Reproducing Vogels et al. (2011): Inhibitory Plasticity and E/I Balance in NEST

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1 Project

We propose to replicate the main results of Vogels et al. [1], a seminal study that shows that a simple Hebbian learning rule acting on inhibitory synapses can robustly self-organize excitation–inhibition (E/I) balance in recurrent circuits. In this framework, inhibitory plasticity adjusts synaptic strengths in response to ongoing activity (equation detailed in Section 2), yielding stable network dynamics without the need for fine-tuning parameters and accounting for a broad range of experimentally observed phenomena. Our central objective is to reproduce key results and figures from the original paper and, in parallel, to develop a clear and reusable implementation of the Vogels inhibitory plasticity rule in the NEST simulator.

Beyond reproducing published findings, this project is motivated by two complementary goals. First, it provides a structured opportunity to deepen practical experience with NEST, including best practices for building, stimulating, and analyzing large-scale spiking networks. Second, it offers focused engagement with an important synaptic plasticity mechanism that was not covered in the school curriculum. Importantly, while the Vogels inhibitory plasticity model is already available in NEST, there is currently no widely used reference example that demonstrates how to deploy it in complete, figure-level replication workflows. By producing such an example, the project aims to contribute a small but meaningful resource to the NEST community.

Our work will be guided primarily by the Vogels et al. article and its extensive supplementary materials, including the accompanying MATLAB and NEURON code, NEST documentation [2] together with one implementation in ModelDB [3]. Methodologically, the network components required by the study: integrate-and-fire neurons, conductance-based synapses, Poisson external drive, large recurrent excitatory/inhibitory connectivity, stimulus-induced perturbations, assembly formation via synaptic weight scaling, and spike recording; are all standard elements supported by NEST. The critical learning mechanism is implemented via NEST's existing inhibitory plasticity synapse model, which we will configure to match the original study as closely as possible. Where temporally varying external input is required, we will employ inhomogeneous Poisson processes to generate appropriate spike trains.

At the end of summer school, we expect to reproduce at least two of the main figures of the paper and to provide a robust, well-documented NEST example implementing the Vogels inhibitory synaptic plasticity rule. Successful completion will both validate the original findings in an independent simulation environment and provide a practical, reusable template for future work on E/I balance and inhibitory plasticity in spiking neural networks.

2 Inhibitory plasticity rule

The inhibitory synaptic plasticity proposed in the paper is

$$\Delta w \;=\; \eta\Big(\mathrm{pre}\cdot\mathrm{post} \;-\; \rho_0\cdot\mathrm{pre}\Big), \tag{1}$$

where Δw is the change in synaptic efficacy, η is the learning rate, pre denotes the presynaptic activity term (a presynaptic spike trace), and post denotes the postsynaptic activity term (a postsynaptic spike indicator). The first term, pre·post, implements a Hebbian component that strengthens inhibition when pre- and postsynaptic activity co-occur, whereas the second term, $\rho_0 \cdot \mathrm{pre}$, introduces a homeostatic reference level ρ_0 that counteracts potentiation and sets the target for postsynaptic activity. To note, these weights are constrained to remain within fixed bounds to ensure stability.

References

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