SOE 2: Focus Session: Physics of Behavior (joint session SOE/DY)

Organizers: Greg Stephens (Vrije Univ. Amsterdam), Pawel Romanczuk (HU Berlin)

Physics has made important contributions to the remarkable progress in characterizing the molecules, cells, and circuits that generate natural behavior. Yet our understanding of behavior at the scale of the whole organism and in ecological and social contexts remains significantly less advanced. Even in simpler organisms, natural behavior is complex, requiring new tools for measurement (often through novel imaging), analysis, and theoretical insight. The emerging field of the physics of behavior addresses this gap by seeking to quantitatively characterize complex behavior in naturalistic settings. This focus session will highlight recent advances at the intersection of physics, neuroscience, biology, and social sciences with contributions from both theorists and experimentalists.

Time: Monday 9:30–12:45 Location: GÖR/0226

Invited Talk SOE 2.1 Mon 9:30 GÖR/0226

Memory and equilibrium in collective animal behaviour — •Thierry Mora — Ecole normale supérieure and CNRS, Paris, France

Some animal groups behave in a highly coordinated way, reminiscent of ordered phases in physics. However, animals are also heterogeneous, have memory, and operate out of equilibrium. I will present recent attempts at modeling the complex dynamics of social groups of mice interacting freely in a controlled environment. I will then assess how far from equilibrium collective behaviour might be, both in recordings of real bird flocks and in flocking models.

SOE 2.2 Mon 10:00 GÖR/0226

Spin-Waves without Spin-Waves: A Case for Soliton Propagation in Starling Flocks — •Andrea Cavagna — Institute for Complex Systems, Rome, Italy

Collective turns in starling flocks propagate linearly with negligible attenuation, indicating the existence of an underdamped sector in the dispersion relation. Beside granting linear propagation of the phase perturbations, the real part of the frequency should also yield a spin-wave form of the unperturbed correlation function. However, new high-resolution experiments on real flocks show that underdamped traveling waves coexist with an overdamped Lorentzian correlation. Theory and experiments are reconciled once we add to the dynamics a Fermi-Pasta-Ulam-Tsingou term.

SOE 2.3 Mon 10:15 GÖR/0226

Modelling filamentous fungal growth — •Pascal Klamser[1], Carlos Aguilar-Trigueros[2] und Dirk Brockmann[1] — [1]Technische Universität Dresden, Dresden, Germany — [2]University of Jyväskylä, Jyväskylä, Finland

The growth of a filament forming fungi is mesmerizing and a great example of an organism that forms a transport network and explores its environment for nutrients. While recent research shows how nutrients and other compounds are transported through the network, we will focus on a transport-agnostic model to explore the possible ways of how the tip of a filament can choose its growth direction. We assume a purely external communication via the diffusion of enzymes released by the filaments and can recreate a wide range of phenotypes. We compare it with experiments by estimating the hierarchical structure of the network from microscopic images.

15 min. break

SOE 2.4 Mon 10:45 GÖR/0226

Understanding how movement behaviors shape animal encounters and their ecological consequences — •Anudeep Surendran — Helmholtz-Zentrum Dresden-Rossendorf, Görlitz, Germany

Encounters between individuals underlie key ecological processes such as predation, mating, and disease transmission, making encounter rates a direct link between individual movement behavior and population-level outcomes. We investigate how two common features of animal movement-directional persistence and range residency-jointly shape encounter rates. Using the Ornstein Uhlenbeck with foraging (OUF) model, which integrates these two properties of animal movement, we derive exact analytical expressions for encounter rates and show that, for range-resident animals, the effect of persistence depends strongly on the degree of home-range overlap. Based on this theoretical result, we then introduce a new encounter-based metric that quantifies the spatial organization of home ranges at scales relevant to animal encounters. We finally apply this metric to movement data from lowland tapirs (Tapirus terrestris) in Brazils Pantanal region, and find a significant level of home-range spatial segregation that is consistent with the solitary behavior of this species.

SOE 2.5 Mon 11:00 GÖR/0226

Composite and combined games in evolutionary dynamics in finite populations — Henry Brooks, Suzannah Gebbett, and •Jens Christian Claussen — University of Birmingham, UK

Evolutionary game theory connects dynamics to strategy by assuming few behavioral strategies, modeling costs and benefits from interactions via a payoff matrices, then casting these into replicator equations (in infinite populations) resp. stochastic processes (in finite populations) which comprise a "physics of behaviour" model of the collective decision dynamics (which may include cyclic oscillations). We build on previous results (PRL 95, 238701 and PRL 100, 058104 and subsequent) and discuss combinations of 2- and 3 strategy games in the context of different replicator dynamics, and stochastic processes derived from agent interaction models. We demonstrate how the previous concepts of drift reversal - how an attracting fixed point resulting from a Hopf bifurcation loses stabilty below a critical population size, applies to the combined games.

SOE 2.6 Mon 11:15 GÖR/0226

A reversal in agent preference reveals partial segregation in the Schelling model — •Maksim Prusakov and Dirk Brockmann — Center Synergy of Systems, TUD Dresden University of Technology, Dresden, Germany

The Schelling model is one of the most famous and seminal models used to describe spatial segregation in social systems. We introduce a small modification to the basic rules of the model: instead of avoiding locations with too many neighbors of a different type, agents now seek places with a high proportion of same-type neighbors. Although this change may seem minor, it leads to qualitatively different behavior. For certain parameter values the system enters an unexpected and new partial-segregation phase, where macroscopically stable segregated clusters coexist with mixed, dynamically active regions.

We construct the phase diagram across tolerance and density values and characterize all macroscopic regimes of the model. The partial-segregation phase emerges robustly across different neighborhood sizes, lattice geometries, and numbers of agent types, which suggests that this behavior follows from the modified preference rule itself rather than from microscopic implementation details. To complement these results, we develop a theoretical framework that describes the stability conditions of the observed phases, with particular attention to the mechanisms that sustain partial segregation. Ultimately, our findings show that even a minor change in the type of local preference can generate fundamentally new collective behavior within Schelling-type models.

SOE 2.7 Mon 11:30 GÖR/0226

Emergence of power-laws and the uncertainty principle in human contact duration — •Jun Sun — GESIS - Leibniz Institute for the Social Sciences, Cologne, Germany

Consider the mechanism underlying human contact duration distributions as an aggregate effect of time-homogeneous processes, where the persistent probability of a contact (pairwise or higher-order) is drawn from a distribution but remains constant during its lifetime (Starnini

et al., 2013). I propose a thermodynamic interpretation of the model, in which the persistent probability of a contact is mapped to a negative log-energy, identifying time as the inverse temperature, and the duration distribution as the partition function. I prove that under mild conditions, the contact duration distribution exhibits a power-law with potential cutoffs, a phenomenon commonly observed in empirical data. Such distributions are special in the thermodynamic framework as they have constant specific heat capacity, which corresponds to both the power-law exponent and the effective degrees of freedom. When contact agents act independently, the degrees of freedom equal the contact order. Behavioral correlation between agents reduces the effective degrees of freedom (therefore also the power-law exponent). Finally, I establish an uncertainty relation between time and persistent probability, revealing a fundamental limit within which contact durations can be characterized. Unlike the once-controversial notion of temperature fluctuation, the uncertainty of time in contact data is well-defined.

15 min. break

SOE 2.8 Mon 12:00 GÖR/0226

Wired differently: Individual-level Adaptive Belief Networks — •Peter Steiglechner, Victor Møller Poulsen, Mirta Galesic, and Henrik Olsson — Complexity Science Hub, Vienna, Austria

Our beliefs about political issues are not independent; they are embedded within interconnected belief systems. Models such as the Networks of Beliefs (NB) theory (Dalege et al, 2025) formalise how individuals adjust their beliefs to reduce dissonance, and study how this leads to polarisation or consensus. In these models, the relations between beliefs are static, and the same belief network structure is assumed across individuals. This overlooks that perceived dissonance and belief relations can differ across individuals. And such heterogeneity in belief system structures can affect how individuals respond to external pressures or interventions, such as economic shocks or political scandals. We extend NB theory by allowing belief networks to evolve over time, shifting the focus from dynamics of belief content to the co-evolution of content and structure. In simulations of the model, individuals start with identical belief networks, but their structures diverge, producing stable disagreement between individuals. External events, inducing temporary pressure on a single belief, triggers lasting belief changes in some individuals (compliant), but only temporary or no changes in others (resilient and resistant), regardless of the strength of the pressure. Our model offers an illustrative and endogenous explanation of such asymmetries in responses to external events without requiring traits such as stubbornness, motivated cognition or identity biases.

SOE 2.9 Mon 12:15 GÖR/0226

Critical Transitions of Reinforcement Learning Dynamics in Social Dilemmas — •Balakrishna Prabhu B N and Wolfram Barfuss — Center for Development Research(ZEF), University of Bonn, Germany

Understanding how cooperation emerges and persists among self-interested agents remains a crucial question in the human, animal, and machine behavioral sciences. Specifically, the aspect of the timescales required to reach a cooperative outcome has received little attention.

While the field of equilibrium game theory has addressed the possibility of cooperative outcomes, it offers little insight into how agents select and reach these equilibria, or the timescales required to do so. Evolutionary game theory and reinforcement learning have addressed some of these questions, but are yet to examine the temporal aspects of strategy adaptation and the critical transitions that occur with changes to basic payoff structures.

In this work, we develop a framework based on deterministic dynamics of reinforcement learning to study critical transitions between different social dilemma games. We find that boundaries involving the Chicken game exhibit strong criticality, whereas transitions involving the StagHunt game do not. We also explore convergence times and equilibrium selection and their variations across these boundaries for static and dynamic systems.

By uncovering the dynamic behavior between game transitions, our work lays the foundation for an integrated theory of coupled social-ecological tipping elements.

SOE 2.10 Mon 12:30 GÖR/0226

Statistical mechanics of connected graphs in Scrabble — •Olivier Witteveen and Marianne Bauer — Department of Bionanoscience, Kavli Institute of Nanoscience Delft, TU Delft, Van der Maasweg 9, 2629 HZ Delft, The Netherlands

The crossword-like patterns of tiles in Scrabble form connected graphs of occupied sites on a square lattice. We are interested in describing the ensemble of these Scrabble graphs and comparing them across different languages. To find the most structureless description of Scrabble graphs, we build a maximum-entropy probability distribution; using real tournament data, we adapt a pseudo-likelihood method to the case of connected graphs on a lattice. We find that a maximum-entropy distribution that includes means and pairwise correlations captures the data: it correctly predicts simultaneous square occupation, word-length statistics, and geometric features of the Scrabble graphs, as well as the hierarchy among square types. Finally, we explore how language affects the structure of the Scrabble graphs. We adapt a Scrabble bot to self-play and generate graphs using different lexica. We find that the graphs produced by the bot have lower entropy compared to human players, and that lexica with shorter words yield higher entropy graphs. Remarkably, the pairwise maximum-entropy distribution is almost sufficient to correctly assign Scrabble graphs to their corresponding lexica.