Impact of delayed interactions on the dynamical properties of spiking neural networks

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Synaptic delays between neurons are a fundamental feature of neuronal networks, having direct implications on the characteristics of their collective dynamics. Delayed inhibition, for instance, is responsible for the emergence of neural rhythms [1], which are found across animal species, sensory systems and are associated with diverse cognitive functions [2]. Interaction delays also play a main role in defining the frequency of these oscillations [3], frequencies that are thought to act as separate channels of neural information transmission [4].

Spiking neural networks with synaptic delays can be modeled as coupled differential equations in an infinite dimensional space, for which an initial history function needs to be specified for each neuron in the network. The problem can, however, be reduced to be of finite, although varying dimension, in the case of delta coupling between units [5]. The evident complexity that such systems present, challenges its analytical tractability and therefore the study of its dynamics. In this work we make progress in the treatment of such networks and in analyzing their fundamental properties for finite and fixed degrees of freedom. We derive an analytical expression for the single spike Jacobian of the delayed neural network, circumventing the dependence on its history by introducing, for every neuron, a postsynaptic single-compartment-axon (SCA) modeled as a sub-threshold unit. Synaptic interaction therefore remains instantaneous, but effective transmission delays are introduced by the additional steps of input integration; the delay is thus the finite time that is required by the delayer SCA to "spike". This novel procedure allows us to numerically obtain the full Lyapunov spectrum and its derived quantities such as the attractor dimension and the entropy production rate. We provide a framework to study the impact of heterogeneous delayed interactions on the relation between two crucial aspects: The emergence of network oscillations and their properties on the one hand, and the stability and the possible limitations for information storage in such networks on the other.

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