Selective feature integration with critical dynamics in cortical subnetworks

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Recent experimental and theoretical work increasingly suggests that cortical neurons operate close to a critical state which describes a phase transition from chaotic to ordered dynamics and optimizes multiple aspects of information processing (e.g. [1-2]). However, although critical dynamics have been demonstrated in recordings of spontaneously active cortical neurons [3], the link between criticality and active cortical computation remains largely unexplored. Establishing this link requires addressing major conceptual challenges, namely: making abstract complexity measures work in realistic computational settings and considering—instead of homogeneous, spontaneously active networks—strongly driven systems with high firing rates and networks with structured connectivity.

In our work we focus on visual feature integration as a prototypical and prominent example for cortical computation. Visual feature integration refers to neural processes which link localized image information into more global representations such as contours, shapes, and objects. We study feature integration in a figure-ground segregation task, where cortical subnetworks operate close to the critical state when part of a visual stimulus matches a 'figure' which is to be detected by the visual system. Within the simple, but analytically well-described framework of the Ernst-Herrmann-Eurich (EHE) model, we embed a large number of figures into a recurrently coupled network. Out of N units representing each figure, we allow for n units to represent multiple figures at the same time and characterize the network dynamics for different stimuli.

We find that presenting a visual stimulus with a target figure dynamically organizes the network into two parts: one with critical dynamics, encoding the ensemble of features making up the figure, and one with subcritical dynamics, encoding the background elements. We show that figure representation in the oscillatory dynamics of the system as well as the task performance in a 2AFC-scenario is maximized near the critical point. Adding inhibitory interactions between neurons encoding different figures ensures that the coupling strength for which the network is critical is robust against changes in n (Figure 1), the network size and the number of figures in the network.

Our model extends the idea of criticality being optimal for computation to inhomogeneous systems, establishes links to spatial computation performed in the visual system and predicts that local subnetworks can display supercritical activity, contained by inhibition, while the cortex at large is poised at subcritical regimes.

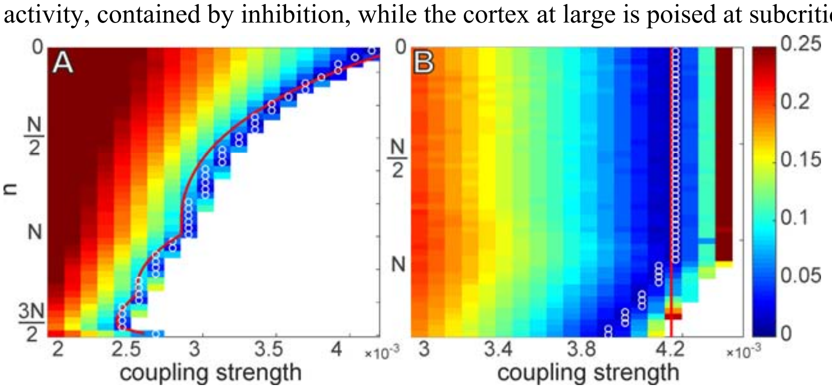

Figure 1. The Kolmogorov–Smirnov (KS) statistic, quantifying the distance of spike statistics from a power-law, for an excitatory network **(A)** and for a network with both excitation and inhibition **(B)**, as a function of the coupling strength and the overlap between figures, n. In the white regions the network starts to exhibit infinite avalanches. White circles mark where the KS statistic is lowest and the red line shows our theoretical approximation for the critical point. We find that for the network with inhibition, the critical coupling strength does not change as n increases until $n = N$.

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References

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