Ubiquity of macroscopic chaos in balanced networks of spiking neurons

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In this Letter we focus on the characterization of the balanced states that emerge in a network of spiking neurons. A theory of balanced states has been developed in rate models, which however miss a crucial ingredient: the spiking activity of the single neurons, so that it is still unclear to what extent the resulting findings apply to more realistic setups [van Vreeswijk and Sompolinsky(1996)].

A prototypical network model of excitatory and inhibitory leaky integrate-and-fire neurons was proposed by Brunel [Brunel(2000)], more recently the same model has been examined by Ostojic [Ostojic(2014)] for a not negligible connectivity. In particular, Ostojc claims the existence of two different asynchronous regimes when the coupling strength is progressively increased [Ostojic(2014)]. Even though this statement has been challenged by Engelken et al. [Engelken et al.(2016)], who claim that a single, standard, asynchronous regime does exist, the network dynamics need to be better understood.

We revisit such a type of balanced regimes, going beyond the limit of strong dilution. By performing a finite-size scaling analysis, we conclude that the asymptotic regime is not asynchronous but rather a manifestation of a collective irregular dynamics (CID), similar to what found in a heterogeneous network of globally coupled inhibitory neurons [Luccioli and Politi(2010)]. Collective dynamics can be detected by implementing the same indicators introduced to quantify the degree of synchronization. With the help of one such order parameter, specifically designed to characterize neuronal synchrony in large ensembles of neurons [Golomb(2007)], we find that CID is a general and robust phenomenon, which persists down to very small coupling strengths. In the same set-up, we observe that CID persists in presence of noise and even for a different neural model, namely the quadratic integrate-and-fire spiking neuron.

Finally, the study of the fully-coupled limit helps to clarify the importance of noise, either endogenous and quenched (e.g., diversity of connections), or exogenous and dynamical (e.g., a fluctuating external current).

References

[van Vreeswijk and Sompolinsky(1996)] C. van Vreeswijk and H. Sompolinsky, Science **274**, 1724 (1996).

[Brunel(2000)] N. Brunel, Journal of Computational Neuroscience **8**, 183 (2000).

[Ostojic(2014)] S. Ostojic, Nat Neurosci **17**, 594 (2014).

[Engelken et al.(2016)] R. Engelken, F. Farkhooi, D. Hansel, C. van Vreeswijk, and F. Wolf, F1000Research **5** (2016).

[Golomb(2007)] D. Golomb, Scholarpedia **2**, 1347 (2007).

[Luccioli and Politi(2010)] S. Luccioli and A. Politi, Phys. Rev. Lett. **105**, 158104 (2010).