Exploring Neural Communication via Phase-Amplitude Dynamics: Efficient numerical methods

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Abstract: Macroscopic oscillations in the brain play a crucial role in cognitive tasks, yet their exact functions remain incompletely understood. One prominent hypothesis suggests that oscillations enable dynamic modulation of communication between neural circuits by rhythmically altering neuronal excitability. In this study, we use mean-field models to explore synchronization dynamics between connected Excitatory-Inhibitory (E-I) networks generating Gamma rhythms. These networks interact with one another while receiving external periodic inputs.

Our investigation employs the phase-amplitude framework, which extends classical phase reduction methods by incorporating amplitude coordinates (or isostables) to describe transient dynamics transverse to limit cycles. To simplify the system while maintaining accuracy, we focus on reducing the dynamics to a slow attracting invariant submanifold associated with the slowest contracting direction. In this work, we present an efficient numerical method to compute the parameterization of the attracting slow submanifold of hyperbolic limit cycles and the simplified dynamics in its induced coordinates. Additionally, we compute the infinitesimal Phase and Amplitude Response Functions restricted to this manifold, which characterize the effects of perturbations on phase and amplitude. These methods offer a powerful framework for understanding the interplay of phase, amplitude, and synchronization in neuronal network communication.