SOE 4: Poster Session

Time: Monday 18:00–21:00 Location: P4

SOE 4.1 Mon 18:00 P4

Artificial "Minimal" Intelligence in a Decentralized Mechanical System — •Alex Leffell and Manu Prakash — Stanford University, California, USA

Computation is not exclusive to neurons or transistors. Simple, aneural organisms like Placozoa exhibit complex behaviors, demonstrating that intelligence can arise from non-neuronal physical dynamics. We model these organisms as Phased Active Elastic Sheets (PhAES) – networks of coupled active oscillators that compute via the dynamics of their vibrational modes. This approach builds on established work in both physical learning and active solids and extends it to understand animal behavior. Using both in-silico and robophysical models, we show that this system can perform complex behaviors like gradient climbing without any implicit memory and purely mechanical communication between cells. This perspective offers a direct path towards a new class of computational materials that physically embody sensing, actuation, and learning. Such systems would bridge the gap between rigid, centrally-controlled robots and task-specific soft matter, fundamentally expanding our notions on the physical basis of intelligence.

SOE 4.2 Mon 18:00 P4

Validating diffusion-based dimensionality reduction of political regimes: conflict and child mortality benchmark — •Paula Pirker-Diaz[1], Radost Waszkiewicz[1], Matthew Wilson[2], and Karoline Wiesner[1] — [1]University of Potsdam — [2]University of South Carolina

Political regime indices such as the Electoral Democracy Index (EDI) are widely used for measurement and policy analysis, yet their additive aggregation rules can obscure nonlinear relationships among regime indicators. In earlier work, we showed that a subset of EDI components lies on a low-dimensional nonlinear manifold recovered with the Diffusion Map method [1]. Here we introduce a new one-dimensional regime index by fitting this manifold, identifying the latent dimension along which regime features co-vary most strongly while preserving their nonlinear structure. The resulting index parallels the EDI's characterization of democracies but produces a different ordering among autocracies. By varying the smoothness penalty, we identify the indicators whose contributions to the latent structure remain most stable, providing a robustness-based measure of their relevance. The new index improves the resolution of intra-regime conflict onset probability and child mortality relative to the EDI, with the largest gains among autocratic regimes that the manifold distinguishes more effectively. These findings reinforce that political regimes lie on a nonlinear low-dimensional manifold identified by diffusion methods, which capture social and political variation more effectively than linear aggregation rules. [1] Pirker-Diaz et al., RSOS (2025)

SOE 4.3 Mon 18:00 P4

Realizable Circuit Complexity: Embedding Computation in Space-Time — •Benjamin Prada and Ankur Mali — University of South Florida, Tampa, FL

Parallel computation is typically modeled as a process carried out by abstract machines that ignore the constraints of physical reality. Although the evolution of real-world systems may be mapped to these abstractions, reverse translation is almost always impossible; most computations cannot be simulated in real-time by any device obeying finite propagation speed, bounded volume, or finite entropy. To remedy this discongruity between computational and physical theory, we introduce a framework of *realizable circuits* $\mathbf{RC}_d$ that incorporates a d-dimensional spatial embedding directly into the computation model. The key is that information must cross geometric boundaries at a finite rate: fine-grained entropy flow through a $(d-1)$-dimensional boundary limits the number of independent bits that can be transformed or erased within a d-dimensional region. This yields physically motivated lower bounds on parallel depth and communication, connecting known theoretical and empirical results such as Landauer's principle and Rent's rule. Although the framework is general, we illustrate its usefulness by analyzing modern neural architectures (e.g., transformers and recurrent networks), whose parallel speedups are similarly constrained by entropy flux through bounded interfaces. The resulting theory offers a physics-aligned perspective on the fundamental limits of parallel computation, independent of any specific classical or quantum computing substrate.

SOE 4.4 Mon 18:00 P4

Dynamics of Behavioral Contagion in Human and Artificial Agent Collectives: A Drift-diffusion Simulation Study — •Maryam Karimian[1,2] and Pawel Romanczuk[1,2] — [1]Institute for Theoretical Biology, Department of Biology, Humboldt-Universität zu Berlin, 10115 Berlin, Germany — [2]Science of Intelligence, Research Cluster of Excellence, Berlin, Germany

Behavioral contagion, the spread of behavior within a group, is a central topic in cognitive and collective behavior research. Prior work has either relied on first-person perspective that overlook dynamic social structure or on idealized collective models that neglect individual decision processes. To bridge this gap, we use an extended drift-diffusion model to simulate virtual-reality (VR) experiments, integrating cognitive mechanisms with group-level dynamics. We model agents' decision-making processes, responding to uncertain environmental signals, and influencing one another through an increment drift-diffusion process. Decision states evolve based on accumulated environmental evidence and socially conveyed information. Social information is derived from visually grounded interaction networks capturing first-person sensory constraints shaped by distance and occlusion. These networks are implemented as weighted, directed graphs modulated by group size and density. Using controlled experimental data, we parameterize the model and generate testable predictions on decision dynamics across different environmental and social conditions, highlighting how visual network properties shape vision-mediated contagion and related cognitive processes such as selective attention.

SOE 4.5 Mon 18:00 P4

Optimal transport with constraints: from mirror descent to classical mechanics — •Abdullahi Ibrahim[1,2], Michael Muehlebach[2], Caterina De Bacco[2], and Dirk Brockmann[1] — [1]Center Synergy of Systems, Dresden University of Technology, Dresden, Germany — [2]Max Planck Institute for Intelligent Systems, Cyber Valley, Tuebingen 72076, Germany

Over the past decades, a variety of transportation systems have been successfully modelled using optimal transport (OT), from biological networks as leaf venation, to engineering networks as urban transportation. In this context, adaptation equations that describe how conductivities, flows and pressure potentials evolve interdependently to consolidate into an optimal network structure. This has been used extensively to study a variety of transportation scenarios, and it has been shown to explain with a high degree of similarity observed on real networks. However, current approaches based on adaptation equations suffer from not considering constraints (beyond standard ones like conservation of mass and positivity) as part of the general framework. As a result, networks output from these models can be unrealistic in practice. We address this flaw by proposing a general framework powerful enough to accommodate nonlinear and nonconvex constraints in OT problems. Our approach follows a physics-based perspective on including constraints by leveraging the principle of d'Alembert-Lagrange from classical mechanics. This leads to a sparse, local and linear approximation of the feasible set leading in many cases to closed-form updates.

SOE 4.6 Mon 18:00 P4

GPU-Parallel Load-Flow Solvers with Low-Rank Updates for Contingency Analysis and Topology Optimization — •Marc Hunkemöller[1,2], Nico Westerbeck[3], Lars Schewe[4], and Dirk Witthaut[1,2] — [1]Forschungszentrum Jülich, Institute of Climate and Energy Systems – Energy System Engineering (ICE-1), 52428 Jülich, Germany — [2]Institute for Theoretical Physics, University of Cologne, Köln, 50937, Germany — [3]University of Edinburgh, School of Mathematics, Peter Guthrie Tait Road, Edinburgh, EH9 3FD, UK — [4]Elia Group, Boulevard de l'Empereur 20, 1000 Brussels, Belgium

Power-flow simulations based on the Newton-Raphson method are key tools for transmission system operators. GPUs may accelerate these computations and thus enable fast contingency analysis and new applications such as transmission topology optimization, which are increasingly important for integrating large shares of renewable energy and reducing dependence on fossil fuels. However, parallelization on GPUs is challenging, as the treatment of different topologies does not align well with the "Single Instruction, Multiple Data" paradigm. We present a GPU-parallel AC load-flow solver designed to overcome the difficulties introduced by changing sparsity patterns in the Jacobian matrix when the network topology varies. Our approach uses low-rank updates to separate the Jacobian's dependence on the network structure from its dependence on the system state, allowing topology changes to be incorporated efficiently. In combination with iterative linear solvers, we explore different update orders and strategies to identify stable and fast solver configurations suitable for large sets of topology scenarios.

SOE 4.7 Mon 18:00 P4

Modeling Predator-Prey Encounters via Interacting Ornstein-Uhlenbeck Motions — •Zihao Liu and Ricardo Martinez-Garcia — Helmholtz-Zentrum Dresden-Rossendorf

Most population dynamics models assume well-mixed and independent individuals. However, many animals anchor their movement around key resources such as food, water, or shelter, a behavior well captured by Ornstein-Uhlenbeck home-range dynamics. Previous work has shown that incorporating home-range behavior already leads to substantial deviations in encounter rates from classical predictions. In this study, we further relax the assumption of independence by introducing an explicit attractive interaction from the predator to the prey. Using analytical approximations and individual-based simulations, we explore how this interaction reshapes the encounter landscape across different home-range sizes, spatial separations, force magnitudes, and interaction ranges. We also discuss how small changes in individual movement behavior may influence group-level dynamics, with possible implications for foraging efficiency, spatial clustering, and coexistence conditions.

SOE 4.8 Mon 18:00 P4

Inference of network structures from partial observations — •Matthias Klaus[1,2], David Dahmen[1], and Moritz Helias[1,2] — [1]Institute for Advanced Simulation (IAS-6), Jülich Research Centre, Jülich, Germany — [2]Department of Physics, Faculty 1, RWTH Aachen University, Aachen, Germany

Today's recording techniques for neural activity allow one to access finite time windows of a few hundred to thousands of neurons. Since they are embedded in strongly connected networks of 10^5 neurons, the recorded data will be considerably influenced by the structure of these unobserved parts. Theoretical descriptions of the problem often assume spatial and temporal homogeneity across the system, i.e. that structure and activity of the entire network, on a statistical level, are close to the recorded part.

Here we model this statistical homogeneity by the variances of connectivity and of a globally independent driving white noise. Estimates for these parameters exist from prior experiments. Consequently, we use a Bayesian approach to obtain a posterior for the local connectivity by conditioning on the locally recorded activity. The theory involves a marginalization over unobserved activity, which is exact for a linear network with Gaussian activity. This condition can be relaxed by reasonably assuming a large network and applying dynamic mean-field theory (Sompolinsky, Crisanti, Sommers 1988; Schuecker, Goedeke, Helias 2018). We find that reconstruction of local connectivity is possible if the influence from unobserved parts reduces to a colored noise whose statistics is estimated correctly.

SOE 4.9 Mon 18:00 P4

A Conceptual Model for Temperature dynamics in the Climate System — •Fatemeh Aghaei and Holger Kantz — Max Planck Institute for the Physics of Complex Systems

we propose a simple conceptual model for tipping of the Earth's atmospheric dynamics due to feefback loops from global mean temperature on the release of greenhouse gases by natural processes. The model shows that the strength of this feedback is a relevant parameter which determined the speed of climate change after passing through a tipping point, to be extracted from earth system models. Also, we show that by data analysis, it might be possible to reconstrict the functional form of the feedback process. We illustrate both by the analysis of model data.