Parallel stochastic networks approximate large-scale interconnected populations of spiking neurons

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Simulations of massively-interconnected networks of spiking neurons require computation of the membrane potentials of individual neurons and transmission of spikes between neurons. The membrane computations scale linearly with the number of neurons, but for fully-interconnected networks the number of transmissions between neurons scales as the square of the number of neurons. Approximations that reduce the requirement for transmission could facilitate such simulations.

Consider a network that consists of 2 distinct populations, each with $N$ neurons. Suppose that each neuron $n_{2,i}$ in population 2 is fully connected to all neurons $n_{1,j}$ in population 1 through synapses with transmission probabilities $w_{ij}$. Then if $s_{2,i} \in \{0, 1\}$ indicates the presence of absence of a spike in neuron $n_{2,i}$, the expected value is $E[s_{2,i}] = \sum_j w_{ij} E[s_{1,j}]$. If all the neurons in each population obey the same first-order statistics and all the synaptic weights are equal, then $E[s_{2,i}] = NwE[s_{1,j}] \forall i, j$. Therefore the expected value of the output population is unchanged if each output neuron is connected to only a single input neuron.

The approximation consists of a set of parallel circuits, where each circuit contains only a single neuron from each population. For example, consider a network of 600 Izhikevich neurons arranged in 6 populations, roughly corresponding to pyramidal tract neurons, anterior horn cells, and dorsal horn cells for the agonist and antagonist muscles about a single joint. The interconnections form a feedback controller, so that the pyramidal cells specify the reference position of the joint, the dorsal horn cells provide proprioceptive feedback, and the anterior horn cells provide the driving signal to muscle (simulated using a Hill model). To approximate this network, a set of 100 parallel independent micro-networks is created, each with 6 neurons (one of each type). The networks are linked only through their outputs to common muscles. Each micro-network provides a very poor feedback controller, but the average behavior of the 100 controllers provides good step tracking and disturbance rejection, as shown in the figure.

**Figure**: Left: agonist, Right: antagonist, Row1: pyramidal neurons, Row2: anterior horn cells, Row3: Ia afferents, Row4: reference trajectory and tracking response, for a reference step at 1000msec and torque disturbances at 500 and 1500msec.