

Mitigating mismatch in neuromorphic circuits using neuromodulation loops

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1 Introduction

Carver Mead and collaborators envisioned fast, low-power, and efficient computing inspired by biological systems. This vision has been pursued by research groups and companies, leading to the development of multiple neuromorphic chips [1, 2]. In recent years, neuromorphic chips have demonstrated their envisioned high energy-efficiency and have even shown promising results on real-world tasks [3].

A fundamental challenge hindering the deployment of analog neuromorphic chips is device mismatch. Mismatch refers to the inherent variability in circuit parameters introduced during production. Designs that do not mitigate mismatch are impractical to deploy at scale; either each chip must be precisely calibrated during production or design parameters need to be adjusted individually for each chip.

Biological systems face similar variability yet operate reliably despite it, owing to homeostatic and neuromodulatory mechanisms [4]. The role of neuromodulation in real neural circuits is crucial, as blocking it leads to the collapse of the circuit’s function [5]. Inspired by biology, we propose using neuromodulation-based regulation loops to stabilize the behavior of neuromorphic circuits in the presence of mismatch. We demonstrate this approach using simulations performed with our Neuromorphic Control Toolbox [6, 7], which provides all the necessary blocks (neurons, synapses, neuromodulation) as well as tools for mismatch emulation.

2 Counteracting Mismatch in a Half-Center Oscillator

To illustrate a regulatory loop using neuromodulation, we study the example of a half-center oscillator (HCO) affected by mismatch. In simulation, mismatch is applied to all neuronal parameters, as well as to all parameters of the neuromodulation loop, since the loop should also be implemented on chip. The objective of the neuromodulation loop is to balance the HCO neurons, ensuring that each neuron’s burst duration is equal.

Each neuron participates in a neuromodulation loop that adjusts the synaptic strengths based on the bursting activity of both neurons. When the HCO is balanced, the activities of the two neurons are equal but in opposite phases, and their modulatory effects cancel each other out. When there is an

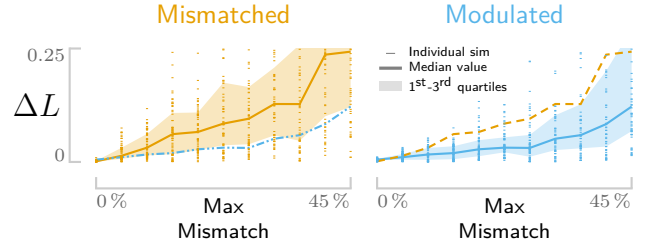


Figure 1: Comparison of the relative difference in burst duration (ΔL) between the two neurons of an HCO circuit as a function of the mismatch strength (maximum per-parameter deviation from nominal, in %) with and without a neuromodulation loop.

imbalance, neuronal activities no longer cancel, leading to a gradual drift in synaptic strengths until balance is restored.

Figure 1 shows that introducing mismatch perturbs the HCO and results in unequal burst durations. However, it also demonstrates that activating the neuromodulation loop reduces the deviation from the balanced state. These preliminary results indicate the potential effectiveness of using neuromodulatory feedback for stabilizing neuromorphic circuits.

References

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