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PhD proposal

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Memristor-based spiking neural network: coding and architecture

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1. Scientific context

The limitations imposed by power consumption (130 W, reached in 2004), the end of Dennard scaling theory (describing consistent improvements in transistor density, cost performance and power) and high variability in nanoscale technology are very significant problems with respect to Moore's Law. Even if few concepts in our time have had as much influence on the economy in the last 50 years, it is now very clear that we are reached the end of the exponential growth with the computer performance doubling every two years. By current estimates the 10 nm technology is projected to be reached by semiconductor companies in the 2016 timeframe. This roadmap has been based on the continuing extension of CMOS technology for at least 20 years, but this roadmap does not guarantee anymore that silicon-based CMOS will extend beyond.

On the other hand, a new electronic component, the memristor, has been physically realized in 2008 at Hewlett-Packard Labs using a thin film of titanium dioxide. This new type of component, for which several realizations are now available,

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combines the functions of memory and logic like the synapses of biological neural networks.

In others words, this nanocomponent is capable of learning and one may be able to create an artificial neural network using memristors which mimic the synapses in biological brains.

The purpose of this PhD thesis is to explore hardware neural architectures based on memristors, and coding and learning technics for neuro-inspired architectures. Such accelerators have great potential due to their usability to a large class of applications (see the Recognition-Mining-Synthesis benchmarks proposed by Intel) and their intrinsic robustness capabilities.

Several major international research programs have been launched on this new model of computation, called *neuromorphic* or *neuro-inspired*: for instance, the European projects *Human Brain* [1] for the most accurate modeling of the human brain and *BrainScaleS* [2] which aims at understanding function and interaction of multiple spatial and temporal scales in brain information processing, the American project funded by DARPA, *Mometa, A Mind Made from Memristors* project *Variability Expedition* for a new class of computing machines that are adaptive but highly energy efficient.

These researchers from biology, biophysics, nanoelectronics and theory of computation are trying to build experimental platforms able to reproduce the biophysics of biological neural systems. The size and number of these research programs show the importance of scientific issues and expected economic benefits.

2. Emerging interdisciplinary area of research

The research topic of neuromorphic architectures based on memristors is an emerging topic (the memristors were physically discovered only 5 years ago). Inside are three main axes of research and development aimed to provide key cutting-edge technology and methods advances for computing:

- biology, from more and more precise knowledge on brain, through the neurons, their interconnections (synapses) and learning models based on spiking neural network (STDP: Spike-Timing-Dependent Plasticity);
- electronics from discovery at the nanoscale of this missing element, memristor and the realization of the new hardware architectures using this component;
- theory of computing, from the potential gain of artificial neural networks for "approximate" applications that tolerate approximation such as Recognition, Mining and Synthesis (RMS Intel benchmarks).

These three approaches also take into account the increasing variability of nanoscale circuits because of the intrinsic robustness capabilities of neural networks.

This topic is new in our team, DART/Emeraude. We started preliminary research in 2012 at IRCICA (http://www.ircica.univ-lille1.fr/) in collaboration with two IEMN research teams in electronics.

The aim of IRCICA is to develop exploratory research work on software and hardware components of the future and at the interface between hardware and software worlds. It is supported by the two main national research organisms in this field in France (CNRS and Inria) and one university. It is built on nine groups of research belonging to three high level laboratories of this country, in the field of microelectronics (IEMN), computer science (LIFL) and photonics (PhLAM). Among 140 people (80 permanent research scientists and 60 PhD students) are working together in this institute. They benefit of very high level facilities in term of software platforms and technological equipment (1600 m^2 clean room, electronic masking) for fabricating and testing (up to 220 GHz) nanoelectronic devices.

The particular point on which we will work is the hardware architectures of memristors developed by our colleagues Philippe Pernod and Nicolas Tiercelin (IEMN-NEMP) and Dominique Vuillaume and Fabien Alibart (IEMN).

3. Expected work

A first soft and hard implementation has been realized by Olivier Bichler. He showed in his thesis [3] that memristive nano-devices are particularly suitable for the implementation of natural unsupervised learning algorithms like Spike-Timing-Dependent Plasticity (STDP), requiring very little control circuitry. He proposes synaptic models for memristive devices and simulation methodologies for architectural design exploiting them.

The program of this thesis is to continue in this direction and experiment other applications in the field of video or audio recognition using artificial neural networks, and in collaboration with IEMN researchers to implement these new algorithms on crossbar arrays of tens of thousands of memristors. A dual thesis “Memristif component approaches for neuromorphic” is proposed by Philippe Pernod and Nicolas Tiercelin. Actually, there are now several emerging memory technologies: Phase-Change Memory (PCM), Conductive-Bridging RAM (CBRAM), Resistive RAM (RRAM) …

Such an integration of memristive devices could provide the huge density required by this type of architecture (several thousand synapses per neuron), which is impossible to match with a CMOS-only implementation and offer very significant gains in computation time and power consumption for realistic applications

This work would consist first

- To study software and hardware simulators of spiking neural networks.

- To test these simulators, especially in the field of vision and supervised / unsupervised learning; theoretical work will focus on coding information to spiking form.
- To implement neural networks on architectures based crossbar arrays of memristors, as developed at IEMN.

4. Scientific and economic impacts

Computer vision algorithms and their implementation in real time via neuromorphic accelerators are a very rich scope for example, adaptive navigation of autonomous vehicles, smart cameras, surveillance and augmented reality.

If such accelerators become a reality, they could improve time and energy performance by several orders of magnitude. These applications are increasingly important: classification, learning machine, mining, synthesis. They are indeed a part of the future challenges of IT.

5. Collaborations

This thesis is part of a collaboration that we have been carrying more than one year with several research teams IEMN, especially with Philippe Pernod (Professor Centrale Lille) and Nicolas Tiercelin (CNRS researcher) who are realizing a 2D crossbar array which can connect two layers of neurons with 256 65536 (256^2) synapses.

Funding and actions underway or in connection with this thesis are:

- With Nicolas Philippe Pernod and Tiercelin Lille1 - BQR (Bonus Qualité Recherche) 2012 “Memristive components and neuromorphic approaches”.
- With Dominique Vuillaume and Alexis Vlandas (CNRS researcher), we organized a workshop on architectures and bio-inspired computing in December 2012 (http://www.lifl.fr/emeraude/?page_id=175, these conferences are available on Lille1 TV).
- At IRCICA, Project 2012–2013: “Interfaces between IT and bio-inspired architectures” under the action of the Mission for the Interdisciplinary of CNRS.
- Participation to the MEMCO workshop [4].

References

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