Engineering Sciences and Applied Mathematics

ESAM Seminar Series Presents:

Frequency Preference Response to Oscillatory Inputs in Neuronal Models: A Geometric Approach to Subthreshold Resonance

Presented by:

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Many neuron types exhibit preferred frequency responses to subthreshold oscillatory input currents reflected in a voltage amplitude peak (resonance) and a zero phase-shift (phasonance or phase-resonance). These phenomena may occur in the absence of intrinsic oscillations in the corresponding autonomous system. The dynamics principles that govern the generation of resonance and the effect of the biophysical parameters on the resonant properties are not well understood.

We propose a framework to analyze the role of different ionic currents and their interactions in shaping the properties of the impedance amplitude and phase profiles (graphs of these quantities as a function of the input frequency) in linearized and quadratic biophysical models. We adapt the classical phase-plane analysis approach to account for the dynamic effects of oscillatory inputs and develop a tool, the envelope-plane diagrams, that capture the role that conductances and time scales play in amplifying the voltage response at the resonant frequency band as compared to smaller and larger frequencies. We use envelope-plane diagrams in our analysis to explain why the resonance phenomena do not necessarily arise from the presence of imaginary eigenvalues at rest, but rather it emerges from the interplay of the intrinsic and input time scales. This interaction is based mostly on transient effects. We further explain why an increase in the time scale separation causes an amplification of the voltage response in addition to shifting the resonant and phase-resonant frequencies. We extend this approach to explain the effects of nonlinearities on both resonance and phase-resonance.

We demonstrate that nonlinearities in the voltage equation cause amplifications of the voltage response and shifts in the resonant and phase-resonant frequencies that are not predicted by the corresponding linearized model. The differences between the nonlinear response and the linear prediction increase with increasing levels of the time scale separation between the voltage and the gating variable, and they almost disappear when both equations evolve at comparable rates. In contrast, voltage responses are almost insensitive to nonlinearities located in the gating variable equation. The method we develop provides a framework for the investigation of the preferred frequency responses in three-dimensional and nonlinear neuronal models as well as simple models of coupled neurons.

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For further information see http://www.esam.northwestern.edu
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