A whole-brain spiking neural network model linking basal ganglia, cerebellum, cortex and thalamus

Introduction

In order to investigate the dynamic nature of the whole brain network, we built biologically constrained spiking neural network models of the basal ganglia [1,2,3], cerebellum, thalamus, and the cortex [4,5] and ran an integrated simulation using K supercomputer [6] using NEST 2.16.0 [7,8].

Resting State Simulations on K computer

We replicated resting state activities of 2.5 biological seconds of time in models with increasing scales, from 1x1mm² to 7x7mm² of cortical surface, and observed plausible values of excitatory and inhibitory population firing rates. Largest simulated model included 51 million neurons and 54 billion synapses, more than an entire hemisphere of a mouse brain [Herculano-Houzel, 2009].

To our knowledge, this is the first time a whole-brain model, of such size, implements interactions between regions such as cortico-cerebellum-thalamo-cortical and cortico-basal ganglia-thalamo-cortical loops.

Simulation Performance

Simulations using a hybrid parallelization approach showed a good weak scaling performance in simulation time lasting between 10-30 minutes, but identified a problem of long time (between 1-3 hours) for network building, reinforcing the limit of memory consumption.


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References:

Arm-reaching task on cortico-basal ganglia-thalamo-cortical closed loop

We evaluated the properties of action selection with realistic topographic connections in the Ctx-BG-TH-CTX closed loop circuit in 2-D target reaching task and observed selective activation and inhibition of neurons in preferred directions in every nucleus leading to the output.

We circular information “channels” of 160 µm radius with some overlap are generated by a simultaneous activation of M1, L5A-L5B, S1 L5A-L5B and TH CM/PR.

We modelled cortical activity similar to the one observed in arm-reaching tasks [10]. Firing rates of different channels are related to the direction to reach. Preferred direction is 90° (channel 2) for this example, M1 and S1 provides the maximum firing rate amplitude to channel 2, while other channels receive lower inputs. CM/PR provides same input to all channels.

Reinforcement learning based on dopamine-dependent STDP

We performed tests of reinforcement learning based on dopamine-dependent STDP (spike-timing dependent synaptic plasticity).

We incorporated STDP [Izhikevich 2007, Potjans et al., 2010] at MNDA and AMPA excitatory connections from Cortex to Basal Ganglia.

Given an inter-spike time, the eligibility trace and dopamine concentration dynamics governs the synaptic LTD (long term depression) and LTP (long term potentiation).