Linear Response of General Observables in Spiking Neuronal Network Models

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The response of a spiking neuronal network to a stimulus depends on the stimulus itself, but also on the nonlinear neuronal dynamics and the synaptic interactions between neurons. It is not possible in general to disentangle these three effects. We investigate, within the framework of a mathematical spiking neuronal network model, the following question: What is the effect of a weak amplitude time-dependent stimulus on the high order spatiotemporal correlations of a spiking neuronal network? We address this question using methods from statistical mechanics: Gibbs distributions and linear response theory. We consider a conductance-based spiking neuronal network model introduced in [1], without external stimulation up to some fixed reference time, when we apply a stimulus of small amplitude. The spike train statistics is stationary before the application of the stimuli; it becomes time-dependent in the presence of the stimulus. A seminal result in non-equilibrium statistical physics is the fluctuation-dissipation theorem, where the linear response only depends on the correlation functions of the unperturbed system. Our approach proceeds along similar lines using standard results from ergodic theory and thermodynamic formalism. We provide an explicit formula for the linear response expressed in terms of a convolution where the kernel depends on the observable, network characteristics (i.e. the parameters fixing the collective neurons dynamics) and spike history. Our approach generalize previous results in this field to more general observables than rates and synchronous pairwise correlations, including general spatiotemporal correlations. We discuss the interpretation of our results in the context of population receptive fields for sensory neurons.

References

[1] M. Rudolph and A. Destexhe Analytical Integrate and Fire Neuron models with conductance-based dynamics for event driven simulation strategies., *Neural Computation* 18, pp. 2146-2210, 2006.