Towards a field theory for neuronal networks

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Mean-field descriptions of neuronal networks yield stability constraints that guide efficient model development (Schuecker et al. 2017). Linear response theory allows the study of spontaneous fluctuations and responses to weak stimuli (Bos et al. 2016).

But existing approaches cannot be systematically extended beyond weak departures from stationarity, ignore non-linear apsects of neuronal interaction, and describe only population-averaged activities. Massively parallel recordings of neuronal activity, however, expose a large cell-to-cell variability outside the realm of a population-level description.

We here present recent developments within SP4 towards a systematic theory of fluctuating and correlated activity in neuronal networks.

Leaving the population description, we present a cumulant expansion that includes higher order statistics and non-linearities to accurately predict mean activities and fluctuations on the level of individual neurons (Dahmen et al. 2016a): It exposes the intrinsically generated wide distribution of pairwise correlations and explains the rich repertoire of network responses to external stimulations.

The framework readily extends to the non-stationary setting, explaining the temporal modulation of correlations in oscillatory network states (Kuehn et al. 2016).

Moreover, the approach reduces the non-linear neuronal dynamics to an effective stochastic differential equation, which enables the investigation by field theoretical methods (Schuecker et al. 2016): Treatment of disordered connectivity (Dahmen et al. 2016b), analysis of phase transitions (Goedeke et al. 2016), and systematic corrections to mean-field results.

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