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Lecture presentation

Large scale model of the human brain

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Introduction

I will describe an ambitious project of constructing a detailed large-scale thalamocortical model based on experimental measures in several mammalian species. The model spans three anatomical scales: (1) It is based on global (white-matter) thalamocortical anatomy obtained via diffusion tensor imaging (DTI) of a human brain. (2) It includes multiple thalamic nuclei and six-layered cortical microcircuitry based on in vitro labeling and three-dimensional reconstruction of single neurons of cat visual cortex. (3) It has 22 basic types of neurons with appropriate laminar distribution of their branching dendritic trees. The model simulates one million multi-compartmental spiking neurons calibrated to reproduce known types of responses recorded in vitro in rats. It has almost half a billion synapses with appropriate receptor kinetics, short-term plasticity, and long-term dendritic spike-timing dependent synaptic plasticity (dendritic STDP).

Results

Spatio-temporal dynamics of the simulation show that some features of normal brain activity, although not explicitly built into the model, emerged spontaneously. Even in the absence of external input, the distribution of firing rates among various types of neurons is similar to that recorded in vivo – pyramidal neurons fire just a few spikes per second with the lowest firing rate observed in layer 2/3, whereas basket cells fire tens of spikes per second with the highest firing rate in layer 5. Individual neurons exhibit somatic and dendritic spikes, forward- and back-propagation of spikes along the dendritic trees, and spike-timing-dependent plasticity that is coupled to the dendritic compartments rather than to the somatic spikes. The model spontaneously generated rhythms and propagating waves that had frequency distributions, spatial extents, and propagation velocities similar to those observed in mammalian in vivo recordings (including humans). In a fashion similar to human data, the simulated fMRI signal exhibited slow oscillations with multiple fronto-parietal anticorrelated functional clusters.

The computer model allowed us to perform experiments that are impossible (physically or ethically) to carry out with animals. For example, we put the model into the noiseless regime to demonstrate that it can produce self-sustained autonomous activity. We perturbed a single spike in this regime (out of millions) and showed that the network completely reorganized its firing activity within half a second. I will discuss the results of simulations of structural perturbations (lesions, strokes, and tumors) and their effect on the global dynamics, as well as the effect of sleep oscillations on synaptic plasticity, learning, and memory.

References

1. Izhikevich EM, Edelman GM: **A large-scale model of mammalian thalamocortical systems.** *PNAS* 2008, **105:**3593-3598.