Firing rate distributions in plastic networks of spiking neurons

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Networks of spiking neurons have been widely used as models to represent neuronal activity in the brain. These models are reasonably realistic but they are also difficult to treat analytically. Mean-field theory has nevertheless proven to be successful as a method for deriving some of their statistical properties at equilibrium, such as the distribution of firing rates, both in homogeneous networks and in networks which exhibit a large heterogeneity in their structure.

However, these models lack realism in the sense that they assume a fixed connectivity, whereas the connection strengths in brain networks evolve in time according to plasticity rules that depend on the neuronal activity. We have addressed this issue by extending the mean-field formalism to networks of leaky integrate-and-fire neurons with connections that are defined by a static binary scaffold but whose non-zero synaptic weights are prone to plastic, activity-dependent modulation. This formalism provides a set of equations whose solution specifies the stationary firing rate and synaptic weight distributions. We show that the results are in good agreement with the distributions obtained by simulating the full spiking dynamics for quite general forms of plasticity functions. Our formalism sheds light on the interplay between the characteristic time scales of the neuronal and the plasticity dynamics, and can take into account the role of different types of neuronal communities. Overall, it offers a new perspective to explore and better understand the way in which plasticity shapes both activity and structure in neural networks.