Master 2 Research Internship and PhD Proposal

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Training Electronic Systems to Perform Artificial Intelligence Using the Physics of their Components

In recent years, deep learning has revolutionized the field of Artificial Intelligence (AI). 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[1]**.

An emerging solution to reduce the energy consumption of AI consists in, instead of using computers, *training* electronic systems to perform AI tasks[1]. By changing the parameters of a circuit, we can train it to perform a task in a way that is particularly optimal with regards to the structure of the circuit and the device physics of its components[1,2]. Toward that purpose, circuits exploiting emerging memory devices based on nanotechnology, known as memristors or restive memory[3,4,5], are particularly ideal, as each memory device features a memory state that can be tuned by the training process, exploiting the physics of the devices. This original way of exploiting circuits – training them rather than programming or calibrating them – will be particularly flexible and robust to device imperfections and varied environments. This approach can have many applications. For example, the availability of low-energy consumption AI could deeply transform the field of medical devices.

The student will use already-available circuits featuring hafnium oxide-based memristors and CMOS circuitry. **The project is experimental**: the goal of the internship and of the PhD is to train real circuits and show the outstanding energy efficiency and robustness of the approach. The project will still require a good understanding of modern AI: the student should be excited to learn about it, and the project will involve some significant programing. The project is therefore ideal for an engineering student with broad interest or for a physics student with interest in computers and AI.

During the Master's internship, the student will train an existing CMOS-memristor circuit[3,5], following a backpropagation-inspired approach that we have already identified, but not yet implemented. This will be the opportunity to learn the methodology of memristor-based circuit testing and the fundamentals of modern AI.

During the subsequent PhD thesis, the student will scale the approach to much more sophisticated tasks, using larger circuits and incorporating samples. The student will use a relevant medical application as a clear goal for this research.

In terms of methods, for testing, the student will use the extensive state-of-the-art electrical characterization facilities at IM2NP. The experiments will involve programming in the Python language using AI frameworks (TensorFlow and/or Pytorch). Knowledge of Python or AI frameworks is not mandatory for this internship, but some programming experience is essential.

This ambitious project takes place within the memory group of IM2NP, on the beautiful campus of Aix-Marseille Université, which possesses extensive experience on testing of memory circuits, based on numerous industrial and academic collaborations. The project will feature tight collaboration, including visits, with the INTEGANO group at C2N on the new Paris-Saclay campus. This group specializes in brain-inspired electronics and the connection between nanotechnology and AI. The amount of time spent in Marseille and Paris-Saclay can be adjusted depending on the personal situation of the student.

[1]*D. Marković, A. Mizrahi, D. Querlioz, J. Grollier. "Physics for neuromorphic computing", **Nature Reviews Physics**. 2020 2(9):499.*
[3]*A. Mizrahi, ... , J. Grollier, D. Querlioz, "Neural-like computing with populations of superparamagnetic basis functions", **Nature Communications** 9, Article number: 1533 (2018).*

[3]*M. Bocquet, T Hirztlin, ..., D. Querlioz, "In-memory and error-immune differential RRAM implementation of binarized deep neural networks". In 2018 IEEE International Electron Devices Meeting (**IEDM**) 2018 Dec 1.*
[4]*T. Dalgaty, ..., D. Querlioz, E. Vianello. "In situ learning using intrinsic memristor variability via Markov chain Monte Carlo sampling".* ***Nature Electronics****. 2021 Feb;4(2):151-61.*
[5]*A. Majumdar, M. Bocquet, ..., D. Querlioz, "Model of the Weak Reset Process in HfOx Resistive Memory for Deep Learning Frameworks",* ***IEEE Transactions on Electron Devices****. 2021 Sep 8;68(10):4925-32.*

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