Brain-morphic algorithms on Neuromorphic Hardware: Towards energy-efficient and versatile Neu-Robotics

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Abstract

The emergence of neuromorphic computing calls for a bottom-up rethinking of computational algorithms that seamlessly integrate into non-Von Neumann hardware architectures, offering unparalleled energy efficiency and challenging the brittle inference-based AI solutions. In this work, we chose to tackle the problem of robotic navigation in an unexplored environment where energy-efficiency is crucial and current state-of-the-art solutions depend on literal, deterministic views of events that lack context and commonsense understanding.

Efficient solutions to the navigation problem have long been supported by biological brains. In my talk, I will first describe the relevant brain mechanisms that are understood well enough to become amenable to neuromorphic applications. Specifically, I will refer to the dedicated network of neuronal and astrocytic cells exhibiting asynchronous computations, event-based communications, and local plasticity. I will present our energy-efficient brain-morphic algorithm that emulates the brain's navigation system and describe its integration into Intel's Loihi, a neuromorphic research chip that is available in a handful research sites in the world, including our Lab. I will then demonstrate how a Loihi-run spiking neural network (SNN) solves the 1-Dimensional simultaneous localization and mapping (SLAM) by employing spike-based reference frame transformation, visual likelihood computation, and Bayesian inference. I will also give evidence that our neuromorphic algorithm exhibits comparable accuracy in head direction localization and map-generation while consuming 100 times less energy, compared to GMapping on a CPU.

Additionally, I will present our first fruits of our efforts to introduce, for the first time, a second processing unit on neuromorphic hardware: Astrocytes. I will briefly talk about our Loihi Astrocytic Module (LAM) that we released recently to the public. I will then talk about real-world applications of spiking neural-astrocytic networks (SNANs) run on Loihi that expand the

spatiotemporal domain of computation in SNNs. I will show that, by imposing mesochronous parallelism and extending the main learning rule in the brain, spike-timing-dependent plasticity (STDP), astrocytes can learn their own memories and sense the network's states.

Overall, my research paves the way for energy-efficient robotic perception and navigation solutions that are applicable to Loihi-controlled mobile robots.

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Examination Committee: Prof. Konstantinos Michmizos (Chair), Prof. Kostas Bekris, Prof. Santosh Nagarakatte, Prof. Badri Nath