How Neuronal and Glial Cells Interact: Modeling Brain Networks for Information Processing and Memory

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Abstract: Astrocytes are increasingly recognized as active participants in brain information processing, learning, and memory. They interact with neurons and other glial cells through complex signaling pathways that shape synaptic transmission, plasticity, and network dynamics. In this study, we present an advanced computational framework for modeling neuron–astrocyte interactions, with a particular focus on astrocyte-induced synaptic currents and their influence on neuronal networks. Our model extends conventional binary neuron-to-neuron connectivity by implementing tripartite synapses, where astrocytes interact with both presynaptic and postsynaptic neurons. Built within the NEST simulation platform, the framework integrates detailed astrocytic calcium dynamics and their downstream effects on neuronal activity. In silico experiments reveal that astrocytes modulate local network coordination, enhance the synchronization of neuronal populations, and influence transitions between asynchronous and synchronous activity states. Benchmark simulations demonstrate that the model scales efficiently to large-scale networks, making it suitable for mechanistic studies of astrocytic contributions to memory formation, network stability, and pathological states such as epilepsy and neurodegeneration. Overall, this work introduces a biologically grounded, computationally efficient model of neuron–astrocyte networks, providing a foundation for studying how glial interactions shape brain information processing and cognitive function.

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