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Neurons hear their echo

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The functional implications of correlations in cortical networks are still highly debated [1] and theoreticians are intensely searching for a self-consistent solution of the correlation structure in recurrent networks. Feed-forward descriptions have been presented as approximations [2] and different aspects of correlation functions in the asynchronous irregular state have been accurately predicted, such as the zero time lag correlation [3] and its scaling with network size on a coarse time scale [1]. Previous approaches do, however, not explain the differences between the correlation functions for excitatory and inhibitory neurons and they do not describe their temporal structure, an experimentally observable feature that has important functional consequences for synaptic plasticity [4].

The approximation of neural dynamics by a linear response kernel is a powerful technique in the analysis of recurrent networks. Here we use Hawkes processes [4,5] to model the spiking activity of a neuron as a rate-modulated Poisson process, where incoming synaptic events cause exponentially decaying deflections of the instantaneous firing rate that superimpose linearly. We analytically determine the correlation structure of recurrent random networks of these excitatory and inhibitory linear neurons with delayed pulse-coupling. We show that this minimal linear model is sufficient to explain generic features of correlations: The origin of troughs near the center peak, the asymmetry between excitatory and inhibitory neurons, and the emergence of damped oscillatory correlation functions (Fig. 1A). In our derivation we employ a novel series expansion of the correlation function in terms of resonance frequencies of the delayed feedback system, that is valid in the whole parameter regime of inhibition dominated networks. Previous expansions were limited to a feedback gain below 1 [4]. Our results identify two distinct contributions to the correlation: a feed-forward term due to correlated inputs (Fig. 1B, black) and a self-feedback term due to the activity of the neurons under consideration (Fig. 1B, gray). This self-feedback explains the asymmetry of correlations between excitatory and inhibitory neurons (Fig. 1A, black: simulation, gray: theory).

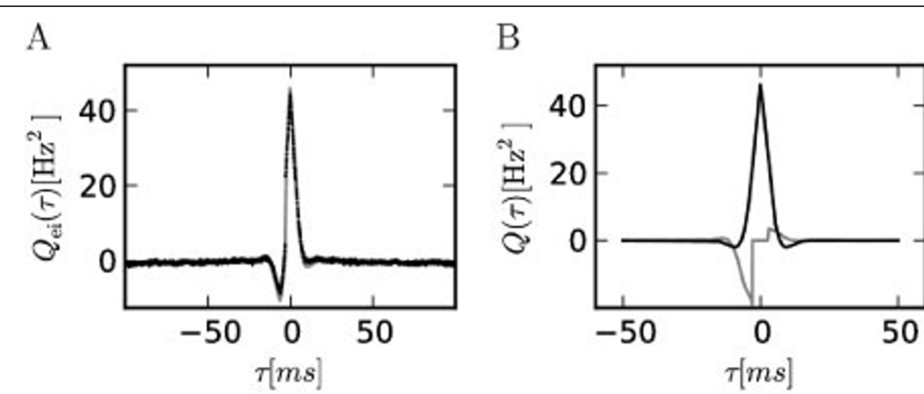

Figure 1

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