The Investigation of Small Worldness in Pancreatic Islets

UMBC REU Site: Interdisciplinary Program in High Performance Computing

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Problem

Diabetes occurs when the body's blood sugar levels are in a state of sustained elevation. The pancreas contains beta cells organized in the islets of Langerhans, which secrete a hormone called insulin that is responsible for maintaining blood glucose at appropriate levels. The electrical synchronization of the beta cells has been correlated with the healthy insulin secretion. The role of small worldness (the ratio of normalized cell clustering and normalized connection efficiency) properties in establishment of the synchronization was investigated.

Single Slow Channel Model

$$-C_M \frac{dV}{dt} = I_{Ca}(V) + I_{K_{ATP}}(V) + I_K(V,n) + I_S(V,s)$$
$$\frac{dn}{dt} = \frac{n_\infty(V) - n}{\tau_n}$$
$$\frac{ds}{dt} = \frac{s_\infty(V) - s}{\tau_s}$$
$$\frac{d[Ca^{2+}]_i}{dt} = f[-\alpha I_{Ca}(V) - k_{Ca}[Ca^{2+}]_i]$$
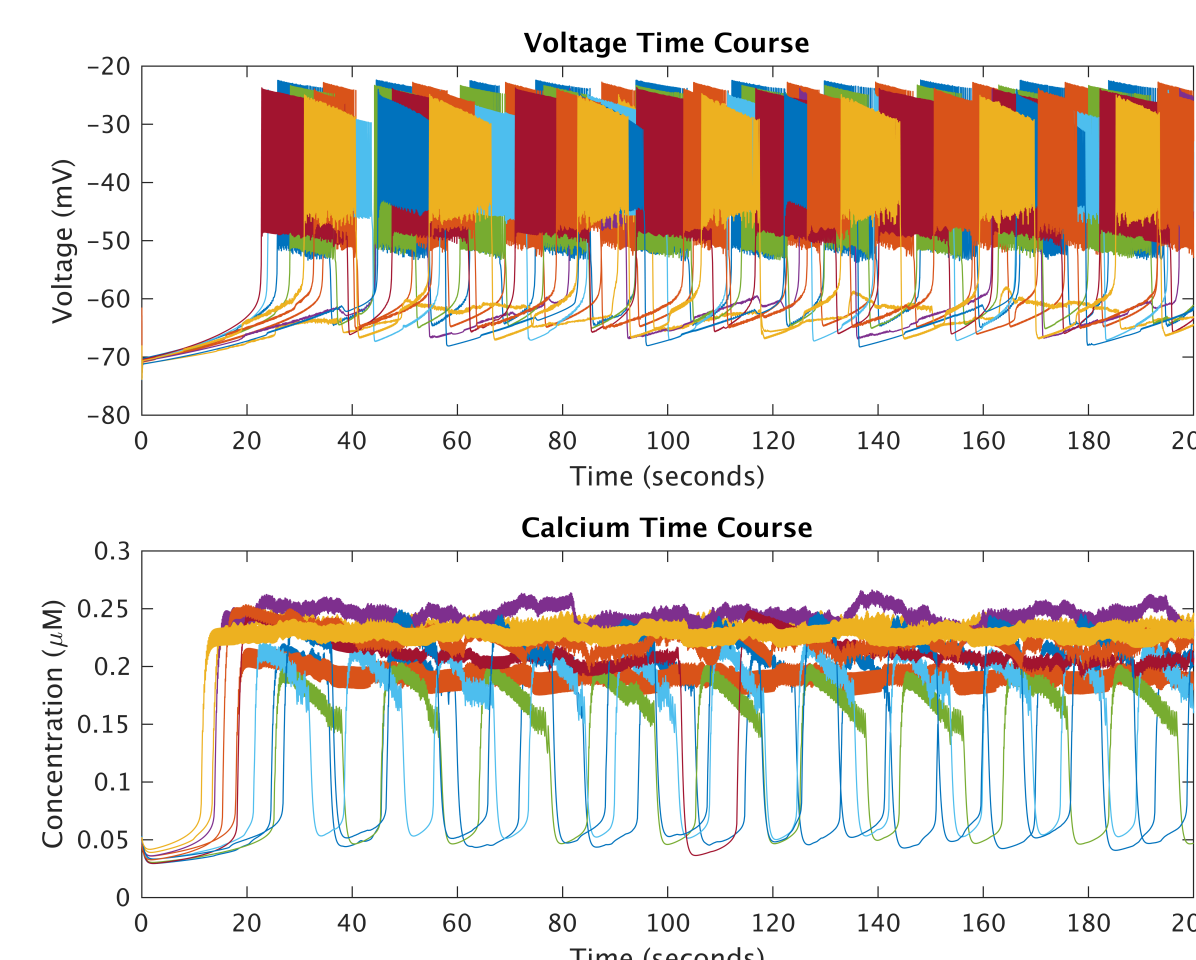
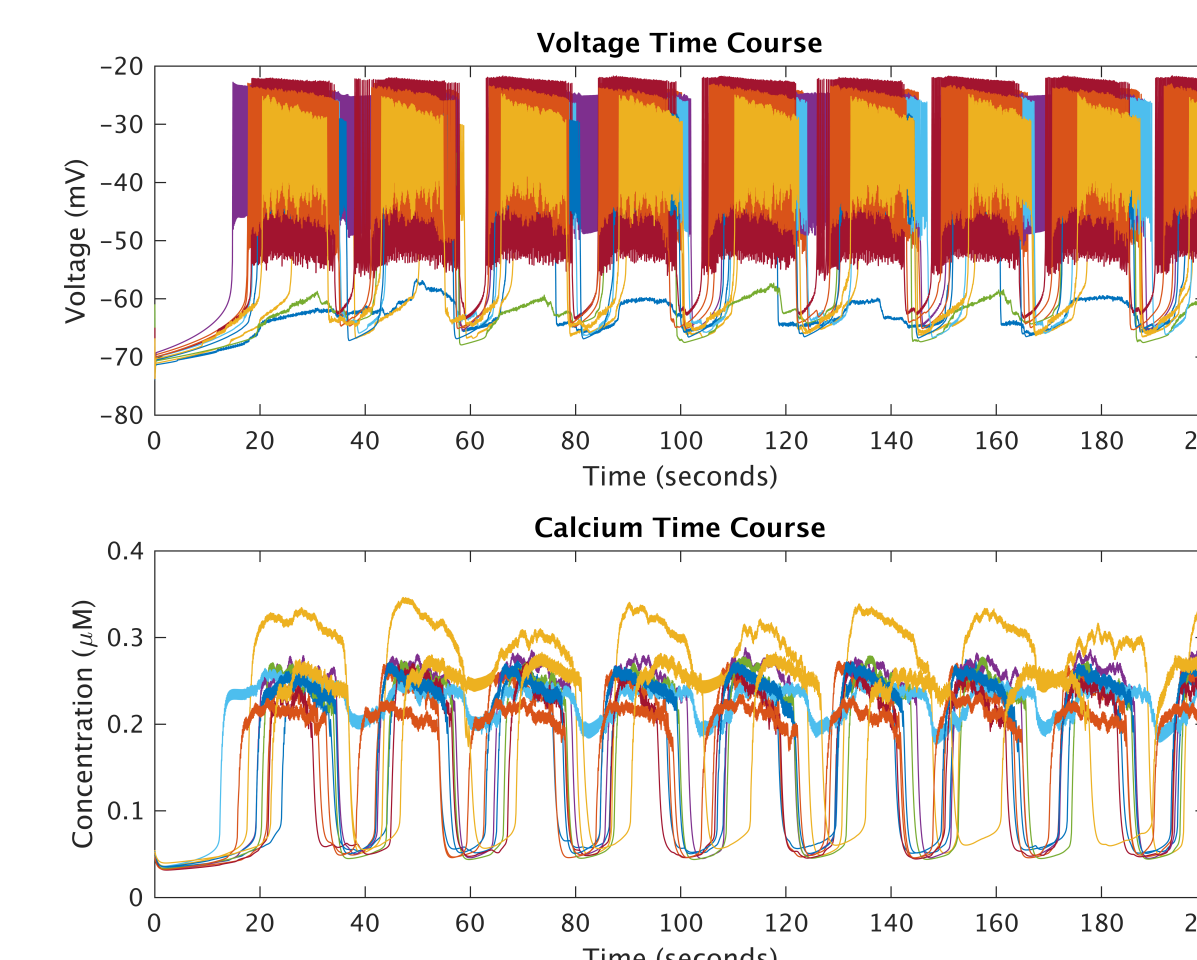## Hexagonal Lattice
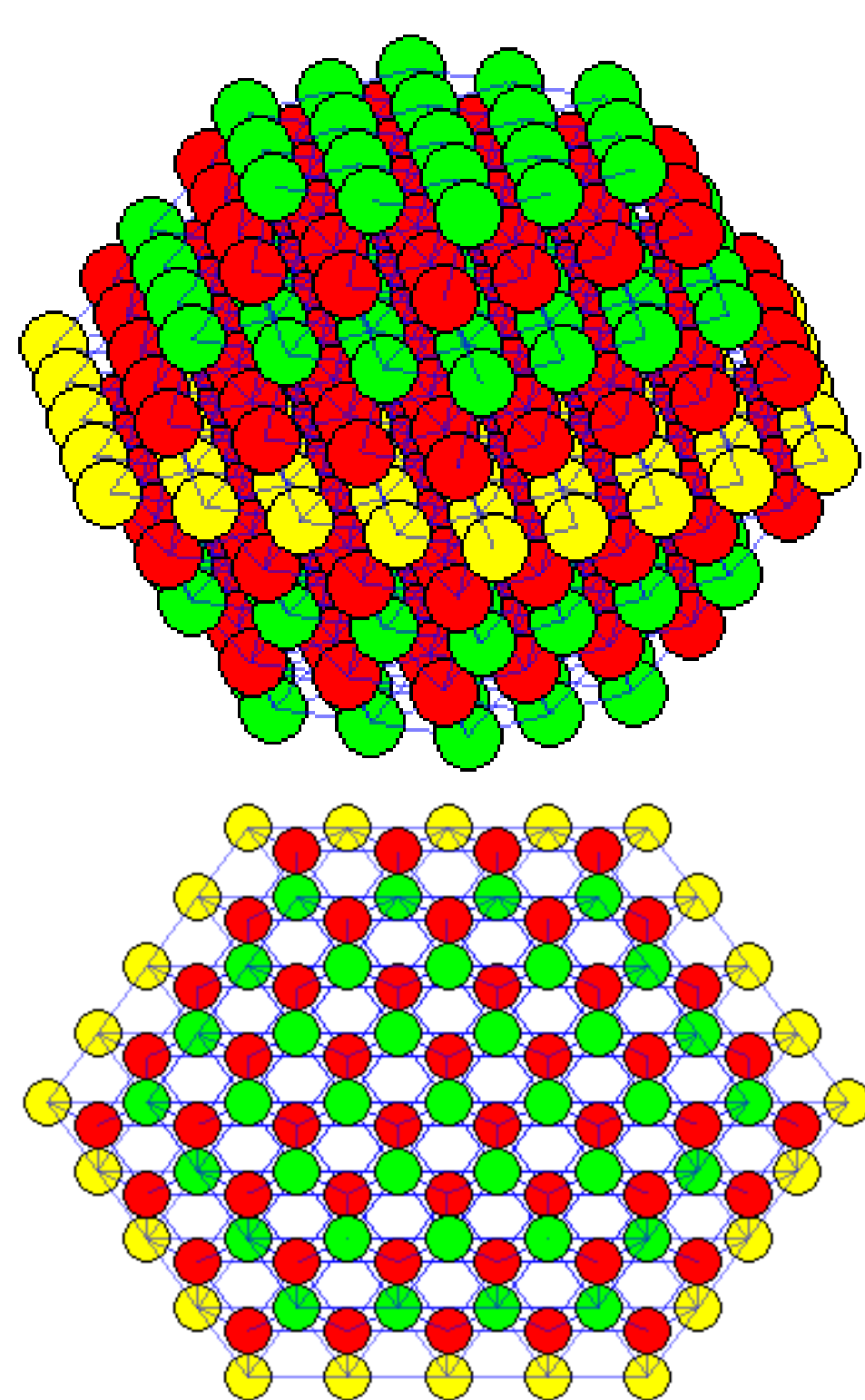
323 cells (Edge length $n = 5$)

Acknowledgments

- REU Site: hpcreu.umbc.edu

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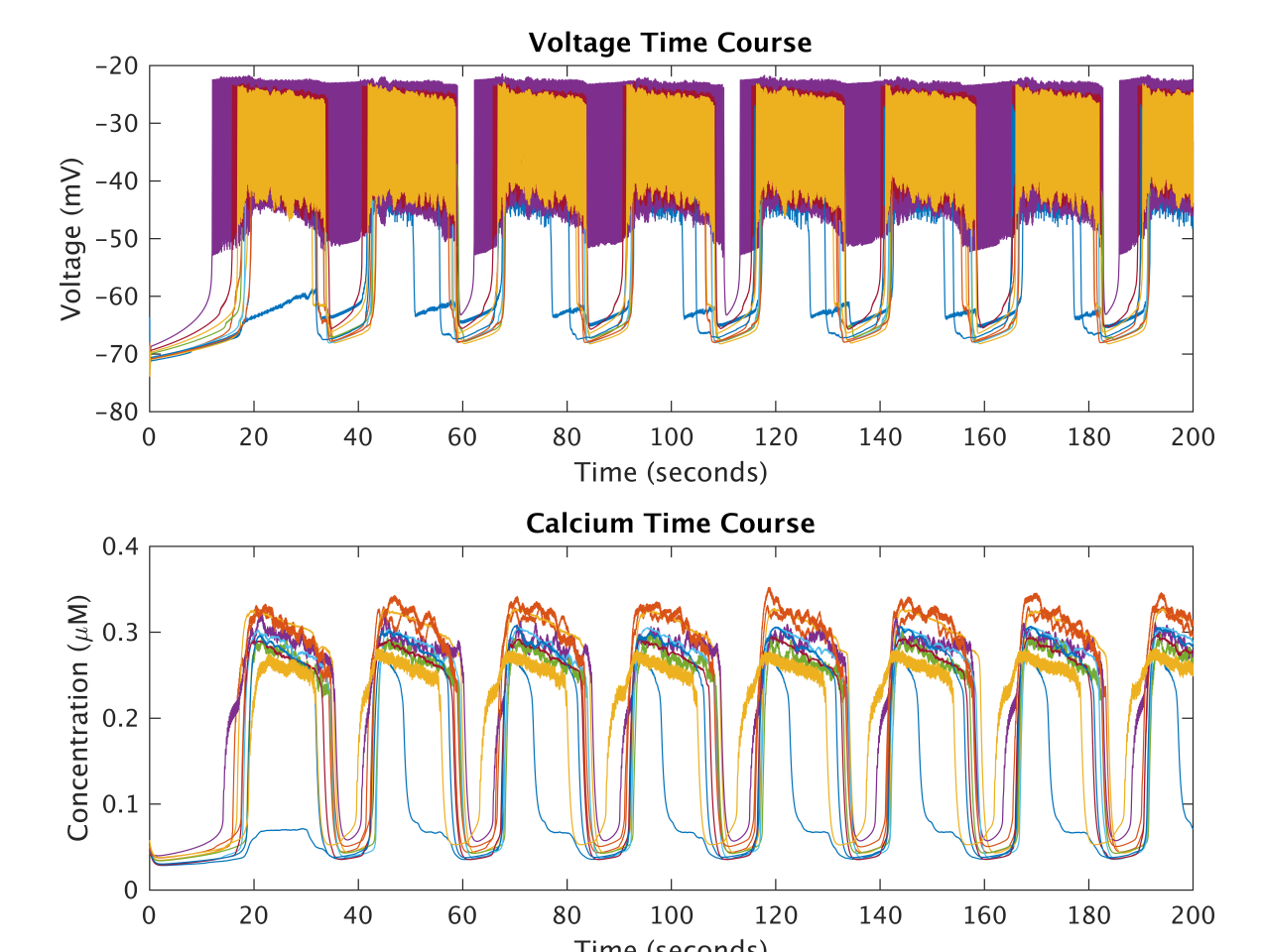- Dr. Arthur Sherman's lab and Dr. Sushil Rane's lab, NIDDK, NIH

Synchronization Increases with Increasing Average Coupling Strength

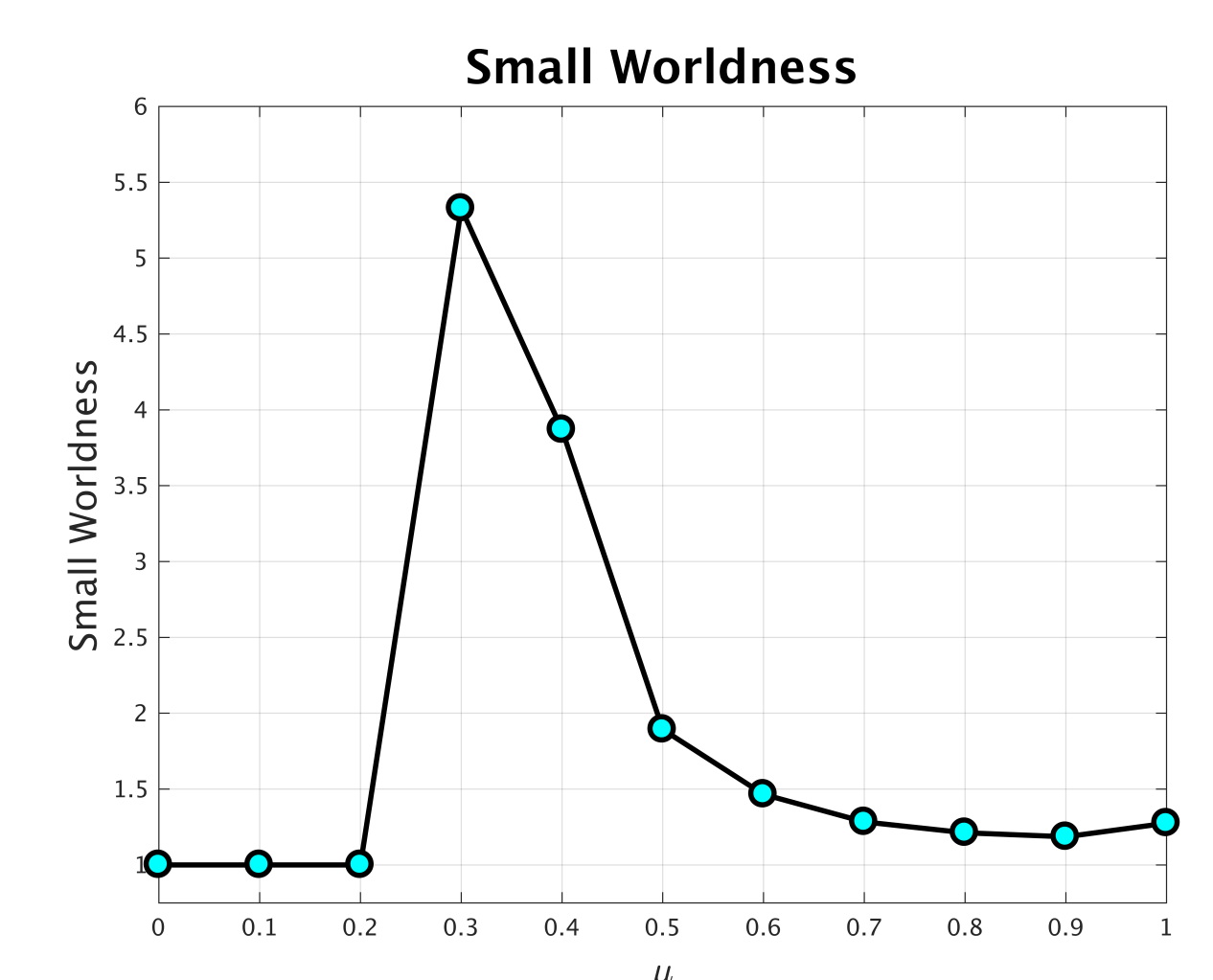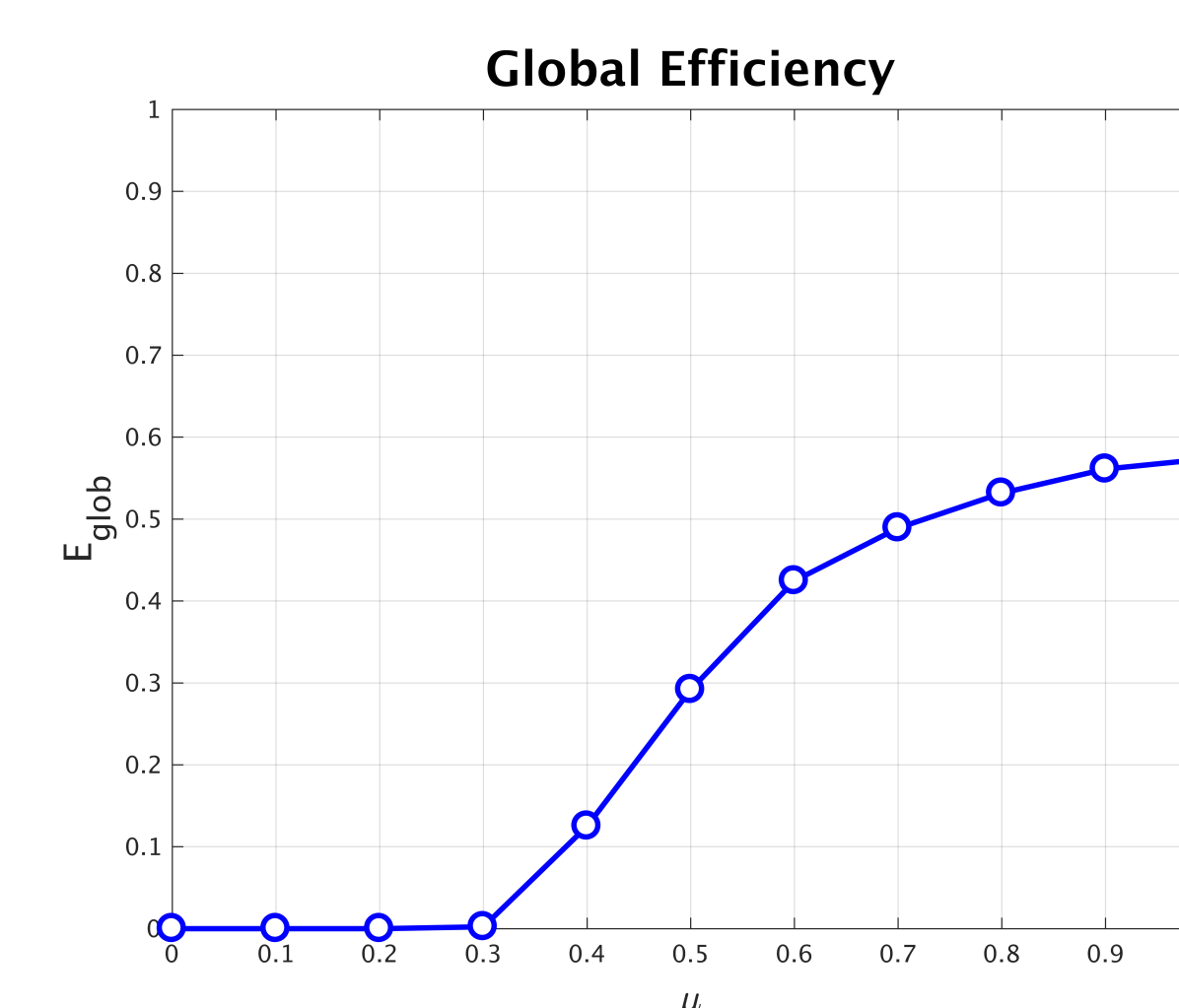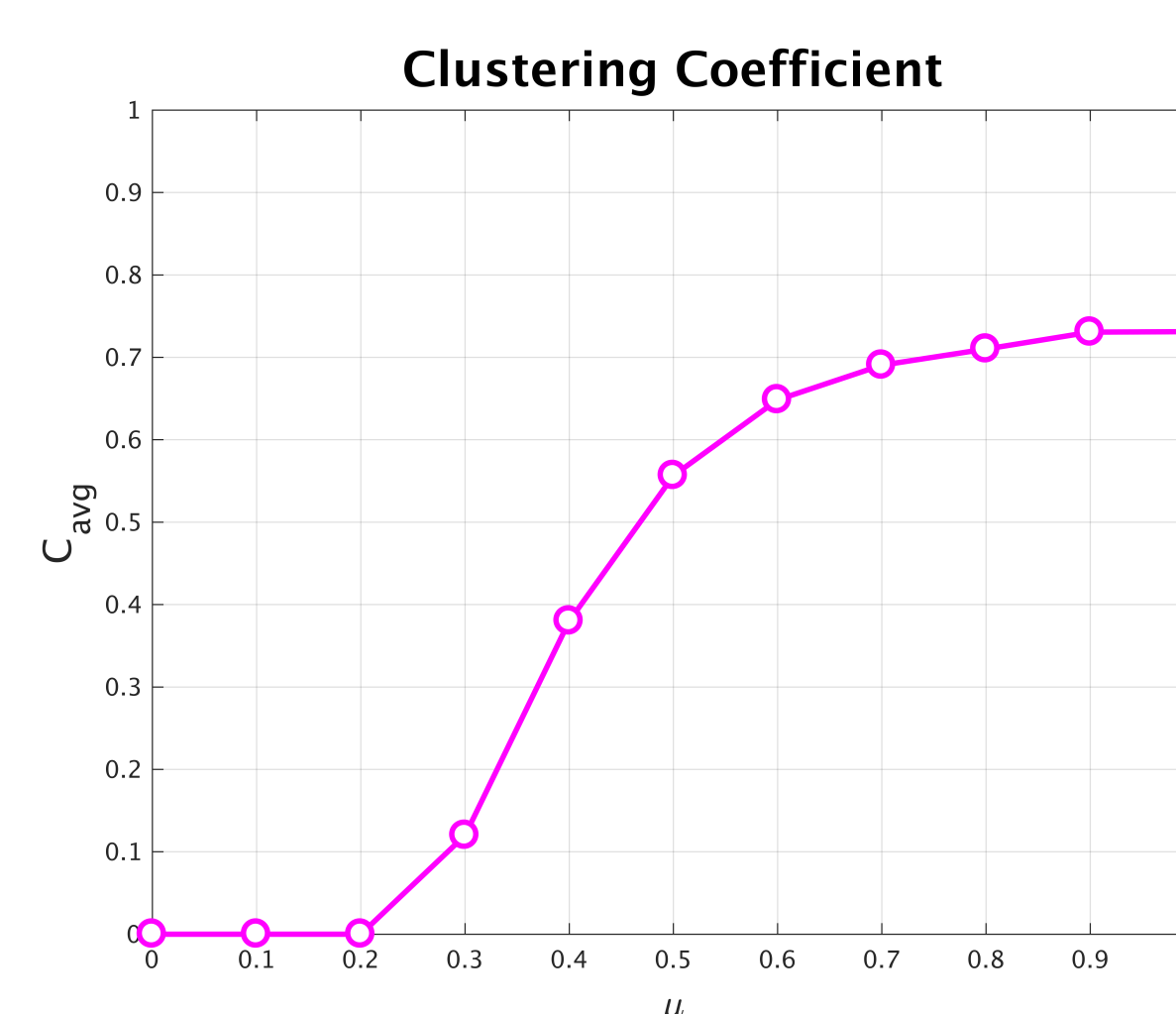
0% synchronization with $\mu = 0$ 33.31% synchronization with $\mu = 0.3$ 87.73% synchronization with $\mu = 0.6$
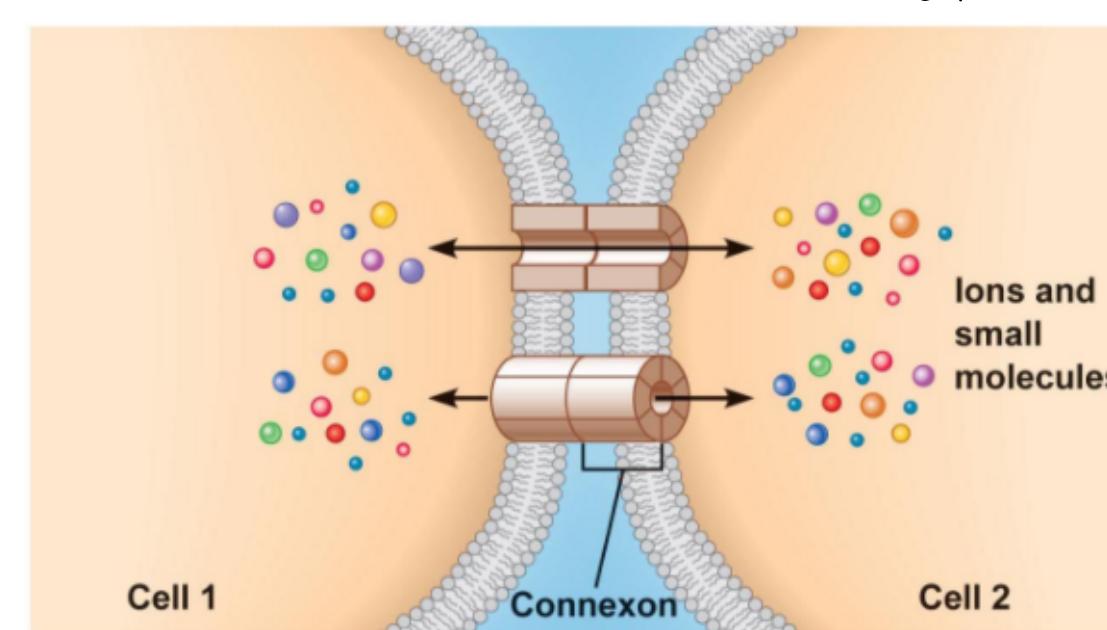
μ is the mean of the normally distributed coupling strengths ($k_{ij} \sim N(\mu, 0.2)$).

Small Worldness Peaks for Moderate Coupling Strengths

Cell Coupling

$$\vec{I_c} = \begin{bmatrix} \sum_{j \neq 1} k_{1j}g_{1j} & -k_{12}g_{12} & \dots & -k_{1j}g_{1j} \\ -k_{21}g_{21} & \sum_{j \neq 2} k_{2j}g_{2j} & \dots & -k_{2j}g_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ -k_{N1}g_{N1} & -k_{N2}g_{N2} & \dots & \sum_{j \neq i} k_{Nj}g_{Nj} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_N \end{bmatrix}$$

https://lindsaza.wordpress.com/muscle-cell-cell-cell-interactions/

References

[1] G. Cappon and M.G. Pederson, Heterogeneity and nearest-neighbor coupling can explain small-worldness and wave properties in pancreatic islets, *CHAOS: An Interdisciplinary Journal of Nonlinear Science*, 2016
[2] N. Johnston et al. Beta cell hubs dictate pancreatic islet responses to glucose, *Cell Metabolism*, 2016
[3] Full technical report: HPCF–2017–14
hpcf.umbc.edu > Publications

Hub Cells in Functional Networks

Functionally Coupled Small World Network
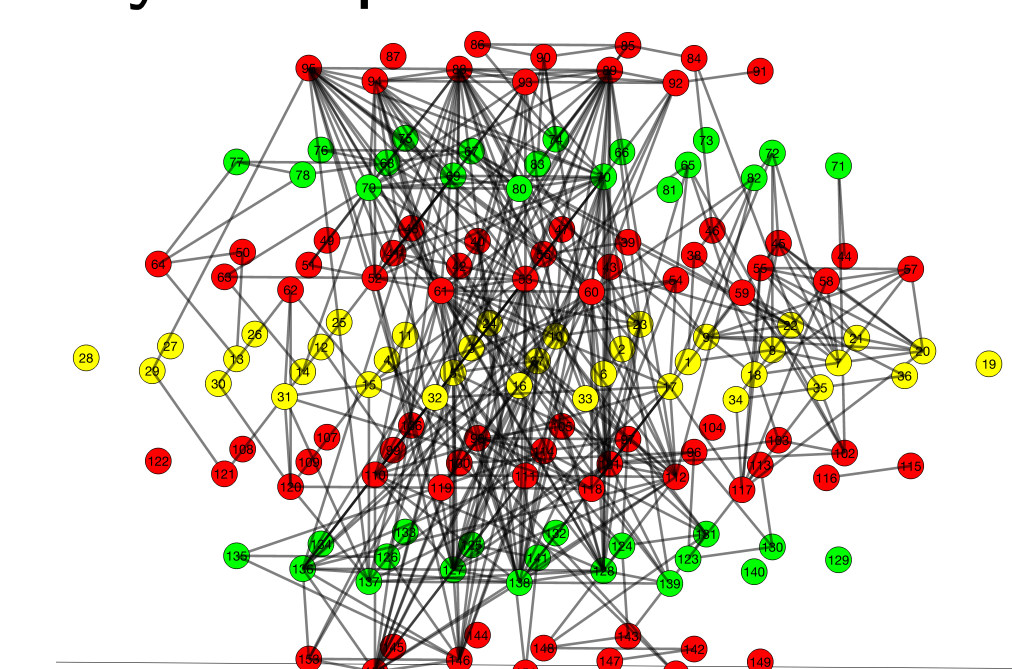
Hub Cell Functional Connections
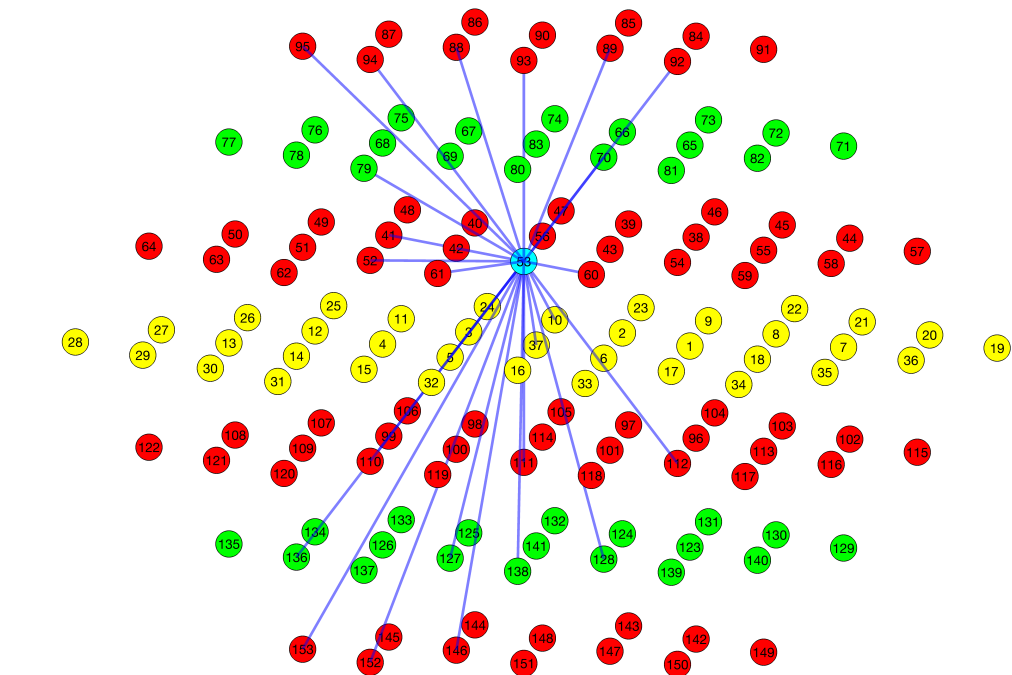
Distribution of Functional Connections