Real-time Spiking Neural Network (SNN) using multicompartmental neuron model for neurological disorder studies

Romain Beaubois[1], Pascal Branchereau[2], Yoshiho Ikeuchi[3,4,5], Timothée Levi[1]

[1] IMS Laboratory, UMR5218, University of Bordeaux, France
[2] INCIA, UMR5287, CNRS, University of Bordeaux, France
[3] Institute of Industrial Science (IIS), the University of Tokyo, Japan
[4] LIMMS, CNRS-Institute of Industrial Science, UMI 2820, University of Tokyo, Japan
[5] Institute for AI and Beyond, The University of Tokyo, Japan

Characterization and modeling of biological neural networks is an expanding field opening to major advances in our understanding of the mechanisms governing the functioning of the brain and the different pathologies that can affect it. Neuroelectrophysiology requires an accurate understanding of basic mechanisms involved in the functioning and properties of neurons. The complexity of interfacing specific cells in vivo, due to the surrounding native environment, dramatically limits the analysis and interpretation of basic mechanisms. Standard in vitro procedures used by electrophysiologists generally require long-term recordings and accurate monitoring of the electrical activity of the cell. Furthermore, to create bioelectrical therapeutic solution for health care, a real-time bidirectional interface is mandatory.

To date, there is no real-time bi-directional neuro-hybrid platform with adaptive stimulation depending on spiking neural network (SNN) dynamic.

My main objective is to design an embedded real-time neuromorphic system allowing bi-directional bio-hybrid experiments and exploring large set of parameters to answer fundamental neuroscience questions including neurological disorders. Two neuroscience applications will be addressed:

- Design a new technological instrument as a novel form of neuroprosthesis aimed at treating disabling brain pathologies via adaptive bioelectrical stimulations.
- Perform massive parallel simulations of complex multicompartmental neuronal models to understand neurological disease as pathogenesis mechanisms of neuron diseases.

My PhD focus on the design of real-time SNN with multicompartmental model. This SNN will be used in two applications: massive parallel simulation of neurological disorder and generation of adaptive stimulation to the biological neural network.

Application 1: Parallel simulations to explore neurological disease:

From in vitro neuron characterization, multicompartmental modeling will be developed. Thanks to this SNN system in FPGA, massive parallel simulation can be performed for the space exploration of parameters and then characterize better neurological disorder like over-excitation of neural excitatory circuits. While these simulations usually take a long time with software-based solutions, this system could drastically decrease computation time allowing large parameters sweeping. From the results obtained, experiments could be conducted in biology with the parameters showing promising results in simulation to verify and investigate the associated behavior.

Application 2: Real-time bi-directional communication neuroprosthesis:

This new closed-system will improve the state of the art in terms of spatial and temporal adaptive stimulation thanks to SNN and to apply it on brain-organoid which are not yet realized in the literature. SNN will be integrated in a bio-hybrid system to perform adaptative stimulation on brain organoid to investigate its possible usage for the recovery of healthy activity on culture affected by neurological disorders.