Delving into UP and DOWN States in Cortical Networks: Mechanisms Underlying Synaptic Plasticity

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Abstract:

Cortical neuronal circuits undergo transitions between periods of sustained neural activity (UP state) and periods of silence (DOWN state), alternating in a rhythmic manner. This UP-DOWN dynamic is commonly observed in cortical activity, and the mechanisms responsible for generating this alternation have been widely explored in the literature (see [1], among others). However, when the network is influenced by short-term synaptic plasticity (STP), either through depression (STD) or facilitation (STF), the alternating behavior can be modified depending on the specific level of STP present in the network. Despite numerous mathematical models proposed to explain the underlying mechanisms of these plasticity-induced changes, the precise functional role of STP in shaping network dynamics is still not fully understood.

In this work, we present a rate model (see [1] in supporting information) that reproduces the neuronal dynamics observed when different levels of plasticity are applied to a bio-inspired computational model of an Excitatory-Inhibitory (EI) network of Hodgkin-Huxley type neurons, introduced in [2,3,4], which simulates cortical activity in V1. To conduct the study, we identify three distinct states of the rate model. Initially, a two-dimensional rate model is introduced, capturing the firing rate dynamics of both excitatory and inhibitory populations in the network. By incorporating neuronal adaptation into both populations, we next model the transition between UP and

DOWN states, reflecting the dynamic changes between sustained neural activity and silence (see [2] in supporting information). Finally, by adding dynamics to the synaptic connections, we model the effects of short-term synaptic plasticity (STP), which alters the network's behavior based on the type and strength of the involved plasticity (see [3] in supporting information). Specifically, we explore how depression (STD) drives the transition from UP and DOWN states to asynchronous activity, while facilitation (STF) pushes the network from a silent state to UP and DOWN states. Our simulations reveal the existence of three distinct activity states: (1) UP and DOWN states, (2) an asynchronous activity regime, and (3) a silent state, along with the underlying bifurcations driving these transitions. These states are determined by the level of depression and facilitation in the network, as well as the steady-state probability of facilitation release.

References:

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