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Mesoscopic model of balanced neuron networks using a Master equation formalism

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Cortical activity in awake animals manifests highly complex behaviour [1]. It is during this regime that the main computational tasks are performed and no model is yet able to explain how this complex dynamics is exploited to provide a fast and accurate information processing. However, many efforts have been devoted to the study of how such activity emerges.

Balanced networks have been introduced as a possible model to generate dynamical states similar to the biological ones [2]. The stability of such states was studied for current-based Integrate-And-Fire (IAF) neurons with respect to external input and excitatory-inhibitory synaptic strength ratio [3]. In particular, stable asynchronous irregular (AI) states with a relatively low level of activity have been obtained. Recently, AI states have been observed in balanced networks of conductance-based IAF neurons with self-sustained activity [4].

However, no simple description of the network activity dynamics has been developed yet. First-order mean-field approximation fails to describe these networks because of their inherent dynamics which rely dramatically on activity fluctuations. Moreover, the thermodynamic limit is usually performed for randomly connected networks despite the lack of biological relevance.

We introduce here a new framework in which network dynamics as well as inherent neuron behaviour is taken into account. We aim to obtain a reduced description of mesoscopic balanced networks where finite size effects are not neglected. The model is intended to describe AI states far from critical boundaries where long-term behaviours appear. Furthermore, we set the spatial and temporal scales of the model by using biological data. Using the master equation formalism, we derive a second-order mean-field set of ordinary differential equations.

The transition matrix necessary in the master equation context is computed based on the Fokker-Plank approach. Conductance-based as well as current-based IAF neurons are constructed. The kernel of this formalism lays in the way activity micro-fluctuations are modelled. We discuss different possibilities and considerations in regard to this question.

This model provides at the same time an extracellular and a sub-threshold description of finite size neuron networks. Once the couplings will be adjusted, it will be possible to build a large-scale model of cortical area with specific architectures, where the fundamental unit is the randomly connected network. We further discuss the possibility to compare large-scale behaviour observed in voltage-sensitive dyes experiments with our model.

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