The Next Generation of Neural Mass Models

Now Stochastic!

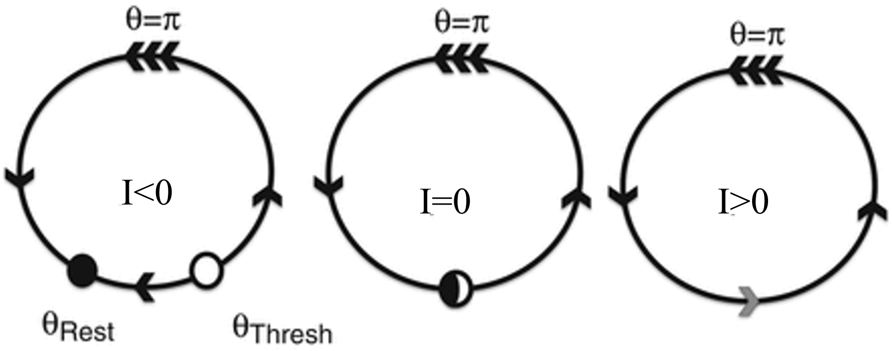
John Kruper & Max Weil

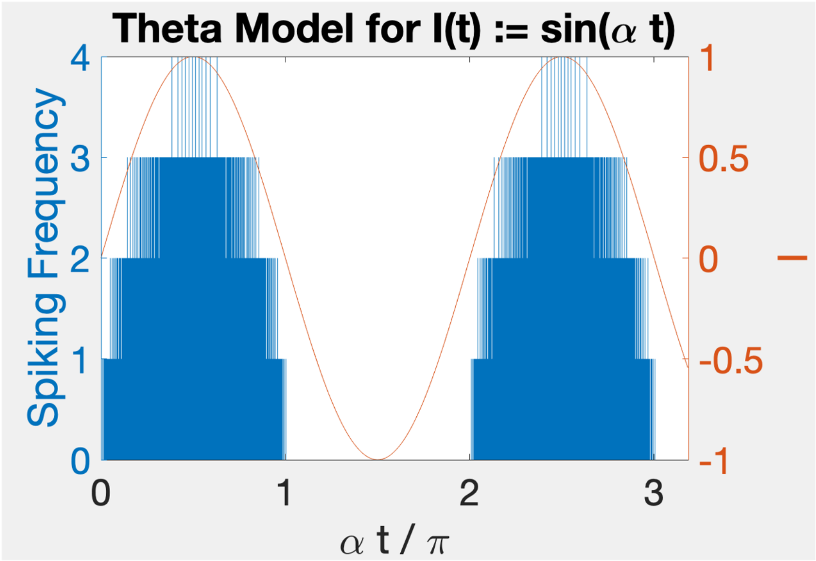
Paper by Stephen Coombes and Áine Byrne

Introduction of Theta Neuron Model

- Model describing “bursting” behavior of certain neurons (cortex, pacemaker)
- Utilizes one state variable to describe firing

$$\frac{d\theta}{dt} = 1 - \cos\theta + (1 + \cos\theta) I(t)$$





From Encyclopedia of Computational Neuroscience

Modeling A Network of Theta Neurons

- Bursting is thought to play a role in rhythmic neural patterns
- Large scale models of bursting (theta) neurons can allow us to simulate network wide brain rhythms, giving insight to the meaning of these phenomena
- Authors simulated a network of 500, fully connected theta neurons

θ is a parameter each neuron model (tan(θ/2) is proportional to voltage)

g is Synaptic Conductance

$$Using \quad I_i = g(t)(v_{\mathrm{syn}} - v_i)$$

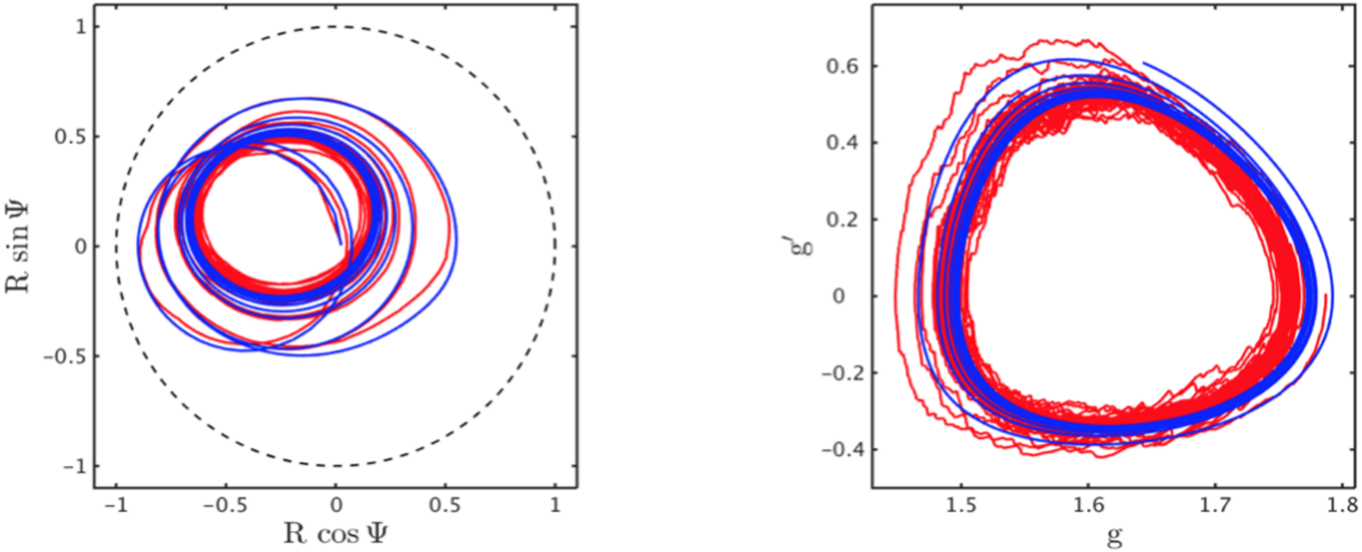
$$\frac{\mathrm{d}}{\mathrm{d}t}\theta_i = (1-\cos\theta_i) + (1+\cos\theta_i)(\eta_i + g(t)v_{\mathrm{syn}}) - g(t)\sin\theta_i,$$

$$Qg = 2\frac{k}{N}\sum_{j=1}^{N} P(\theta_j). \quad Q = \left(1 + \frac{1}{\alpha}\frac{\mathrm{d}}{\mathrm{d}t}\right)^2.$$

501 coupled ODEs! Yikes!

Mean Field Reduction for Neural Mass Modeling

- To create a simplified model of neuronal dynamics, an approach known as mean field reduction is used
- Authors used this method to create a coupled system of two ODEs to simulate a network of theta neurons:

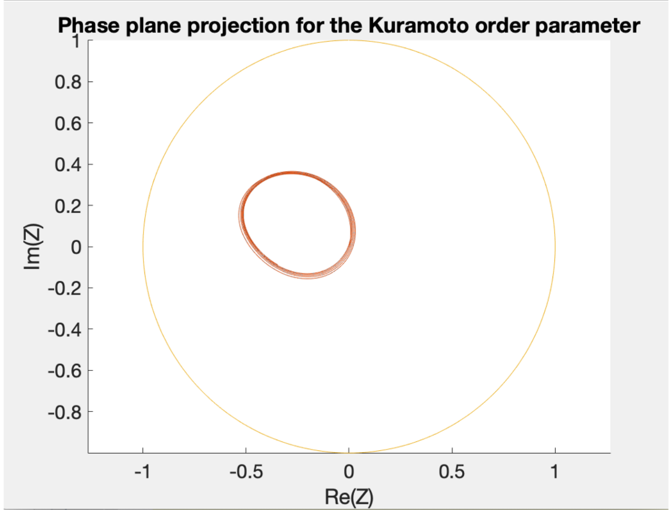


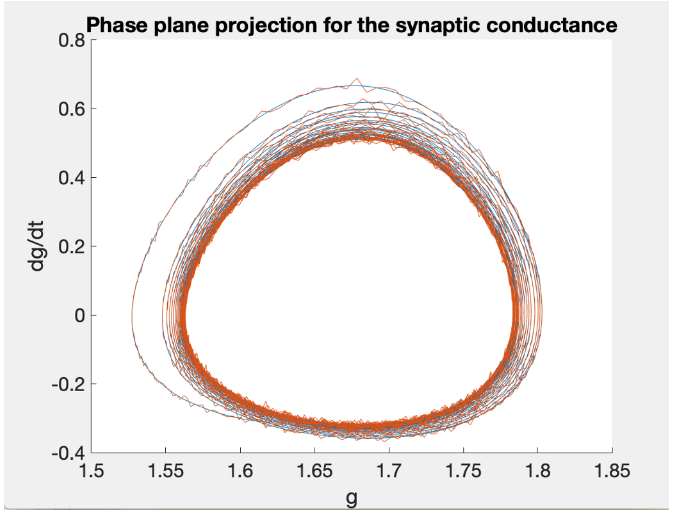
Our Next Steps

- Add stochastic elements into reduced model
  - May allow model for an improved representation of dynamics seen in vivo
- Adding white noise to synaptic conductance term
  - $n(t) = \varepsilon \cdot rand \cdot sqrt(\Delta t)$
  - Can result from neurotransmitter release, thermodynamics, diffusions of particles, etc.
- Comparison of noisy model to that used in paper
  - How does stochasticity reflect the variation seen in network of individual neurons?

Results and Insights

- Our model does appear to capture some of the noise seen from a network of individual neurons
  - Not as fine as single spikes, smoother and longer changes
- Looking to reproduce 500 theta neuron network
  - Adding stochasticity here may give a better comparison to our model





References

Coombes S., Byrne Á. (2019) Next Generation Neural Mass Models. In: Corinto F., Torcini A. (eds) Nonlinear Dynamics in Computational Neuroscience. PoliTO Springer Series. Springer, Cham

Jaeger, Dieter, and Ranu Jung. *Encyclopedia of Computational Neuroscience*. Springer New York, 2019.

Schaworonkow N., Nikulin V. (2019) Spatial neuronal synchronization and the waveform of oscillations: Implications for EEG and MEG. PLOS Computational Biology.