Spring 2004 Math 8540

Topics in Mathematical Biology

Mathematical Modeling of Neurons and Neural Networks

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Lecture: MWF 3:35 pm – 4:25 pm, Vincent Hall 2

As with modeling any complex system, detailed mathematical modeling of neural networks can quickly become too complicated to allow analysis, or even simulation, of the resulting systems of equations. In this course, we will explore methods of simplifying neuron and neural network models to better understand their behavior. We will examine how these models, coupled with experimental data, can yield insights into the functions of neural networks in the brain.

We will first derive equations describing the evolution of neurons and their coupling using the Hodgkin-Huxley formalism. This will allows us, at least in theory, to write down detailed equations describing the evolution of arbitrary neural networks.

We will tame the equations using standard mathematical techniques such as time/space scale separation, asymptotic analysis, ensemble averaging, ad hoc approximation, and neglect of unpleasant details. We will explore such approximations as the space-clamped neuron, the integrate-and-fire neuron, the theta-neuron, mean-field approximations, the population density approach, and phenomenological approaches. We will show how these models can be applied to neuroscience questions such as feature selectivity in local cortical circuits, working memory, analysis of auditory or visual signals, and the estimation of connectivity patterns in neuronal networks.

No previous experience in neuroscience required. Moderate mathematical sophistication (e.g. basic familiarity with differential equations) will be assumed.