M2 internship offer (2027)

From Synaptic Delays to Neural Sequences: *Modelling Temporal Neural Coding with Spiking Neural Networks*

Cerco (CNRS UMR 5549, Toulouse) & IPAL (CNRS IRL2955, Singapore)

Starting date: First semester of 2027

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Keywords: ***Computational neuroscience, Spiking Neural Networks, neuronal sequences, neural coding, temporal dynamics, recurrent delays, visual perception.***

Context

How does the brain encode sensory information? Traditionally, this question has been studied by looking at how strongly individual neurons respond to a stimulus, for example through their firing rate (i.e., how frequently they are active). This idea is also central to many artificial neural networks, where information is mainly represented by the strength of neuronal activity, implicitly assumed to be static. However, growing evidence suggests that the brain may also encode information through the precise timing and order in which neurons become active. In particular, groups of neurons can form reproducible sequences of activity, with different neurons becoming active one after another over very short periods of time. Such sequences have been observed in several brain regions and may play an important role in perception and behaviour. In visual cortex, the consistency of these sequences has been shown to be related to the detection of visual stimuli (Montijn et al., 2016). More recently, recordings from the human cortex have shown that the order in which neurons become active can also carry information about visual categories, suggesting that the temporal organization of neural activity provides an additional dimension of neural coding (Xie et al., 2024).

This project will investigate **how such information-rich temporal sequences can emerge from recurrent neuronal networks**. We will use **Spiking Neural Networks (SNNs)** and *DelRec*, a recently developed approach that learns both synaptic weights and transmission delays in recurrent connections (Queant et al., 2025).

The central hypothesis is that **learning recurrent delays can organize neuronal activity into temporally precise and information-rich sequences**, potentially providing a computational mechanism for some of the temporal dynamics observed in the brain.

Methodology

The project will investigate:

- the emergence of stereotyped **population bursts and neuronal sequences** in recurrent SNNs;
- whether temporal sequences carry information complementary to firing rate;
- whether sequence consistency is related to visual stimulus detection;
- the role of learned recurrent delays in generating these temporal codes.

Different SNN architectures and delay configurations will be compared, and ablation/perturbation experiments will be used to determine the causal contribution of learned delays.

The project will combine **deep learning, spiking neural networks, computational neuroscience and neural data analysis**.

Candidate profile

The candidate should have a strong interest in **computational neuroscience and artificial intelligence**, with excellent programming skills, preferably in Python/PyTorch. A background in neuroscience, computer science, physics, mathematics or a related field is suitable. Experience with SNNs or deep learning would be appreciated but is not mandatory. The candidate should have a good level of English and be motivated to work in a multidisciplinary research environment.

Research environment

The project will be conducted at **CerCo (CNRS UMR 5549, Toulouse)** in between the **SV3M** (Spatial Vision in Man, Monkey and Machine) and **NeuroAI** teams. Toulouse is a student city (the second university hub in France) with high quality of life located in the south west of France (close to the Pyrenees, the Mediterranean Sea and the Spanish border). Interactions with Benoit Cottereau's group in Singapore are anticipated.

The internship is intended as a research project with the **possibility of continuation as a PhD thesis**, subject to funding and satisfactory progress. Applications should be sent to: timothee.masquelier@cnrs.fr, alexandre.queant@cnrs.fr and benoit.cottereau@cnrs.fr

Selected references:

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- Luczak, A., McNaughton, B. L., & Harris, K. D. (2015). *Packet-based communication in the cortex*. **Nature Reviews Neuroscience**.

- Montijn, J. S., Olcese, U., & Pennartz, C. M. A. (2016). *Visual stimulus detection correlates with the consistency of temporal sequences within stereotyped events of V1 neuronal population activity*. **Frontiers in Systems Neuroscience**.

- Pastalkova, E., et al. (2008). *Internally generated cell assembly sequences in the rat hippocampus*. **Science**.

- Singer, W. (2021). Recurrent dynamics in the cerebral cortex: Integration of sensory evidence with stored knowledge. **Proceedings of the National Academy of Sciences.**

- Vaz, A. P., Wittig Jr, J. H., Inati, S. K., & Zaghloul, K. A. (2023). Backbone spiking sequence as a basis for preplay, replay, and default states in human cortex. **Nature communications.**

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