Introducing neuromodulation of excitability in artificial spiking neural networks to improve adaptability of low power AI systems

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1 Introduction

State-of-the-art Artifical Intelligence (AI) models are providing impressive results in various fields, outperforming humans in certain tasks. While able to become highly specialized in a task, these models still lack the ability to adapt to unobservable changes. This problem is studied in a framework called meta Reinforcement Learning (RL), where an agent learns to quickly adapt to a distribution of tasks instead of solving a single task.

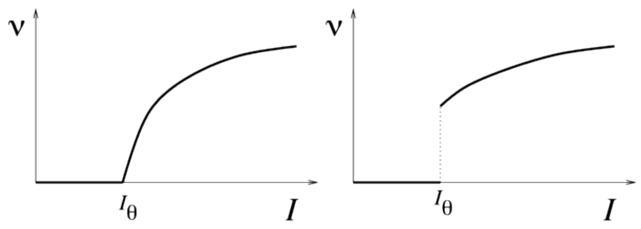
The high degree of adaptability shown by animals is associated with a physiological mechanism called neuromodulation [1][2], which is the ability of biological neurons and synapses to tune their input-output properties to reshape signal transmission at the cellular level, generally in response to an external signal carried by biochemicals called neuromodulators.

When implemented in Artificial Neural Networks (ANNs), neuromodulation helps meta-RL agents learn faster and receive higher rewards [3]. However, this mechanism is not explored in the context of artificial Spiking Neural Networks (SNNs). These models offer richer neuromodulation capabilities since they are based on neuronal models and mimic their behaviour by transmitting information through spikes. As a result, they also reduce the energy consumed compared to traditional ANNs. Introducing neuromodulation into SNNs could enhance their adaptability due to their unique underlying model and improve the performance of low-power AI systems.

2 Contribution

In this work, we propose a modification of a classical Recurrent Neural Network (RNN) cell to exhibit spiking activity that can be neuromodulated between different modes of excitability. To achieve this, the activation function used by the RNN cell is modified to emulate the feedback structure of excitable systems. These modified cells are capable of type I, II, and bursting behaviors depending on feedback gain values.

Types I and II neurons exhibit different patterns of spike frequency in response to varying input currents. Type I shows a continuous increase in frequency, as shown in fig. 1a, while type II displays a discontinuous evolution, as shown in fig. 1b. When bursting, a neuron fires repeatedly without going back to its resting potential.



(a) Type I. (b) Type II.

Figure 1: Gain functions showing the evolution of spike frequency ν given the input current I. [4]

These different behaviors allow neurons (and modified RNN cells in our case) to react differently given the same input and an external neuromodulatory signal.

In the context of meta-RL, a separate neural network computes the neuromodulatory signal based on a context signal that includes the previous state, last action, and last reward perceived by the agent. This enables the main neural network to adapt faster and generate higher rewards when faced to unobservable changes in the environment.

References

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