Heterogeneous neural networks for time-series prediction on neuromorphic hardware

The Group of Computational Synaptic Physiology led by Prof. Dr. Christian Tetzlaff at the University Medical Center Göttingen (https://tetzlab.com) offers a **Bachelor's /Master's thesis project** on investigating heterogeneous neural networks for time-series prediction on neuromorphic hardware (part of the below proposal may be conducted for a Bachelor's thesis). The project will encompass the study of spiking heterogeneous neural networks using Intel's neuromorphic chip Loihi 2. The project shall start as soon as a suitable candidate is found.

Description

Biological neurons exhibit a large degree of heterogeneity. Recent work has shown that heterogeneity in the timescales of rate-based neurons can be exploited for a better input representation in networks, leading to better performance on various tasks comprising nonlinear transformations of time-shifted input. To investigate this, we use a recurrent balanced network driven by multidimensional chaotic input as a dynamic reservoir, and determine the respectively best linear readout approximation for any particular task. As a next step, we are employing the widely used Brian 2 library to extend our previous studies to networks of spiking neurons. Compared to conventional networks of rate neurons, spiking neural networks have the benefit of being more biologically realistic as well as more energy efficient due their sparse signal transmission. The biological realism and the larger number of parameters of the spiking model may provide further benefits of heterogeneous timescales for predicting, memorizing, and processing chaotic time series in biological and artificial intelligence systems.

The goal of the proposed project is to investigate the behavior of our spiking model on neuromorphic hardware systems. Using the recently developed Brian2Lava package, which connects Brian 2 to the neuromorphic computing framework Lava, the model shall be implemented on Intel's neuromorphic chip Loihi 2. This will enable to test the performance of the model on a system that promises to be extremely energy efficient and scalable. Furthermore, a first exploration of the performance of the model on other neuromorphic systems such as SpiNNaker 2 and memristive devices may be done. The project will be supported and co-supervised by Arash Golmohammadi and Dr. Jannik Luboeinski.

Specific objectives

- Investigating and adjusting the algorithm using the Brian 2 simulator.
- Executing and investigating the algorithm on the Loihi 2 chip using the Brian2Lava framework.
- Testing and benchmarking the implementation in different task paradigms.
- Exploring further implementations of the algorithm.

Requirements

- Programming experience, preferably in Python.
- English skills sufficient for reading papers and scientific interaction.
- Experience with recurrent and/or spiking neural networks (preferable but not mandatory).
- Experience with Brian 2 (preferable but not mandatory).

Key references

- Davies, M., Wild, A., Orchard, G., Sandamirskaya, Y., Guerra, G. A. F., Joshi, P., ... & Risbud, S. R. (2021). Advancing neuromorphic computing with Loihi: A survey of

results and outlook. Proceedings of the IEEE, 109(5), 911–934. https://doi.org/10.1109/JPROC.2021.3067593
- Perez-Nieves, N., Leung, V. C., Dragotti, P. L., & Goodman, D. F. (2021). Neural heterogeneity promotes robust learning. Nature Communications, 12(1), 5791. https://doi.org/10.1038/s41467-021-26022-3
- Stimberg, M., Brette, R., & Goodman, D. F. (2019). Brian 2, an intuitive and efficient neural simulator. eLife, 8, e47314. https://doi.org/10.7554/eLife.47314

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