Abstract Invited

Gašper Tkačik

Avalanches and oscillations in a simple model near criticality

Neurons in the brain are wired into adaptive networks that exhibit collective dynamics as diverse as scale-specific oscillations and scale-free neuronal avalanches. Although existing models account for oscillations and avalanches separately, they typically do not explain both phenomena, are too complex to analyze analytically or intractable to infer from data rigorously. Here we propose a feedback-driven Ising-like class of neural networks that captures avalanches and oscillations simultaneously and quantitatively. In the simplest yet fully microscopic model version, we can analytically compute the phase diagram and make direct contact with human brain resting-state activity recordings via tractable inference of the model's two essential parameters. The inferred model quantitatively captures the dynamics over a broad range of scales, from single sensor oscillations to collective behaviors of extreme events and neuronal avalanches. Importantly, the inferred parameters indicate that the co-existence of scale-specific (oscillations) and scale-free (avalanches) dynamics occurs close to a non-equilibrium critical point at the onset of self-sustained oscillations.

Gianluigi Mongillo

Is the cortical dynamics ergodic? A numerical study in partially-symmetric networks of spiking neurons

Cortical activity in-vivo displays relaxational time scales significantly longer than the underlying neuronal and synaptic time scales. The mechanisms responsible for such slow dynamics are not understood. Here, we show that slow dynamics naturally, and robustly, emerges in dynamically-balanced networks of spiking neurons. This only requires partial symmetry in the synaptic connectivity, a feature of local cortical networks observed in experiments. The symmetry generates an effective, excitatory self-coupling of the neurons that leads to long-lived fluctuations in the network activity, without destroying the dynamical balance. When the excitatory self-coupling is suitably strong, the same mechanism leads to multiple equilibrium states of the network dynamics. Our results reveal a novel dynamical regime of the collective activity in spiking networks, a regime where the memory of the initial state persists for very long times and ergodicity is broken.

Henrik Jeldtoft Jensen

Statistical Physics of Cognition: The spatial and temporal structure of two-photon detected neuronal activity in mice.

We report the analysis of neuronal activity data obtained by two-photon microscopy on the visual cortex of mice in the laboratories of Simon Schults at Imperial and Spencer Smith at UCSB. The time series of activity are investigated from the viewpoint of bursts of activity, avalanches, and their spatial and temporal character is related to how correlated the neural activity is with pupil dynamics. Neural avalanches sharing the highest Mutual Information with the pupils exhibit statistics that can be interpreted as most similar to critical scale free statistics.
From the time series of neuronal activity, we define a network in which nodes, corresponds to single neurons. The nodes are linked together with a strength given by the Mutual Information time series of activity of the pairs of neurons. We study the hierarchical community structure of the network and compare it to the histological regions.
Finally, we use information theory to separate the interdependence between the activity of neurons into so-called redundant and synergetic relations. We find that redundant interdependence is shorter ranged in space and time than is synergetic.

The team:
Doers: Hardik Rajpal, Meghdad Saeedian, Cedri Stevns, and Mengke Yang
Collaborators: Joe Canzano and Spencer Smith
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A Unified Framework for Sensory Coding in Feedback-Modulated Canonical Networks

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In recent decades, the principles of neural coding have largely been studied at the level of single neurons or unimodal sensory networks. However, brain networks interact in complex ways, often integrating information across sensory modalities. Notably, we lack a theoretical framework for understanding coding in interacting networks, where information converges from different sources. In this talk, I will introduce a fully analytical normative framework for neural coding in feedback-modulated canonical networks, a ubiquitous motif in the brain. In our model, feedback is exogenous rather than endogenous to a given modality, mediating interactions between the senses. Our theory demonstrates that predictive coding is an emergent property of efficient codes, unifying two primary coding schemes. It further demonstrates how the computational principles of efficient and predictive coding can be implemented at the algorithmic level by a shared neural substrate, with different network components performing distinct and interpretable mathematical operations. Finally, the theory provides a coherent normative explanation for a variety of observed unimodal and multimodal sensory effects and makes new predictions about the role of feedback in optimizing multimodal codes. I will conclude by showing how such optimal codes can be learned in biological networks through distributed Hebbian learning. Altogether, our theory provides a unifying view of computational, algorithmic, and implementational principles underlying sensory coding in feedback-modulated canonical networks