RHYTHMS IN THE NEOCORTEX AND IN CPG NEURONS: A DYNAMICAL SYSTEMS ANALYSIS

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Quantifying electrical activity of neuronal networks is an essential aspect of understanding complex nervous systems of animals and humans. In this thesis, we investigate the electrical activity of two specific networks of neurons: (1) cortical neurons of the rat brain, and (2) central pattern generator (CPG) neurons of the crayfish swimmeret system. Both systems are modeled and analyzed using dynamical systems theory techniques.

Cortical neurons in rats display a range of different rhythms, with the frequency, and the degree of synchronization over distances, being behavior dependent. We first focus on rhythms in the alpha-frequency range (7-14 Hz) and develop a mathematical model of synaptically coupled excitatory and inhibitory cells, with cortical distance captured by a delay in synaptic propagation. We show that the h and T currents in layer V pyramidal cells, where the alpha-frequency rhythms are thought to originate, produce the alpha-frequency and lead to the occurrence of spatial asynchrony. Mathematical analysis of this model employs a one-dimensional map that captures the ability of the rhythm to synchronize over distances. Second, transitions between alpha, beta (20-25 Hz) and gamma (30-80 Hz)-frequency rhythms are simulated by varying the levels of depolarizing current and the maximal conductance of an outward potassium current. Changes in these parameters mimic biophysical changes in the animal as it experiences different levels of arousal. The one-dimensional map technique is again used to capture the synchronization properties of beta and gamma-frequency rhythms and confirms previous results showing that both of these rhythms promote synchrony over short distances, with beta also supporting synchrony over long distances.

CPG neurons of the crayfish swimmeret system produce oscillatory electrical activity with a 90-degree phase lag between swimmerets on neighboring abdominal segments. This phase lag persists as the frequency of the rhythm changes. Using a modified version of an existing model that captures the dynamics of the swimmeret network, we find that the primary parameters controlling this phase lag and its invariance with frequency are: the rate of decay of local inhibition, the anatomy of intersegmental connections, and the relative intersegmental coupling strengths. The impact of these parameters is quantified using the mathematical theory of weakly-coupled oscillators and singular perturbation theory.