Computational Astrocyence: Astrocytic Learning in Spiking Neural Networks

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Abstract

Prevailing over a century, the neuronal paradigm of studying the brain has left us with limitations in both our understanding of how the brain processes information to achieve biological intelligence and how such knowledge is translated into artificial intelligence. Overturning our assumptions of how brain behavior emerges at the network level, the recent exploration of astrocytes, the most abundant yet long-neglected non-neuronal brain cells, has ignited a revolution in our fundamental understanding of intelligence.

In this talk, I will present our ongoing effort to harness and nurture the learning ability of non-neuronal cells and unleash it into Brain-Inspired Computing. I will propose a biophysically realistic multi-compartmental model of an astrocyte whose activity replicates recent experimental results. I will describe how we integrated the astrocytic model into spiking Neural-Astrocytic Networks (SNANs), extending learning beyond weight changes and introducing time as a learnable computational component in our networks. I will demonstrate how we used SNANs to both explore and exploit these fundamentally different learning abilities of astrocytes, by introducing single-shot memories, overcoming the limitations that spike timing dependent plasticity (STDP) rules have.

Specifically, I will propose: 1) a non-linear, diffusion-based astrocytic mechanism for detecting and imposing neuronal synchronization (Polykretis et al. 2018a); 2) an astrocytic mechanism for spatially constraining plasticity into functional groups of neuronal inputs (Polykretis et al. 2018b) and 3) an inhibitory astrocytic mechanism that may increase the contrast among active and inactive information pathways (Polykretis et al. 2019). I will conclude my talk by demonstrating spike-based single-shot pattern learning using SNANs in Intels Loihi, a neuromorphic research chip that is available in a handful of research sites, including our Lab.

Overall, my research identifies possible mechanisms of astrocytic-induced neuronal synchronization and plasticity, adding a distinct computational layer that expands information processing beyond neuronal activity. Our results show preliminary evidence that, by inheriting their properties from their biological counterparts, SNANs can intrinsically tolerate noisy, unexpected data while introduce new efficient types of learning. This is a new research area towards functionally predominant SNANs that we have started to explore - and expand.

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Examination Committee: Prof. Konstantinos Michmizos, Prof. Casimir Kulikowski, Prof. Dimitri Metaxas, Prof. Bahman Kalantari