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Reliability of response spike timings in pulse-coupled networks of neurons

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Introduction

Reliable information processing requires a code that can be represented and transmitted reliably within the precision of the devices. In the brain, neurons use spikes to convey information to other neurons and temporal codes hypothesize that information is encoded into fine spatio-temporal structure of precisely timed spike trains. Single neurons are known to generate highly precise spike trains when they are repeatedly activated by the same fluctuating input [1]. Neurons, however, work collectively rather than individually in their network. It remains unclear whether neurons in a network can still respond precisely since mutual couplings may affect the response of the individual neurons. To answer this question, we investigate the temporal precision of responses of a pulse-coupled network of neurons when a set of independent fluctuating inputs, frozen noise, is repeatedly applied to the network.

Methods

To study this problem analytically, we introduce uncoupled copies of the network that commonly receive the set of fluctuating inputs. Suppose that the original network repeatedly generates identical precisely timed spike responses. Then, we can interpret these responses across trials as responses of the individual copies in a trial. Thus, in-phase synchronization between identical networks implies precisely timed responses of a single network across trials. Such noise-induced synchronization was previously studied between single oscillators [2]. Here, we study the noise-induced synchronization between networks of neurons to clarify whether each network is able to encode information about fluctuating inputs into precisely timed spikes [3].

Results

We develop a mean-field theory of noise-induced synchronization between the copies of the pulse-coupled network of neurons. We can analytically derive a self-consistent equation for the distribution of spike-time differences between the corresponding neurons and obtain the distribution as a function of the coupling strength of the network, which allows us to reveal the nontrivial effect of mutual couplings on the temporal precision of response spikes in the recurrent network of neurons. Spike sequence generated by the network is not perfectly the same across trials. Instead, the result implies enough coherence of spike trains between different trials, as indicated by the obvious peak of the distribution. The width of the peak measures a degree of the coherence, up to which spike trains can be used reliably. The result tells us how the coherence changes qualitatively as a function of the coupling strength in the network.

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