Linking Connectome Structure to Transient Dynamics in Large-Scale Brain Networks

Understanding how structural connectivity, together with intrinsic dynamics, shapes brain activity is a central problem in theoretical neuroscience. Large-scale brain rate models provide a bridge between anatomical connectivity and neural dynamics, yet it remains unclear how specific inter-areal connectivity patterns, especially local motifs embedded in heterogeneous whole-brain networks, shape transient responses such as timescale and amplification. This gap limits our ability to extract interpretable dynamical principles from increasingly detailed connectome data.

To address this gap, we develop a systematic mathematical framework for quantifying dynamic responses in brain network rate models. We first examine classical global structural patterns, namely weak orthogonality and weak localization, observed in both simulations and experimental data. We then use toy models to isolate the effects of specific local motifs, extend the analysis to more general network structures, and test the resulting predictions using real connectome data from marmoset and primate brains. Together, this work provides a quantitative and interpretable framework for understanding how inter-areal structural patterns govern transient dynamics and offers theoretical guidance for linking local circuit elements to large-scale functional responses.

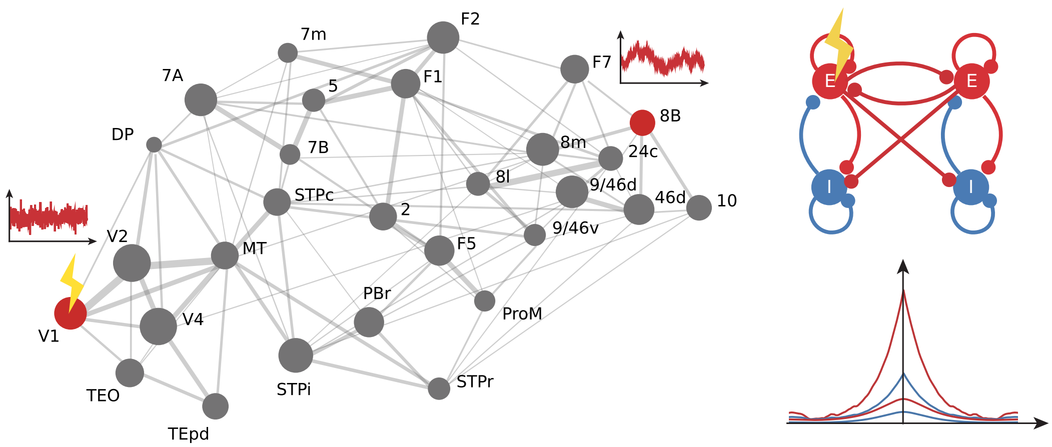

Figure 1: Mathematical framework for quantifying transient dynamics in network rate models. Left: Schematic of node-to-node propagation under noisy input in a heterogeneous network, illustrated here using a primate cortical network. An input is applied to a single node, and the resulting transient response is quantified at any target node. Upper right: Toy Wilson-Cowan model for propagation between two brain regions, each consisting of an excitatory (red) and inhibitory (blue) population. Inputs and outputs can be assigned to any population. Lower right: Autocovariance of the noisy output, which is quantified analytically and linked exactly to structural properties and intrinsic dynamics.