Colloque GDR BioComp 2025

<u>Wednesday 03/12/2025</u>

15:00	Welcome
15:30	Ultrafast neural sampling with spiking nanolasers by Alfredo De Rossi The detection and analysis of analog signals are central to the systems engineered by Thales. Digital computers are employed to execute complex algorithms, including those based on artificial intelligence, in order to extract features, classify data, and transform temporal waveforms originating from the physical world. While digital computers are "universal," capable of executing any algorithm, they are not always optimal in terms of speed or energy efficiency. Analog computing, an older paradigm, exploits physical laws to perform specialized computations; as a result, efficiency and speed may arise from the intrinsic dynamical evolution of a suitably designed physical system. Ideally, we seek to set the parameters of a sufficiently complex system such that, when presented with input related to a specific question, its output corresponds to the desired answer. This process, which is closely related to machine learning, is highly non-trivial and is attracting significant interest across scientific disciplines—from applied mathematics to statistical and nonlinear physics, electronics, and optics. Optical systems initially garnered attention for their potential in this context, due to their capacity to implement a large number of reconfigurable connections (analogous to "synapses"). More recently, a large variety of optical systems have been explored, leveraging advances in parallelism, integrated photonics, and laser physics, to name just a few examples. Here, we focus on a recent theoretical result demonstrating that networks of spiking photonic crystal nanolasers can be trained to perform Bayesian inference by sampling from multivariate probability distributions. A photonic crystal nanolaser is a miniature laser that utilizes a specific type of optical confinement; it is termed "photonic crystal" due to its analogy with electron propagation in periodic potentials. Such lasers require only a minimal injection current to emit light (as little as 1 μA), making them attractive candidates for constructing large-scale networks. Experimentally, we have shown that these devices can be engineered to mimic leaky integrate-and-fire neurons: the laser is kept below the emission threshold, but when the cumulative excitation exceeds a certain threshold, it emits a well-defined optical spike.

	Furthermore, the inherently small size of these lasers results in stochastic emission properties. These characteristics are leveraged in a recently developed computational framework that maps a network of spiking neurons onto a Boltzmann machine. Through extensive simulations involving more than 1,000 individual lasers, we demonstrate that spiking nanolaser networks, similar to their electronic counterparts, can be mapped onto Boltzmann machines; they are capable of learning various distributions (such as the MNIST dataset) and performing both inference and data generation tasks. Owing to the exceptionally fast timescale of nanolasers (approximately one nanosecond or less), inference can be performed with both high speed and energy efficiency.
16:00	**Mott memristors, new components for neuromorphic devices** by **Pascale Diener** The memristor, a concept first theorized in 2008, has generated growing interest due to its promising applications in neuromorphic systems. This presentation introduces the memristor, exploring the various technologies currently under development and their initial applications in the field of bio-inspired computing. Special attention will be given to Mott-material-based memristors, a particularly innovative technology. These devices enable the creation of single-component artificial synapses and neurons, offering remarkable energy efficiency. Finally, recent advances obtained at IEMN in collaboration with IMN will be presented, including the fabrication of the first crossbar arrays for character recognition and the integration of Mott nanomaterials for high device miniaturization.
16:30	Coffee break
17:00	Ateliers
19:00	Diner

Thursday 04/12/2025

09:00	**Basal ganglia models of decision making: from robots to spikes** by **Benoit Girard** The Basal Ganglia are a set of interconnected subcortical nuclei, organized in a number of parallel loops involving various cortical areas and the thalamus. They are heavily suspected to be involved in the intricated decision-making and reinforcement learning mechanisms. The understanding of their complex structure is a fascinating questions, that has been interrogated with computational models for more that 30 years. I wil present some of my contributions to this effort, first (and rapidly) from a robotics point of view, and then from a neuroscience point of view, up to the recent biophysical spiking neural networks models of cortico-baso-thalamo-cortical loops I have been involved in.
10:00	**Properties of memory networks with excitatory-inhibitory assemblies** by **Claire Meissner Bernard** Classical views suggest that memories are stored in assemblies of excitatory neurons that become strongly interconnected during learning. However, recent experimental and theoretical results have challenged this view, leading to the hypothesis that memories are encoded in assemblies containing both excitatory (E) and inhibitory (I) neurons. Understanding the effects of these E-I assemblies on memory function is therefore essential. Using a biologically constrained model of an olfactory memory network, I will describe how introducing E-I assemblies reorganizes odor-evoked activity patterns in neural state space. Indeed, the "geometry" of neural activity provides valuable insights about the computational properties of neural networks. I will also discuss recent experimental data supporting predictions of the model.
10:30	Coffee break
11:00	Walk and Talk
12:30	Lunch
13:30	Atelier
14:00	**Empirical and computational study of perceptual consciousness** by **Nathan Faivre** Perceptual consciousness is defined as the subjective experience associated with processing sensory information from the environment. It

	is characterized by a continuous flow of percepts that emerge and fade with different intensities. While significant progress has been made over the past thirty years in identifying the neural correlates of consciousness, few studies have examined the dynamic nature of the stream of consciousness. In this presentation, I will share findings from intracranial recordings in humans that clarify the cortical basis of the temporal dynamics of consciousness. I will also introduce a theoretical framework based on evidence accumulation, offering a simple computational mechanism to explain these results.
14:30	Short presentations and posters A Spiking Neural Model of Dual Dopamine Contribution to Learning and Action Selection Roberto Sautto, Nicolas Cuperlier, Thanos Manos, Marwen Belkaid Sensorimotor dynamics as a readout for sparse place cell encoding Moubeche Aëlien BrAMA : Leveraging brain inspired principles for data-efficient multimodal learning Grienay Jonathan, Reyboz Marina, Mermillod Martial, Rodriguez Laurent, Miramond Benoît Navigation neuro-robotique pour véhicules autonomes Mariem Thabet Cr:V_2O_3-based mottronic devices as volatile elements for neuromorphic computing Sirjita eduard-Nicolae, Haydoura Mohammad, Corraze Benoit, Tranchant Julien, Cario Laurent Improving Human Action Recognition with Neuronal Competition in Spiking Neural Networks Oanea Tudor Cosmin, Goupy Gaspard, Cojocar Grigoreta-Sofia, Bilasco Ioan Marius Mott Insulator based artificial neuron for neuromorphic computing: a modelling approach Troger Karl, Berthelot Laurent, Blond Nathanael, Janod Etienne, Corraze, Tranchant, Cario Laurent Toward Tunable Coupled VO2 Spiking Circuits Li Ke Predicting Critical Exponents in VO2 Insulator-Metal Transition *Matthew Golden*
16:30	Coffee break

17:00	**Analog in-memory computing attention mechanism for fast and energy-efficient large language models** by Nathan Leroux Generative Transformer models rely on self-attention mechanisms that cache token projections to avoid recomputation during sequence generation. However, repeatedly transferring these projections between GPU memory and SRAM caches introduces significant latency and energy overhead, creating a major bottleneck in generative AI. We addressed these challenges by designing a self-attention architecture that leverages Gain Cells, an innovative charge-based analog memory technology, through hardware–software co-design to optimize latency and energy efficiency with minimal accuracy loss. Training Large Language Models on non-ideal analog hardware poses challenges in both accuracy and computational cost. To overcome these, I developed a training algorithm that rapidly adapts pre-trained models to our architecture and employed optimization techniques to accelerate computation. Our design achieves performance comparable to conventional LLMs up to 1.5B parameters, while delivering up to two and four orders of magnitude improvements in latency and energy efficiency, respectively.
17:30	**Energy-efficient memristive synapses based on oxygen-overstoichiometric oxide thin films** by Aleksandra Koroleva Emerging neuromorphic architectures require compact, energy-efficient, and highly integrable components capable of mimicking the behavior of biological neural networks in hardware implementations. A central building block of such architectures is the artificial synapse, which must combine nonvolatility, analog tunability, and low-energy operation. Among others, memristive devices based on oxide thin films are considered promising candidates for the emulation of synaptic connections because of their simple two-terminal geometry, high scalability, and the ability to gradually change their conductance under the application of an external bias. However, many state-of-the-art memristive devices rely on oxygen-deficient oxides and filamentary switching mechanisms, a strategy often associated with high variability as well as with difficulties in achieving reliable analog behavior. This talk will present a contrasting materials approach, focusing on overstoichiometric $La_2NiO_{4+\delta}$, a layered nickelate known for its high density of mobile oxygen interstitials and mixed ionic-electronic

	conductivity. Instead of creating oxygen vacancies, the presence and redistribution of excess oxygen are leveraged to enable analog capabilities in TiN/La2NiO4+**δ**/Pt devices. Furthermore, several optimization strategies are proposed with the objective of developing memristive artificial synapses that can operate with short electrical pulses, low current, and reduced energy consumption. In the first part of the talk, the ability to finely tune memristive and synaptic properties of the device through control of the oxygen content in the La2NiO4+**δ** layer will be presented. The second part of the talk will address the impact of device geometry and electrode configuration on the switching kinetics, supported by finite element modeling of the local electrothermal environment.
18:00	CNRS
19:00	Dinner

Friday 05/12/2025

09:30	**Excitabilité des neurones à impulsions analogiques** by **Leopold Van Brandt** Les neurones à impulsions sont les cellules élémentaires fondamentales des circuits neuromorphiques. La propriété d'excitabilité de ces neurones décrit leur capacité à produire un potentiel d'action (ou impulsion) en temps réel en réponse à un courant d'excitation synaptique. On retrouve dans la littérature une large gamme d'architectures de neurones analogiques de complexité variable et présentant des comportements excitables plus ou moins bio-physiquement plausibles. Nous commençons par étudier le mécanisme d'impulsion d'un neurone CMOS à ultra-basse consommation énergétique. Celui-ci se veut représentatif de la famille des neurones implémentés avec des transistors MOS fonctionnant sous seuil. À partir de simulations SPICE conventionnelles, nous établissons un critère d'excitation, quantifié soit en termes de charge critique fournie, soit comme un seuil que le potentiel de membrane doit dépasser. Seul ce dernier semble être intrinsèque au neurone, c'est-à-dire indépendant du stimulus d'entrée. Les travaux futurs devront apporter des éclaircissements sur les liens entre dynamique non linéaire du neurone, excitabilité et bruit intrinsèque. La seconde partie de la présentation décrit des neurones à impulsions implémentés à l'aide de memristors micro-fabriqués en chambre propre avec de l'oxyde de vanadium (VO2). La configuration always-spiking (« oscillateur à relaxation ») a été abondamment étudiée dans la littérature des capteurs neuromorphiques. Le régime de stochastic bursting (« éclatement stochastique ») a été observé expérimentalement mais demeure insuffisamment compris et modélisé à ce stade. Motivé par de renommées expériences en neurosciences, ce comportement excitable se veut prometteur en matière de fiabilité pour des applications de détection et de calcul neuromorphique basé sur les évènements plutôt que sur l'amplitude des signaux.

10:00	Vanadium Dioxide as a Single-Material Platform for Neuromorphic Chips by Alexandre Zimmers The brain-inspired codes of the AI revolution primarily run on conventional silicon computer architectures that were not designed for this purpose. This could soon lead to unrealistic energy consumption as AI continues to grow. Neuromorphic devices offer the promise of lower energy consumption by mimicking the brain's basic components—neurons and synapses—ideally using a single material. Unfortunately, among the few quantum materials which naturally act as spiking "neuristors" (artificial neurons), non-volatile "synaptor" memory (artificial synapses) has been hard to implement. One promising candidate functioning at room temperature is vanadium dioxide (VO_2). Interestingly, this material exhibits multiscale fractal electronic patterns during its insulator-metal transition, which must be understood and controlled before hoping to fully use it as neuromorphic devices. To achieve this, we have developed a new optical microscopy method that allows for the precise sub-micron recording of these insulator-metal patterns. More recently, by utilizing various temperature sweeps, a focused laser beam, and an AFM scanning tip, we have been able to locally modify and write specific insulator–metal patterns in the material. These findings could enable rewritable synaptic connections between neuristors within a single VO_2-based neuromorphic chip.
10:30	Coffee break
11:00	Atelier & Conclusions
12:30	Lunch