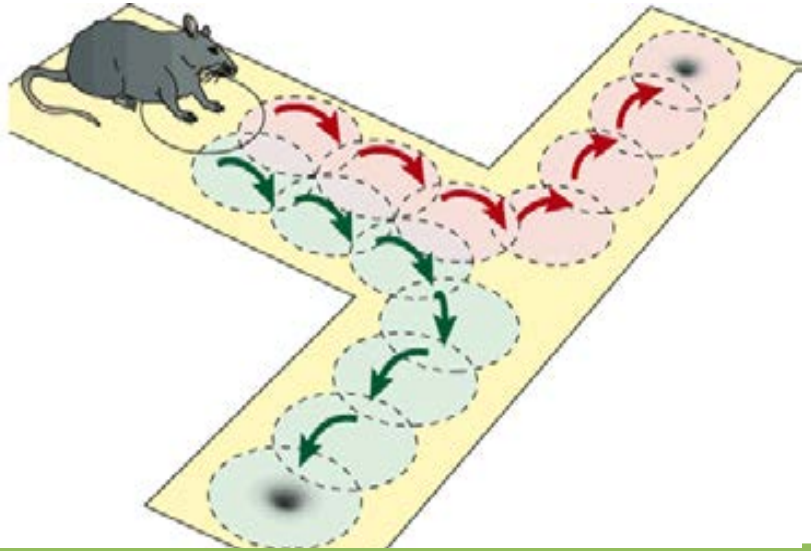
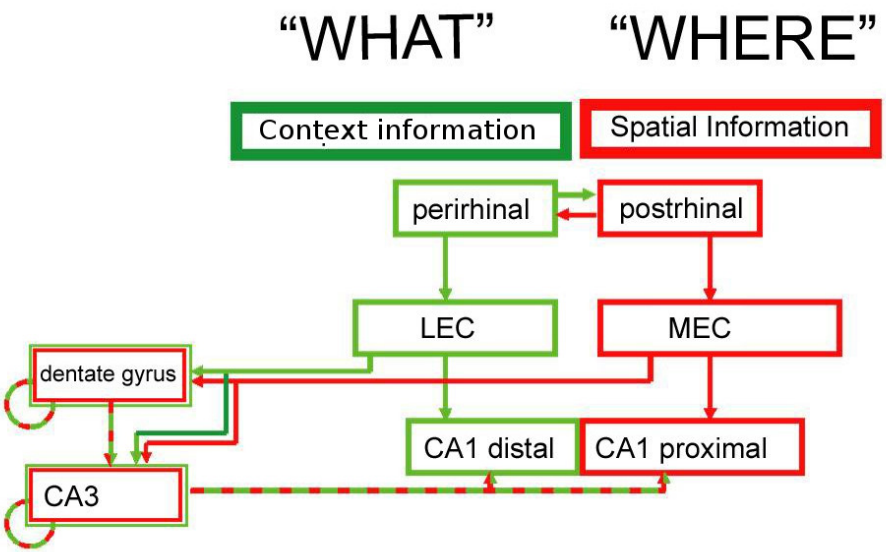
Spatial Coding in a Full-Scale Computational Model of the Hippocampus

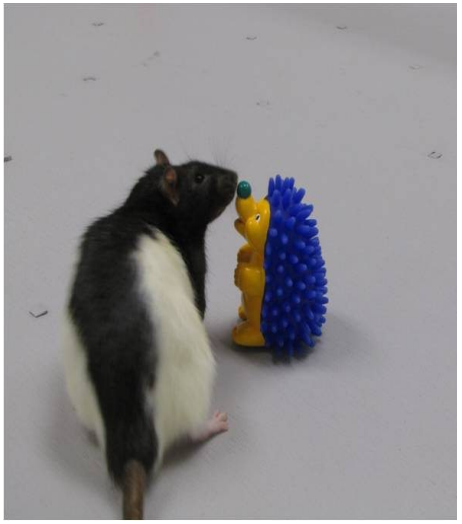


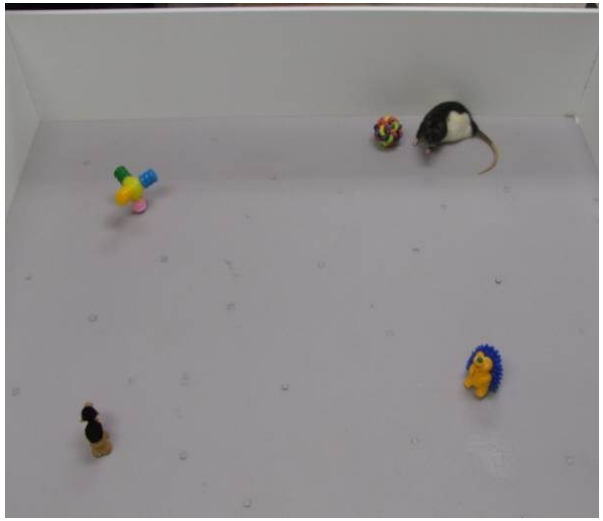
Ivan Raikov, Aaron Milstein, Grace Ng, Ivan Soltesz
Department of Neurosurgery, Stanford University

Blue Waters Symposium 2018

Information Coding in the Hippocampus

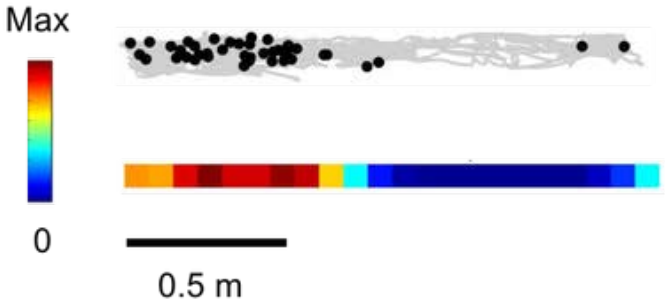




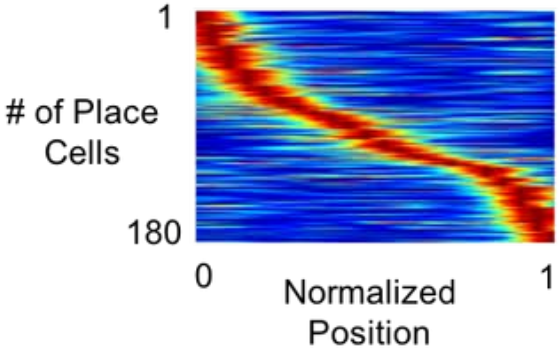


Knierim, 2012

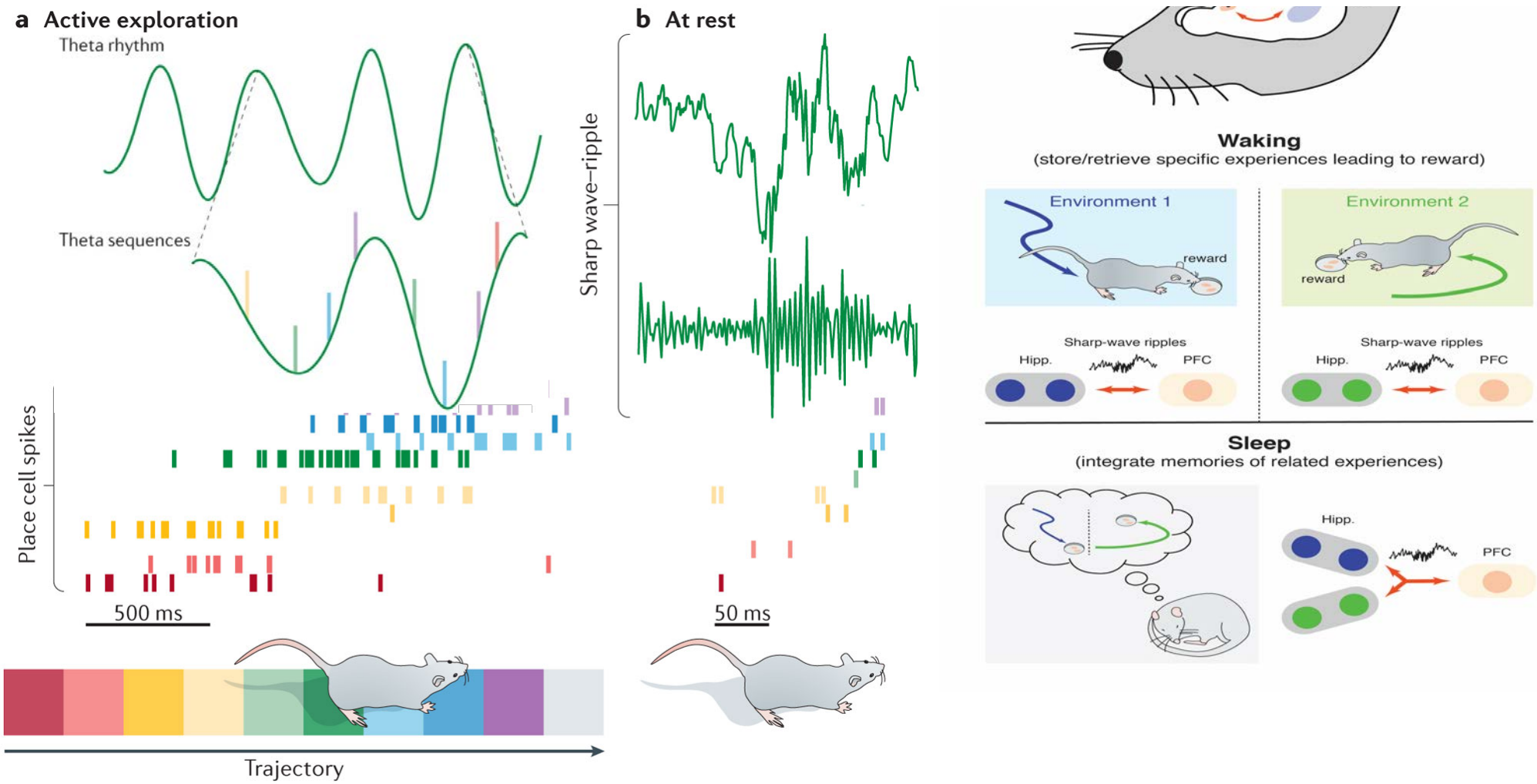
Place Cell on a Linear Track



Population of Place Cells on a Track



Towards a Complete Description of the Circuitry Underlying Sharp Wave-Mediated Memory Replay

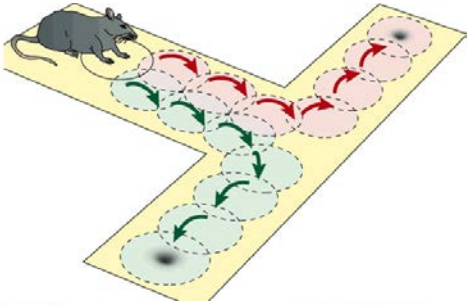


Nature Reviews | Neuroscience

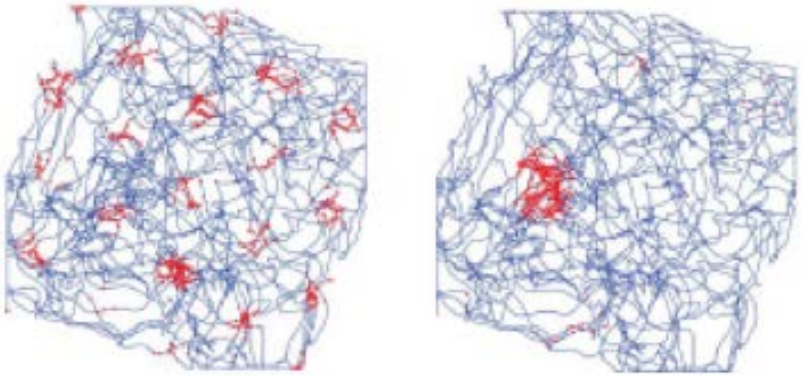
Colgin, 2017.

Understanding Neural Systems

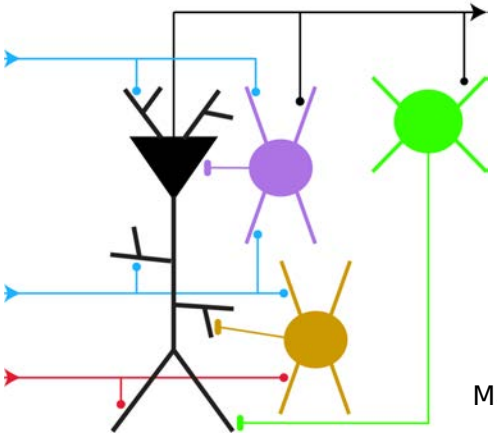
1. **Computational level**: What is the task? What logic is used to solve it?



2. **Algorithmic level**: How is relevant information represented and manipulated to perform the task?



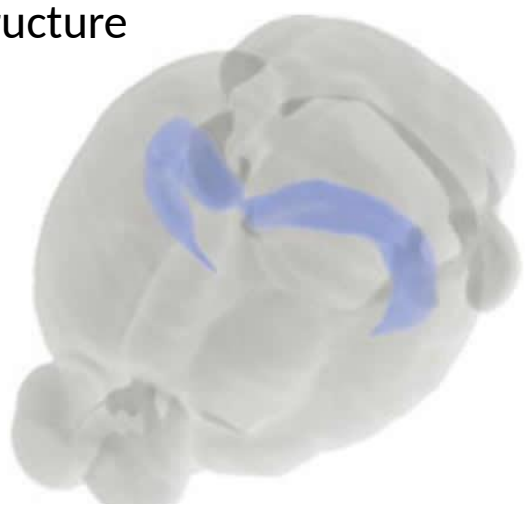
3. **Implementational level**: How does hardware implement the algorithms?



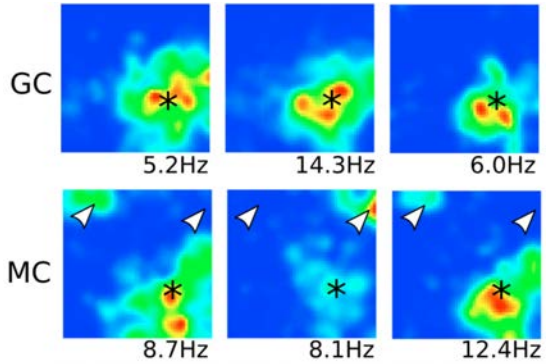
Marr, D.; Poggio, T. (1976).

Understanding Neural Systems

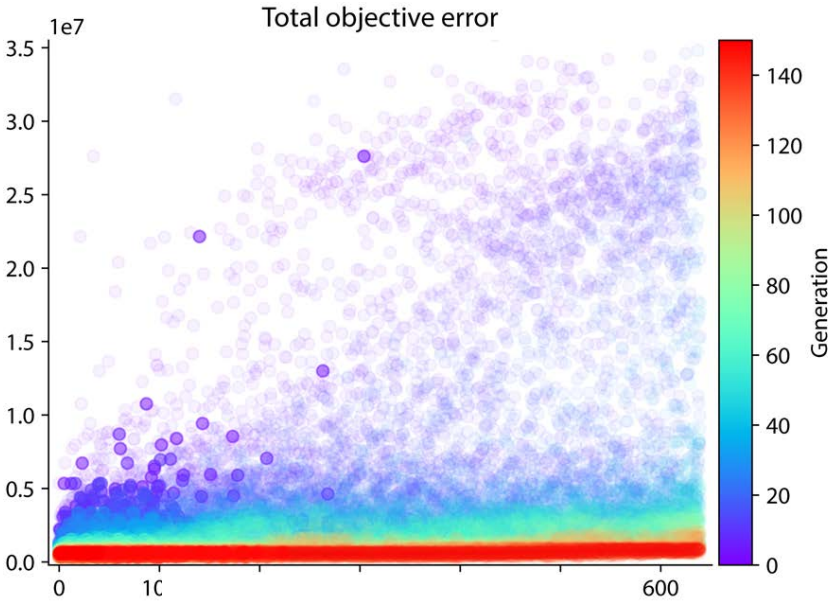
Modeling hippocampal neuroanatomy and connectivity structure

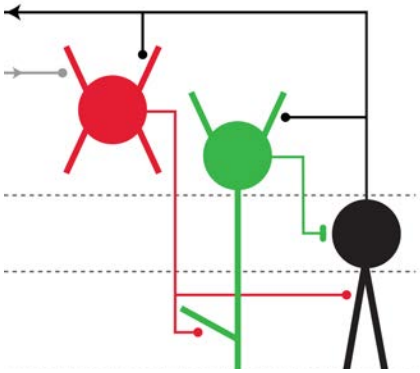


Investigating hippocampal spatial and temporal coding at scale



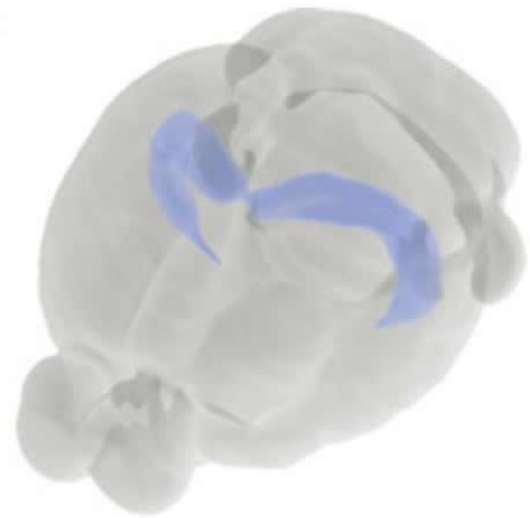
Cell and circuit-level parameter optimization



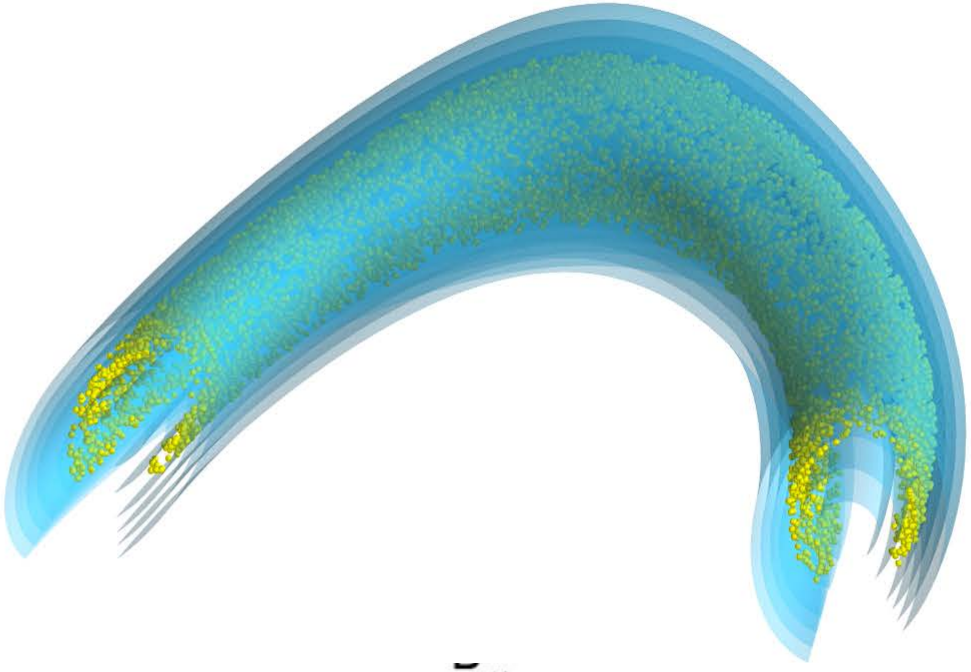


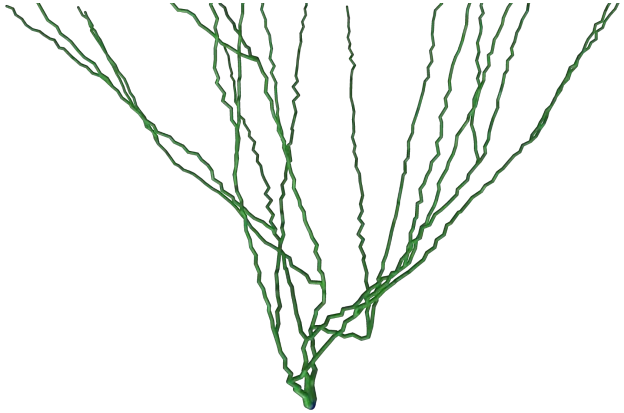
Modeling the Hippocampus at Full Scale

Hippocampus of rat in 3D brain volume

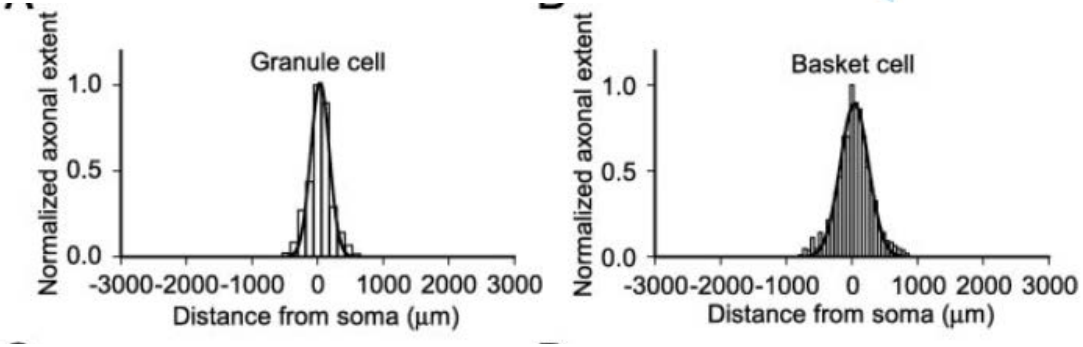


3D distribution of 1,000,000 granule cells



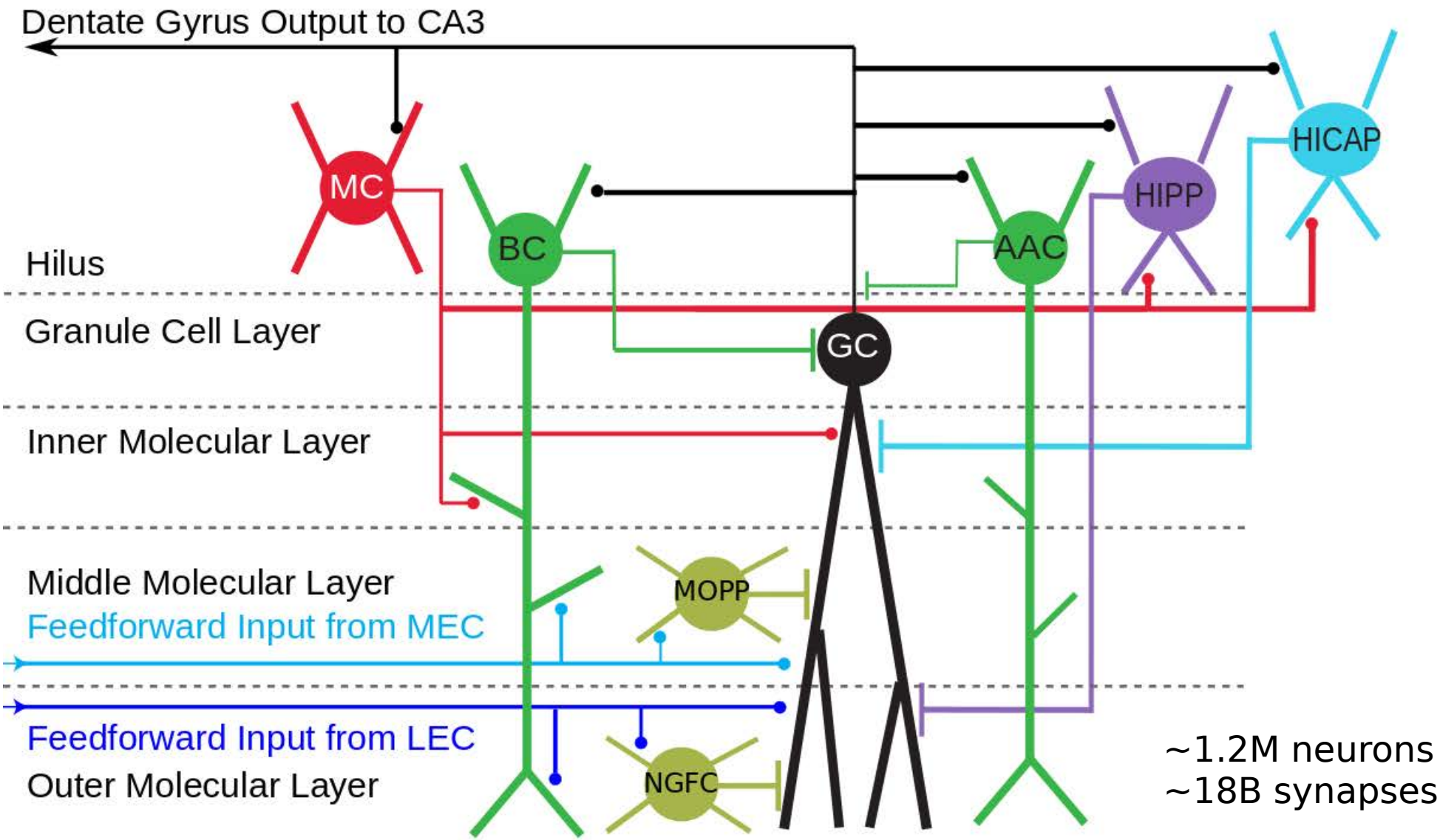


Unique synthetic
granule cell morphology



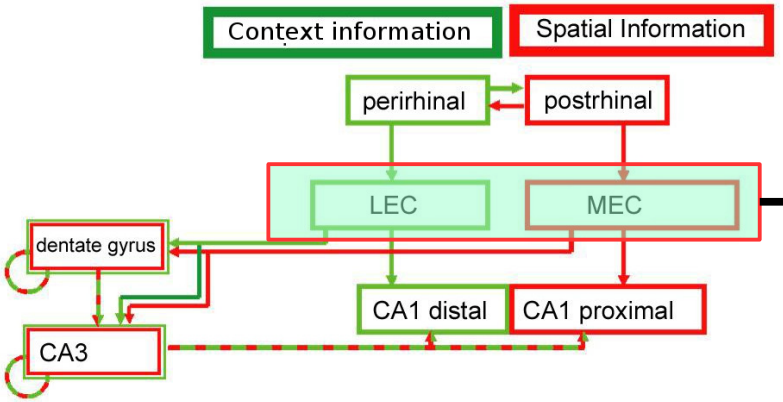
Axonal distributions

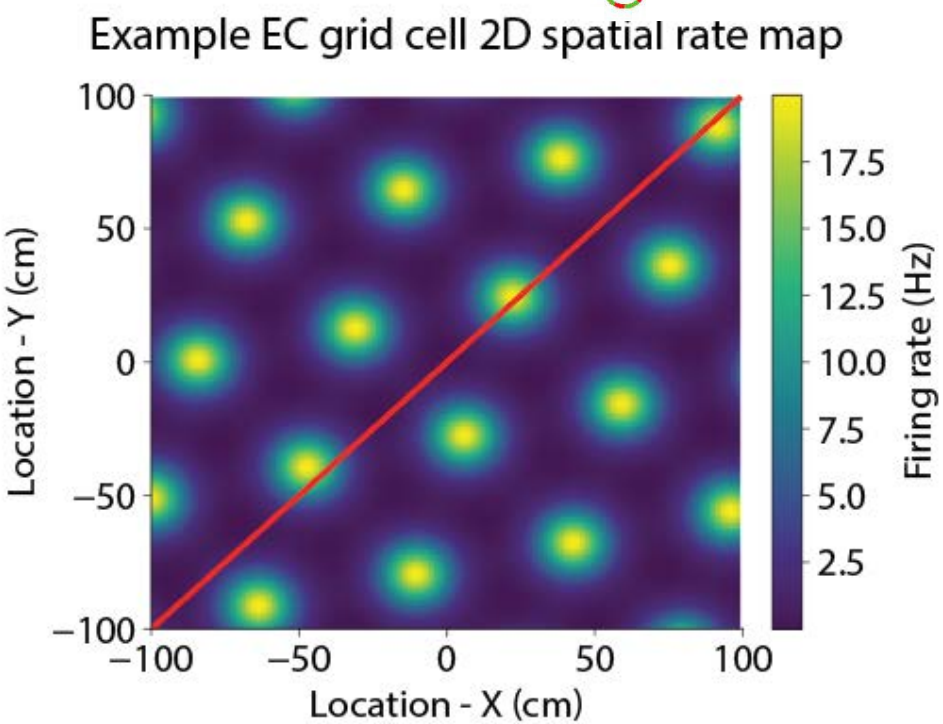
Modeling the Hippocampus at Full Scale

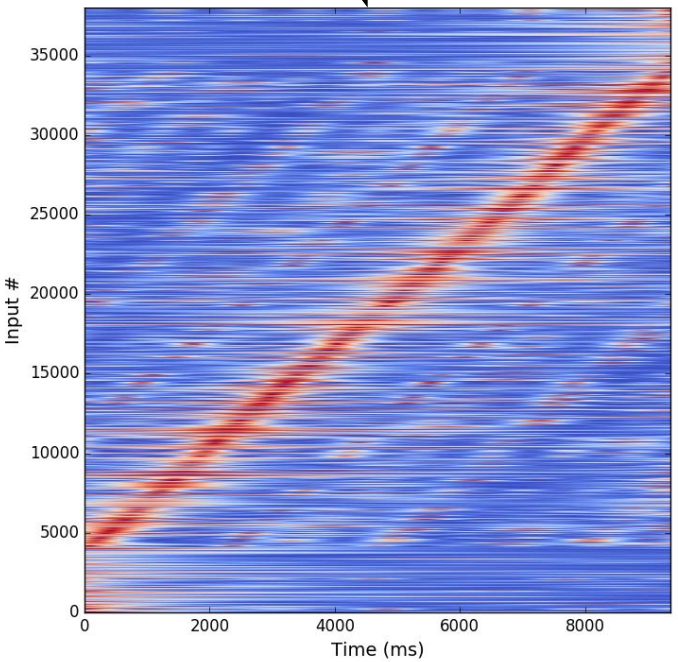


~1.2M neurons
~18B synapses

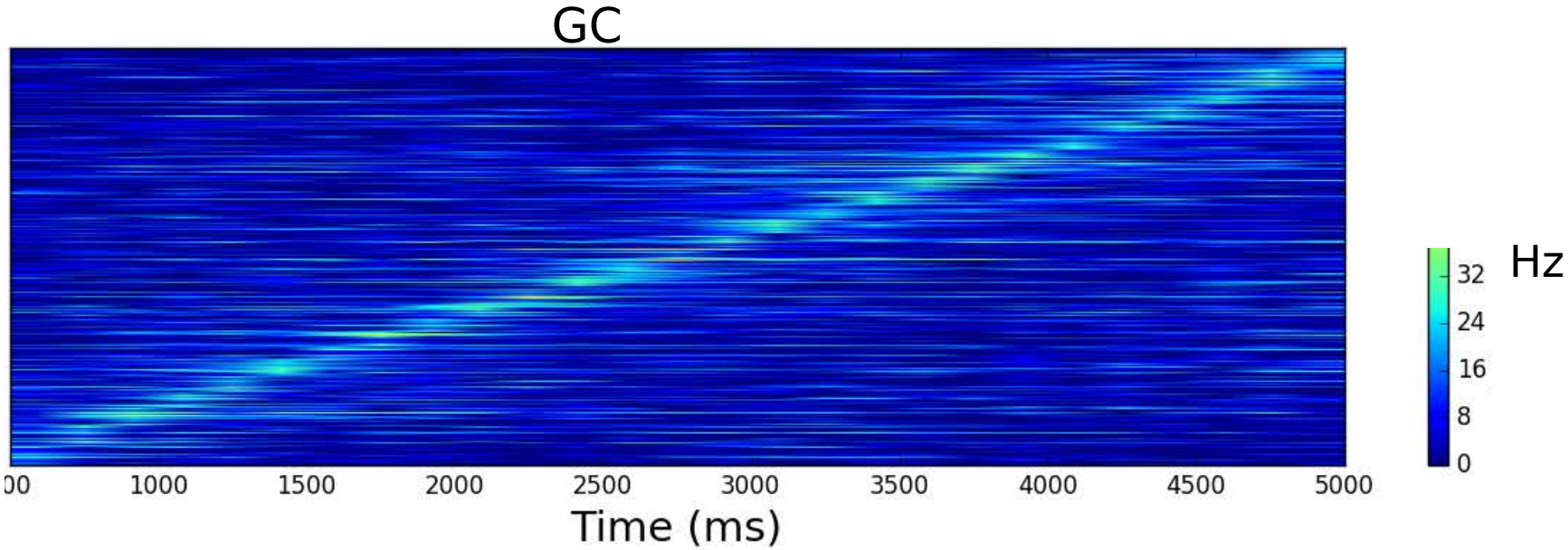
Simulation of hippocampal spatial navigation

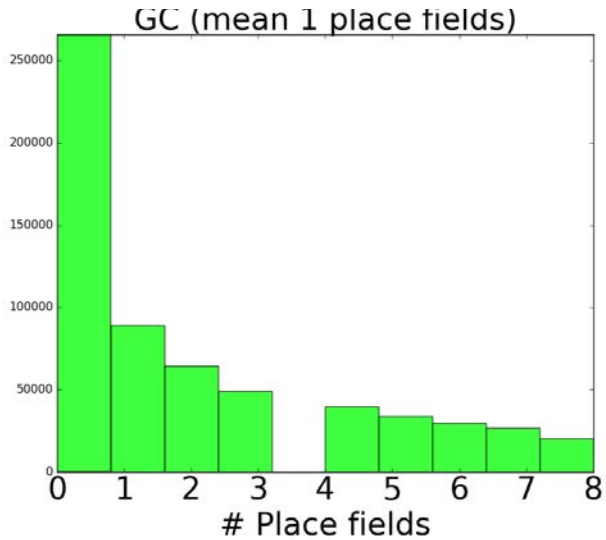


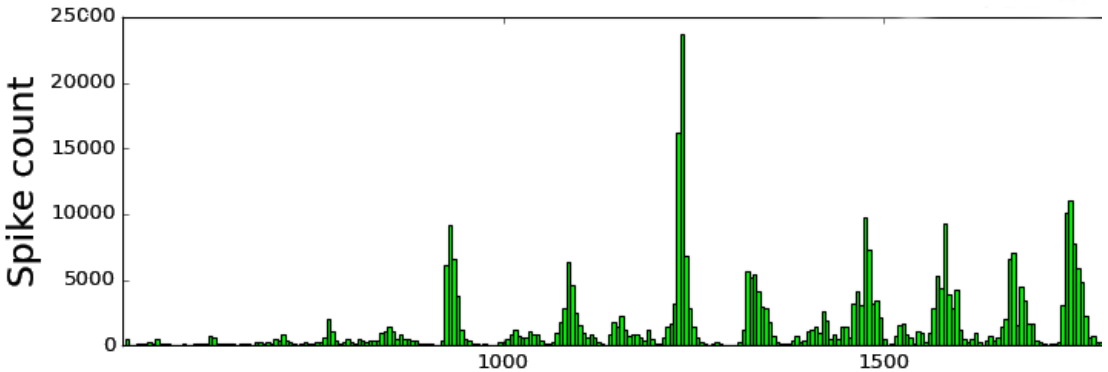




Spatial coding of full-scale hippocampal simulation on Blue Waters

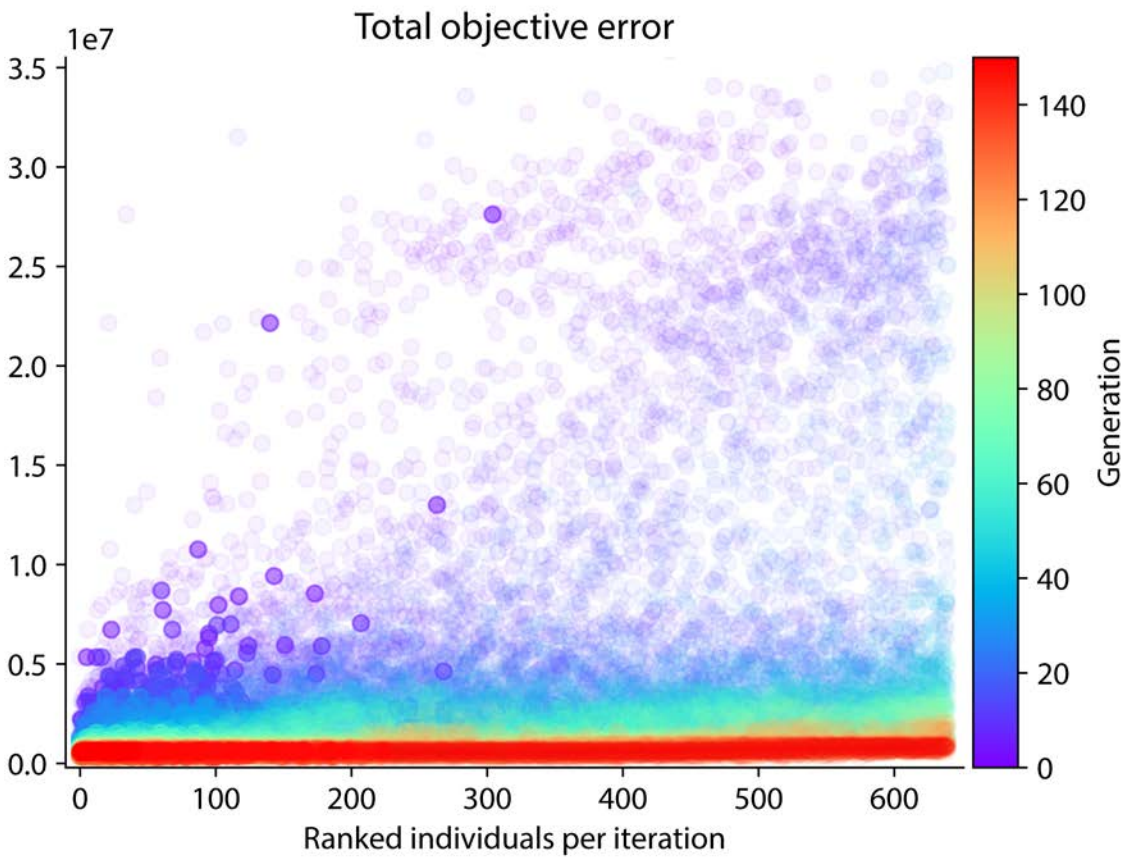


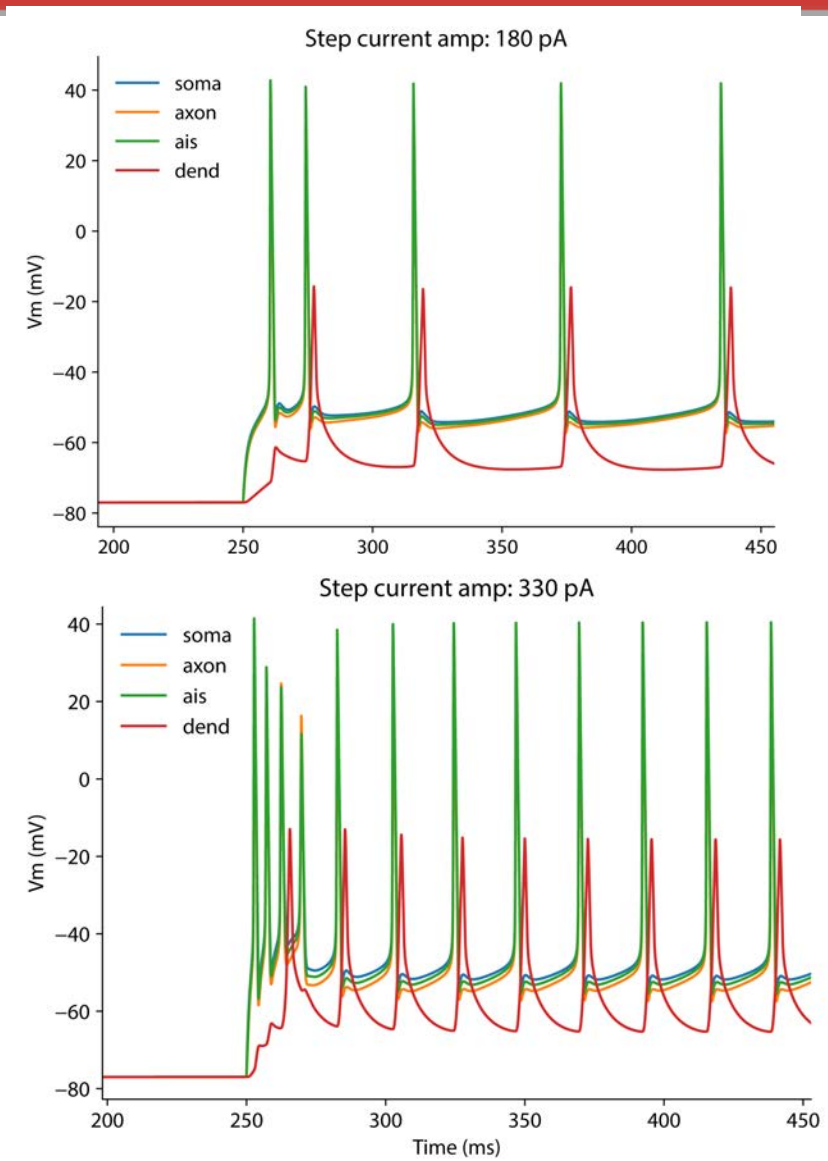




5 s physical time / 2048 BW nodes for 3 hrs

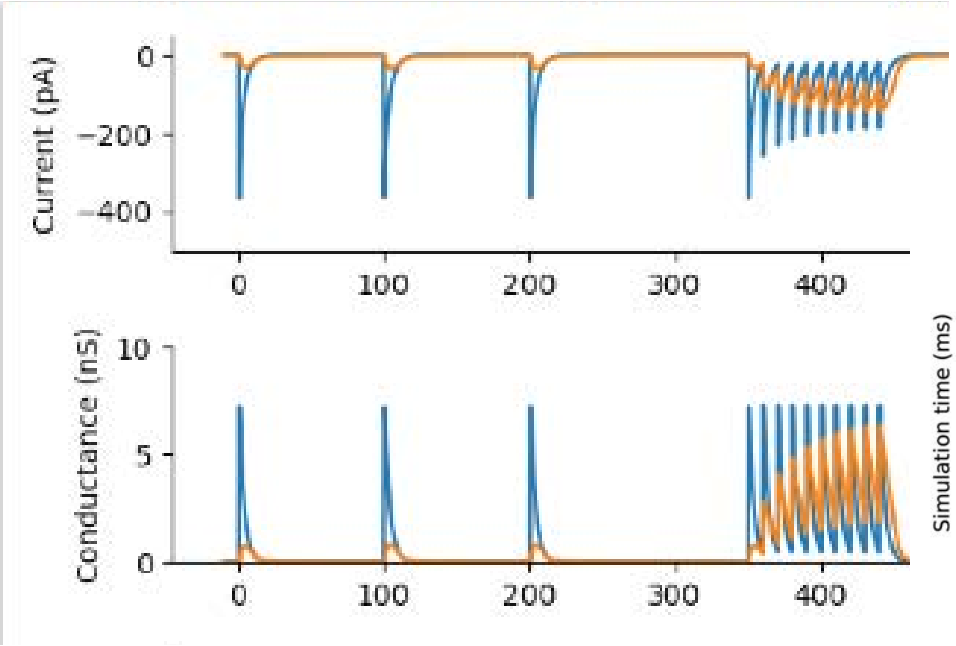
Nested parallel multi-objective optimization



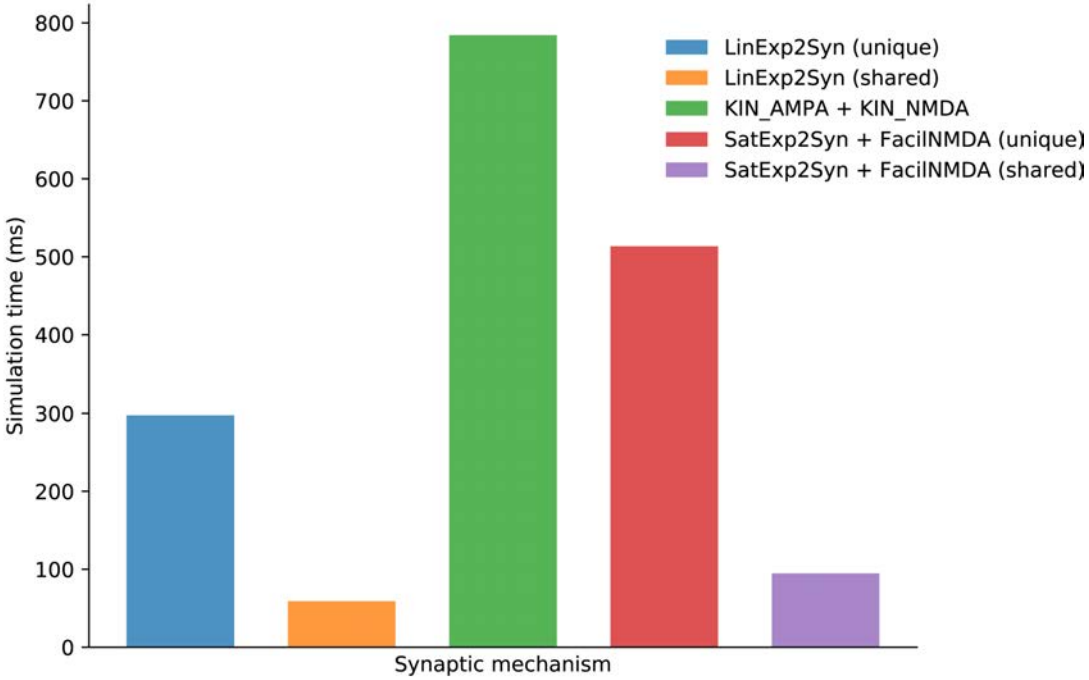


https://github.com/neurosutras/nested

Realistic synaptic mechanisms compatible with full-scale simulations



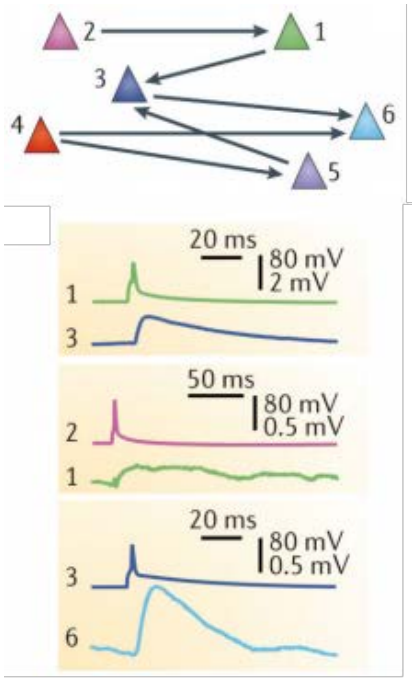
Saturating AMPA-R +
Facilitating NMDA-R

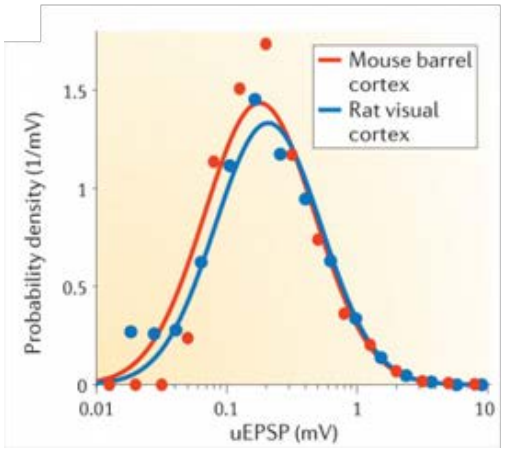


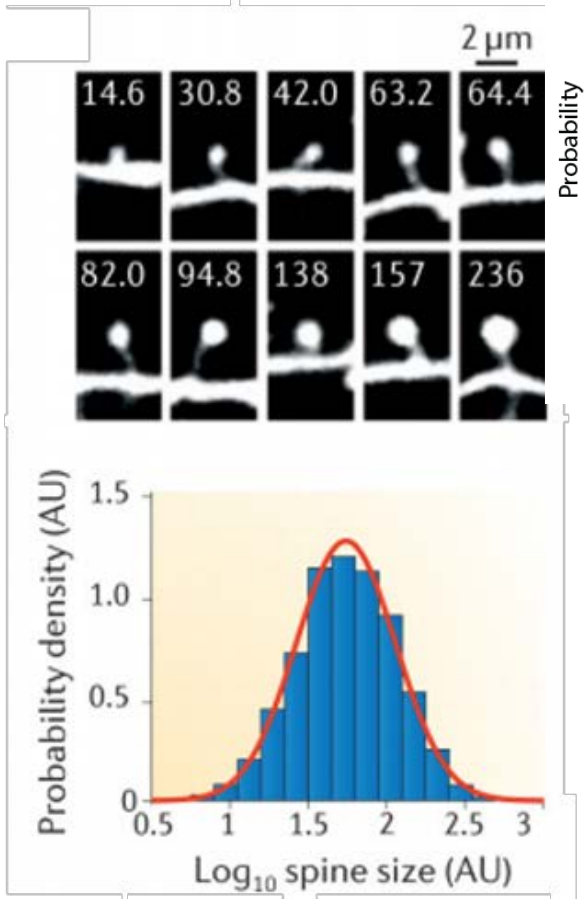
-- Blue Waters can simulate full-scale networks with unique synapses, but this is an inefficient use of resources

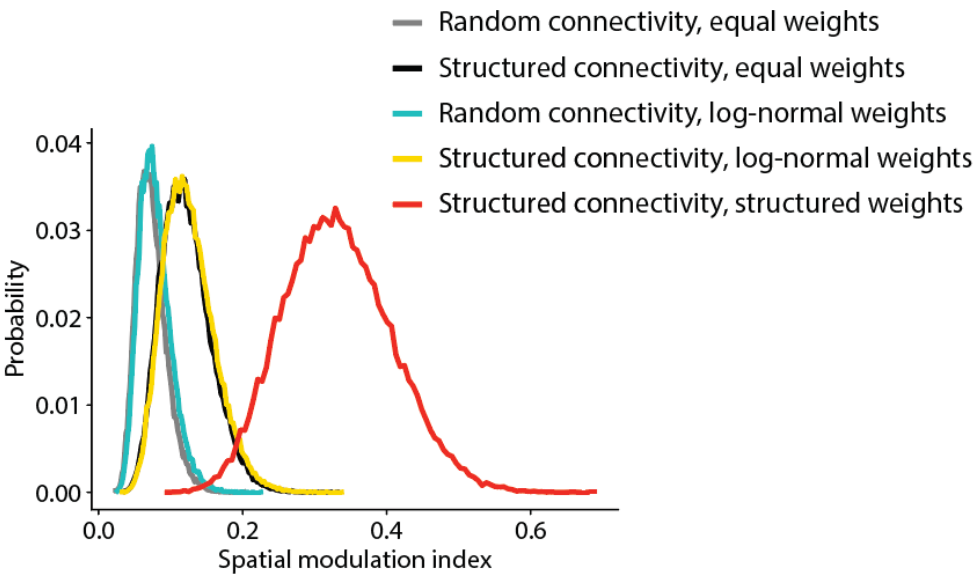
-- new synapse mechanism implementation combines biophysical realism with computational efficiency

Synaptic weight distributions



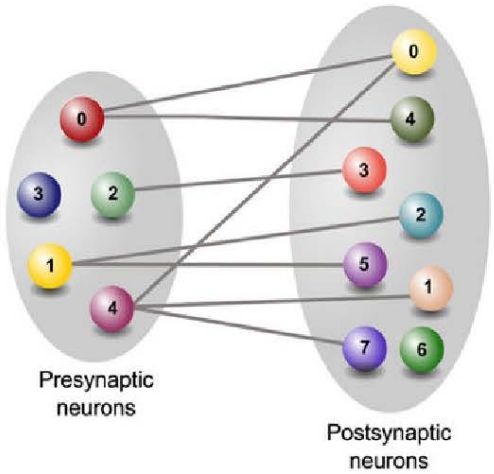


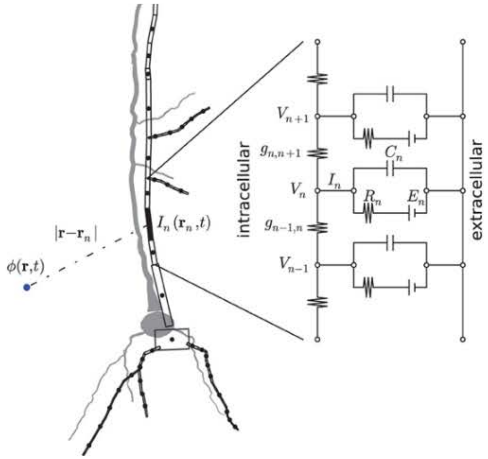


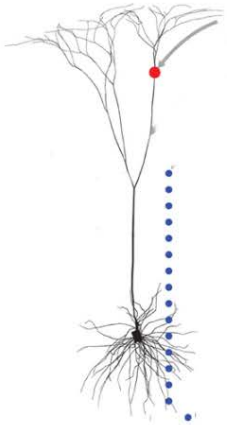


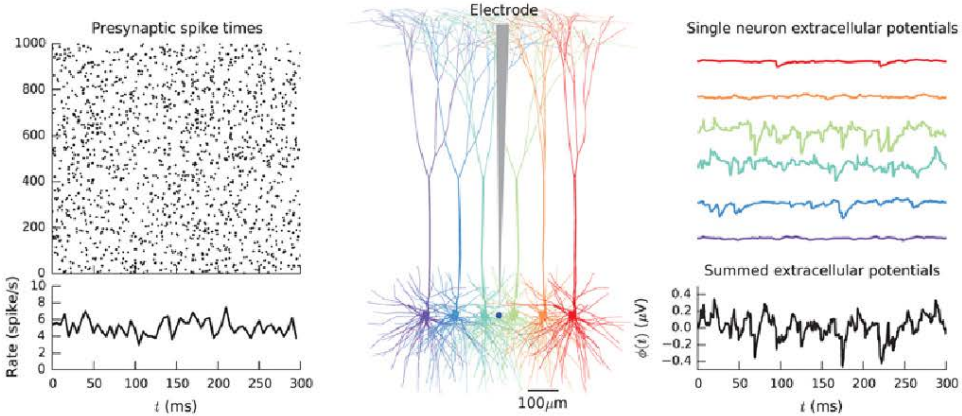
Buzsáki & Mizuseki
Nat. Rev. Neurosci., 2014

A scalable framework for parallel IO and analysis of full-scale neuronal network structure









Linden et al., Front Neuroinform. 2014

Connectivity

Morphology+ Biophysics

NeuroIO library (C++ and Python)

PHDF5

MPI

NEURON Simulator (C++)

A scalable framework for generation, simulation, and analysis of full-scale neuronal network structure

Connectivity

Synapses

Morphology+ Biophysics

Biophysics Optimization

Spike train analysis

Mesh-free 3D Volume

NeuroH5 library (C++ and Python)

Nested library (Python)

Visualization & Plotting

PHDF5

NEURON Simulator (C++)

RBF

MPI

SciPy

Thank You!

BLUE WATERS
SUSTAINED PETASCALE COMPUTING

NCSA

NSF

XSEDE
Extreme Science and Engineering Discovery Environment

NEURON
for empirically-based simulations of neurons and networks of neurons

BRAIN INITIATIVE
BRAIN RESEARCH THROUGH ADVANCING INNOVATIVE NEUROTECHNOLOGIES

Project funded by BRAIN grant 1U19NS104590