Master 2 Research Internship and PhD Proposal

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Design of Ultralow-Power Machine Learning Accelerators Inspired by Principles of Brain Learning and Employing Novel Memory Technologies

In recent years, deep learning has revolutionized the field of Artificial Intelligence, and computers are now able to recognize image, understand spoken language or even translate texts at near-Human or even sometimes above Human-level performance. However, **deep learning comes with a major challenge: its considerable energy consumption**.

It is now well understood that reducing the energy consumption of deep learning can come from a close association of logic and memory[1]. This association cannot be achieved using CMOS technology only, as CMOS-based memory (SRAM) has considerable area cost and is a volatile memory. By contrast, **novel technologies coming from nanoechnologies[2,3] can provide ideal features for neural networks implementation**. One of the most exciting opportunity are technologies such as Spin Torque MRAM that rely on spintronics, i.e. that exploit the magnetic properties of electrons. These technologies, now widely developed in industry (Intel, Samsung, GlobalFoundries, TSMC…) provide multiple features for deep learning[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).

In this project, we will implement a novel deep learning approach, partially inspired by how the brain works, *Equilibrium Propagation*, which is able to take advantage of spintronic technologies particularly well. Our design will use digital circuits as neurons, and spintronic devices as synapses, which can be integrated monolithically within CMOS. The goal of the internship and of the subsequent PhD will be to design all the digital system to implement deep learning, as well as the interface circuitry between CMOS and spintronic devices.

During the Master's internship, the student will learn the basics of our deep learning approach and propose a first design incorporating logic and spintronic memory and implementing a basic "shallow" deep learning task. He/she will take special attention on all the energy aspects, to try and demonstrate record in energy efficiency. The project focuses mostly on digital and some mixed/signal design.

During the subsequent PhD thesis, the student will focus on the scaling of this approach to proper deep learning tasks. The project will then include more work on AI, and especially adapting a deep learning technique to the constrains of AI. In term of design, in addition to digital design, the project will include some **design of interface circuitry** (e.g., sense amplifiers) between spintronics and digital CMOS. During the PhD, the systems incorporating spintronic elements will be fully designed, fabricated by our European partners and tested by the student.

In terms of methods, the student will mostly use simulations of the system using the programing language of his/her choice (our lab typically uses Python), and digital ASIC design (SystemVerilog or VHDL) using industry standard tools.

This ambitious project takes place within the interdisciplinary INTEGNANO research group at the Centre de Nanosciences et de Nanotechnologies and the Cognitive Information Processing group at the Unité Mixte de Physique CNRS/Thales. These groups associate research on nanodevices, bioinspired computing and artificial intelligence, with researchers and students of very diverse backgrounds, making them exciting environments that foster interdisciplinary thinking.

[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, M. Ernoult, B. Scellier, Y. Bengio, J. Grollier, D. Querlioz. "Scaling equilibrium propagation to deep convnets by drastically reducing its gradient estimator bias". **Frontiers in neuroscience**. 2021 Feb 18;15:129.*

Prerequisties: The student should have a general knowledge of electrical engineering, and good analytical skills. Some experience with VHDL, Verilog, or SystemVerilog is expected, as well as some experience with programming. Experience with neural networks is appreciated, but not required.

Skills to be learned: The student will learn principles of modern AI, and its hardware implementation, as well as advanced ASIC design skills.

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