Next generation neural mass models: rate and coherence

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Many popular neural mass models for describing cortical population dynamics, such as Wilson-Cowan or Jansen-Rit, track an average activity without recourse to describing the degree of synchronisation or coherence within a population. This could of course be tracked within a large-scale model of synaptically interacting conductance based neurons, though at the expense of analytical tractability. Thus it is of interest to seek levels of description that provide a bridge between microscopic single neuron dynamics and coarse grained neural mass models, while preserving some notion of within-population coherence.

For a theta neuron choice of microscopic dynamics we can make use of the Ott-Antonsen ansatz [1] to find an exact mean field description of the population dynamics on a reduced invariant manifold. We consider an all-to-all coupled network of such neurons, allowing us to track the complex valued Kuramoto order parameter z as follows:

$$\dot{z} = -i\frac{(z-1)^2}{2} + \frac{(z+1)^2}{2}\left[-\Delta + i\eta_0 + iV_{syn}G\right] - \frac{z^2-1}{2}G,$$

$$\left(1 + \frac{1}{\alpha}\frac{\mathrm{d}}{\mathrm{dt}}\right)^2 \cdot G = kH(z,\bar{z}),$$

where

$$H(z,\bar{z}) = 1 + \frac{z}{1-z} + \frac{\bar{z}}{1-\bar{z}},$$

η_0 and Δ are the centre and width of the Lorentzian distribution from which we draw our constant background drive, k is the synaptic coupling strength, V_{syn} is the synaptic reversal potential.

Simulations for a population of 100 theta neurons were carried out and the results were compared to the reduced mean field approximation. The phase plane in Figure 1 shows such a comparison for the Kuramoto order parameter $z = Re^{i\theta}$ (where R is the coherence and θ is the average phase); the dotted black circle indicates the unit circle. The solid black curve represents the mean field approximation and the red trajectory shows the 100 neuron simulation. Even with 100 neurons it can be seen that our reduction is a good approximation of the average population dynamics.

Extensive bifurcation analysis has been carried out for a single population and for a two population excitatory-inhibitory structure. As expected the addition of a second population allows for richer dynamics.

A similar approach can be taken for a population of quadratic integrate-and-fire neurons [2]. In this framework the mean field variable tracks the population firing rate. A simple transformation exists which allows us to switch between these two representations.

This work involves collaboration with colleagues in the Sir Peter Mansfield Magnetic Resonance Centre at Nottingham to use this new framework to understand the generation of beta-rhythms seen in motor cortex, and deliver a suitable model for understanding so-called beta-rebound. This is readily observed in MEG recordings whereby the initiation of hand movement causes a drop in the beta power band attributed to a loss of network synchrony.

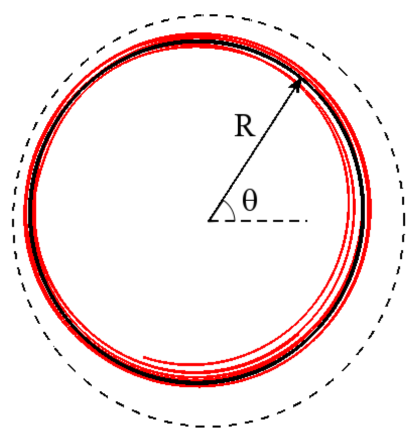

Figure 1: Phase plane comparing the Kuramoto order parameter for a simulation of 100 theta neurons and the mean filed approximation of such a population. The dotted black curve is the unit circle, the solid black curve represents the mean field approximation and the red the 100 neuron simulation.

References

[1] T. Luke, E. Barreto, P. So. Complete Classification of the Macroscopic Behavior of a Heterogeneous Network of Theta Neurons, *Neural Computation* 25, pp. 32073234, 2013.

[2] A. Roxin, Exact mean-field descriptions of networks of heterogeneous quadratic integrate-and-fire neurons, presented at workshop on Neurodynamics July 2014, Castro-Urdiales, Spain.