Theory of multi-scale neuronal networks

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The brain is organized on different spatial scales: on the smallest scale, single neurons are connected with synapses, on an intermediate scale neural populations are organized in structures with layer-specific connectivity and on the largest scale, multiple microcircuits form a network of networks. Today we can simulate networks comprising whole brain areas at the microscopic resolution of single cells. In order to understand the dynamics emerging in these highly interconnected and correlated systems, it is however desireable to develop effective mathematical descriptions in terms of coarse-grained quantities. Examples are summed population activities or average pairwise correlations. This level of description allows the analysis of dynamical phenomena, such as the emergence of collective oscillations and correlated activity. In this talk we give a brief overview of the mean-field methods and the linear response theory of fluctuating dynamics developed and applied in our group. We show how the original system of coupled spiking integrate-and-fire models can be mapped to an effective linear equation describing activity fluctuations [1]. As an example, we apply this theory to answer the question for the origin of correlated activity, showing that intrinsically generated fluctuations are as important as the external input supplied to the network [2]. The talk introduces the basic methods for the investigation of transfer properties of neurons (see contribution by Jannis Schücker) and for the analysis of the emergence of collective oscillations in structured networks (see contribution by Hannah Bos).

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[1] Grytskyy D, Tetzlaff T, Diesmann M and Helias M (2013) A unified view on weakly correlated recurrent networks. Front. Comput. Neurosci. 7:131.
[2] Helias M, Tetzlaff T, Diesmann M (2014) The Correlation Structure of Local Neuronal Networks Intrinsically Results from Recurrent Dynamics. PLoS Comput Biol 10(1): e1003428.

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