Self-organization of neuronal dynamics by plasticity and adaptation

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It is widely believed that the structure of neuronal circuits plays a major role in brain functioning. Although the full synaptic connectivity for larger populations is not yet assessable even by current experimental techniques, available data show that neither synaptic strengths nor the number of synapses per neuron are homogeneously distributed. Several studies have found long-tailed distributions of synaptic weights with many weak and a few exceptionally strong synaptic connections [1]. Little is known about how inhomogeneities could arise in the developing brain and we hypothesize that there is a self-organizing principle behind their appearance. We show how structural inhomogeneities can emerge by a combination of simple synaptic plasticity mechanisms from an initially homogeneous network [2].

The neuronal dynamics in dissociated cultures is dominated by intermingled periods of very low and very high activity, forming population bursts. Classical models of neuronal firing and plasticity are aiming at capturing the asynchronous state devoid of such burst [3]. We discuss how the parameters of these models shell be altered to obtain dynamics similar to hippocampal cultures. Along the way we discover, that adaptation is required to capture the essential features of the neuronal dynamics.

What can be a goal-state of such adaptation and plasticities? We discuss the information-theoretical evaluation of the development in dissociated cultures. We observe that information transfer and active information storage increase with development beyond the bounds explained by the increase in rate.

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Song, S., Sjöström, P. J., Reigl, M., Nelson, S., & Chklovskii, D. B. (2005). Highly nonrandom features of synaptic connectivity in local cortical circuits. PLoS Biology, 3(3), 0507–0519.
Effenberger, F., Jost, J., & Levina, A. (2015). Self-organization in Balanced State Networks by STDP and Homeostatic Plasticity. PLoS Computational Biology, 11(9), 1–20.
Brunel, N. (2000). Dynamics of Sparsely Connected Networks of Excitatory and Inhibitory Spiking Neurons, 208, Computational Neuroscience, 183–208.