Posters

Fatemeh Aghaei (Max Planck Institute for the Physics of Complex Systems, Germany)

A Conceptual Model for GHG-Temperature Feedback in the Climate System

The interaction between greenhouse gas (GHG) emissions—particularly carbon dioxide—and global temperature is central to climate dynamics. In recent decades, processes such as permafrost thaw, ice sheet melt, and large-scale biomass burning have demonstrated that temperature and GHGs form a bidirectionally coupled system, creating a reinforcing loop: GHG emissions drive warming, and warming in turn increases GHG emissions.
Despite well-established concept, the complexity of the system—combined with distinct temperature thresholds and timescales— the mechanisms behind massive GHG releases are not fully understood.
Here, focusing on two different tipping elements We find that feedback can either accelerate warming beyond a trend change point or to multistability and tipping. From this perspective, the first type may increase the risk of the second.

Bahar Hamzehei (University of Bologna, Italy)

Spatial Decoding of Lateralized Pain Anticipation from EEG Using Deep Temporal Neural Networks

We present a deep learning framework to decode spatially specific pain anticipation from electroencephalography (EEG) recorded during a Pavlovian threat conditioning paradigm. Beyond binary threat-versus-safety classification, the main objective is to determine whether anticipatory neural activity contains sufficient information to distinguish the predicted spatial location of pain delivery to the left or right arm before stimulus onset. Thirty healthy participants completed acquisition and reversal phases in which visual cues predicted painful stimulation to either arm or signaled safety. EEG data were recorded from 64 channels, preprocessed, and analyzed using a Temporal Convolutional Network for multiclass classification of CS+L, CS+R, and CS− conditions. In parallel, time-frequency representations were also evaluated as model inputs. Preliminary results suggest above-chance classification of lateralized pain anticipation during the cue period, indicating that EEG signals encode spatially organized predictive states prior to nociceptive input. This work supports the idea that anticipatory brain states show structured lateralized dynamics and provides a basis for combining computational neuroscience and explainable AI to study predictive brain processes.

Jobst Heitzig (Potsdam Institute for Climate Impact Research, Germany)

AI systems that empower humans in a complex world

We present results from experiments where AI systems are tasked to empower human agents in multi-agent environments with complex dynamics.

Ali Rana Atilgan (Sabanci University, Istanbul, Turkey)

Trajectory Ensembles to Elucidate Mutant-Induced Kinetic Modulation of Proteins

Many experiments and coarse-grained models of protein conformational change report only a single rate, while the underlying dynamics are high-dimensional, contact-structured, and heterogeneous. We develop a two-layer sequence–structure framework that uses Maximum Caliber (MaxCal) to lift such coarse kinetic information into an explicit trajectory ensemble on a structurally defined path, and to quantify how mutations reshape that ensemble.

In the first layer, a compact sequence–structure theory estimates mutation-induced changes in gating rates. A Potts model inferred from a multiple-sequence alignment (MSA) is blended with a Gaussian Network Model built on the closed conformation; Potts couplings modulate effective spring constants, deforming the

Kirchhoff matrix in a sequence-dependent manner. A gating contribution is extracted from the lowest-frequency mode that best aligns with the closed → occluded displacement, and an Arrhenius-like barrier factor accounts for non-harmonic reorganization. Applied to E. coli DHFR, this layer predicts mutant-to-wild-type rate ratios in close agreement with experiment and yields a target closed ↔ occluded rate for each sequence.

In the second layer, we use two endpoint structures and the target rate to construct a one-dimensional structural path, a contact-breaking barrier profile, and an effective free-energy landscape. MaxCal then infers nearest-neighbor transition rates that obey local detailed balance and reproduce the prescribed mean first-passage time (FPT), yielding the maximum-entropy Markov dynamics consistent with the structural and kinetic constraints. From the resulting ensemble we obtain dwell-time maps, state-resolved fluxes, path-length and FPT distributions, and path entropies that quantify route diversity, kinetic bottlenecks, and gating robustness. Whenever two structures, an MSA, and a few kinetic observables are known, the framework furnishes a minimally biased non-equilibrium process on a constrained graph.

Wolfgang Renz (University of Applied Sciences, Hamburg, Germany)
Combining Machine Learning and Dynamic Network Models for Sepsis Prediction

We enhance short-term sepsis predictions by integrating machine learning techniques like Auto-Encoders and Gated Recurrent Units with a dynamical 2-layer network model of adaptive phase oscillators [1,2] representing the interaction between parenchymal cells (functional organ cells) and the immune system via cytokines. The model trajectories determined by machine learning are used for detection and prediction of critical infection states and mortality. The model-based predictions are compared with those of purely data-based approaches in terms of predictive power and interpretability. To this end we project real high-dimensional medical patient data into the low-dimensional parameter space of the model.

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Georg Reich (TU Berlin, Germany)
CA3 Network Model Learns to Replay Hundreds of Chaotic Attractor Dynamics via Global Remapping and Synaptic Delays

Place cells in the hippocampus are thought to provide a sparse code of locations and abstract variables, and during rest or sleep replay their previous activation sequences for memory consolidation and planning. Animals can encounter many different environments in their life, and learn to predict complex spatiotemporal patterns in different contexts. Global remapping refers to the observation that place field representations are decorrelated between different contextual environments. It has been previously found that delays can provide a powerful embedding of chaotic dynamical systems and enable an "unprecedented memory capacity" in neural circuits. In this work we make use of such transmission delays in a single network of place cells. For a given chaotic system and delay, synaptic weights are learned through the Ulam-Galerkin method where the basis is given by disjoint place fields on the attractor. This learning rule is local and online, and thus biologically plausible. In our contribution, we extend this approach to multiple delays and multiple learned systems. As a result, our model can learn the attractor dynamics of hundreds of systems and selectively replay each system in response to an initial stimulus. We empirically measure the memory capacity of our model on permutations of place fields on the Lorenz attractor, and make first steps towards an analytical treatment.

Rossella Rizzo (University of Palermo, Italy)

Stationary and oscillatory patterns in a FitzHugh-Nagumo model with anomalous diffusion

Anomalous diffusion phenomena frequently occur in natural systems. Interesting examples include autocatalytic chemical reactions on porous media, the preferential movement of species driven by safety or hunting strategies, and long-range interactions in ion channels within the plasma membrane. Cross-diffusion is a kind of nonlinear diffusion used to describe population dynamics where the gradient of one species induces the flux of the other species [1, 2]. On the other hand, super-diffusive processes, such as Levy flights, can describe the mass diffusion in plasmas or foraging dynamics of birds and oceanic predators for randomly located resources and lead to fractional derivative modeling [3, 4].
In this talk, we investigate how anomalous diffusion influences the formation of stationary patterns in the FitzHugh-Nagumo model, which represents the paradigm system to describe excitable dynamics both in chemical reactions and population dynamics [5, 6]. We find that introducing anomalous diffusion terms allows for pattern formation in both short-range activation/long-range inhibition or long-range activation/short-range inhibition, relaxing the typical requirement for a rapidly diffusing inhibitor in the case of classical diffusion [7]. Moreover, in the presence of cross-diffusion, the spatial structures induced by long-range activation/short-range inhibition mechanisms are always out of phase (cross-Turing patterns) and subcritical in most of the instability regions [8].
Finally, using the formalism of amplitude equations, we derive the asymptotic profiles of the stationary solutions and classify the bifurcation, distinguishing between super- and subcritical transitions. Moreover, we investigate the dynamics near a co-dimension 2 Turing-Hopf bifurcation point, and find the conditions under which we can have oscillatory Turing patterns.

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Merten Stender and Manish Yadav (TU Berlin, Germany)
Understanding Structure-Function Relationships through Performance-Dependent Network Evolution

How do network Structure and Function co-emerge under performance pressure? We address this through the Performance-Dependent Network Evolution (PDNE) framework, a biologically inspired mechanism that grows reservoir computing networks from minimal seed topologies via iterative, performance-gated node addition and deletion. Rather than fixing architecture before training, PDNE evolves structure alongside function, producing compact, task-specialized networks that consistently outperform Erdős–Rényi random networks and uninformed growth strategies, while revealing emergent scaling laws, self-organized symmetry-breaking distributions, and a task-complexity quantifier encoded in evolved network size and density. To illuminate how structural organization encodes functional capacity, we present two complementary results: task-specific node pruning identifies functionally critical sub-networks by eliminating redundant dynamical pathways, improving efficiency and interpretability; and applying PDNE to Wilson-Cowan excitatory-inhibitory (E-I) neuronal dynamics shows that evolved reservoirs spontaneously recover the correct E-I sign structure of the target system at the population level, without this being imposed by design and generalize zero-shot to novel stimulus configurations. Together, these results establish PDNE as a principled framework for uncovering *structure-function* relationships in evolving networks, with implications for complex dynamical systems, network science, neuromorphic computing, and interpretable machine learning.

Ronja Strömsdörder (TU Berlin, Germany)
Spike-frequency and h-current based adaptation as candidate modulators of the propagation of traveling waves

During non-REM sleep, the brain shows repetitive patterns of slow oscillations (SOs, <1 Hz) between periods of active (up-state) and silent (down-state) neuronal activity, which are assumed to play a crucial role in memory consolidation (Rasch and Born, 2013).
Cortical whole-brain modeling studies found the connectome to be a key driver of propagation features (e.g., directionality) of these waves (Koller et al., 2024; Cakan et al., 2022) while intrinsic mechanisms are also candidate modulators of propagation features (see Alegre-Cortés et al. (2025), who showed in-silico that changes in adaptation affected neighboring neuronal populations). Both spike-frequency adaptation (SFA) and hyperpolarization-activated (h-)current based adaptation were experimentally and computationally shown to drive traveling waves of SO-like dynamics (Dalla Porta et al., 2024; Mehrotra et al., 2024) while their modulatory contribution to propagation features remains unclear. Mechanistically contrary, meaning reduced to their canonical roles as negative feedback activated in high-activity states (SFA) vs. positive feedback activated in low-activity states (h-currents), they are dynamically equivalent under transformation and compensation (Strömsdörfer and Obermayer, 2025).
Building on the publication of Strömsdörfer and Obermayer (2025), we implement an adaptive Wilson–Cowan field model incorporating both mechanisms with equivalency-breaking properties on a two-dimensional spatial domain. We investigate how these equivalency-breaking properties differentially affect propagation features of traveling waves, and how their effects compare to recurrence weights. Preliminary results indicate that spatial gradients in adaptation strength induce directionality independent of initialization, and that gradient steepness increases wave speed.

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Simon Vock (Charité Berlin, Germany)

Criticality governs deep learning: enhancing performance, enabling continual learning, mitigating model collapse

The rapid advances in artificial intelligence (AI) have largely been driven by scaling deep neural networks (DNNs) - increasing model size, data, and computational resources. However, performance is ultimately governed by network dynamics. The lack of a principled understanding of DNN dynamics beyond heuristic-based design has contributed to challenges with their robustness, suboptimal performance, high energy consumption and pathologies in continual and AI-generated content learning. Increasing evidence suggests that the human brain may avoid these problems by operating at a critical phase transition. Inspired by this principle, we here propose that criticality may provide a unifying framework linking structure, dynamics, and function also in DNNs. First, by analyzing more than 80 state-of-the-art DNN models and well established benchmark datasets (ImageNet, MNIST), we report that a decade of AI progress has implicitly driven successful networks towards criticality, as measured by largest Lyapunov exponents λ_0 (Spearman $r = -0.5$, $p < 10^{-4}$), explaining why certain architectures succeeded while others failed. Second, incorporating criticality explicitly into training improves even highly optimized models by more than 0.4 percentage points ($p < 0.001$) and establishes robustness across weight initializations, preventing key limitations of current models. Third, we show that catastrophic AI pathologies, including continual learning degradation and model collapse from AI-generated training data, constitute a loss of critical dynamics. By keeping networks critical, we provide the first principled solution to these fundamental AI problems by mitigating performance degradation and model collapse. This work confirms criticality as substrate-independent principle of intelligence, connecting AI advancement with core principles of brain function. For systems neuroscience, this work offers a link between optimal function in biological and artificial neural networks. For AI, it provides profound theoretical insights along with immediate practical value solving major challenges to ensure long-term DNN performance and resilience as models grow in scale and complexity.

Yu Wang (Potsdam Institute for Climate Impact Research, Germany)

Universal dynamic phenomena in delay systems: fundamentals and applications

The majority of delay differential equations (DDEs) with one delay have only a few bifurcation scenarios, which can be explicitly described. We explore absolute stability and universal bifurcation scenarios in DDEs using asymptotic continuous spectrum (ACS) theory. We then combine the Master Stability Function (MSF) method for discussing the dynamics of active-agent systems. First, we present how universality classes and Hopf bifurcation sequences in single-delay DDEs can be characterized through the ACS, reveal general transversality results in the large-delay regime, and consider the three most common universality classes. For each of them, we explicitly describe the sequence of stabilizing and destabilizing bifurcations. Then, we apply the above framework to active-agent systems with inertia and delayed feedback, analyzing stability conditions for formation patterns in both uncoupled and coupled settings. These results provide a unified perspective on stable coordination, pattern formation, and universal delay-induced dynamics in complex systems. Additionally, we investigate interactions in the large-delay limit, where delays affect inter-agent coupling, while local feedback remains instantaneous. In this limit, we prove rigorously that the stability region in the complex plane of the eigenvalues of the Laplacian matrix converges to a circle centered at the origin, a phenomenon previously observed in delay-coupled networks. Our findings provide a universal framework for understanding stable formations and motions of active agents with delayed interactions.

Dan Zhao (Potsdam Institute for Climate Impact Research, Potsdam, Germany)

Synchronization transitions and spike dynamics in a higher-order Kuramoto model with Lévy noise

Synchronization in complex networks is influenced by higher-order interactions and non-Gaussian perturbations, yet their mechanisms remain unclear. We investigate the synchronization and spike dynamics in a higher-order Kuramoto model subjected to Lévy noise. Using the mean order parameter, mean first-passage time, and basin stability, we identify boundaries distinguishing synchronization and incoherence. The stability index governs the tail heaviness of the probability density function for Lévy noise, while the scale parameter affects the magnitude. Synchronization weakens as the stability index decreases, and even completely disappears when the scale parameter exceeds a critical threshold. By varying coupling, we find bifurcations and hysteresis. Lévy noise smooths the synchronization transitions and requires stronger coupling compared to Gaussian white noise. We then define spikes as extreme excursions of the order parameter and study their statistical and spectral properties. The maximum number of spikes is observed at small scale parameters. A generalized spectral analysis based on an edit distance algorithm measures the similarity between spike sequences and identifies spike patterns. These findings deepen the understanding of synchronization and extreme events in complex networks driven by non-Gaussian noise.