Data-driven large-scale simulations of fine-scale cortical network dynamics

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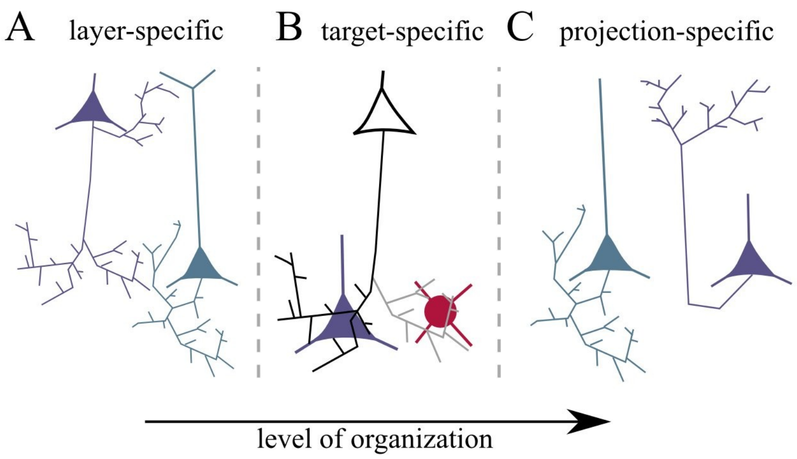
Abstract: We present a hierarchical simulation framework that is capable of capturing multiple levels of the fine-scale circuitry of cortical networks. We apply this framework to large-scale simulations of a layered cortical network model. In so doing we assess the relationship of the connectivity structure of the cortex to its activity.

1 Introduction

The local cortical network consists of specifically interconnected neuronal populations (see [1] for review). This microcircuitry determines the possible interactions between neurons and thus may play a crucial role in shaping neuronal activity. We investigate the dynamical implications of the specificity of connections in the local network by means of large-scale simulations [2] of a spiking layered network model. To this end, we quantify the specificity of connections measured by diverse experimental techniques and develop the simulation framework for fine-scale cortical networks.



2 Hierarchical simulation framework

The simulation framework is based on a hierarchy of specificity of cortical microcircuits (see figure): neuronal connectivity depends on the cortical layer (see fig. A) and the type of the target neuron (see fig. B) [3]. Further subdivision is based on the specific projection patterns of subpopulations (see fig. C, [4]) and fine-scale connectivity [5]. The basic unit in our simulation framework is the neuronal population. Multiple populations instantiate a cortical layer and multiple layers in turn constitute a local cortical network. We employ a data-driven approach to address in particular the explosion of the number of parameters when increasing the level of detail of the fine-scale circuitry: On the one hand, the level of description in the network simulation is determined by the available experimental data (e.g. [5]). On the other hand, the hierarchical framework allows us to model highly specific circuits despite the limitations and incompleteness of the data by demanding consistency of connectivity on all hierarchical levels. This framework has been developed in the high-level scripting language SLI of the NEST simulator [2] and is instantiated into distributed network models by high-level connection routines.

3 Application to layered cortical network models

We apply the hierarchical simulation framework to layer-specific and fine-scale cortical network models. Thereby, we can exploit the framework by easily integrating additional connectivity data into established data sets [3]. We investigate the impact of the detailed statistics of connectivity on the spike train statistics by parametrizing our layered cortical network model with increasing details in specificity. The model consists of 80,000 integrate-and-fire neurons and explains about 90% of the synapses constituting the local cortical microcircuit. We instantiate the network model using the parallel simulation tool NEST [2]. The application scales excellently to thousands of processors on Blue Gene supercomputers. This enables us to carry out systematic studies including synaptic plasticity which requires simulation times on the scale of minutes of biological time. The network may serve as a building block for brain-scale simulations. As we focus on the relationship between connectivity and network activity, we use identical dynamics and parameters for all neuron types in the network. Despite this homogeneity, we observe that the layer-specific connections alone cause layer- and type-specific firing rates. These rates are in excellent agreement with experimental observations, exhibiting lowest firing in superficial layers and highest rates in layer 5. Furthermore we find that a small subset of target-specific connections [3] strongly influences the stability of network activity. Finally, the incorporation of projection-specificity enables us to investigate the influence of fine-scale connectivity on global activity patterns. We conclude that specific connections represent a structural correlate of the experimentally observed network dynamics.

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