Speaker

Gašper Tkačik

Title

Avalanches and oscillations in a simple model near criticality

Abstract
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.

Speaker

Gaia Tavoni

Title

A Unified Framework for Sensory Coding in Feedback-Modulated Canonical Networks

Department of Neuroscience, Washington University in St. Louis
Department of Physics, Washington University in St. Louis
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Abstract
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

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Speaker

Gianluigi Mongillo

Title

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

Abstract
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.

Speaker

Nima Dehghani

Title

Symmetry's Edge: Multiscale E/I Balance and Functional Symmetry Breaking in the Cortex

Abstract
A fundamental challenge in neuroscience is to develop a quantitative theory explaining how the cerebral cortex maintains both stability and computational flexibility. Moving beyond traditional mean-field models, we adopt a physics-inspired framework to analyze multiscale ensemble dynamics of excitatory (E) and inhibitory (I) populations from high-density human and monkey neocortical recordings. Our

analysis reveals a foundational organizing principle: a remarkably precise, scale-invariant E/I balance that is robustly maintained across four orders of temporal magnitude and all states of the wake-sleep cycle. The fluctuations around this balance are not random noise but follow a universal scaling law, evidenced by the collapse of their statistical distributions onto a single master curve—a hallmark of systems operating near criticality. We propose that function arises not from this symmetry itself, but from its structured breaking. Using a novel multiscale co-occurrence analysis, we show that different vigilance states are distinguished by unique quantitative "fingerprints" of E-I co-fluctuations, suggesting the cortex operates on a 'critical manifold' rather than at a single critical point.4 In contrast, pathological states like seizures represent a catastrophic breakdown of this symmetry, which is followed by an active, homeostatic reset that restores the system to its pre-seizure trajectory, revealing a powerful 'balance homeostat'. Together, these findings support a model of the cortex operating at the 'edge of symmetry,' where a stable, balanced substrate is dynamically modulated by controlled symmetry-breaking to enable the vast repertoire of cortical computation.

Speaker

Athena Akrami

Title

Cross-species study of statistical learning – from behaviour to mechanism

Abstract

A defining feature of animal intelligence is the ability to discover and update knowledge of statistical regularities in the sensory environment, in service of adaptive behaviour. This allows animals to build appropriate priors, in order to disambiguate noisy inputs, make predictions and act more efficiently. Despite decades of research in the field of human cognition and theoretical neuroscience, it is not known how such learning can be implemented in the brain. By combing highly quantifiable cognitive tasks in humans, rats, and mice, as well as neuronal measurements and perturbations in the rodent brain and computational modelling, we seek to build a multi-level description of how regularities in temporally extended tasks are learned and utilised. In this talk, I will specifically focus on a cross-species model to study statistical learning, in both feedback-based and non-feedback-based settings.

Speaker

Henrik Jeldtoft Jensen

Title

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

Abstract
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
Mentors: Simon Schultz and Mauricio Barahona
Adviser: Lucilla de Arcangelis