphic computing, aims at reducing dramatically the energy consumption of Artificial Intelligence, by **imitating major principles of the architecture of the brain**. Neuromorphic computing functions by assembling artificial neurons and artificial synapses[1].

One of the most exciting developments of the neuromorphic field, in recent years, has been the use of novel technologies of artificial neurons and synapses coming from spin electronics, i.e. that exploit the magnetic properties of electrons[2,3,4]. Spintronic technologies, now widely developed in industry (Intel, Samsung, GlobalFoundries, TSMC…) provide multiple features for neuromorphism[4] (see also our article "*Quand la spintronique imite le cerveau*", cover story of the French magazine Pour la Science, September 2020, https://www.pourlascience.fr/sd/technologie/quand-la-spintronique-imite-le-cerveau-19913.php).

Currently, however, spintronic artificial synapses remain relatively simple objects, far from the complexity of their biological counterparts. For this reason, our group is developing a new generation of spintronic artificial synapses, where spintronic effects are coupled with effects emerging from other types of physics. This allows us to create tiny synapses, capable of highly sophisticated behaviors with multiple types of memory over several timescales. **The goal of the Master's and PhD project is to create the neuromorphic systems capable of exploiting such synapses.** Our preliminary works suggest that complex synapses, implementing the concept of "metaplasticity" can allow artificial neural networks to avoid the issue of catastrophic forgetting[5], a major limitation of modern Artificial Intelligence, which prevents it from learning tasks sequentially.

In the Master's project, the student will study how our theoretical results on complex synapses with metaplasticity may be implemented with Multiphysics artificial synapses. This first phase of the project will consist mainly of simulation and theoretical works.

In the subsequent PhD project, the student will explore other ideas exploiting complex synapses, and also realize an experimental demonstration of the concept using real spintronic artificial synapses, fabricated by other members of our group.

This project can be adapted to students in engineering, physics, or computer science. Students should have a strong interest in AI. No specific experience with artificial neural networks is required. The student should, however, have some programming experience. In terms of methods, the student will mostly develop Python-based simulations of the system, as well as already-existing physics-based simulators.

This ambitious project takes place within the interdisciplinary INTEGNANO research group at the Centre de Nanosciences et de Nanotechnologies. This group associates research on materials, nanodevices, bioinspired computing, and artificial intelligence, with researchers and students of very diverse backgrounds, making it ab exciting environment that fosters interdisciplinary thinking. The Centre is located within the new campus of Université Paris-Saclay, featuring multiple academic and industrial labs, engineering schools, restaurants, shops, and sports facilities, as well as beautiful and protected forests.

[1] *D. Marković, A. Mizrahi, D. Querlioz, J. Grollier, "Physics for neuromorphic computing", **Nature Reviews Physics**. 2020 2(9):499.*
[2] *M. Romera, … D. Querlioz, J. Grollier, "Vowel recognition with four coupled spin-torque nano-oscillators", **Nature** 563, 230, 2018.*
[3] *A. Mizrahi, … , J. Grollier, D. Querlioz, "Neural-like computing with populations of superparamagnetic basis functions", **Nature Communications** 9, Article number: 1533 (2018).*
[4] *J. Grollier, D. Querlioz, "Neuromorphic spintronics", **Nature Electronics**, 1-11 (2020).*
[5] *A. Laborieux, …, D. Querlioz, "Synaptic metaplasticity in binarized neural networks". **Nature communications** 12(1), 1, 2021.*

Skills to be learned: The student will learn principles of modern AI, and its hardware implementation.

The PhD is adapted to a career in both academia and industry.