Transitions between Asynchronous and Synchronous States: A Theory of Correlations in Small Neural Circuits

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The study of correlations in neural circuits is a topic of central importance to systems neuroscience **[1,2]**. Notwithstanding, a theory is still to be formulated that could explain how the parameters of small networks composed of a few tens of neurons affect their correlation structure. In this work we introduce a mathematical formalism for studying correlations which is not based on statistical averaging and which can be applied to networks of arbitrary size **[3]**. We study the correlation structure in different regimes, showing that external stimuli cause the network to switch from asynchronous states characterized by weak correlation and low variability, to synchronous states characterized by strong correlations and wide temporal fluctuations. Asynchronous states are generated by strong stimuli, while synchronous states occur through critical slowing down when the stimulus moves the network close to a local bifurcation. In particular, strongly positive correlations occur at the saddle-node and Andronov-Hopf bifurcations of the network, while strongly negative correlations occur when the network undergoes a spontaneous symmetry-breaking at the branching-point bifurcations. Branching points describe the spontaneous formation of heterogeneous activity in populations of homogeneous neurons **[4]**, and they are not predicted by large-scale theories such as the mean-field approximation. They quantify the network's ability to regulate its degree of functional heterogeneity, which is thought to help reducing the detrimental effect of noise correlations on cortical information processing **[5,6,7]**. Moreover, the branching points may explain the still poorly understood origin and functional role of negative correlations observed in experimental recordings of cortical activity **[8,9]**.

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