Speaker Title & Abstracts

Criticality in Neural Systems 2024:

www.braincriticality.org

Hybrid meeting on the main campus of the National Institutes of Health, Bethesda, Maryland, USA from Nov. 6th – 8th, 2024.

Organizers:
Demian Battaglia, Mauro Copelli, Lucilla De Arcangelis, Miguel Muñoz, & Dietmar Plenz

Criticality in Neural Systems 2024, Nov. 6 - 8, 2024, Hybrid

Natcher Conference Center, National Institutes of Health, USA

			Conference Agenda		Titles
Wednesday	**Nov. 6, 2024**				
			Day 1: Hybrid online/in person		
7:45	**Departure to NIH**		Hotel Shuttle/ Security/Natcher		
8:45	**Welcome**		Host, Organizers		
9:00	**Session 1**		*Computation*		
	20 + 15 min		**Pedro Mediano**	i	Beyond correlation: High-order structure in critical neural systems
	20 + 15 min		**Miguel Munoz**	o	Scaling of brain activity and optimal functionality: from real neurons to artificial intelligence
10:15	**Coffee break**				
10:45	**Session 2**		*Experiments*		
	20 + 15 min		**Jason MacLean**	i	Dynamic functional networks: A graph-theory approach to understanding flexible computation in neocortex
	20 + 15 min		**Demian Battaglia**	i	Dynamic functional networks: "how" and "why"
12:00	**LUNCH**				
13:30	**Spotlight Talks**		*4 online 5 min talks + 10 min Q&A*	o	*Selected from submitted abstracts*
14:00	**Session 3**		*Neuronal Dynamics & Criticality*		
	20 + 15 min		**Audrey Sederberg**	i	Understanding diverse signatures of neural criticality using the dynamic latent variable model
	20 + 15 min		**Tiago Ribeiro**	i	Critical scaling of novel spikes in cortical networks in vivo
15:15	**Coffee break**				
15:30	**Special Lecture**		*Collective Decision Making*		
	45 + 15 min		**Carmen Miguel**	i	Signatures of criticality in animal collective decision-making
16:30	**Closing Discussion**		Return - Hotel shuttle, walk		
Thursday	**Nov. 7, 2022**				
			Day 2: Hybrid online/in person		
8:45	**Announcements**		Host, Organizers		
9:00	**Session 4**		*Clinical findings I*		
	20 + 15 min		**Matias Palva**	i	Structural control parameters for Griffiths phase in human brain dynamics
	20 + 15 min		**Klaus Linkenkaer-Hansen**	i	The many faces of excitation-inhibition balance in neuronal network oscillations
	20 + 15 min		**Silvia Scarpetta**	i	Extended region of criticality in a spiking modular network with spatio-temporal attractors
10:45	**Coffee break**				
11:15	**Session 5**		*Clinical findings II*		
	20 + 15 min		**Chris Meisel**	i	Critical dynamics predicts cognitive performance and provides a common framework for heterogeneous mechanisms impacting cognition
	20 + 15 min		**Ana Millan**	i	Epidemic spreading in large-scale brain modeling: clinical applications
12:30	**LUNCH**				
14:00	**Spotlight Talks**		*4 online 5 min talks + 10 min Q&A*	o	*Selected from submitted abstracts*
14:30	**Special Lecture**		*Critical Dynamics*		
	45 + 15 min		**Hans Herrmann**	o	Ising-like model replicating time-averaged neural spiking
15:30	**Coffee & Posters**		*Poster Session with Online Attendence*		Virtual poster gallery
16:30	**Session 6**		*Neuronal Dynamics & Criticality*		
	20 + 15 min		**Joern Davidsen**	i	Brain criticality, consciousness, connectivity & behavior
	20 + 15 min		**Woodrow Shew**	i	Arousal: the brain's control parameter of a critical phase transition
17:40	**Closing Discussion**		Return - Hotel shuttle, walk		
18:00			**Dinner at Virray, Downtown Bethesda**		
Friday	**Nov. 8, 2022**				
			Day 3: Hybrid online/in person		
8:45	**Announcements**		Host, Organizers		
9:00	**Session 7**		*Collective dynamics & Time Scales*		
	20 + 15 min		**Irene Giardina**	o	Out-of-equilibrium response, dissipation, and control in flocking systems
	20 + 15 min		**Leonardo Gollo**	i	How to conciliate criticality with a hierarchy of timescales in the brain
	20 + 15 min		**Anna Levina**	o	Tuning timescales to suit computational needs
10:45	**coffee break**				
11:00	**Special Lecture**		*Criticality Perspective I*		
	45 min + 15 min		**Dante Chialvo**	o	Is brain criticality controversial? No
12:00	**LUNCH**		**Bldg 10 or Porter**		
13:30	**Special Lecture**		*Collective Dynamics in Humans*		
	45 + 15 min		**Kareem Zaghloul**	i	Insights into neural coding in the human brain through the study of human episodic memory formation
14:30	**Coffee break**				
14:45	**Spotlight Talks**		*4 online 5 min talks + 10 min Q&A*	o	*Selected from submitted abstracts*
15:15	**Session 8**		*Criticality Perspective II*		
	20 + 10 min		**Mauro Copelli**	i	Neuronal scaling in the mouse visual cortex during a visual recognition task
	20 + 10 min		**Dietmar Plenz**	i	Collective behavior, synchronization, complexity
16:15	**Close Out**		*Open forum*		Future plans

Maria Del Carmen Miguel Lopez

Signatures of criticality in animal collective decision-making

Collective decision-making is a self-organized process where a group of individuals, each with their own decision mechanisms, reaches a common agreement. This phenomenon occurs across a wide range of biological and artificial systems, from human elections to flocking fish, insect colonies, and robot swarms. In animal behavior, the study of collective motion and consensus has been greatly influenced by the diversity of animal signals, which play a key role in understanding how animals communicate and make decisions as a group.

Social insects, in particular, have become prime examples of collective behavior. Despite their simple individual actions, they demonstrate complex, emergent decision-making as a group. I will first present a decision-making model inspired by honeybee behavior, which incorporates individual exploration, social interactions, and the quality of options. Our model adheres to Weber's Law of relative stimulus perception and exhibits a critical transition under certain conditions, where consensus reaches its highest values.

In animal groups, information spreads through waves or behavioral cascades, similar to systems near a critical point in statistical physics. By studying schooling fish in experimental conditions, we observe spontaneous turning avalanches, where directional changes ripple through the group. These avalanches are linked to collective decision-making when the school chooses a new direction. Our findings reveal power-law distributions and scale-free behavior —key indicators of criticality in fish schools. The connection between criticality and optimal decision-making is common in biological systems and offers valuable insights into how adaptive systems make effective decisions when facing similar options.

Demian Battaglia

TBA

Mauro Copelli

Neuronal scaling in the mouse visual cortex during a visual recognition task

The critical brain hypothesis proposes that neural systems operate near a phase transition, potentially maximizing efficiency in information transmission, storage, and processing. Although hallmarks of criticality, such as scale invariance and non-Gaussian dynamics, have been observed in brain activity, establishing a direct connection between criticality and task outcome remains an open question. In this talk, we explore neuronal activity in the visual cortex of mice engaged in a visual recognition task using a phenomenological renormalization group (PRG) approach. Our findings point to intriguing relationships between neuronal scaling behavior and task performance under various conditions, offering new perspectives on the potential role of critical dynamics in cortical processing.

Dante R. Chialvo

Center for Complex Systems & Brain Sciences. Universidad de San Martín, (Argentina) & Physics, Hong Kong Baptist University, (Hong Kong)

Is brain criticality controversial? No

The idea that the brain operates near a critical point - a state poised between order and disorder- similar to physical systems undergoing a phase transition, matured enough over the last two decades, as documented in hundreds of publications on both theory and experiments. Nonetheless, from time to time, brain criticality is referred as a ``controversial'' concept. We will first refresh the fundamental idea of criticality and then discuss some of the examples used to support the alleged controversy, to then conclude suggesting that such examples only amount to trivial misunderstanding or directly less than careful science.

Joern Davidsen

Brain criticality, consciousness, connectivity & behavior

Does the brain optimize itself for storage and transmission of information, and if so, how? The critical brain hypothesis is based in statistical physics and posits that the brain self-tunes its dynamics to a critical point or regime to maximize the repertoire of neuronal responses. Yet, the robustness of this regime, especially with respect to (i) natural alternations between "up" and "down" states, (ii) distinct neural states in which consciousness is altered by anesthetic agents, and (iii) changes in the functional connectivity, remain unsolved fundamental challenges. In this talk, I will give an overview of our recent advances to tackle these challenges through in vitro and in vivo experiments and model studies. Specifically, we found that both "up" and "down" states can exhibit scale-free behavior when taking into account their intrinsic time scales. In particular, the statistical signature of "down" states is indistinguishable from those observed previously in cultures without "up" states. We also found the existence of multiple transitions of the critical state due to anesthetics, not only reflecting differences between common anesthetics but also showing significant variations in individual responses. This is suggestive of a non-trivial relationship between criticality and the underlying state of the subject. Finally, we found that both scale-free neuronal dynamics and self-similar features of behavioral dynamics can persist following significant changes in functional connectivity. Despite this a one-to-one correspondence between scale-free neuronal and behavioral dynamics might be absent, indicating a non-trivial relationship between the two.

Irene Giardina

Out-of-equilibrium response, dissipation, and control in flocking systems

Flocking systems are known to be strongly out of equilibrium. Energy input occurs at the individual level to ensure self-propulsion, and the motility in turn contributes to ordering, strengthening collective motion. However, even beyond ordering, a crucial feature of natural aggregations is response. How, then, off-equilibrium features affect response behavior? I will address this issue both from an empirical and a theoretical perspective. I will first summarize what we know from experiments on natural swarms

and flocks and show that out-of-equilibrium effects are stronger in one case than in the other. Then I will consider a minimal model of flocking and investigate theoretically and numerically the response behavior. Violations of equilibrium fluctuation-dissipation relations occur both at the local and at the global level and their amount peaks at the ordering transition. Entropy is always produced locally. However, cooperative mechanisms close to the transition spread off equilibrium effects on the whole system, producing an out-of-equilibrium response on the global scale. This picture reconciles nicely with the data, providing an explanatory framework for natural systems.

Leonardo Gollo

How to conciliate criticality with a hierarchy of timescales in the brain?

Research on brain criticality often focuses on identifying phase transitions, typically assuming that brain dynamics can be described by a single control parameter. However, this view overlooks the inherent heterogeneity across brain regions, which enables the brain to operate across a broad hierarchy of timescales, ranging from rapid neural responses to external stimuli to slower cognitive processes. These frameworks can be reconciled by recognizing that brain regions lie at different distances to criticality: regions higher in the hierarchy, with slower timescales, are positioned closer to criticality. This allows for the coexistence of both critical and subcritical dynamics, naturally generating a hierarchy of timescales. This perspective provides new insights into the neurophysiological mechanisms underlying the time-based hierarchical organization in the brain.

Hans Herrmann

Dept. de Física, UFC, Fortaleza, Brazil and PMMH, ESPCI Paris, France

Ising-like model replicating time-averaged neural spiking

The activity of the resting state of the brain exhibits avalanches of spiking activity of sizes that follow a power-law distribution. In an attempt to grasp brain criticality, we investigate the spiking patterns of in vitro rat cortices and in vivo mice cortices as well as of an Integrate-and-Fire (IF) model that can be tuned at criticality. Through a Pairwise Maximum-Entropy method, we identify through an inverse binary Ising-like model the local fields and interaction couplings which best reproduce the average activities of each neuron as well as the statistical correlations between the activities of each pair of them in the system. The activity of the neurons is mainly stored in the local fields, while a symmetric distribution of interaction constants which becomes sharper with system size seems generic. Interestingly, for the in vitro rat cortex data the three−point correlations are remarkably well reproduced. Under the framework of the inherent thermodynamic analogy brought by the Ising-like models built in this work, we found through Monte Carlo simulations that they exhibit in all cases second-order phase transitions between ferromagnetic and paramagnetic phases at a temperature consistent with $T\_c = 1$, which is exactly the temperature used in the Maximum-Entropy method. The numerical data from the IF model allow to study systematically the dependence on parameters like size and concentration of inhibitory neurons avoiding the use of subsampling. We found that networks with higher percentage of inhibitory neurons lead to Ising-like systems with reduced thermal fluctuations. Finally, considering only neuronal pairs associated with the largest correlation functions allows the study of larger system sizes.

Anna Levina

Tuning timescales to suit computational needs

Attentional states influence performance and are reflected in the activity of cortical neurons. Particularly, visual attention that has affected local populations and can rapidly shift opens an avenue to investigate how the dynamical state can be controlled. I will correlate the states with the timescales of the local population activity (that also reflects the distance to the critical state). Surprisingly, population spiking activity recorded from individual cortical columns of the primate area V4 during a spatial attention task unfolds on at least two distinct timescales. The slower timescale was significantly longer on trials when monkeys attended to the location of the receptive field of the recorded neurons than on control trials when monkeys attended to a different location. Using computational models, I will show that the observed timescales emerge from the recurrent network dynamics shaped by the spatial connectivity structure.

To investigate the importance of long timescales and methods of their emergence, I will then introduce recurrent neural networks that solve memory tasks of increasing memory demands. Long timescales required for solving such tasks may arise from biophysically inspired properties of individual neurons (single-neuron timescale, e.g., membrane time constant) or recurrent interactions among them. While both mechanisms operate in brain networks, their exact contribution to optimally solving memory-dependent tasks remains poorly understood. Interestingly, depending on the training, individual timescales can be used in the network to increase memory or be ignored (making them very short). However, I will show that using network-mediated mechanisms to develop long timescales increases training speed and stability to perturbations and allows RNNs to generalize better, indicating that it is a better mechanism for controlling the dynamical state.

Klaus Linkenkaer Hansen

Department of Integrative Neurophysiology, Center for Neurogenomics and Cognitive Research, (CNCR), Amsterdam Neuroscience, Vrije Universiteit Amsterdam, 1081 HV, Netherlands

The many faces of excitation-inhibition balance in neuronal network oscillations

Proposed functions of network oscillations range from epiphenomenal shadows of neurons coincidentally spiking in synchrony to being crucial for the coordination and integration of computing neuronal ensembles. Similarly, the concept of excitation/inhibition balance (E/I) has been touted as a too vaguely defined concept to be useful, to being an essential property of neuronal systems to function properly. In this talk, I will update you on our progress in using computational modelling of critical oscillations to understand the impact of excitatory and inhibitory forces on the character and function of neuronal oscillations and, importantly, how we translate this insight into novel algorithms for a better understanding of E/I regulation in health and disease from measurements of neuronal network oscillations.

1.   Poil, Hardstone et al. Critical-state dynamics of avalanches and oscillations jointly emerge from balanced excitation/inhibition in neuronal networks. Journal of Neuroscience, 2012.
2.   Bruining, Hardstone, Juarez-Martinez, Sprengers, et al. Measurement of excitation/inhibition ratio in autism spectrum disorder using critical brain dynamics. Scientific Reports, 2020.

3.   Avramiea et al. Amplitude and phase coupling optimize information transfer between brain networks that function at criticality. Journal of Neuroscience, 2022.
4.   Avramiea et al. Pre-stimulus phase and amplitude regulation of phase-locked responses is maximized in the critical state. eLife, 2020.
5.   Houtman, Lammertse, et al. STXBP1 syndrome is characterized by inhibition-dominated dynamics of resting-state EEG. Frontiers in Physiology, 2021.
6.   Diachenko M, Sharma A, Smit D, Mansvelder HD, Bruining H, de Geus E, Avramiea A-E, Linkenkaer-Hansen K. Functional excitation-inhibition ratio indicates near-critical oscillations across frequencies. Imaging Neuroscience, 2024.
7.

Jason MacLean

Dynamic functional networks: A graph-theory approach to understanding flexible computation in neocortex

Computation in the neocortex must balance flexibility and robustness to support complex behaviors, but the relationship between network dynamics and ongoing computation and information processing remains unclear. To address this, we propose a graph-theory-inspired framework that integrates both single-neuron and network-level perspectives. By computing pairwise spike timing correlations and representing them as edges in functional networks (FNs), we enable the analysis of network dynamics in a way that holistically integrates both functional and genetic neuron classes, along with their interactions, providing valuable insights into circuit mechanisms and information processing. Across different cortical regions and species—from visual processing in mice to motor behaviors in mice and nonhuman primates—we find that while the set of active neurons remains largely consistent across conditions, the correlation patterns between these neurons vary significantly depending on the sensory stimulus or motor behavior. In the visual cortex, neurons with different functional properties exhibit distinct topological properties within the FN. A decoder based on FN topology accurately decodes visual stimuli, and by analyzing performance degradation, we determined the relative contributions of specific functional neuron classes and their connections to visual processing. In the motor cortex of nonhuman primates, low-dimensional embeddings and graph alignment scores show that FNs corresponding to similar target reach directions are closer in network space. Temporal FNs, based on correlations computed over short timescales, follow low-dimensional trajectories that are specific to each reach direction. Additionally, we identified a context-specific functional group, determined by correlations among neurons tuned to specific kinematic variables, which reorganizes its connectivity depending on whether movements are spontaneous or goal-directed. Collectively, these findings highlight the adaptability and correspondence of FNs to different behavioral contexts and suggest that pairwise correlations between neurons may be a fundamental mechanism supporting robust and flexible neural computation.

Pedro Mediano

Beyond correlation: High-order structure in critical neural systems

The spontaneous emergence of long-range interactions is one of the key hallmarks of criticality. These interactions are typically measured with a standard two-point correlation function. In this talk, we will explore the growing field of high-order interactions — statistical effects that affect three or more components of a system — and show that these interactions also display characteristic behaviour under

criticality. The talk will introduce a principled theory of high-order interactions, arguing that these capture novel phenomena over and above standard pairwise correlations. We will then describe methods to measure high-order interactions in simulated systems and experimental data and provide evidence linking them to consciousness and cognition in the human brain. Taken together, these results place high-order interactions as a promising, unexplored frontier at the intersection of criticality and neural information processing.

Christian Meisel

Critical dynamics predicts cognitive performance and provides a common framework for heterogeneous mechanisms impacting cognition

The brain criticality hypothesis postulates that brain dynamics are set at a phase transition where information processing is optimized. Long-range temporal correlations (TCs) characterizing the dissipation of information within a signal have been shown to be a hallmark of brain criticality. However, the experimental link between human cognitive performance, criticality and thus TCs has remained elusive due to limitations in recording length, and spatial and temporal resolution. In this talk, I will discuss recent work on multi-day intracranial EEG recordings of persons with epilepsy that also underwent an extensive cognitive test battery. We will discuss how short TCs predict cognitive impairment. Further, we show that heterogeneous factors, including interictal epileptiform discharges (IEDs), antiseizure medications (ASMs) and intermittent periods with slow-wave activity (SWSs), all act directly to perturb critical dynamics and thus cognition. Finally, I will also discuss recent work on neural networks used in artificial intelligence and how optimal function relates to critical dynamics. Collectively, our work suggests critical dynamics to be the setpoint to measure optimal network function, thereby providing a unifying framework for the heterogeneous mechanisms impacting cognition in conditions like epilepsy

Ana P Millan

Epidemic spreading in large-scale brain modeling: clinical applications

Computational models of brain dynamics offer novel insights into the prognosis of neurological disorders, enhancing our understanding and management of conditions such as epilepsy and Alzheimer's Disease (AD). Abstract models like epidemic spreading facilitate the interpretation of complex behaviors while requiring less data, as it is often the case in clinical settings. I will present our recent studies regarding the clinical applicability of epidemic spreading models in two neurophysiological disorders: epilepsy surgery and AD. Epilepsy surgery is the treatment of choice for patients with drug-resistant epilepsy, yet up to 50\% of the patients continue to experience seizures post-resection. Computational models of epilepsy surgery allow us to simulate in silico different strategies, to optimize the resection in a patient-specific manner and improve surgical outcomes [1,2,3,4].In the case of AD, spreading dynamics model the propagation of abnormal proteins, such as pathological τ, over the brain. Epidemic-spreading models allow us to investigate the underlying mechanisms driving τ propagation and identify the role of functional and structural connections in it [5]. These studies highlight the potential of epidemic spreading models in large-scale brain modeling, paving the way for innovative clinical applications in both epilepsy and Alzheimer's Disease.

References:

[1] I.A. Nissen et al. Scient. Rep. 11.1 (2021). [2] A.P. Millán et al. Scient. Rep. 12.1 (2022). [3] A.P. Millán et al. Netw. Neurosci. 1.55 (2022). [4] A.P. Millán et al. Network Neuroscience 8.2 (2024). [5] D. Schoonhoven et al. Brain awad189 (2023)

Miguel Munoz

Scaling of brain activity and optimal functionality: from real neurons to artificial intelligence

I will review recent advances in data-driven analyses of brain activity, which complemented with theoretical studies including renormalization-group techniques and others, allow us to shed light onto the dynamical regime in which neural activity operates in different brain regions. We leverage these insights to design and scrutinize artificial neural networks with recurrent interactions. We find that, in genral, both biological and artificial networks achieve optimal performance when balanced to operate close, but with some flexibility, to the edge of instability.

J. Matias Palva

Department of Neuroscience and Biomedical Engineering, Aalto University, Finland

Structural control parameters for Griffiths phase in human brain dynamics

Brains *in vivo* appear to operate at the critical phase transition between ordered and disordered states, which leads to emergent spatio-temporal power-law correlations in brain dynamics and several functional benefits. While this phase transition is point-like in homogeneous systems, recent theoretical and experimental studies suggest that heterogeneity may stretch the critical point into an extended regime of critical-like dynamics, known as the Griffiths Phase (GP). GP in brain dynamics would allow the preservation of critical-like dynamics across a range of spontaneous or intentional shifts in control-parameter values, which would be catastrophic in homogeneous systems. It has, however, remained unclear, which forms of heterogeneity in the human structural connectome of white-matter connections constitute the predominant "heterogeneity control parameters" for GP *per se*. We addressed this question with computational modeling using a new Hierarchical Kuramoto approach and large-scale structural connectivity data from N = 230 subjects. We found the individual structural connectomes to endow individual subjects with widely different capacities to express emergent dynamics. In this presentation, I will address the relationships among GP width, nodal and global synchronizability, and the graph properties of the individual structural connectomes. These findings will be discussed in the context of neurophysiological and behavioural functional implications.

Dietmar Plenz

Collective behavior, synchronization, and complexity

Since the discovery of neuronal avalanches in 2003, experimental evidence has accumulated in support of - and sometimes contrary to - expectations of how the brain might optimize successful navigation in an uncertain environment. In this last talk of our 3-day conference, I will provide an updated historical slice through the colorful history of criticality. I will highlight breakthroughs in identifying collective

dynamics, measures of synchronization over many scales, and how those approaches affect the complexity observed in brain dynamics. I will discuss these insights with respect to future directions in applying critical phenomena to understand basic aspects of brain functions.

Tiago L. Ribeiro

Critical scaling of novel spikes in cortical networks in vivo

The brain's capacity to learn new information is fundamentally tied to the influence of individual neurons on their networks. With cortical regions in awake animals generating thousands of action potentials per second, it is difficult to assess how new spikes from a single pyramidal neuron affect the network. Using an all-optical approach, we show that holographically triggered, novel spikes from a single pyramidal neuron in layer 2/3 rapidly evoke wide-spread responses in visual cortex of awake mice. The predominantly excitatory, short-lasting responses emerge within the fluctuation-dominated regime of neuronal avalanches, exhibit critical scaling similar to local, ongoing fluctuations, and carry significant information about their origin across long distances in many neurons. Our findings demonstrate the exquisite sensitivity of critical brain networks in efficiently transmitting novel information from individual neurons across extensive areas.

Silvia Scarpetta

Extended region of criticality in a spiking modular network with spatiotemporal attractors

Healthy brains exhibit a rich dynamical repertoire with flexible and varied spatiotemporal patterns of activity on both microscopic and large scales. Neurodegenerative diseases reduce this functional repertoire. We hypothesize that microscopic dynamics must be near a critical regime for the functional repertoire to be fully explored and for realistic flexible dynamics to emerge.

To test this hypothesis, we use a modular Spiking Neuronal Network model, where each group of Leaky Integrate and Fire neurons represents a cortical region. A STDP-based rule is used to learn patterns of activations which propagate between modules based on a probabilistic distribution linked to the quantity of white-matter fibers for long-range connections and an exponential decay rule for nearby regions. Consequently, information is encoded both as specific neuron sequences and trajectories of activated modules.

The model reveals two main dynamical states: a low-rate uncorrelated state and a high-rate strongly correlated state, distinguished by the value of the order parameter (measuring the similarity of spontaneous activity with the stored spatio-temporal patterns of activity).

These regimes are separated by either a first-order or second-order phase transition, depending on the strength of global inhibition and structured connections. A second-order phase transition occurs as the hysteresis loop diminishes, creating an extended region with significant fluctuations in the order parameter, characterized by a maximal number of intermittently recurring motifs events.

The model's predictions are compared with empirical data from magnetoencephalographic (MEG) recordings in healthy adults. Notably, a significant correlation between the functional connectivity in synthetic data and MEG is observed only when the model operates in the critical extended regime.

In conclusion, our research provides a framework for understanding the role of the brain's modular structure and the importance of critical states in achieving optimal functional repertoire.

Audrey Sederberg
Understanding diverse signatures of neural criticality using the dynamic latent variable model

Different "kinds" of signatures of criticality have been observed in neural data, including scaling of activity avalanches and scaling under the phenomenological renormalization group (pRG) analysis. Recently, we showed that both of these signatures of criticality appear in a statistical model of a neural population coupled to hidden variables with dynamics, in which average activity and correlations are comparable to those observed in neural data. In our model, different kinds of criticality emerge under different parameter regimes: pRG scaling requires multi-dimensional systems, which avalanche scaling does not. Additionally, scaling exponents under pRG are related to simple model parameters, suggesting an explanation for differences observed across brain areas in the pRG analysis. Thus, this model provides a simple mechanism explaining signatures of criticality as well as predictions for which kinds of criticality are expected across diverse brain areas and recording conditions.

Woody Shew
Arousal: the brain's control parameter of a critical phase transition

It has long been hypothesized that the brain tunes itself to operate near the critical point of a phase transition. Every phase transition has control parameters, but it has been unclear what sort of control parameters are used by the brain to tune itself around criticality. Here we employ a temporal renormalization group (tRG) approach to show in mouse motor cortex and in a computational model that the mechanisms underlying arousal serve as important control parameters in the brain. We find that cortical neuronal activity is maximally scale-invariant (closest to a tRG fixed point) at an intermediate level of arousal, when the animal is awake and alert, but not too active nor too sedentary. Both inactivity (low arousal) and intense body movement (high arousal) cause a break down of scale-invariance. We benchmarked our tRG analysis against a ground truth computational model, in which arousal-related biophysical mechanisms tune the model through a critical phase transition. Agreement of our model and experiments suggest that motor cortex comes closest to criticality for intermediate arousal, between drowsy rest and hyper-aroused running.

Kareem Zaghloul

Insights into neural coding in the human brain through the study of human episodic memory formation

Our research efforts are focused on investigating the neural correlates of human episodic memory formation by leveraging the opportunities to directly record neural activity across multiple spatial scales from the human brain in patients receiving surgical treatment for drug resistant epilepsy. At larger spatial scales, we find that both specific patterns of localized neural activity and dynamic connections between brain regions emerge as people encode individual items into memory, and similar patterns of activity and connectivity are reinstated when people retrieve those same items from memory. At the smallest spatial scale, we find that populations of individual neurons in the anterior temporal lobe exhibit temporally organized sequences of spiking activity that are specific to the individual items people are encoding into memory, and that similar sequences are replayed when people retrieve those items from memory. The sequences of spiking activity are ordered based on the semantic category of the individual items, suggesting that sequences of spiking activity may be a fundamental unit of information in the human brain. In addition, these sequences of spiking activity are distributed across spatially contiguous yet distinct functional modules that are approximately the same size as the cortical columns hypothesized to exist throughout the human brain, suggesting a functional organization to how information is encoded across neuronal populations. Together, our results provide novel insights into how information specific to individual memories is represented in the brain, and how this information is accessed as people recall previous experiences from memory.