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An integrated model linking structural and dynamical properties of cortical microcircuits

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Experimental studies have begun revealing essential properties of the structural connectivity and the spatiotemporal activity dynamics of cortical microcircuits. To integrate these properties from anatomy and physiology, and to elucidate the mechanistic links between them, we develop a cortical microcircuit model that captures a range of realistic features of synaptic connectivity. We show that the model accounts for the emergence of higher-order connectivity structures, including overrepresented three-neuron motifs and highly connected hub neurons that form an interconnected rich-club. The microcircuit model exhibits a rich repertoire of activity states, ranging from asynchronous to localized and global propagating wave states. We find that around the transition between asynchronous and localized propagating wave states, our model quantitatively reproduces a variety of major empirical findings regarding neural spatiotemporal dynamics, which otherwise remain disjointed in existing studies. These dynamics include diverse coupling (correlation) between spiking activity of individual neurons and the population, propagating wave patterns with variable speed and precise temporal structures of neural spikes. We further illustrate how these neural dynamics are mechanistically linked to the structural connectivity properties by analyzing the contributions of connectivity to neural spiking dynamics and by showing that the rich-club structure is fundamentally related to the emergence of the diverse population coupling. These findings establish an integrated account of structural connectivity and activity dynamics of cortical microcircuits, and provide novel experimentally testable predictions.

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