DHSU Translational Brain Health and Resilience Research Summit

Computational Simulations and Mathematical Models to Better Understand Neural Brain Function and Disorders

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In the Dura-Bernal lab, we use computational simulations and mathematical models to better understand neural brain function and disorders, and help develop novel treatments. We build and simulate large-scale biophysically detailed models of the brain neural circuits linking data at multiple scales: molecules, cells, networks and systems. We run these simulations on supercomputers to reproduce experimental data and make predictions. We developed the most detailed model of mouse primary motor cortex circuits, containing over 10,000 biophysically and morphologically realistic neurons and 30 million synapses; with neuronal density, distribution and synaptic connectivity patterns constrained by data. The model reproduced in vivo cell type-specific dynamics associated with different behaviors and experimental conditions. We developed similarly detailed models of the somatosensory cortex, auditory cortex, thalamic circuits and hippocampus. We use models to identify and characterize neural coding mechanisms within and across scales, including synchronous firing of neuronal ensembles, phase-amplitude oscillatory coupling, dendritic and network resonance, neuromodulatory interactions (e.g. noradrenaline and dopamine), neuronal avalanches, and information flow. The models also help identify the biophysical cell and circuit mechanisms underlying common experimental measures such as LFP/CSD, EEG, MEG and fMRI. We have used our models to study several brain disease and disorders, including epilepsy, dystonia, schizophrenia, depression, and ischemic stroke; as well as potential neurostimulation and pharmacological treatments such as electrical stimulation, optogenetics and ketamine. We also develop a software tool (netpyne.org) to facilitate building these multiscale brain circuit models which has been used in over 40 labs, to study multiple brain regions and disease.