Quantifying dynamics in neuronal networks

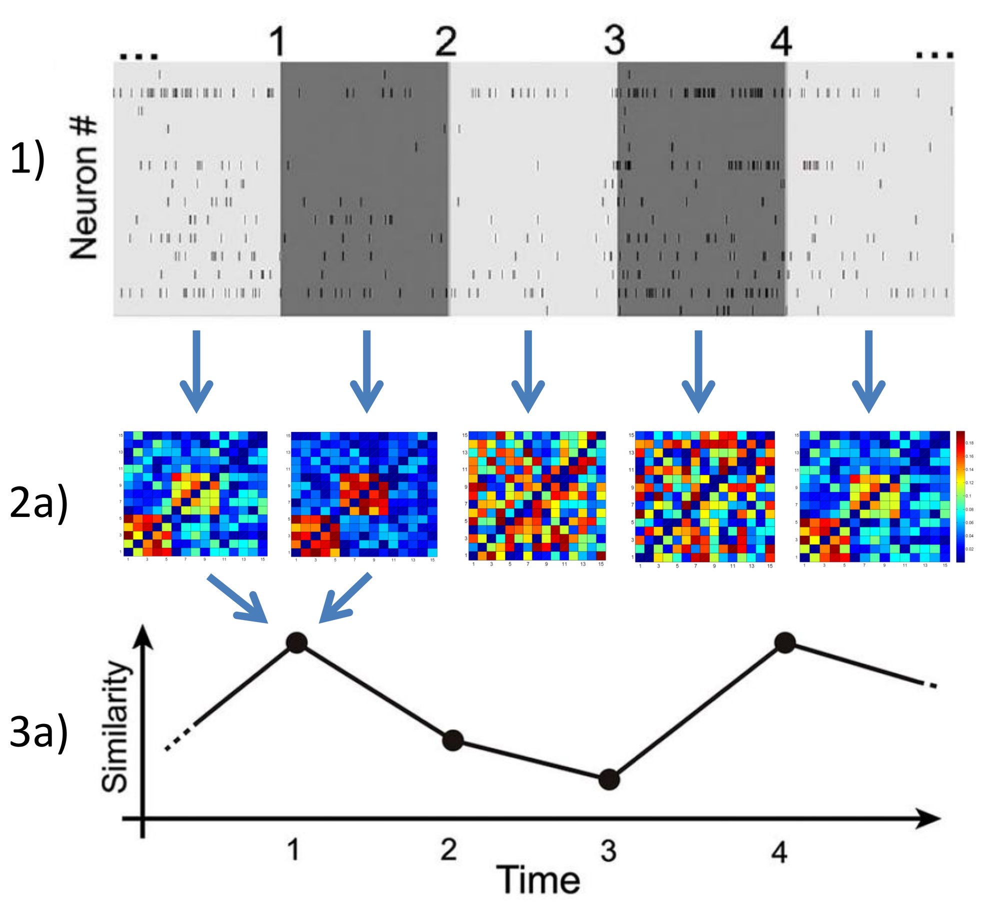
D. Maruyama[1], N. Ognjanovski[2], S. Aton[2], M. Zochowski[1,3] - 1. Department of Physics, University of Michigan; 2. Molecular Cellular and Developmental Biology[2], University of Michigan; 3. Biophysics Program, University of Michigan.

Intro:

The steady development of MEAs and other modern measurement devices is opening up access to data streams composed of large numbers of neuronal signals. The ability to effectively analyze these signals is already bottlenecking device use and threatens to fall far further behind the projected advances in data collection. Here we investigate two methods capable of handling large network throughput to assess patterns in neuronal datasets. Specifically, by employing a fast analytic approach to capture neuronal correlations over short periods of time we can quantify both slower structural changes, by looking at large scale functional connectivity shifts, and faster dynamical changes, by tracking the evolution of the neuronal network. These methods are applied to simulated datasets and to in-vivo data of contextual fear conditioning in mice. The techniques reveal signs of network wide structural changes and measure significant changes in the network stability during mouse sleep states. Namely we observe that increased stabilization of network wide functional structure with mice improved performance on the task.

Methods: Evaluate network as a series of connectivity matrices

Quantifying short scale changes

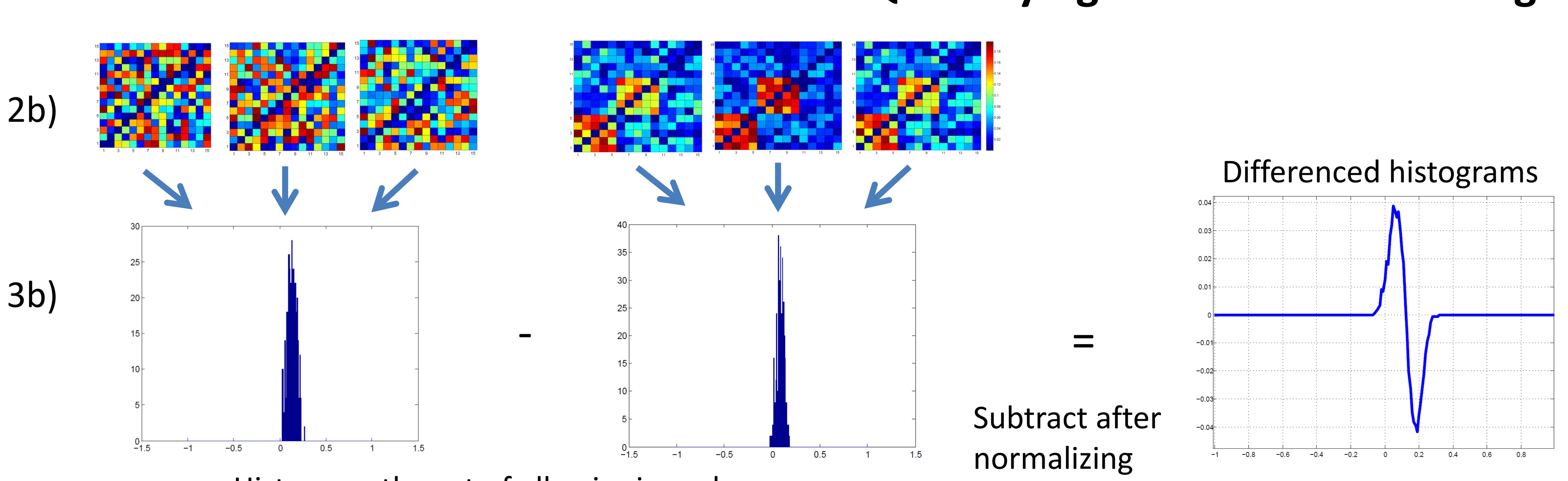


Determine functional connectivity matrices from the raster plots

Compare the matrices to get a measure of similarity

$$< A, B > = \frac{\sum_{i,j} A_{ij} * B_{ij}}{\|A\| * \|B\|};$$

Quantifying slow structural changes



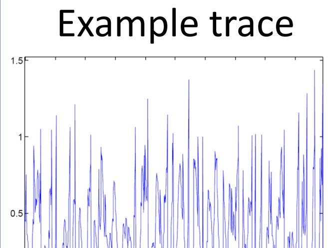
Subtract after normalizing

Histogram the set of all pairwise values

Model: Leaky Integrate-and-Fire neuron model

$$\frac{dV_i}{dt} = -\alpha V + I_{ext,i} + I_{noise} + \sum_{connections} \gamma_2 * A_{ij} * I_{synaptic};$$

Example trace

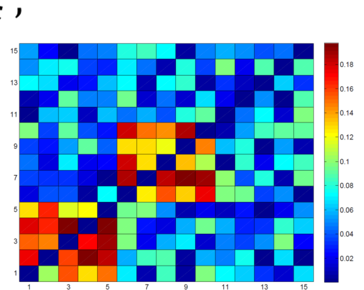


Leak term

Constant driving current

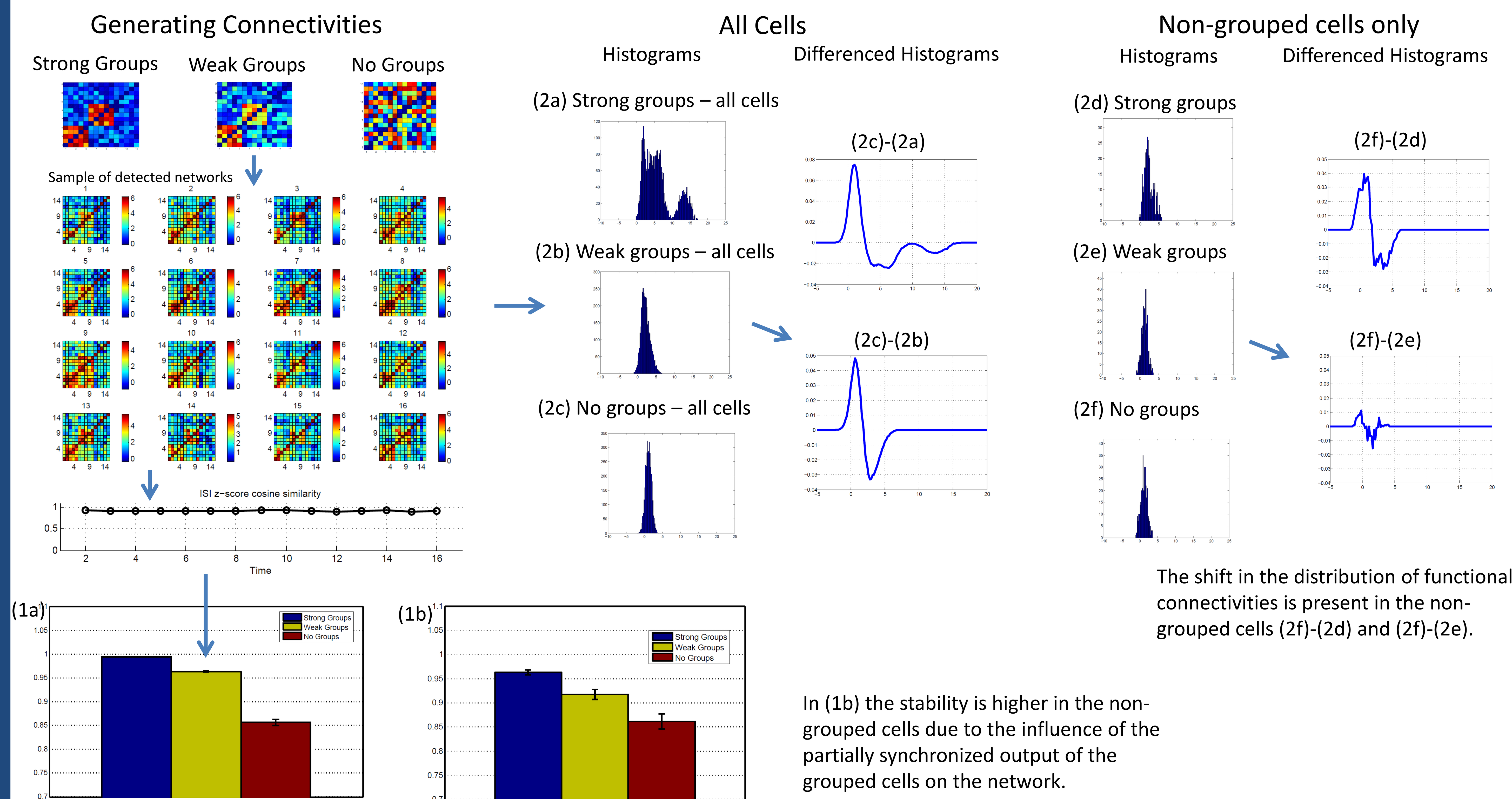
Noisy external stimulation

Synaptic current



Connectivity matrix

-**Simulation findings**: Local measurements of network stability detected changes within the global network



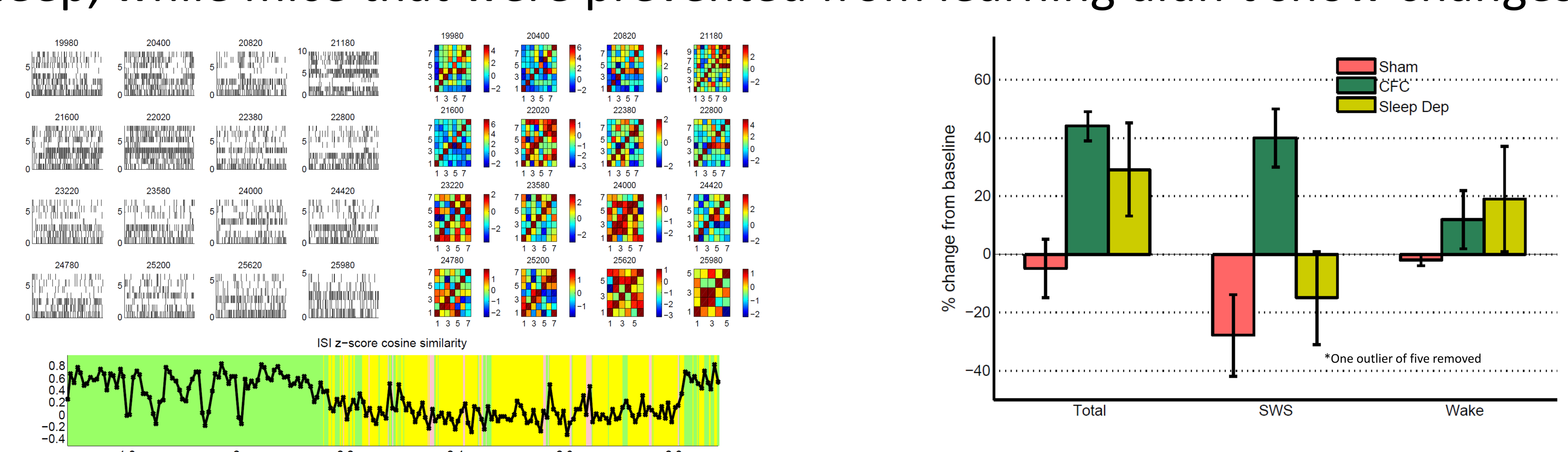
Stability of all cells

Stability of non-grouped cells

In (1b) the stability is higher in the non-grouped cells due to the influence of the partially synchronized output of the grouped cells on the network.

The shift in the distribution of functional connectivities is present in the non-grouped cells (2f)-(2d) and (2f)-(2e).

-**Experimental findings**: Learning mice showed an increase in network stability during slow wave sleep, while mice that were prevented from learning didn't show changes.



During slow-wave sleep(SWS) the animals which learned show an increase in network stability

Summary and Future Directions:

Slight adjustments to the connectivity matrix in a simple IAF model are detectable with two different measures. One which quantifies the stability of the network over relatively short time scales, and another which reveals shifts in the structure distribution over longer durations. Both of these measures can identify change beyond the location of their recording sites, thereby measuring a state of the global network.

In the future we hope to address more relevant network topologies, scale up the simulation size, and add inhibitory connections.

Acknowledgements: NSF PoLS 1058034(MZ), NIH NIBIB 1R01EB018297(MZ, SA), NIH DP2MH104119(SA) and a Young Investigator Award from the Brain and Behavior Research Foundation(SA)

Contact: dmaruyam@umich.edu