Physics of Socio-economic Systems Division
Fachverband Physik sozio-ökonomischer Systeme (SOE)

Fakhteh Ghanbarnejad
Robert Koch Institute
Ludwig-Witthöft-Straße
15745 Wildau
GhanbarnejadF@rki.de

Philipp Hövel
Christian-Albrechts-Universität
zu Kiel
Kaiserstraße 2
24143 Kiel
philipp.hoevel@gmail.com

Eckehard Olbrich
Max Planck Institute for
Mathematics in the Sciences
Inselstraße 22
04103 Leipzig
olbrich@mis.mpg.de

Overview of Invited Talks and Sessions

(HSZ 03 and ZEU 260; Poster HSZ 02)

Invited Talks

SOE 5.1	Tue	9:30–10:00	ZEU 260	**Digital Pandemiology – Is that physics?** — •Dirk Brockmann
SOE 14.1	Thu	9:30–10:00	ZEU 260	**Networks in space and time – Exploring the physics in graph learning** — •Ingo Scholtes
SOE 21.1	Fri	9:30–10:00	ZEU 260	**Marginal Stability and Excess volatility in firm networks** — •Jean-Philippe Bouchaud

Invited Talks of the joint Symposium Dynamics of Opinion Formation – From Quorum Sensing to Polarization (SYOF)

See SYOF for the full program of the symposium.

SYOF 1.1	Mon	9:30–10:00	HSZ 01	**Towards understanding of the social hysteresis – insights from statistical physics** — •Katarzyna Sznajd-Weron
SYOF 1.2	Mon	10:00–10:30	HSZ 01	**Polarization in attitude distributions from surveys and models of continuous opinion dynamics** — •Jan Lorenz, Martin Gestefeld
SYOF 1.3	Mon	10:30–11:00	HSZ 01	**Collective patterns and stable misunderstandings in networks striving for consensus without a common value system** — •Johannes Falk, Edwin Eichler, Katja Windt, Marc-Thorsten Hütt
SYOF 1.4	Mon	11:15–11:45	HSZ 01	**A yet undetected cognitive bias, revealed by opinion dynamics simulations** — •Guillaume Deffuant
SYOF 1.5	Mon	11:45–12:15	HSZ 01	**Extreme switches in kinetic exchange models of opinion.** — •Parongama Sen, Kathakali Biswas

Invited Talks of the joint Symposium SKM Dissertation Prize 2023 (SYSD)

See SYSD for the full program of the symposium.

SYSD 1.1	Mon	9:30–10:00	HSZ 04	**Diffusion of antibodies in solution: from individual proteins to phase separation domains** — •Anita Girelli
SYSD 1.2	Mon	10:00–10:30	HSZ 04	**Intermediate Filament Mechanics Across Scales** — •Anna V. Schepers
SYSD 1.3	Mon	10:30–11:00	HSZ 04	**Ultrafast Probing and Coherent Vibrational Control of a Surface Structural Phase Transition** — •Jan Gerrit Horstmann
SYSD 1.4	Mon	11:00–11:30	HSZ 04	**Electro-active metasurfaces employing metal-to-insulator phase transitions** — •Julian Karst
SYSD 1.5	Mon	11:30–12:00	HSZ 04	**The role of unconventional symmetries in the dynamics of many-body systems** — •Pablo Sala

Sessions

SOE 1.1–1.3	Sun	16:00–18:15	HSZ 02	**Tutorial: Stochastic Processes of Opinion Formation (joint session SOE/TUT)**
SOE 2.1–2.1	Mon	12:30–13:00	ZEU 250	**Invited Talk: Dynamics of Networks (joint session DY/SOE)**
SOE 3.1–3.2	Mon	15:00–17:00	HSZ 03	**Award Session: Young Scientist Award for Socio- and Econophysics (YSA)**
SOE 4.1–4.14	Mon	17:00–19:00	P2/OG2	**Poster**
SOE 5.1–5.1	Tue	9:30–10:00	ZEU 260	**Physics of Contagion Processes I (joint session SOE/DY)**
SOE 6.1–6.3	Tue	10:00–10:45	ZEU 260	**Physics of Contagion Processes II (joint session SOE/DY)**
SOE 7.1–7.5	Tue	11:00–12:15	ZEU 260	**Networks: From Topology to Dynamics I (joint session SOE/DY)**
SOE 8.1–8.4	Tue	14:00–15:00	ZEU 260	**Semantic Networks, Language and Culture**
SOE 9.1–9.5	Wed	9:30–11:45	ZEU 260	**Focus Session: Critical Transitions in Society, Economy, and Nature (joint session SOE/DY)**
SOE 10.1–10.6	Wed	15:00–16:30	ZEU 260	**Traffic Dynamics, Urban and Regional Systems I**
SOE 11.1–11.6	Wed	16:45–18:15	ZEU 260	**Traffic Dynamics, Urban and Regional Systems II**
SOE 12	Wed	18:30–19:30	ZEU 260	**Members' Assembly**
SOE 13.1–13.8	Thu	9:30–12:00	MOL 213	**Data Analytics of Complex Dynamical Systems (joint session DY/SOE)**
SOE 14.1–14.1	Thu	9:30–10:00	ZEU 260	**Networks: From Topology to Dynamics II (joint session SOE/DY)**
SOE 15.1–15.3	Thu	10:00–10:45	ZEU 260	**Networks: From Topology to Dynamics III (joint session SOE/DY)**
SOE 16.1–16.5	Thu	11:00–12:15	ZEU 260	**Collective Dynamics in Animal and Human Societies**
SOE 17.1–17.2	Thu	15:00–15:30	ZEU 260	**Evolutionary Game Theory (joint session SOE/DY)**
SOE 18.1–18.4	Thu	15:30–16:30	ZEU 260	**Social Systems, Opinion and Group Dynamics I**
SOE 19.1–19.5	Thu	16:45–18:00	ZEU 260	**Social Systems, Opinion and Group Dynamics II**
SOE 20.1–20.8	Fri	9:30–11:45	ZEU 250	**Networks: From Topology to Dynamics IV (joint session DY/SOE)**
SOE 21.1–21.1	Fri	9:30–10:00	ZEU 260	**Financial Markets and Risk Management I**
SOE 22.1–22.3	Fri	10:00–10:45	ZEU 260	**Financial Markets and Risk Management II**
SOE 23.1–23.4	Fri	11:00–12:00	ZEU 260	**Economic Models**

Members' Assembly of the Physics of Socio-economic Systems Division

Wednesday 18:30–19:30 ZEU 260

- Bericht
- Verschiedenes

SOE 1: Tutorial: Stochastic Processes of Opinion Formation (joint session SOE/TUT)

Time: Sunday 16:00–18:15 Location: HSZ 02

Tutorial SOE 1.1 Sun 16:00 HSZ 02

Bounded Confidence Revisited: What We Overlooked, Underestimated, and Got Wrong — •Rainer Hegselmann — Frankfurt School of Finance & Management, 60322 Frankfurt, Adickesallee 32-34

The talk will discuss the so called bounded confidence model (BC-model, for short). The model is very simple: Period by period, all agents average over all opinions that are not further away from their actual opinion than a given distance Epsilon, their *bound of confidence*.

The simplicity of the model is deceptive. Two decades ago, Ulrich Krause and me published an analysis of the model in which we overlooked completely a decisive feature of our model: For increasing values of Epsilon, our analysis back then suggests smooth transitions in the model*s behavior. But in fact, the transitions are wild, chaotic, and non-monotonic.

In my talk I will present a new type of approach in which everything we overlooked at the time becomes directly obvious and, in a sense, unmissable. Key component of the new approach is an algorithm that identifies, exactly and exhaustively, all bounds of confidence, that make a difference. We get a list that, then, allows direct checks for wild behavior exhaustive of all possible cases. That is a good news. But it is accompanied by a bad one: The algorithm that does the work, requires an absolutely exact fractional arithmetic with integers of arbitrary length. As a consequence, we have to pay a price in terms of computational speed.

Tutorial SOE 1.2 Sun 16:45 HSZ 02

When intuition fails: the complex effects of assimilative and repulsive influence on opinion polarization — •Michael Maes[1], Andreas Flache[2], Shuo Liu[3], and Haoxiang Xia[3] — [1]Karlsruhe Institute of Technology, Karlsruhe, Germany — [2]University of Groningen, Groningen, The Netherlands — [3]Dalian University of Technology, Dalian, China

There is a debate about whether personalized services of social-media platforms contribute to the rise of bipolarization of political opinions. On the one hand, it is argued that personalized services of online social networks generate filter bubbles limiting contact between users who disagree. This reduces opportunities for assimilative social influence between users from different camps and prevents opinion convergence. On the other hand, empirical research also indicated that exposing users to content from the opposite political spectrum can activate the counter-part of assimilative influence, repulsive influence. Fostering contact that leads to opinion assimilation and limiting contacts likely to induce repulsive interactions, it has been concluded, may therefore prevent bipolarization. We demonstrate that these conclusions fail to capture the complexity that assimilative and repulsive influence generate in social networks. Sometimes, more assimilative influence can actually lead to more and not less opinion bipolarization. Likewise, increasing the exposure of users to like-minded individuals sometimes intensifies opinion polarization.

Tutorial SOE 1.3 Sun 17:30 HSZ 02

How growing connectivity and self-organization changes opinion dynamics — •Philipp Lorenz-Spreen — Center for Adaptive Rationality, Max Planck Institute for Human Development, Berlin, Germany

Information technology has made various aspects of our lives more dynamic and self-organized. Connections with others can be made across spatial and socio-demographic boundaries and undone with the click of a button. Since the famous six degrees of separation, networks seem much more connected; Facebook reports 3.5 degrees of separation on its friendship graph. Yet there have been repeated reports of segregated, homophilic network structures and related trends of increasing polarization on most online platforms. The mechanism that could resolve this apparent paradox may lie behind the question of whether we change our opinions according to our friends or whether we change our friends according to our opinions. We have recently proposed that an agent's opinion changes as a process of mutual reinforcement within clusters of shared attitudes and a coevolution of the associated network structure that dynamically adapts to changing opinions and follows a probability distribution governed by homophily. This combination helps explain the potential emergence of increasing polarization even as connectivity increases. Moreover, extending this model to multiple dimensions of topics can explain the empirical observation of increasing alignment of issues, where opinions become increasingly correlated within ideological clusters.

SOE 2: Invited Talk: Dynamics of Networks (joint session DY/SOE)

Time: Monday 12:30–13:00 Location: ZEU 250

Invited Talk SOE 2.1 Mon 12:30 ZEU 250

Novel phenomena and analysis methods in oscillator networks: higher-order interactions, higher-order averaging, and inference — •Hiroshi Kori — The University of Tokyo, Japan

Synchronization of oscillator networks is essential for functionalization of systems. Examples include heart pacemaker, circadian clock, and locomotion, to name a few. In this talk, after reviewing a general background, I will present recent studies with an emphasis on novel phenomena and analysis techniques. (i) A network of three oscillators shows complex synchronization transitions when the network structure or overall coupling intensity is varied [1]. The transition is analyzed using a higher-order averaging method. (ii) In the assembly of noisy oscillators with a three-body interaction, synchronized state appears only transiently and its persistent time increases exponentially with the interaction strength of three-body coupling. (iii) I will present our proposed inference methods of coupling intensity from spike data [2] and the phase from oscillatory time series [3].

[1] M. Kato, H. Kori, PRE (2023)
[2] F. Mori and H. Kori, PNAS (2022)
[3] A. Matsuki, H. Kori, R. Kobayashi. arXiv (2022)

SOE 3: Award Session: Young Scientist Award for Socio- and Econophysics (YSA)

Time: Monday 15:00–17:00 Location: HSZ 03

Presentation of the Award to the Awardee

Prize Talk SOE 3.1 Mon 15:10 HSZ 03

Initial Progress on the Science of Science — •Dashun Wang — Northwestern University

The increasing availability of large-scale datasets that trace the entirety of the scientific enterprise, have created an unprecedented opportunity to explore scientific production and reward. Parallel developments in data science, network science, and artificial intelligence offer us powerful tools and techniques to make sense of these millions of data points. Together, they tell a complex yet insightful story about how scientific careers unfold, how collaborations contribute to discovery, and how scientific progress emerges through a combination of multiple interconnected factors. These opportunities–and challenges that come with them–have fueled the emergence of a multidisciplinary community of scientists that are united by their goals of understanding science and innovation. These practitioners of the science of science use the scientific methods to study themselves, examine projects that work as well as those that fail, quantify the patterns that characterize discovery and invention, and offer lessons to improve science as a whole. In this talk, I will highlight some examples of research in this area, hoping to illustrate the promise of science of science as well as its limitations.

Presentation of the Award to the Awardee

Prize Talk SOE 3.2 Mon 16:00 HSZ 03

Complexity science can address marginalization in society and algorithms — •Fariba Karimi — Technical university of Vienna — Complexity Science Hub Vienna

Structural marginality refers to structural conditions that push certain groups towards a network*s margins, limiting their access to resources. Despite its importance, there are minimal quantitative understanding of its manifestation in networks and are thus we are unequipped to answer several urgent societal questions. For example, what underlying structural mechanisms drive marginalization? How can marginalized groups improve their social positions? How do AI systems reinforce these effects? Do hard (mathematical) limits exist on actions that would alleviate structural inequalities? In this talk, I argue that tools in complexity science are instrumental in measuring structural marginalities that emerge in society and algorithms.

After the Award Session, there will be an informal get-together with beer and pretzels at the poster session

SOE 4: Poster

Time: Monday 17:00–19:00 Location: P2/OG2

SOE 4.1 Mon 17:00 P2/OG2

Identifying subdominant collective effects in a large motorway network — •Shanshan Wang, Michael Schreckenberg, and Thomas Guhr — Faculty of Physics, University of Duisburg-Essen, Duisburg, Germany

In a motorway network, correlations between parts or, more precisely, between the sections of (different) motorways, are of considerable interest. Knowledge of flows and velocities on individual motorways is not sufficient, rather, their correlations determine or reflect, respectively, the functionality of and the dynamics on the network. These correlations are time-dependent as the dynamics on the network is highly non-stationary. Apart from the conceptual importance, correlations are also indispensable to detect risks of failure in a traffic network. Here, we proceed with revealing a certain hierarchy of correlations in traffic networks that is due to the presence and to the extent of collectivity. In a previous study, we focused on the collectivity motion present in the entire traffic network, i.e. the collectivity of the system as a whole. Here, we manage to subtract this dominant effect from the data and identify the subdominant collectivities which affect different, large parts of the traffic network. To this end, we employ a spectral analysis of the correlation matrix for the whole system. We thereby extract information from the virtual network induced by the correlations and map it on the true topology, i.e. on the real motorway network. The uncovered subdominant collectivities provide a new characterization of the traffic network. We carry out our study for the large motorway network of North Rhine-Westphalia (NRW), Germany.

SOE 4.2 Mon 17:00 P2/OG2

Feasibility and goodness of bimodal on-demand public transportation. — •Puneet Sharma, Knut Heidemann, Helge Heuer, Steffen Muehle, and Stephan Herminghaus — Max Planck Institute for Dynamics and Self Organization, Goettingen

Decarbonization of passenger transport is essential for fighting climate emergency. While modern cities offer various modes of transportation, considered separately, none of them is both, sustainable and convenient. A taxi service is convenient, in a sense, due to door-to-door service, but is inefficient since it usually serves one customer only. Demand-responsive ridepooling (DRRP) with minibuses is more efficient, but leads to undue competition with line services (LS), which provide even better pooling but are less convenient due to fixed routes and stops. A combination of both modes, DRRP and LS, may provide an ideal solution but is challenging to organize. Here we introduce a model for such bimodal on-demand transportation based on a square-grid geometry. Our model quantifies under what circumstances bimodal public transportation is feasible, both in terms of convenience and ecological footprint. Moreover, the model yields estimates for how to operate (LS frequency, modal split) a bimodal transportation system optimally. Perhaps surprisingly, we find that operating LS at maximum capacity is not necessarily optimal. We also consider the intricate interplay between LS operations and DRRP performance, i.e., detours, waiting times, and occupancy, via simulations.

SOE 4.3 Mon 17:00 P2/OG2

Just in time vs. all in sync: an analysis of two types of synchronization in a minimal model of machine activity in industrial production based on excitable dynamics on graphs — •Sanghita Bose[1], Annick Lesne[2,3], Julia Arlinghaus[4], and Marc-Thorsten Hütt[1] — [1]Department of Life Sciences and Chemistry, Jacobs University Bremen, Germany — [2]Institut de Génétique Moléculaire de Montpellier, University of Montpellier, CNRS, F-34293, Montpellier, France — [3]Sorbonne Université, CNRS, Laboratoire de Physique Théorique de la Matière Condensée, LPTMC, F-75252, Paris, France — [4]Otto-von-Guericke University Magdeburg, Universitätsplatz 2, 31904, Magdeburg, Germany.

The notion of synchronization in logistics is distinct from that encountered in the natural sciences, and in particular, in physics. In logistics, synchronization is often associated with a 'just in time' paradigm in supply and production systems. A perfect synchronization therefore is that the arrival (of goods at a warehouse or parts at a machine) is a cue for a subsequent transportation or manufacturing event. Globally, this type of synchronization can be envisioned as a wave of activity running through a distribution network or a production network. Here our goal is a deeper theoretical understanding of these two types of synchronization, the one from logistics and the one from physics, as well as their interplay in the context of production systems. We employ a minimal model of propagating excitations (representing machine activity) in a graph (representing a production network).

SOE 4.4 Mon 17:00 P2/OG2

Impact of interactions between layers on source localization in multilayer networks — Robert Paluch, Łukasz Gajewski, •Krzysztof Suchecki, and Janusz Hołyst — Faculty of Physics, Warsaw University of Technology, Koszykowa 75, Warsaw, 00-662, Poland

Nowadays, it is not uncommon to have to deal with dissemination on multilayered networks, and often finding the source of said propaga-

tion can be a crucial task. We examine the issue of locating the source of Susceptible-Infected spreading process in a multilayer network using the Bayesian inference and the maximum likelihood method established for general networks and adapted here to cover multilayer topology. We show how its accuracy depends on the network and spreading parameters and find the existence of two parameter ranges with different behavior. If the inter-network spreading rate is low, observations in different layers interfere, lowering accuracy below that of relying on single-layer observers only. If it is high, on the other hand, observations synergize, raising accuracy above the level of a single-layer network of the same size and observer density. We also show a heuristic method to determine the case in a system and potentially improve accuracy by rejecting interfering observations.

SOE 4.5 Mon 17:00 P2/OG2

Mean field approach for link coupling in Heider dynamics in bilayer network — •Krishnadas Mohandas and Janusz Hołyst — Warsaw University of Technology, Poland

Structural balance was observed in many social groups with simultaneous friendly and hostile relations. Frequently these interactions need to be described by muticomponent attributes and different components can be coupled together. In this study we consider a bilayer topology of Heider balance in a link multiplex, a unique multiplex in which coupling not only exists between different agents but also between corresponding links of the same agent. In social networks, for instance, agents can belong to the family, professional and friends group, where links in each layer could address either sports or politics. The dynamics of agents differs inside and between the layers and the coupling coefficients between the layers govern the strength of influence of one link-layer on another. Numerical simulations and analytical calculations using heat-bath approach and mean-field approximation demonstrate that the link polarization for both layers of a complete signed network of N agents tends towards Heider balance below critical temperature. The effect of such inter-layer coupling results in the increase of critical temperature with the strength of positive coupling. Periodical and chaotic trajectories of mean polarisations of both components are observed for a range of temperatures in the case of negative interlayer coupling.

SOE 4.6 Mon 17:00 P2/OG2

Counting Graphs and Molecules — •Rana Shojaei[1,2,3] and Thilo Gross[1,2,3] — [1]Helmholtz Institute for Functional Marine Biodiversity at the University of Oldenburg (HIFMB), Oldenburg, Germany — [2]Alfred Wegener Institute- Helmholtz Centre for Marine and Polar Research, Bremerhaven, Germany — [3]Carl von Ossietzky University- Institute for Chemistry and Biology of the Marine Environment (ICBM), Oldenburg, Germany

Counting the number of simple graphs that can be constructed between a given number of unlabeled (indistinguishable) nodes is a long-standing challenge. We consider this problem using Polya's counting theory. For illustration, we first consider a related problem that has historically received much attention: counting the number of chemical molecules with a given number of atoms. Indeed, it was in the context of this problem that the term 'graph' was first coined. Application of the same principles and procedure leads to a simple closed-form formula for the number of simple graphs, however, the efficient evaluation of the formula for large graphs remains an open problem.

SOE 4.7 Mon 17:00 P2/OG2

How random are team sports leagues? — Maciej Pawlik[1], Michał Boruta[2], Robert Paluch[1], and •Janusz Hołyst[1] — [1]Faculty of Physics, Warsaw University of Technology, Warsaw, 00-662, Poland — [2]Faculty of Mathematics and Information Science, Warsaw University of Technology, Warsaw, 00-662, Poland

To answer the title question, the historical ranking tables of four team sports leagues (Premier League, Bundesliga, La Liga, Svenska Hockeyligan) are analyzed. We investigate the predictability level of a given league by calculating the average absolute rank change $\overline{\rho}$ between two subsequent seasons of every team. The data are applied to calibrate an agent-based model of team sports leagues where every team possesses a certain strength equal to the sum of strengths of all players that have been selected to the team from a draft list. The sign of the difference between the strengths of two teams indicates the favorite of a given game, and there is a determinism parameter $\beta \in (0, \infty)$ that controls the game predictability. We use the model to simulate many seasons of various leagues and to compute the average absolute rank change $\overline{\rho}$ of a given team between two consecutive seasons. Plotting $\overline{\rho}$ as a function of β reveals a continuous transition between phases of luck– and skill–based sports. Comparing the results of our model with the ranking tables of selected professional leagues, we show that they operate close to the transition line but in the deterministic phase. This finding suggests that random factors and abilities of team players are of comparable importance, with an advantage of the latter.

SOE 4.8 Mon 17:00 P2/OG2

Simulating neutral biodiversity in large-scale networks — •Jeffrey Kelling[1,2], Richa Tripathi[3], and Justin M. Calabrese[3] — [1]Helmholtz-Zentrum Dresen-Rossendorf, Dresden, Germany — [2]Chemnitz University of Technology, Chemnitz, Germany — [3]Center for Advanced Systems Understanding (CASUS), Helmholtz-Zentrum Dresen-Rossendorf, Görlitz, Germany

The neutral model of biodiversity describes a Markov process of death and replacement of neutral individuals constituting the species occupying an ecosystem. It predicts a number macroscopic ecosystem observables, including local and global abundances, and can serve as advanced null-hypothesis for more complex models. We present a massively parallel approach to simulating the neutral model which both enables simulations on large networks, to, e.g., capture fine details of real river networks, and efficiently produces averages results to enable comparisons with empirical data or other models at high statistical significance or accurately compute correlations or responses.

SOE 4.9 Mon 17:00 P2/OG2

A toy model for the rise and collapse of societies — •Alexander Jochim and Stefan Bornholdt — Institute for Theoretical Physics, University of Bremen

Societal collapse as in ancient Rome is rather common than an exception along history. Similar patterns can be observed along time and space, and modern societies are potentially as vulnerable. Relying on empirical data, recent work has introduced mathematical models for long term processes in society. Here we report on a simple, physics-inspired model that exhibits metastable states and phases of collapse or sustained prosperity

SOE 4.10 Mon 17:00 P2/OG2

The Verification Dilemma in computer security: a game-theoretic perspective — •Jens Christian Claussen and Aad van Moorsel — School of Computer Science, University of Birmingham, UK

Verification protocols, as the Proof-of-Work (PoW) in blockchains, are essential mechanisms to ensure security in distributed networks. The computational costs of verification can also be organized in a shared way through special users, called miners. It has been pointed out that a Verifier's Dilemma arises between verifying and non-verifying miners [1]. Here we analyze the verification problem from game theory, identifying it as a strategic dilemma similar to a public goods game.

[1] D. Smuseva, I. Malakhov, A. Marin, A. van Moorsel and S. Rossi, Verifier's Dilemma in Etherum Blockchain: A Quantitative Analysis, LNCS 13479, 317 (2022)

SOE 4.11 Mon 17:00 P2/OG2

Investigating the Impacts of Regulatory Changes in Energy Systems with Explainable Artificial Intelligence — •Sebastian Pütz[1], Dirk Witthaut[2,3], and Benjamin Schäfer[1] — [1]Institute for Au- tomation and Applied Informatics, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany — [2]IEK-STE Research Centre Jülich, Jülich, Germany — [3]University of Cologne, Cologne, Germany

The stable supply of electrical energy is essential for the functioning of our society. Therefore, the operation of the electrical power grid and its related markets is subject to strict regulations. As the external technical, economic or social influences on the power grid change permanently, e.g. due to the energy transition, these regulations must also be constantly adapted. It is important to find out whether the regulatory changes lead to the intended results or whether they entail undesired side effects. We investigate regulatory changes using a data-driven approach based on publicly available techno-economic data on European power grids and electricity markets. We employ explainable machine learning models to identify important dependencies and disentangle the interaction of individual features. Using additive Shapley explanations, we identify changes due to the introduction of the 'Mischpreisverfahren' in the German balancing energy market or the splitting of the German-Austrian bidding zone.

SOE 4.12 Mon 17:00 P2/OG2

Delay Dynamics in a Nonlinear Economic Model — •Sándor Kovács[1], Szilvia György[1], Júlia Tompa[2], and Noémi Gyúró[2] — [1]Department of Numerical Analysis, Eötvös LorándUniversity, \\ Pázmány Péter sétány 1/C, H-1117 Budapest, Hungary\\ E-mail: alex@ludens.elte.hu — [2]Eötvös Loránd University, \\ Pázmány Péter sétány 1/C, H-1117 Budapest, Hungary

This talk is about the qualitative behavior of an economic model proposed by D. Meyer (cf. [1]). It is shown that under certain conditions on the parameters the system has uniformly bounded and no non-trivial periodic solutions. Subsequently, a possible equilibrium on the boundary of the positive phase space not discussed in [1] was founded and showed that if there is no interior equilibrium, then the equilibrium at the boundary will become unstable, whereas the equilibrium at the boundary will be stable. In order to have more realism, two types of delay will be introduced: an infinite distributed delay and a discrete delay. It is shown that contrary to the result in [1] the distributed delay does not change the stability of the equilibrium points. Finally, by introducing a discrete delay, it was showed that at a certain parameter value Hopf bifurcation takes place: periodic solutions arise. [1] Meyer, D. Equity and Efficiency in Regional Policy. Periodica Mathematica Hungarica Vol. 56 (1), 2008, 105*119.

SOE 4.13 Mon 17:00 P2/OG2

A model of public opinion with time-dependent media influence, audience attention and social influence. — •Michael Schnabel[1] and Daniel Diermeier[1,2] — [1]Vanderbilt University, Department of Political Sciences, Nashville, TN, USA — [2]Vanderbilt University, Owen School of Management, Nashville, TN, USA

We consider a simple model of binary opinions. Individuals form their opinions based on individual preferences, time-dependent media influence and the overall opinions in the population. In addition, we also incorporate a mechanism that is responsive to the salience of the media influence and can be used to account for variations in public attention. We explore how attention affects the opinion dynamics in the population as well as the equilibrium properties in a hypothetical quasi-static environment. Our model can account for populations with heterogeneous preferences and can also be used to examine the dynamics of opinion polarization within a population.

SOE 4.14 Mon 17:00 P2/OG2

Analysis of changes of opinions and social network structure of NetSense experiment participants — •Bartłomiej Zwoliński and Piotr Górski — Faculty of Physics, Warsaw University of Technology, Warsaw, 00-662 Poland

We study the interrelation between interactions and opinions by using data on Bluetooth contacts between college freshmen. We research evolution of social network structure and their opinions on eight topics within two-year period.

We find weak but significant correlation between students' vectors of opinions and their further interactions. Higher number of interactions had different impact on students' opinions depending on the period of the study, polarising them or leading to opinion alignment.

Throughout the experiment, we observed change of the students' contact network from overall community to smaller groups worse interconnected with each other.

SOE 5: Physics of Contagion Processes I (joint session SOE/DY)

Time: Tuesday 9:30–10:00 Location: ZEU 260

Invited Talk SOE 5.1 Tue 9:30 ZEU 260

Digital Pandemiology – Is that physics? — •Dirk Brockmann — Humboldt University of Berlin, Berlin, Germany

Three years of COVID-19 lie behind us. Experts from various fields worked constantly on understanding, mitigating and making sense of the pandemic. Novel digital tools became an essential part and complemented traditional, epidemiological methods. I will report on research activities and digital projects we launched during the past years that delivered important insights and were helpful as real-time assessment tools during the pandemic. These include the Covid-19-mobility monitor and the Corona Data Donation Project in which more than 500,000 participants donated daily data collected by their smartwatch or wearable device. I will summarize the results we obtained from these technologies and discuss why physics, as a mindset, is helpful for understanding phenomena that unfold across the borders of traditional scientific disciplines.

SOE 6: Physics of Contagion Processes II (joint session SOE/DY)

Time: Tuesday 10:00–10:45 Location: ZEU 260

SOE 6.1 Tue 10:00 ZEU 260

Explosive Epidemics — •Georg Börner[1], Malte Schröder[1], Davide Scarselli[2], Nazmi Burak Budanur[2,3], Björn Hof[2], and Marc Timme[1,4,5] — [1]Chair for Network Dynamics, Center for Advancing Electronics Dresden (cfaed) and Institute of Theoretical Physics, Technische Universität Dresden, Dresden 01062, Germany — [2]Institute of Science and Technology Austria, Klosterneuburg, Austria — [3]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [4]Cluster of Excellence Physics of Life, Technische Universität Dresden, Dresden 01062 Germany — [5]Lakeside Labs, Lakeside B04b, 9020 Klagenfurt, Austria

Standard epidemic models exhibit one continuous, second order phase transition to macroscopic outbreaks. However, interventions to control outbreaks may fundamentally alter epidemic dynamics. We reveal how such interventions modify the type of phase transition. In particular, we uncover three distinct types of explosive phase transitions for epidemic dynamics with capacity-limited interventions. Depending on the capacity limit, interventions may (i) leave the standard second-order phase transition unchanged but exponentially suppress the probability of large outbreaks, (ii) induce a first-order discontinuous transition to macroscopic outbreaks, or (iii) cause a secondary explosive yet continuous third-order transition. These insights highlight inherent limitations in predicting and containing epidemic outbreaks. More generally our study offers a cornerstone example of a third-order explosive phase transition in complex systems.

SOE 6.2 Tue 10:15 ZEU 260

Large-deviations of the SIR model under the influence of Lockdowns — Leo Patrick Mulholland[1], •Yannick Feld[2], and Alexander K. Hartmann[2] — [1]Queen's University Belfast, United Kingdom — [2]Institute of Physics, Carl von Ossietzky University, Oldenburg, Germany

Due to the high real-wold impact of diseases, the modelling of its dynamics has long since become an important aspect of various disciplines. Statistical physics is one of them as it gives us the tools investigate the fundamental processes through which a disease spreads throughout a population.

The transmission of a disease is affected by a lot of different factors. For example in response to the SARS-CoV 2 pandemic many governmental bodies imposed interventions to impede the spread of disease. One of the earliest non-pharmaceutical interventions (NPIs) that most countries used were lockdowns.

Motivated by that, we numerically [1] study the dynamics of the susceptible-infected-recovered (SIR) model with lockdowns on small-world networks by using a large-deviation approach, which was previously used to study the case of an unimpeded spread [2]. This allows us to obtain the probability density function of the cumulative fraction of infected nodes down to very small probabilities like 10^{-55}. The density exhibits remarkable discontinuties of the first derivative.

[1] A.K. Hartmann, *Big Practical Guide to Computer Simulations* (World Scientific, 2015)

[2] Y. Feld, A. K. Hartmann, Phys. Rev. E **105** 17 (2022)

SOE 6.3 Tue 10:30 ZEU 260

Short messages spread wider in online social networks — Patryk A. Bojarski, •Krzysztof Suchecki, and Janusz A. Holyst — Faculty of Physics, Warsaw University of Technology, Warsaw, 00-662 Poland

We explore the behavior of an online message spreading model, that includes mutable message content, user opinions and limited processing capacities. The model shows robust power-law distribution of the number of shares for different messages and that the tail of the distribution is composed almost entirely of very short messages. The possibility to modify message content by spreaders makes already popular, short messages even more popular if the users are selective about what content they spread, but not too much. The distribution of message variants is also a power-law, in agreement with real message spreading in Facebook. The behavior of the model is robust against model parameters and network topology variations and offers an explanation as to why services focused on short messages, such as Twitter, are popular.

SOE 7: Networks: From Topology to Dynamics I (joint session SOE/DY)

Time: Tuesday 11:00–12:15 Location: ZEU 260

SOE 7.1 Tue 11:00 ZEU 260

Modelling the perception of music in brain network dynamics — •Jakub Sawicki[1,2,3,4], Lenz Hartmann[5], Rolf Bader[5], and Eckehard Schöll[1,4,6] — [1]Potsdam Institute for Climate Impact Research — [2]Institut für Musikpädagogik, Universität der Künste Berlin — [3]Fachhochschule Nordwestschweiz FHNW, Basel, Switzerland — [4]Institut für Theoretische Physik, TU Berlin — [5]Institute of Systematic Musicology, University of Hamburg — [6]Bernstein Center for Computational Neuroscience Berlin

We analyze the influence of music in a network of FitzHugh-Nagumo oscillators with empirical structural connectivity measured in healthy human subjects [1]. We report an increase of coherence between the global dynamics in our network and the input signal induced by a specific music song. We show that the level of coherence depends crucially on the frequency band. We compare our results with experimental data, which also describe global neural synchronization between different brain regions in the gamma-band range and its increase just before transitions between different parts of the musical form (musical high-level events). The results also suggest a separation in musical form-related brain synchronization between high brain frequencies, associated with neocortical activity, and low frequencies in the range of dance movements, associated with interactivity between cortical and subcortical regions. [1] Sawicki, J., Hartmann, L., Bader, R., Schöll, E., Front. Netw. Physiol. 2, 910920 (2022).

SOE 7.2 Tue 11:15 ZEU 260

Order-disorder transition in the zero-temperature Ising model on random graphs — Armin Pournaki[1,2], Eckehard Olbrich[2], Sven Banisch[3], and •Konstantin Klemm[4] — [1]Laboratoire Lattice, CNRS & ENS-PSL, Paris — [2]Max Planck Institute for Mathematics in the Sciences, Leipzig — [3]Karlsruhe Institute for Technology — [4]IFISC (UIB-CSIC), Palma de Mallorca, Spain

The zero-temperature Ising model is known to reach a fully ordered ground state in sufficiently dense graphs. In sparse random graphs, the dynamics gets absorbed in disordered local minima at magnetization close to zero. Here we find that the non-equilibrium transition between the ordered and the disordered regime occurs at an average degree that slowly grows with the system size. The system shows bistability: the distribution of the absolute magnetization in the absorbing state reached is bimodal with peaks only at zero and unity. For fixed system size, the average time to absorption behaves non-monotonically as a function of average degree. The peak value of the average absorption time grows as a power law of system size. These findings have relevance for community detection, opinion dynamics and games on networks. Full manuscript available at https://arxiv.org/abs/2209.09325

SOE 7.3 Tue 11:30 ZEU 260

Analytical methods to stochastic binary-state dynamics on networks. — •Antonio Fernandez Peralta[1] and Raul Toral[2] — [1]Central European University, Vienna, Austria — [2]IFISC (Instituto de Física Interdisciplinar y Sistemas Complejos), Palma de Mallorca, Spain

Recently, there has been a lot of effort in the development of highly accurate mathematical descriptions of the dynamics of binary-state models defined on complex networks. There are two main approaches: (i) individual based-approaches where the variables are the state of each node, and (ii) compartmental approaches where nodes are aggregated based on some topological property such as, for example, the number of neighbors in the network. Except in a few cases where stochastic effects are taken into account at some extent, the approaches are usually followed by a deterministic description, neglecting the stochastic nature of the models defined by the individual transitions rates. Stochastic effects may become relevant even for extremely large system sizes, specially if the system is close to a critical point, or the network has high degree heterogeneity. Besides, there are some models where the deterministic approach does not provide the relevant information sought. For instance, the noisy-voter (Kirman) model, the contact process or the Threshold model, are examples of relevance in which the stochastic effects greatly dominate the dynamics. The main aim of this work is to give a general theoretical approach to binary-state models on complex networks that takes into account stochastic effects, going beyond incomplete deterministic approaches.

SOE 7.4 Tue 11:45 ZEU 260

Infinite sequence of explosive transitions in network robustness — •Laura Barth[1,2,3] and Thilo Gross[1,2,3] — [1]Helmholtz Institute for Functional Marine Biodiversity (HIFMB), Oldenburg, Germany — [2]Alfred-Wegener Institute (AWI), Helmholtz Center for Polar and Marine Research, Bremerhaven, Germany — [3]Institute for Chemistry and Biology of the Marine Environment (ICBM), Carl-von-Ossietzky University, Oldenburg, Germany

Explosive transitions in networks have recently received much attention. Here we show that such transitions also appear in one of the most fundamental problems in network science if it is considered from a certain angle. This problem is the fragmentation of networks under node or link removal, which has been studied extensively in the context of social networks. One key property in this context is v, the probability that a random link of a random node does not connect to the giant component. Now suppose we are constructing a random graph with a prescribed mean degree. How would we choose the degree distribution such that v is minimal after the attack? We show that the optimal degree distributions undergo an infinite sequence of discontinuous transitions as the size of the attack is changed.

SOE 7.5 Tue 12:00 ZEU 260

Information parity to measure the consonance of influence in complex networks — Aline Viol[1] and •Philipp Hövel[2] — [1]Scuola Internazionale Superiore di Studi Avanzati, Italy — [2]Christians-Albrechts-Universität zu Kiel, Germany

We discuss a new analytical tool to quantify the consonance of influence between nodes with respect to the whole network architecture: information parity. Unlike traditional approaches to quantitative network analysis that consider only local or global scales, information parity instead quantifies pairwise statistical similarities over the entire network structure. Based on information theory and using the statistics of geodesic distances, information parity assesses how similarly a pair of nodes can influence and be influenced by the network. This allows us to quantify the access of information gathered by the nodes. To demonstrate the method's potential, we evaluate a social network and human brain networks. Our results indicate that emerging phenomena like an ideological orientation of nodes in social networks can be shaped by their information parities. We also show the potential of information parity to identify central network regions in structural brain networks placed near the mid-sagittal plane. We find that functional networks have, on average, greater information parity for inter-hemispheric homologous regions in comparison to the whole network. Finally, we explore functional brain networks under influence of a psychedelic substance.

SOE 8: Semantic Networks, Language and Culture

Time: Tuesday 14:00–15:00 Location: ZEU 260

SOE 8.1 Tue 14:00 ZEU 260

Evolution of Socio- and Econophysics in the German Physical Society (DPG) — •Armin Pournaki[1,2], Sven Banisch[3], Philipp Hövel[4], and Eckehard Olbrich[1] — [1]Max Planck Institute for Mathematics in the Sciences, Germany — [2]Laboratoire Lattice, CNRS & ENS-PSL, France — [3]Karlsruhe Institute for Technology, Germany — [4]Christians-Albrechts-Universität zu Kiel, Germany

We present an interactive visualization (https://pournaki.com/soe/) that allows to explore the evolution of the semantic network of all abstracts that were submitted to the division *socio-economic systems (SOE)* of the DPG spring meetings from 2002 until 2022. The online interface allows to search for semantically related work in the *DPG-Verhandlungen* (book of abstracts) by also providing a textual interface that links the abstracts back to the actual website of the Verhandlungen. Employing a topic model on the data one can follow the evolution of central topics over time.

Moreover, we use the semantic network to study the role of the network paradigm as an integrative concept and its interaction within and across the different subfields of the SOE division.

SOE 8.2 Tue 14:15 ZEU 260

Network analysis of the Kyiv Bylyny cycle - East Slavic epic narratives — Petro Sarkanych[1,2], Nazar Fedorak[3,4], •Yurij Holovatch[1,2,5], Pádraig MacCarron[6], Joseph Yose[5,2], and Ralph Kenna[5,2] — [1]ICMP, NAS of Ukraine, Lviv, Ukraine — [2]L4 Collaboration Leipzig-Lorraine-Lviv-Coventry, Europe — [3]Ivan Franko National University of Lviv, Lviv, Ukraine — [4]Ukrainian Catholic University, Lviv, Ukraine — [5]Coventry University, Coventry, UK — [6]University of Limerick, Limerick, Ireland

In recent times, the advent of network science permitted new quantitative approaches to literary studies [see e.g. Maths Meets Myths: Complexity-science approaches to folktales, myths, sagas, and histories. R. Kenna, M. Mac Carron, P. Mac Carron (Editors), Springer, 2016]. Here, we bring the Kyiv bylyny cycle into the field - East Slavic epic narratives originating in modern-day Ukraine. By comparing them to other prominent European epics, we identify universal and distinguishing properties of the social networks in bylyny. We analyze community structures and rank most important characters. The method allows to bolster hypotheses from humanities literature - such as the position of Prince Volodymyr - and to generate new ones. We show how the Kyiv cycle of bylyny fits very well with narrative networks from other nations - especially heroic ones. We anticipate that, besides delivering new narratological insights, this study will aid future scholars and interested public to navigate their way through Ukraine's epic story and identify its heroes [P. Sarkanych et al., Adv. Complex Syst. 25(4) (2022) 2240007].

SOE 8.3 Tue 14:30 ZEU 260

Dynamics of language features on complex networks: statistical physics analysis, and the introduction of linguistic temperature — •Christopher Kitching[1], Jordan Abbott[1], Tobias Galla[1,2], Henri Kauhanen[3], Deepti Gopal[4], and Ricardo Bermúdez-Otero[1] — [1]The University of Manchester, UK — [2]Instituto de Fisica Interdisciplinar y Sistemas Complejos (CSIC-UIB) — [3]University of Konstanz, Germany — [4]University of Cambridge, UK

Statistical physics has made important contributions to the study of language dynamics. Here, we focus on a stochastic individual-based model of the spatio-temporal evolution of language features. Features evolve through a combination of descent across generations, and the influence of geographically neighbouring languages.

The dynamics are a variation of the two-state voter model, with spontaneous changes of state and transmission errors in the imitation process. Previous work is restricted to lattices, here we focus on complex networks. We establish a parabolic relation between the feature frequency and the density of active interfaces, modulated by the network, and 'linguistic temperature' - a measure of a feature's stability.

Results are obtained by combining the voter model, pair approximation and a new approach to networks, based on random walks. While the theoretical work has applications in other areas (e.g. opinion dynamics), our main focus is in linguistics: the frequency and isogloss density of real-world language features can be obtained from WALS and from this we calculate their temperatures.

SOE 8.4 Tue 14:45 ZEU 260

The Characteristic Time Scale of Cultural Evolution — •Tobias Wand — Westfälische Wilhelms-Universität Münster, Institut für Theoretische Physik — Center for Nonlinear Sciences Münster

Cliodynamics is a field of research that models human societies as dynamical systems, treating the study of history as a scientific discipline. Previous research on the Seshat databank has revealed one dominant principle component as an indicator of social complexity across diverse geographies and time periods. Our research expands on these findings, showing that there is a typical growth phase in social complexity that can be modelled with a universal functional form for all geographic areas included in the databank. Our findings reveal a characteristic time scale of rapid growth and can serve as a baseline to detect outliers.

SOE 9: Focus Session: Critical Transitions in Society, Economy, and Nature (joint session SOE/DY)

Organizers: Fakhteh Ghanbarnejad (Robert Koch-Institut), Diego Rybski (Potsdam Institute for Climate Impact Research)

Time: Wednesday 9:30–11:45 Location: ZEU 260

Topical Talk SOE 9.1 Wed 9:30 ZEU 260

Many universality classes in an interface model restricted to non-negative heights — •Peter Grassberger[1], Deepak Dhar[2], and Pradeep Mohanty[3] — [1]JSC, Forschungszentrum Jülich, D-52425 Jülich, Germany — [2]Indian Institute of Science Education and Research, Pune, 411 008, India — [3]Indian Institute of Science Education and Research - Kolkata Mohanpur, 741 246, India

We present a simple 1-d stochastic model with two control parameters and a rich zoo of phase transitions. At each (discrete) site x and time t, there is an integer $n(x,t)$ that satisfies a linear interface equation with added random noise. Depending on the control parameters, this noise may or may not satisfy detailed balance, so that the model is – for suitable initial conditions – in the Edwards-Wilkinson (EW) or in the Kardar-Parisi-Zhang (KPZ) universality class. But in contrast to these, there is also a constraint $n(x,t) \geq 0$. Points x where $n > 0$ on one side and $n = 0$ on the other are called "fronts". These fronts can be "pushed" or "pulled", depending on the control parameters. For pulled fronts, the lateral spreading is in the directed percolation (DP) universality class, while it is of a novel type for pushed fronts, with yet another novel behavior in between. In the DP case, the activity at each active site can in general be arbitrarily large, in contrast to previous realizations of DP. Finally, we find two different types of transitions when the interface detaches from the line $n = 0$ (with $\langle n(x,t)\rangle \to const$ on one side, and $\to \infty$ on the other), again with new universality classes. We also discuss a mapping of this model onto a directed Oslo rice pile model in specially prepared backgrounds.

Topical Talk SOE 9.2 Wed 10:00 ZEU 260

Nonequilibrium phase transitions and critical behavior in networks — •Eckehard Schöll — Institut für Theoretische Physik, TU Berlin — Potsdam Institute for Climate Impact Research — Bernstein Center for Computational Neuroscience Berlin

Phase transitions in nonlinear dynamical systems far from thermodynamic equilibrium have been investigated since the 1970s and 1980s, and concepts from thermodynamics and statistical physics have been applied to describe self-organization, spatio-temporal pattern formation, phase coexistence, critical phenomena, and first and second order nonequilibrium phase transitions. Much more recently, phase transitions and critical phenomena have been studied in dynamical networks, where synchronization transitions may arise, giving birth to a plethora of partial synchronization patterns and complex collective behavior, with applications to many natural, socioeconomic, and technological systems. We review these developments, and draw some connections of tipping transitions, explosive synchronization, nucleation, critical slowing down, critical exponents, etc. with nonequilibrium thermodynamics. [1] Tumash, L., Olmi, S. and Schöll, E., Effect of disorder and noise in shaping the dynamics of power grids, Europhys. Lett. 123, 20001 (2018). [2] Berner, R., Sawicki, J., Thiele, M., Löser, T. and Schöll, E., Critical parameters in dynamic network modeling of sepsis, Front. Netw. Physiol. 2, 904480 (2022). [3] Fialkowski, J., Yanchuk, S., Sokolov, I. M. , Schöll, E., Gottwald, G. A. and Berner, R., Heterogeneous nucleation in finite size adaptive dynamical networks, arXiv:2207.02939 (2022).

15 min. break

Topical Talk SOE 9.3 Wed 10:45 ZEU 260

Critical transition to monsoon: statistical physics principles of monsoon forecasting — •Elena Surovyatkina — Potsdam Institute for Climate Impact Research (PIK), Potsdam, Germany — Space Research Institute of the Russian Academy of Sciences (IKI), Moscow, Russia

Numerical weather models are limited to forecasting the weather for up to 5 days in the future. A fundamental problem lies in the chaotic nature of the spatial differential equations used to simulate the atmosphere. The limitations of current prediction models prevent further progress.

I present a recently developed approach fundamentally different from the numerical weather and climate models. It is based on statistical physics principles and recently discovered spatial-temporal regularities (or teleconnections between Tipping Elements) in a monsoon system.

First, I begin with evidence in observational data that the transition from pre-monsoon to monsoon is a critical transition. Second, I show how to detect the Tipping elements in the spatial organization of monsoon using the phenomenon of critical growth of fluctuations. Third, I explain how the regularities between the Tipping Elements allow predicting the upcoming monsoon onset and withdrawal for 40 and 70 days in advance, respectively.

Furthermore, I present the results of retrospective tests from 1951 to 2015, which show 73 % success for monsoon onset and 84 % for a withdrawal date. Remarkably, that forecasts of future monsoons showed to be successful already seven years in a row, 2016-2022.

SOE 9.4 Wed 11:15 ZEU 260

Synchronization-desynchronization transitions in neural networks — •Anna Zakharova — BCCN Berlin, Germany

Synchronization of neurons is believed to play a crucial role in the brain under normal conditions, for instance, in the context of cognition and learning, and under pathological conditions such as Parkinson's disease or epileptic seizures. In the latter case, when synchronization represents an undesired state, understanding the mechanisms of desynchronization is of particular importance. In other words, the possible transitions from synchronized to desynchronized regimes and vice versa should be investigated. It is known that such dynamical transitions involve the formation of partial synchronization patterns, where only one part of the network is synchronized. The most prominent example is given by chimera states [1]. In the present talk, we discuss an alternative scenario. We show how the so-called solitary states in networks of coupled FitzHugh-Nagumo neurons can lead to the emergence of chimera states. By performing bifurcation analysis of a suitable reduced system in the thermodynamic limit we demonstrate how solitary states, after emerging from the synchronous state, become chaotic in a classical period-doubling cascade [2].

[1] A. Zakharova, Chimera Patterns in Networks: Interplay between Dynamics, Structure, Noise, and Delay, Understanding Complex Systems (Springer, Cham, 2020) doi: 10.1007/978-3-030-21714-3

[2] L. Schülen, A. Gerdes, M. Wolfrum, A. Zakharova, Solitary routes to chimera states, Phys. Rev. E Letter 106, L042203 (2022) doi: 10.1103/physreve.106.l042203

SOE 9.5 Wed 11:30 ZEU 260

The war in Ukraine, a statistical analysis — •Juergen Mimkes — Physics Department, Paderborn University

War is a serious disruption of normal social order and may be analyzed by statistics. In homogeneous systems the Lagrange function depends on two Lagrange factors: L (λ, p). In physics, they are mean energy or temperature (λ) and pressure (p). In politics, they are mean capital or standard of living (λ) and military pressure (p). The factors (λ),(p) determine the state or phases of a system. In materials we have solid, liquid, gas, in politics autocratic, democratic, global. Different phases can only coexist at equilibrium in the phase diagram. Outside of equilibrium water and ice cannot coexist in close contact, water is melting ice (climate crisis). Outside of equilibrium democracy and autocracy cannot coexist in close contact, democracy is *melting* autocracy since the Marshall plan in 1947. Accordingly, there has been an aggressive reaction by the autocracy: DDR 1953, Hungary 1956, CSR 1968, Ukraine 2014. There is no chance for peace, unless one party vanishes. The only solution to keep hot and cold together is a thermos, and to keep democracy and autocracy side by side is a new iron curtain like in Korea or Europe (1961 to 1989).

SOE 10: Traffic Dynamics, Urban and Regional Systems I

Time: Wednesday 15:00–16:30 Location: ZEU 260

SOE 10.1 Wed 15:00 ZEU 260

The random walks of ridepooling — •Benjamin Köhler[1], Philip Marszal[1], Marc Timme[1,2], and Malte Schröder[1] — [1]Chair for Network Dynamics, Institute of Theoretical Physics & Center for Advancing Electronics Dresden (cfaed), TU Dresden — [2]Lakeside Labs, Klagenfurt, Austria

Ridepooling services have become an increasingly attractive mobility option in urban areas. As users issue requests for transport, ridepooling vehicles drive through the road network, continually adjusting their routes to pick up and deliver users with similar trips in shared rides. The quality of such services strongly depends on the dynamics of evolving vehicle routes, which collectively emerge from the interactions of the vehicles and requests. So far, theories of ridepooling services have focused on macroscopic and mean-field dynamics, neglecting the underlying microscopic route evolution. Here we analyze the structure and dynamics of these random routes in the limit of high service efficiency. We find an emerging random walk of a route that is specified not only by the current location of the vehicle, but also by the route planned ahead to pick up or drop off passengers who are currently transported in the vehicle or have already requested a ride. We map this process to an ordinary Markov random walk on an abstract graph whose nodes represent the shortest paths of the original street network. We thereby identify emerging routing patterns and evaluate their implications for the ridepooling service. Understanding these random route processes may help to further advance service quality, for instance by designing stop networks and routing algorithms to maximize flexibility.

SOE 10.2 Wed 15:15 ZEU 260

Scaling laws of ridepooling random routes — Philip Marszal, Marc Timme, and •Malte Schröder — Chair for Network Dynamics, Institute of Theoretical Physics & Center for Advancing Electronics Dresden (cfaed), TU Dresden

On-demand ridepooling services are emerging as a new form of urban mobility across the globe. Users request a trip, are assigned to one of the available ridepooling vehicles, and then transported in a shared ride. Despite the complex dynamics of these systems, their efficiency and service quality is characterized by universal macroscopic scaling laws. However, the scaling laws are typically derived from mean-field calculations neglecting the details of the microscopic dynamics of individual vehicles. Here, we analyze these microscopic dynamics in terms of the *ridepooling random routes* of the vehicles as a new type

of random walk process. In contrast to standard random walks, random routes are characterized by a pre-planned route of scheduled stops evolving as new requests are added to the route and users are picked up and delivered. We identify multiple timescales emerging in the routing dynamics and quantify the resulting structure of the random routes in terms of their persistence and diffusion properties. Importantly, microscopic scaling laws of the random route properties directly give rise to macroscopic scaling laws of the overall system efficiency. This perspective of microscopic random routes in ridepooling services may help to better understand their complex dynamics and scaling laws and optimize these services by identifying recurrent route patterns or adjusting allowed stop locations to guide the self-organized routing dynamics.

SOE 10.3 Wed 15:30 ZEU 260

Bi-modal transport: united against the private car — Puneet Sharma, •Knut Heidemann, Helge Heuer, Steffen Mühle, and Stephan Herminghaus — Max-Planck-Institut für Dynamik und Selbstorganisation, Göttingen, Germany

Motorized individual traffic leads to a prohibitive waste of energy and other resources. We show that combining a line service with a fleet of ride-pooling shuttles may provide on-demand door-to-door service with a service quality superior to customary public transportation, while at the same time consuming only about 20% of the energy a corresponding fleet of private cars would require, and with a road traffic volume reduced by orders of magnitude. We find favorable performance not only in urban, but also in rural settings. While the first part relies on a mean-field model and a simple model geometry, in part two, we test our results by simulations of real-word scenarios.

SOE 10.4 Wed 15:45 ZEU 260

Demand-driven design of bike path networks — •Christoph Steinacker[1], David-Maximilian Stroch[1], Marc Timme[1,2], and Malte Schröder[1] — [1]Chair for Network Dynamics, Institute of Theoretical Physics & Center for Advancing Electronics Dresden (cfaed), TU Dresden — [2]Lakeside Labs, Klagenfurt, Austria

Cycling is crucial for sustainable urban transportation. Promoting cycling critically relies on a sufficiently developed bicycle infrastructure. In general, designing efficient infrastructure networks constitutes a highly complex problem that requires balancing multiple, often opposing, constraints. In particular, bike path networks need to enable both safe and direct travel for all cyclists with an often strongly limited budget and strong competition for limited road space.

Here, we present a framework to create families of efficient bike path networks [1]. We reverse the network formation process and iteratively remove bike paths from an initially complete bike path network. In addition, we continually update cyclists' route choices, explicitly taking into account the cyclists' demand and their safety and convenience preferences. In this way, we create a sequence of networks that is always adapted to the current cycling demand.

We illustrate the applicability of this demand-driven planning scheme with empirical infrastructure and demand data. The framework may thus enable us to study properties of the structure of efficient bike path networks across cities and quantify the impact of different demand distributions.

[1] Steinacker *et al.*, Nat. Comput. Sci. **2**, 655-664 (2022).

SOE 10.5 Wed 16:00 ZEU 260

Does unorganized outperform organized public transport? — •Kush Mohan Mittal[1], Malte Schröder[1], and Marc Timme[1,2] — [1]Chair for Network Dynamics, Institute of Theoretical Physics & Center for Advancing Electronics Dresden (cfaed), TU Dresden — [2]Lakeside Labs, Klagenfurt, Austria

Organized public transport is commonly assumed to be more efficient compared to unorganized or self-organized mobility services that often prevail in the Global South. Here, we analyze OpenStreetMap route data from a total of 4500 routes of both organized and unorganized public transport services in more than 40 cities across the globe. Dividing bus routes into smaller segments and comparing their length to the shortest path distance between the segments endpoints, we find that segments more central in a route consistently exhibit substantially less detour than those towards the ends of the route. This non-homogeneous detour distribution occurs universally, irrespective of whether a city is dominated by organized or unorganized transport. These structural properties of the routes have significant implications for the attractiveness of public transport, as people living in the outskirts at the end of the routes typically both have overall longer trips and experience more (relative) detours than people living in the city center. Intriguingly, we provide quantitative evidence that decentrally self-organized transport routes typically exhibit less heterogeneity and at the same time achieve smaller overall detours. Moreover, they may also outperform organized transport in terms of social accessibility and route interconnectivity.

SOE 10.6 Wed 16:15 ZEU 260

Fix or flex? How ridepooling complements public transport — •Verena Krall[1], Marc Timme[1,2], and Malte Schröder[1] — [1]Chair for Network Dynamics, Institute of Theoretical Physics & Center for Advancing Electronics Dresden (cfaed), TU Dresden, Germany — [2]Lakeside Labs, Klagenfurt, Austria

Urban mobility is changing rapidly, not least due to the global rise of on-demand ridepooling services. In contrast to classic public transport with fixed lines and schedules, these new services offer a flexible shared transport with stops and routes determined by demand. This flexibility might attract new users to shared transport and offer higher accessibility to mobility in districts with poor public transport infrastructure. However, a complete shift from fixed line-based to flexible on-demand services would be detrimental, increasing congestion and wasting existing infrastructure. How can the two different service types complement each other to improve public transport? We find that the service quality is optimal if both line-based and on-demand transport are available. Additionally, we investigate adaptations of public transport networks and find that replacing inefficient lines step-by-step with on-demand vehicles may strongly reduce the overall costs. Applying our approach to empirical public transport networks, we identify lines that should be replaced with on-demand service. Our study shows how the combination of classic line-based with on-demand mobility may contribute to a public transport system that is both sustainable and user-friendly.

SOE 11: Traffic Dynamics, Urban and Regional Systems II

Time: Wednesday 16:45–18:15 Location: ZEU 260

SOE 11.1 Wed 16:45 ZEU 260

Response functions as a new concept to study local dynamics in traffic networks — •Shanshan Wang, Michael Schreckenberg, and Thomas Guhr — Faculty of Physics, University of Duisburg-Essen, Duisburg, Germany

Vehicle velocities in neighbouring road sections are correlated with memory effects. We explore the response of the velocities in the sequence of sections to a congestion in a given section and its dynamic characteristics. To this end, we transfer the concept of response functions from previous applications in finance to traffic systems. The dynamical characteristics are of particular interest. We identify two phases, a phase of transient response and a phase of long-term response. The transient response is pronounced when considering the backward propagation of heavy congestions but almost vanishes for forward propagation. For each response phase, we find a linear relation between the velocity response and the congestion correlator, implying that the correlation of congestion is most likely the cause for the velocity response. We also construct a susceptible-decelerated-withdrawing model mathematically inspired by the susceptible-infectious-recovered (SIR) model in epidemiology to describe the transient response. We find that the heavy congestion on a section propagates forward and backward at a similar rate, but the forward sections are more likely to recover from the effect of heavy congestion than the backward sections.

SOE 11.2 Wed 17:00 ZEU 260

A Fast and Modular Framework for Simulating Ridepooling Systems — •Felix Jung[1], Debsankha Manik[1], and Marc Timme[1,2] — [1]Chair for Network Dynamics, Institute of Theoretical Physics & Center for Advancing Electronics Dresden (cfaed), TU Dresden, 01062 Dresden, Germany — [2]Lakeside Labs, Klagenfurt, Austria

Climate change and congested cities urgently call for a transformation of passenger road transport that today still largely relies on flexible but inefficient private cars. Ridepooling services may reduce the environmental impact while maintaining a high level of flexibility. They move passengers between arbitrary locations, ideally on-demand and on short notice, while dynamically combining trips of several passengers into the same vehicle. However, under which conditions these services are simultaneously efficient, sustainable, and performant is not well understood to date.

Most research into such questions primarily relies on extensive computer simulations, because real-world experiments are extremely expensive and may negatively influence user adoption. Existing simulation tools have a much broader scope but are hard to evaluate with respect to fundamental physical observables, are not sufficiently performant, or hard to use. Here we present a new simulation framework that overcomes these challenges and is easy to use, modular and fast. The framework is released under an Open Source license in the hope that it will benefit the research community and further collaborative development.

SOE 11.3 Wed 17:15 ZEU 260

Service Quality Paradox – Guaranteeing early deliveries causes overall delays in ride pooling services — •Philip Marszal[1,2], Marc Timme[1,2,3], and Malte Schröder[1,2] — [1]Center for Advancing Electronics Dresden (cfaed), Technical University of Dresden, 01062, Dresden, Germany — [2]Institute for Theoretical Physics, Technical University of Dresden, 01062, Dresden, Germany — [3]Lakeside Labs, Lakeside B04b, Klagenfurt, 9020, Austria

On-demand ride pooling services become increasingly important for modern human mobility and rely on advanced forms of dispatching and coordination algorithms [1,2]. A central algorithm matches the vehicles of service providers to the trip requests of customers, aiming to efficiently combine passenger trips in order to reduce service time and distance traveled [3]. Here we reveal a service quality (SQ) paradox emerging emerging from how such services self-organize given a dispatching strategy: enforcing a maximum delay an individual passenger can experience may increase the average delay of all passengers. We quantitatively evaluate the SQ paradox in terms of the vehicle route flexibility, a measure of how many possible passengers may be served by a single vehicle. Our results theoretically revealed conditions underlying the novel paradox and may inform future designs of ridepooling algorithms to improve the service quality of the shared mobility ecosystem.

References: [1] Schröder et al., Nature Comm. 11:4831 (2020). [2] Storch et al., Nature Comm. 12:3003 (2021). [3] Alonso-Mora et al., PNAS 114:426 (2017).

SOE 11.4 Wed 17:30 ZEU 260

Short walks enable fast and sustainable ride sharing — •Charlotte Lotze[1], Philip Marszal[1], Malte Schröder[1], and Marc Timme[1,2] — [1]Chair for Network Dynamics, Institute for Theoretical Physics & Center for Advancing Electronics Dresden (cfaed), Technical University of Dresden, 01069 Dresden — [2]Lakeside Labs, Klagenfurt, Austria

Ride sharing - the bundling of simultaneous trips of several people in the same on-demand vehicle - may help to reduce the carbon footprint of human mobility. Yet, predicting the efficiency and sustainability of ride-sharing systems is hard due to their complex collective dynamics. Compared to individual motorized vehicle transportation, standard door-to-door ride sharing services reduce the total distance driven per user. However, they also increase the average travel times due to several additional stops and thus detours to pick up or drop off users. Here we show that requiring some users to walk to nearby shared stops reduces detours for the buses and thus the time users wait for their bus and drive in the bus. These time savings might overcompensate the additional walk time for the users. In this way, dynamic stop pooling reduces the average travel time and may break the trade-off between distance driven and travel time prevailing in door-to-door ride sharing. For example, ride sharing providers may reduce the fleet size to save distance driven without longer travel times when users walk a short part of their trip. Dynamic stop pooling may thus enable more sustainable ride sharing services without compromising service quality.

SOE 11.5 Wed 17:45 ZEU 260

Long-range correlations in city systems — Yunfei Li[1], Jan W. Kantelhardt[2], Celine Rozenblat[3], and •Diego Rybski[1,4] — [1]Potsdam Institute for Climate Impact Research - PIK, Member of Leibniz Association, P.O. Box 601203, 14412 Potsdam, Germany — [2]Institute of Physics, Martin-Luther-University, Halle (Saale), Germany — [3]Institute of Geography and Sustainability, Faculty of Geoscience, University of Lausanne; — [4]Complexity Science Hub Vienna, Josefstädterstrasse 39, A-1090 Vienna, Austria

City systems are characterized by the functional organization of cities on a regional or country scale. While there is relatively good empirical and theoretical understanding of city size distributions, insights about their spatial organization remain on a conceptual level. Here we analyze empirically the correlations between the sizes of cities (in terms of area) across long distances. Therefore, we (i) define city clusters, (ii) obtain the neighborhood network from Voronoi cells, and (iii) apply a fluctuation analysis along all shortest paths. We find that most European countries exhibit long-range correlations but in several cases these are anti-correlations. In an analogous way we study a model inspired by Central Places Theory and find that depending on the level of disorder, both positive and negative long-range correlations can be simulated. We conclude that the interactions between cities of different sizes extend over distances reaching country scale.

SOE 11.6 Wed 18:00 ZEU 260

Mapping the social structure of cities with Diffusion Maps — •Thilo Gross — Helmholtz Institute for Functional Marine Biodiversity,, Oldenburg, Germany — Carl-von-Ossietzky University, Oldenburg, Germany — Alfred-Wegener Institute, Helmholtz Center for Marine and Polar Research, Bremerhaven, Germany

Human society is aggregating and accelerating, leading to a rapid growth of cities. It is well known that the social structure of cities is important for a long list of reasons, including livability, security, sustainability, and disaster resilience. Analysis of the social structure can profit from two complementary data sources: Census datasets provide a wealth of high quality, highly structured information, but are typically only available once per decade. By contrast novel sources of mobility data (e.g. from phone traces) offer an unstructured and indirect, but rich and near-real-time glimpse of human social behavior. In this talk I illustrate how diffusion maps, a network-driven analysis method, reveal important patterns in both of these types of data.

SOE 12: Members' Assembly

Time: Wednesday 18:30–19:30 Location: ZEU 260

All members of the Physics of Socio-economic Systems Division are invited to participate.

SOE 13: Data Analytics of Complex Dynamical Systems (joint session DY/SOE)

Time: Thursday 9:30–12:00 Location: MOL 213

SOE 13.1 Thu 9:30 MOL 213

Reverse-engineering method for XPCS studies of non-equilibrium dynamics — •Anastasia Ragulskaya[1], Vladimir Starostin[1], Nafisa Begam[1], Anita Girelli[1], Hendrik Rahmann[2], Mario Reiser[2], Fabian Westermeier[3], Michael Sprung[3], Fajun Zhang[1], Christian Gutt[2], and Frank Schreiber[1] — [1]Universität Tübingen, Germany — [2]Universität Siegen, Germany — [3]DESY, Germany

X-ray photon correlation spectroscopy (XPCS) is a powerful tool for the investigation of dynamics covering broad time and length scales [1]. For non-equilibrium states, the resulting time-dependent dynamic behavior can be described using the two-time correlation function (TTC), which often contains more interesting features than only the component along the diagonal, and cannot be easily interpreted via classical simulation methods. Here, a reverse-engineering (RE) approach is proposed based on particle-based simulations [1]. This approach is applied to XPCS measurements on a protein solution undergoing liquid-liquid phase separation. We demonstrate that the rich features of experimental TTCs can be well connected with the key control parameters including size distribution, concentration, viscosity, and mobility of domains. The dynamic information obtained from this RE analysis goes beyond existing theory. The RE approach established in this work is applicable to other processes such as film growth, domain coarsening, or phase transformations.

[1] A. Ragulskaya et. al., IUCrJ 9 (2022), 439.

SOE 13.2 Thu 9:45 MOL 213

Sensitivity of principal components to changes in the presence of non-stationarity — •Henrik Bette and Thomas Guhr — Fakultät für Physik, Universität Duisburg-Essen, Duisburg, Deutschland

Non-stationarity affects the sensitivity of change detection in correlated systems described by sets of measurable variables. We study this by projecting onto different principal components. Non-stationarity is modeled as multiple normal states that exist in the system even before a change occurs. The studied changes occur in mean values, standard deviations or correlations of the variables. Monte Carlo simulations are performed to test the sensitivity for change detection with and without knowledge about the non-stationarity for different system dimensions and numbers of normal states. A comparison clearly shows that the knowledge about the non-stationarity of the system greatly improves change detection sensitivity for all principal components. This improvement is largest for those components that already provide the greatest possibility for change detection in the stationary case.

SOE 13.3 Thu 10:00 MOL 213

Inferring partial differential equations from molecular dynamics simulations — •Oliver Mai, Tim Kroll, Uwe Thiele, and Oliver Kamps — Institute of Theoretical Physics and Center for Nonlinear Science, University of Münster

Although integral to scientific or engineering applications, deriving partial differential equations (PDEs) solely from experimental data proves quite challenging and in most cases relies on physical principles in addition to qualitative behaviour of the system. In the last decade various efforts based on empirical data have been put forth to supplement first-principle derivations in theoretical sciences. That is in place of or in addition to typical conservation laws or phenomenological observations, time series data has been used to yield analytic expressions to describe the spatio-temporal evolution of a given dynamical system. While there have been various improvements in the sparsity and interpretability of the results, we provide another approach to optimization using the predictive power of the estimation when integrating it. Additionally aggregated small scale behaviour in macro- or mesoscopic experiments may exhibit unknown governing laws and as such a way for comparing data more directly to models derived in statistical physics may prove critical in furthering our understanding. To this end we study the application of system identification methods on molecular dynamics (MD) simulations.

SOE 13.4 Thu 10:15 MOL 213

Reproducibility of analysis workflows in biomedical physics — •Alexander Schlemmer[1,4], Inga Kottlarz[1,2], Baltasar Rüchardt[1,3,4], Ulrich Parlitz[1,2,4], and Stefan Luther[1,2,3,4] — [1]Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany — [2]Institute for the Dynamics of Complex Systems, Georg-August-Universität Göttingen, Germany — [3]Institute of Pharmacology and Toxicology, University Medical Center Göttingen, Germany — [4]German Center for Cardiovascular Research (DZHK), Partner Site Göttingen, Germany

Sustainable and well-documented data analysis workflows are essential for effectiveness and reproducibility in data-intensive research. In our terminology, documentation includes method and algorithm descriptions as well as human- and machine-readable representations of parameters, initial conditions and data, versions and dependencies and a well-defined software execution environment.

In practice, many software frameworks for reproducibility fail to achieve a widespread adoption. Using examples from data analysis in cardiac research, we illustrate typical challenges and show, how simple guidelines - when implemented in a pragmatic way - can already lead to a high degree of documentation and reproducibility. Furthermore, we discuss the employment of containers and semantic data management which simplify reproducibility, findability and interoperability.

SOE 13.5 Thu 10:30 MOL 213

Bayesian approach to anticipate critical transitions in complex systems — •Martin Hessler[1,2] and Oliver Kamps[2] — [1]Westfälische Wilhelms-Universität Münster, 48149 Münster — [2]Center for Nonlinear Science, Westfälische Wilhelms-Universität Münster, 48149 Münster

Complex systems in nature, technology and society can undergo sudden transitions between system states with very different behaviour. In order to avoid undesired consequences of these tipping events, statistical measures have been proposed as leading indicators. They can give a hint of an ongoing bifurcation-induced (B-tipping) destabilization process. However, we present an alternative approach that is open-source available and more robust under numerous aspects. It assumes the dynamical system to be described by a Langevin equation. Starting from this stochastic description, we combine MCMC sampling, rolling window methods and Bayesian reasoning to derive the drift slope as an alternative early warning sign including credibility bands which make it easier to distinguish significant leading indicator trends prior to B-tipping. Furthermore, our approach provides information about an increasing noise level in a multi-stable system. This is an important information related to the Kramers escape rate of a noise-induced tipping (N-tipping) event. We show some results and discuss the method's potential to be applied in N-tipping scenarios and under more complex conditions like correlated non-Markovian or multiplicative noise. Finally, possible limitations and tasks of future research are mentioned.

15 min. break

Invited Talk SOE 13.6 Thu 11:00 MOL 213

Power law error growth rates – a dynamical mechanism for a strictly finite prediction horizon in weather forecasts — Hynek Bednar[1,2], Jonathan Brisch[1], Burak Budanur[1], and •Holger Kantz[1] — [1]Max Planck Insstiute for the Physics of Complex Systems, Dresden, Germany — [2]Dept. of Atmospheric Physics, Charles University, Prague, Czech Republic

While conventional chaotic systems have a finite positive Lyapunov

exponent, physical arguments and observations suggest that the maximal Lyapunov exponent of the model equations of the atmosphere is the larger the smaller are the resolved spatial scales. Specifically, a power law divergence of the scale dependent error growth rate would translate into a strictly finite prediction horizon, since due to the divergence, additional accuracy of initial conditions is not translated into longer prediction times. We present conceptual toy models with such behavior, we show its presence in a more realistic spatially extended system with advective transport, and we present numerical results from turbulence simulations where the largest Lyapunov exponent scales as an inverse power of spatial resolution. The idea of a power law scale dependence of error growth rates and of a finite prediction horizon is also supported by re-analysis of numerical error growth experiments performed with an operational weather model. Altogether, this suggests that the prediction horizon of numerical weather prediction is strictly finite.

SOE 13.7 Thu 11:30 MOL 213

Wave Digital Optimization of a Modified Compact Models of 1T-1R Random Resistive Access Memory Cells — •Bakr Al Beattie[1], Max Uhlmann[2], Gerhard Kahmen[2], and Karlheinz Ochs[1] — [1]Ruhr-Universität Bochum, Lehrstuhl für digitale Kommunikationssysteme, Bochum, Deutschland — [2]Leibniz-Institut für innovative Mikroelektronik, Frankfurt (Oder), Deutschland

Random Resistive Access Memory (RRAM) cells are popular memristive devices that are commonly used in neuromorphic applications. In this context, RRAM cells are usually utilized to embed synaptic plasticity, a property that is exhibited by biological synapses, into analog-based artificial neural networks. However, since RRAM-based technology has yet to reach a state of maturity, circuit designers are usually forced to make use of compact models to avoid dealing with device-to-device variabilities. The Stanford PKU model is a well-established compact model that has been developed to capture the dynamics of 1T-1R RRAM cells. In this contribution, we present a modified compact model, based on the Stanford PKU model, that takes more properties of real RRAM cells into account, such as the RESET voltage shift in multilevel devices. To demonstrate the capabilities of our model, we exploit the wave digital concept to apply a live parameter optimization, which fits the model parameters to a technologically reproducible device from the Leibniz Institute for High Performance Microelectronics (IHP).

SOE 13.8 Thu 11:45 MOL 213

Discovering Causality and Coupling in high dimensional nonlinear dynamical systems — •Tim Kroll[1,2] and Oliver Kamps[2] — [1]Westfälische Wilhelms-Universität Münster, 48149 Münster — [2]Center for Nonlinear Science, Westfälische Wilhelms-Universität Münster, 48149 Münster

In this talk we present a method to infer causal relationships between observables from data of systems where the underlying dynamics are not known a priori. The method is based on the hypothesis that the system of interest can in principle be described by a set of coupled nonlinear ordinary differential equations. Following the work of Prusseit and Lehnertz in 2008 we can then determine the couplings between observables by integrating out all other observables. Since the estimation of the underlying dynamical system invokes the efficient representation in terms of polynomials the method can be applied also to hight dimensional systems. We demonstrate the capabilities of the method by inferring the network structure of coupled Rössler-Attractors.

SOE 14: Networks: From Topology to Dynamics II (joint session SOE/DY)

Time: Thursday 9:30–10:00 Location: ZEU 260

Invited Talk SOE 14.1 Thu 9:30 ZEU 260

Networks in space and time – Exploring the physics in graph learning — •Ingo Scholtes — Julius-Maximilians-Universität Würzburg, Chair of Machine Learning for Complex Networks, Center for Artificial Intelligence and Data Science, D-97074 Würzburg, Germany

Network Analysis and Graph Neural Networks have become cornerstones for the application of data science and machine learning to complex systems. Addressing geometric machine learning in non-Euclidean data, I will introduce key concepts that help to apply deep learning to graphs. We cover message passing algorithms, convolutional filters, discrete Laplacians and neural representation learning and highlight relationships between graph learning and physics.

We finally explore how time-resolved data on dynamic networks helps us to better understand complex systems and how we can incorporate the time dimension into deep graph learning. We introduce De Bruijn Graph Neural Networks (DBGNNs), a novel time-aware graph neural network architecture. Our approach accounts for temporal-topological patterns that unfold via causal walks, i.e. temporally ordered sequences of links by which nodes can influence each other over time. We develop a graph neural network architecture that utilizes De Bruijn graphs of multiple higher orders to implement a message passing scheme that follows a non-Markovian dynamics, which enables us to learn patterns in the causal topology of complex networks.

SOE 15: Networks: From Topology to Dynamics III (joint session SOE/DY)

Time: Thursday 10:00–10:45 Location: ZEU 260

SOE 15.1 Thu 10:00 ZEU 260

Understanding Braess' Paradox in power grids — •Benjamin Schäfer[1], Thiemo Pesch[2], Debsankha Manik[3], Julian Gollenstede[4], Guosong Lin[4], Hans-Peter Beck[4], Dirk Witthaut[2], and Marc Timme[5,3] — [1]Karlsruhe Institute of Technology — [2]Forschungszentrum Jülich — [3]Max Planck Institute for Dynamics and Self-Organization — [4]Clausthal University of Technology — [5]Technical University of Dresden

The ongoing energy transition requires power grid extensions to connect renewable generators to consumers and to transfer power among distant areas. The process of grid extension requires a large investment of resources and is supposed to make grid operation more robust. Yet, counter-intuitively, increasing the capacity of existing lines or adding new lines may also reduce the overall system performance and even promote blackouts due to Braess' paradox. Braess' paradox was theoretically modeled but not yet proven in realistically scaled power grids. Here, we present an experimental setup demonstrating Braess' paradox in an AC power grid and show how it constrains ongoing large-scale grid extension projects. We present a topological theory that reveals the key mechanism and predicts Braessian grid extensions from the network structure. These results offer a theoretical method to understand and practical guidelines in support of preventing unsuitable infrastructures and the systemic planning of grid extensions.

SOE 15.2 Thu 10:15 ZEU 260

Evolutionary Optimization of networks towards complexity: role of link distribution and cross-consistency of network complexity measures — Archan Mukhopadhyay and •Jens Christian Claussen — University of Birmingham, UK

In a framework utilizing complexity measures for optimizing graphs and networks towards complexity, we use one complexity measure as fitness function of an evolutionary algorithm, and evaluate the resulting graphs through other complexity measures and network properties. We consider both evolution of graphs where the total number of links can evolve, as well as the case of constrained number of links. We find that in a certain range MAg optimizes towards degree-regular graphs, which is not observed for other complexity measures. We also investigate the consistency among the complexity measures on artificial and real-world datasets.

SOE 15.3 Thu 10:30 ZEU 260

On the role of deleterious mutant regime in steering long-term evolution — Nikhil Sharma[1], •Joachim Krug[2], and Arne Traulsen[1] — [1]Department of Evolutionary Theory, Max Planck Institute for Evolutionary Biology, 24306 Plön, Germany — [2]Institute for Biological Physics, University of Cologne, Köln, Germany

Evolutionary Graph Theory aims to understand the interplay of natural selection and genetic drift on spatial structures. A spatial structure is modeled as a graph with nodes representing asexually reproducing individuals, and edges dictate the interaction among these individuals. Based on the fixation probabilities of mutants on graphs, graphs are mainly categorised as amplifiers of selection and suppressors of selection. We study Moran Birth-death origin fixation dynamics on graphs, see https://doi.org/10.1073/pnas.2205424119. As expected, amplifiers of selection attain higher steady-state average fitness than the complete graph. However, we found that a suppressor of fixation, having a lower probability of fixing mutants regardless of their fitness values compared to the complete graph, beats the complete graph in the long term by attaining higher average fitness. It happens because of the suppressor's ability to reject deleterious mutants more efficiently. Similarly, an amplifier of fixation, a structure with a higher probability of fixing mutants regardless of their fitness values, attains lower steady-state average fitness. It happens because of the amplifier's poor ability to reject deleterious mutants. These two examples illustrate the importance of the deleterious mutant regime in steering long-term evolution, which, to our knowledge, has been overlooked in the literature.

SOE 16: Collective Dynamics in Animal and Human Societies

Time: Thursday 11:00–12:15 Location: ZEU 260

SOE 16.1 Thu 11:00 ZEU 260

Individual bias and fluctuations in collective decision making: from algorithms to Hamiltonians — •Mariana Krasnytska[1,2,3], Petro Sarkanych[1,2], Luis Gómez-Nava[4,5], Abel Jonen[4], Pawel Romanczuk[4,5], and Yurij Holovatch[1,2,6] — [1]ICMP, NAS of Ukraine, Lviv, Ukraine — [2]L4 Collaboration Leipzig-Lorraine-Lviv-Coventry — [3]Université de Lorraine, Nancy, France — [4]Humboldt Universität zu Berlin, Germany — [5]Research Cluster of Excellence "Science of Intelligence", Berlin, Germany — [6]Coventry University, UK

We reconsider the spin model suggested recently to understand some features of collective decision making among higher organisms [A.T. Hartnett et al., Phys. Rev. Lett. 116 (2016) 038701]. Within the model, the state of an agent is described by the pair of variables corresponding to its opinion and a bias towards any of the opposing opinions. Collective decision making is interpreted within the non-linear voter model subject to social pressure. Here, we push such physical analogy further and give the statistical physics interpretation of the model via explicit calculation of its partition function. In such interpretation, the temperature serves as a measure of fluctuations that were not taken into account within the original formulation. We find exact solutions for the thermodynamics and dynamics of the model on the complete graph. We discuss the advantages and flaws of such an approach as well as its utility in understanding the impact of population heterogeneity, type of local interaction and fluctuations in collective decision making.

SOE 16.2 Thu 11:15 ZEU 260

Following the information footprint of firms — •Edward Lee[1], Alan Kwan[2], Rudolf Hanel[1], Anjali Bhatt[3], and Frank Neffke[1] — [1]Complexity Science Hub Vienna, Austria — [2]Hong Kong University, China — [3]Harvard Business School, Boston, USA

What a firm does is more revealing than how much it makes, but firms are often described with metrics for economic size. Instead, we characterize what firms know in terms of what they read, the information footprint, using a data set of hundreds of millions of records of news articles accessed by employees in millions of firms. We discover that the reading habits of firms are of limited diversity. This observation suggests that information constraints act on firms. To understand how, we relate a firm's information footprint with economic variables, showing that the former grows superlinearly with the latter. This exaggerates the classic Zipf's law inequality in the economic size of firms and reveals an economy of scale with respect to information. Second, we reconstruct the topic space firms inhabit, finding that the space resembles a tangled "hairball" with a few dense knots of topics and many specialized strands sticking out. Some of the topics are ubiquitous, indicating inescapable demand regardless of firm size. Finally, we connect these pieces in a model of how firms grow in the space of topics. We show that diversity in firm reading habits can be explained by a mixed strategy of local exploration and recurrent exploitation on the topic graph. This shows that the constraints that the space of ideas imposes on firm growth provide a useful and new perspective on firm development.

SOE 16.3 Thu 11:30 ZEU 260

Influence of confirmation biases on collective decision-making in fluctuating environments — •Clémence Bergerot[1,2], Wolfram Barfuss[3], and Pawel Romanczuk[2,4] — [1]Charité - Universitätsmedizin Berlin, Einstein Center for Neurosciences Berlin, Germany — [2]Humboldt Universität zu Berlin, Germany — [3]Tübingen AI Center, University of Tübingen, Germany — [4]Research Cluster of Excellence "Science of Intelligence", Berlin, Germany

In experimental studies of decision-making, it is now established that human agents tend to update confirmatory information with a higher weight than disconfirmatory information. This confirmation bias has been modeled within a reinforcement learning framework, using asymmetric updating of prediction errors. Interestingly, such a bias has been suggested to enhance individual performance in a wide range of multi-armed bandit tasks. However, little is known about the impact of the confirmation bias on collective performance. In order to characterize the circumstances that make this bias beneficial or detrimental to collective decision-making, we develop a multiagent model in which reinforcement learning agents can observe others' actions and rewards, and update this information asymmetrically. With agent-based simulations, we seek to understand how the confirmation bias affects collective performance in changing environments, and how network topology modulates this effect. We also study our multiagent system in the deterministic limit [W. Barfuss et al., Phys. Rev. E, 99(4) (2016) 043305], which allows us to gain an analytical understanding of the biased learning dynamics.

SOE 16.4 Thu 11:45 ZEU 260

Population waves in sessile organisms — •Niraj Kushwaha and Edward Lee — Complexity Science Hub Vienna, Josefstädter Straße 39, 1080 Vienna, Austria

The mathematical laws of life manifest scaling regularities such as the relationship between mass and metabolism for the smallest to the largest organisms on Earth. These laws lack essential components representing interaction between organisms while sharing limited resources. Once accounted for, these components can bring significant variation to the predicted demographic laws using just metabolic scaling theory and can give mathematical descriptions for observed ecological phenomena. The oscillations in population number, where spikes in the number of organisms of a specific size propagate from small to large organisms is an example of such a phenomena. Here, we incorporate spatial competition and resource variation in a differential equation model for the population dynamics of sessile organisms. We use analytic and numerical tools to solve the corresponding equations and to characterize the form of instabilities that generate the oscillations, which we use to identify hidden mechanisms that may drive instabilities in ecological systems such as forests. As a result, we may be able to identify the most significant factors that affect the stability of an ecosystem corresponding to resource fluctuations that may become more prominent with climate change.

SOE 16.5 Thu 12:00 ZEU 260

The role of escape angle in predator-prey interactions: the emergence of fountain effect — •Palina Bartashevich[1,2] and Pawel Romanczuk[1,2] — [1]Institute for Theoretical Biology, Humboldt-Universität zu Berlin, 10115 Berlin, Germany — [2]Excellence Cluster Science of Intelligence, Technische Universität Berlin, 10587 Berlin, Germany

Empirical studies of fish schooling widely described the variety of ways in which fish escape to reduce the chances of being caught by a predator while trying at the same time to stay in a group. The "fountain effect" is one such evasion maneuver that allows small fish to outmaneuver the fast-moving predator by swimming away at a constant angle determined by the rear limit of the visual cone [1]. Our spatially-explicit agent-based numerical simulations recover the same optimal prey-fleeing angle as confirmed by empirical studies. Moreover, our results show that the fleeing angle not only minimizes the distance to the predator but creates a sequence of information flows that best facilitates the information propagation throughout the collective. This finding highlights the direct role of social interaction in the emergence of the fountain effect which was not addressed before. We also address the questions of how the stimulus characteristics such as the initial predator angle of attack and distance to the first responders affect the response as a whole, allowing us to make biological predictions.

[1] Hall SJ, Wardle CS and MacLennan DN 1986. Predator evasion in a fish school: test of a model for the fountain effect. Mar. Biol. 91: 143-148.

SOE 17: Evolutionary Game Theory (joint session SOE/DY)

Time: Thursday 15:00–15:30 Location: ZEU 260

SOE 17.1 Thu 15:00 ZEU 260

Bet hedging in populations evolving in fluctuating environments — Rubén Calvo[1] and •Tobias Galla[2] — [1]Instituto Carlos I de Física Téorica y Computaciona, and Departamento de Electromagnetismo y Física de la Materia, Facultad de Ciencias, Universidad de Granada, 18071 Granada, Spain — [2]Instituto de Física Interdisciplinar y Sistemas Complejos IFISC (CSIC-UIB), Campus Universitat de les Illes Balears, E-07122 Palma de Mallorca, Spain

Bet-hedging strategies are strategies aimed at reducing risk in the face of uncertainty. For example, biological organisms face uncertain time-varying environmental conditions, such as dry years versus wet years. Similarly, future conditions in financial markets or other social systems are often unknown. Traditional bet-hedging theory shows that a reduction of the variance of an agent's payoff may increase their success even when their mean payoff is also reduced. Bet-hedging strategies are often built on maximum growth. Here instead, we ask how a mutant invading a resident wildtype population can maximise its chances of taking over the population (i.e., the fixation probability of the mutant). We consider a birth-death dynamics in fluctuating environments, and show that, depending on the distribution of payoffs across environmental states, a reduction in variance can either be beneficial or detrimental to the mutant. We establish conditions for either scenario to be realised, and show how this is related to the skewness of the payoff distribution.

SOE 17.2 Thu 15:15 ZEU 260

Hawk Dove Game on Networks with Continuous Populations — •Lennart Gevers[1,2], Tobias Wand[1,2], and Svetlana V. Gurevich[1,2] — [1]Institute for Theoretical Physics, University of Münster, Wilhelm-Klemm-Straße 9, D-48149 Münster, Germany — [2]Center for Nonlinear Science (CeNoS), University of Münster, Corrensstrasse 2, D-48149 Münster, Germany

Evolutionary game theory is a population-based approach to game theoretical scenarios by analyzing the evolution of populations resembling competing strategies.
We expand the classical model analysed by (1), which assumes that no spatial or social segregation of populations occurs, with a network-based approach to the hawk-dove game which models the ability of contestants to migrate between neighboring realizations of the game by adapting different migratory behaviors.
Our model reveals that competitive and cooperative populations can show preferred strategies on how to spatially organize on such territories.
Furthermore, we find that the resulting outcomes of the participating species diverge from the original model with increasing mobility of species.

(1) F. Stollmeier and J. Nagler, Phys. Rev. Lett. 120, 058101, 2018.

SOE 18: Social Systems, Opinion and Group Dynamics I

Time: Thursday 15:30–16:30 Location: ZEU 260

SOE 18.1 Thu 15:30 ZEU 260

Homophily-based social group formation in a spin-glass self-assembly framework — •Jan Korbel[1,2], Simon Lindner[1,2], Tuan Pham[1,2,3], Rudolf Hanel[1,2], and Stefan Thurner[1,2,4] — [1]Section for the Science of Complex Systems, CeMSIIS, Medical University of Vienna, Spitalgasse 23, A-1090, Vienna, Austria — [2]Complexity Science Hub Vienna, Josefstädterstrasse 39, A-1080, Vienna, Austria — [3]Niels Bohr Institute, Blegdamsvej 17, 2100 Copenhagen, Denmark — [4]4Santa Fe Institute, 1399 Hyde Park Road, Santa Fe, NM, 87501, USA

Homophily, the tendency of humans to attract each other when sharing similar features, traits, or opinions, has been identified as one of the main driving forces behind the formation of structured societies. Here we ask to what extent homophily can explain the formation of social groups, particularly their size distribution. We propose a spin glass-inspired framework of self-assembly, where opinions are represented as multidimensional spins that dynamically self-assemble into groups; individuals within a group tend to share similar opinions (intra-group homophily), and opinions between individuals belonging to different groups tend to be different (inter-group heterophily). We compute the associated non-trivial phase diagram by solving a self-consistency equation for magnetization (combined average opinion). Below a critical temperature are two stable phases: one ordered with non-zero magnetization and large clusters, the other disordered with zero magnetization and no clusters. The system exhibits a first-order transition to the disordered phase.

SOE 18.2 Thu 15:45 ZEU 260

Heider balance observed for multidimensional attributes — Joanna Linczuk[1], Piotr J Górski[1], Boleslaw K Szymanski[2,3], and •Janusz A Hołyst[1] — [1]Faculty of Physics, Warsaw University of Technology, Warsaw, Poland — [2]Social Cognitive Networks Academic Research Center, Rensselaer Polytechnic Institute, Troy, USA — [3]Społeczna Akademia Nauk, Łódź, Poland

The majority of measured and studied social interactions arise from dyadic relations. An exception is the Heider Balance Theory (HBT) that postulates the existence of a social triad dynamics. Most of the past literature on HBT focuses on opinions about a single topic in such triads. In contrast, we study opinions of university students on a multidimensional set of topics. We discover limits of HBT observability by considering a novel agent-based model that accounts for: (i) multiple topics on opinions of individual students, (ii) influence of such opinions on dyadic relations (social link polarization), and (iii) influence of triadic relations on individual's sets of opinions on all topics. Using longitudinal records of university student behavior, we create a coevolving social network on which we introduce models of student interactions. We validate the model by showing that the triadic influence is empirically measurable for static and dynamic observables in this network. However, when we consider opinions on each topic separately from the others, the influence of triadic interactions is indistinguishable from the noise.

SOE 18.3 Thu 16:00 ZEU 260

Evolution of signed relations due to principles of structural balance and status theories — •Adam Sulik[1], Piotr J. Górski[1], Georges Andres[2], Giacomo Vaccario[2], and Janusz Hołyst[1] — [1]Faculty of Physics, Warsaw University of Technology — [2]Chair of

System Design, ETH Zürich

One of the issues of social science is the analysis of why and how human relationships are formed. The causes of these phenomena are explained by structural balance theory and status theory, among others. Although the structural balance model by Antal et al. is a breakthrough in modeling the formation of social relationship structures, but by the diverse nature of positive and negative relationships in real-world social networks, it is unable to capture a complete picture of the relationships between users of different online communities. In addition to stability as understood by Heider's hypothesis, which is contained in structural balance theory, dynamics based on social status should also be taken into account.

We present two new models: an extended model of structural balance on directed networks and a model combining dynamics of structural balance and status theories. Presented numerical simulation results are consistent with analytical expectations. The theoretical observations have been verified on real networks, where the effect of status on the relationship between users of the studied websites has been noticed.

SOE 18.4 Thu 16:15 ZEU 260

Analysing the structure of opinion spaces — •Eckehard Olbrich[1] and Sven Bansich[2] — [1]Max Planck Institute for Mathematics in the Sciences — [2]Karlsruhe Institute for Technology

Data for understanding opinion dynamics arise in a variety of contexts: from voting patterns and multi-item surveys to hashtags use and users participation in different online groups. Despite their different origins they have a similar mathematical structure: a matrix with rows representing members of a population and columns representing e.g. items of a survey or political issues. Recently various novel methods have been proposed to make sense of correlational patterns in such data in order to identify them with cultural schemata [3] or dimensions of an underlying political space [1]. In this contribution we will compare different such methods including (1) issue bundles [1], (2) latent space models [2] and (3) correlational class analysis [3]. We will discuss their advantages and disadvantages using data sets from a survey on attitudes towards Corona measures and from Swiss public votes.

[1] E. Olbrich, and S. Banisch, The rise of populism and the reconfiguration of the German political space, Frontiers in Big Data 4, 731349 (2021).

[2] F. Gaisbauer, A. Pournaki, S. Banisch, and E. Olbrich, Grounding force-directed network layouts with latent space models. arXiv:2110.11772 (2021).

[3] A. Boutyline, Improving the measurement of shared cultural schemas with correlational class analysis: Theory and method. Sociological Science 4.15 (2017): 353-393.

SOE 19: Social Systems, Opinion and Group Dynamics II

Time: Thursday 16:45–18:00 Location: ZEU 260

SOE 19.1 Thu 16:45 ZEU 260

Evidence-based policy-making in sports funding using a data-driven optimization approach — •Jan Hurt[1], Liuhuaying Yang[1], Johannes Sorger[1], Thomas J. Lampoltshammer[2], Nike Pulda[5], Ursula Rosenpichler[5], Stefan Thurner[3,1,4], and Peter Klimek[3,1] — [1]Complexity Science Hub, Vienna, Austria — [2]University for Continuing Education Krems, Krems, Austria — [3]Section for Science of Complex Systems, CeMSIIS, Medical University of Vienna, Vienna, Austria — [4]Santa Fe Institute, Santa Fe, NM, USA — [5]Austria

Many European countries face rising obesity rates among children. Access to sports facilities depends on multiple factors, such as geographic location, proximity to population centers, budgetary constraints, and other socio-economic covariates. Here we show how an optimal allocation of government funds towards sports facilitators (e.g. sports clubs) can be achieved in a data-driven simulation model that maximizes children's access to sports facilities. We find a characteristic sublinear relationship between the number of active club members and the budget, which depends on the socio-economic conditions of the clubs' districts. In the model, we evaluate different funding strategies. We show that an optimization strategy outperforms a naive approach by up to 115% for 5 million Euros of additional funding to attract children to sports clubs. Our results suggest that the impact of public funding strategies can be substantially increased by tailoring them to regional socio-economic characteristics in an evidence-based and individualized way.

SOE 19.2 Thu 17:00 ZEU 260

Fitting Polling Data with a Minimal Voter Model — •Philipp G. Meyer and Ralf Metzler — Institute for Physics and Astronomy, University of Potsdam, Potsdam-Golm, Germany

The numerous versions of the voter model have various applications in opinion dynamics. We consider a two-state voter model for approval rates measured by political polls. We find that three features are essential for a realistic model.

Firstly, adding zealots (that never change their state) on both sides, prevents consensus. This behavior corresponds to the observations in the polling of parties. Such a voter model can be regarded as a stochastic process in a confining potential. Secondly, the measurement uncertainty of the polls has to be taken into account. It can be modeled by additive noise. Finally, we identify short-time autocorrelations between the steps, which lead to a higher variance than expected from the naive model.

We use techniques developed for voter models along with methods from stochastic processes for fitting data from political polls to the adapted voter model.

SOE 19.3 Thu 17:15 ZEU 260

Reddit Revisited — João Pinheiro Neto and •Riccardo Carlucci — Max Planck Institute for Dynamics and Self-Organization, Am Faßberg 17, 37077 Göttingen

Social media research using Reddit as a data source has greatly increased in recent years. Researchers have used Reddit to study a wide variety of issues such as political polarization, depression, astroturfing, and market manipulation to name a few.

This is primarily made possible by the Pushshift project, which offers an almost-complete dataset of Reddit. Such a degree of completeness is unique among major social media platforms, and bypasses sampling issues that may otherwise make large-scale analysis challenging.

However, a considerable fraction of Reddit research uses data which is now already a few years old. At the same time Reddit has been steadily growing, both in terms of content and userbase. For example: half of all threads and comments ever created date back to the last 2 years, despite Reddit being more than 15 years old. In addition, the global COVID-19 pandemic is known to have affected users' social media consumption.

Here we present an updated overview of Reddit as seen through the Pushshift dataset, using data up to August 2022. First we discuss the evolution over time of various statistical observables from a large-scale perspective. Next, we study the life cycle of subreddits, users, and submissions. Finally, we study the response of individual subreddits to external events.

SOE 19.4 Thu 17:30 ZEU 260

Topological insulators and enhancers in complex systems under generic problem-solving dynamics — •Johannes Falk[1], Edwin Eichler[2,3], Katja Windt[3,1], and Marc-Thorsten Hütt[1] — [1]Constructor University, Bremen, Germany — [2]EICHLER Consulting AG, Weggis, Switzerland — [3]SMS Group GmbH, Düsseldorf, Germany

The collective coordination of distributed tasks in a complex system can be represented as decision dynamics on a graph. For the case of social differentiation tasks, experimental studies on human subject networks demonstrated that shortcuts in small-world networks can speed up the finding of global solutions. Using a computational model, we illustrate that this is not always true: Depending on the actors' reasoning and the length of the added links, shortcuts can serve as topological enhancers that speed up the finding of a solution, but also as topological insulators that make the network more difficult to solve. Our findings have implications for situations where in distributed decision systems regional solutions emerge which are globally incompatible such as e.g. known from the emergence of standards.

SOE 19.5 Thu 17:45 ZEU 260

The emergence of echo-chambers in spatial collective estimation with limited connectivity — •Mohsen Raoufi[1], Heiko Hamann[2], and Pawel Romanczuk[1] — [1]Department of Biology, Humboldt Universität zu Berlin, Berlin, Germany — [2]Department of Computer and Information Science, University of Konstanz, Konstanz, Germany

Using a method inspired by the wisdom-of-crowds effect [1] we study the speed-vs-accuracy tradeoffs (SAT) in a spatial collective estimation scenario. In this work, we highlight the link between the speed-vs-accuracy and exploration-vs-exploitation tradeoffs. Here we elaborate upon the role of network connectivity in the tradeoffs. On one hand, the network structure influences the dynamics of consensus-making in collectives. On the other, agents modify the network based on their opinion. We model this behaviour of agents based on homophily–the tendency of nodes to establish links with other like-minded nodes. This co-evolution of the network structure and opinion of agents shows rich dynamics, even for spatial networks. In particular, we demonstrate that in systems with limited connectivity, homophily can lead to the emergence of echo-chambers, which prevents consensus. Our focus for future work is to provide solutions within the capability of agents to bring global connectivity and thus the consensus back to the collective. [1] Raoufi, M., et. al. Speed-vs-Accuracy Tradeoff in Collective Estimation: An Adaptive Exploration-Exploitation Case. In 2021 International Symposium on Multi-Robot and Multi-Agent Systems (MRS) (pp. 47-55). IEEE.

SOE 20: Networks: From Topology to Dynamics IV (joint session DY/SOE)

Time: Friday 9:30–11:45 Location: ZEU 250

SOE 20.1 Fri 9:30 ZEU 250

Efficient integration of short-range models on complex networks — •Jeffrey Kelling[1,2], Géza Ódor[3], Lilla Barancsuk[3], Shengfeng Deng[3], Bálint Hartmann[3], and Sibylle Gemming[2] — [1]Chemnitz University of Technology, Chemnitz, Germany — [2]Helmholtz-Zentrum Dresden - Rossendorf, Dresden, Germany — [3]Centre for Energy Research, Budapest, Hunguary

Complex, hierarchical or random network topolgies can give rise to unique behavior in many physical models. We study dynamical synchronization behavior in Kuramoto models on power grids and brain connectomes with millons of connections and $\mathcal{O}(100k)$ nodes. At these scales it is crucial to use the sparsity when computing derivatives, which, due to the random network structure, makes employing modern parallel hardware tricky. Here, we present our approach to numerically solving large systems ordinary differential equations on random directed graphs, where we focus on the computationally expensive task of computing derivatives and leave the common integration step to the `boost::odeint` library. Our application can utilize both parallel CPUs and GPUs. We also provide an overview of our results on human and fly brain connectomes as well as failure cascades in power grids and provide a measure of the advantage gained from our computational optimization efforts.

SOE 20.2 Fri 9:45 ZEU 250

Discovering hidden layers in quantum graphs — Łukasz Gajewski, •Julian Sienkiewicz, and Janusz Hołyst — Faculty of Physics, Warsaw University of Technology, Warsaw, Poland

Finding hidden layers in complex networks is an important and nontrivial problem in modern science. We explore the framework of quantum graphs to determine whether concealed parts of a multilayer system exist and, if so, their extent, i.e., how many unknown layers are there. Assuming that the only information available is the time evolution of wave propagation on a single layer of a network, it is indeed possible to uncover that which is hidden by merely observing the dynamics. We present evidence on both synthetic and real-world networks that the frequency spectrum of the wave dynamics can express distinct features in the form of additional frequency peaks. These peaks exhibit dependence on the number of layers taking part in the propagation and thus allowing for the extraction of said number. We show that, in fact, with sufficient observation time, one can fully reconstruct the row-normalized adjacency matrix spectrum. We compare our propositions to a machine learning approach using a wave packet signature method modified for the purposes of multilayer systems.

SOE 20.3 Fri 10:00 ZEU 250

Dynamic network modelling of tumor disease and sepsis — •Eckehard Schöll[1,2,3], Jakub Sawicki[1,2], Rico Berner[1,4], Fenja Drauschke[1], Moritz Alkofer[1], Eckhardt Schneider[5], and Thomas Löser[5] — [1]Institut für Theoretische Physik, TU Berlin — [2]Potsdam Institute for Climate Impact Research — [3]Bernstein Center for Computational Neuroscience Berlin — [4]Institut für Physik, HU Berlin — [5]Institut LOESER, Wettiner Straße 6, 04105 Leipzig

We introduce a novel functional model for tumor disease and sepsis within the framework of complex networks [1,2]. Both diseases are treated in a unified way centered on their effect on the innate immune system. We propose an adaptively coupled two-layer network model of phase oscillators based upon the interaction of parenchymal cells (organ tissue) and immune cells, respectively, and the co-evolutionary dynamics of parenchymal, immune cells, and cytokines. The interaction and information exchange via cytokines between the cells of the parenchyma and the innate immune system is modeled by adaptive coupling weights. The emergent complex collective dynamics is represented with a few fundamental control parameters. Concepts and methods of nonlinear dynamical systems and networks theory, such as partial synchronization and clustering, as well as numerical and statistical methods are applied to describe physiological and pathological states. [1] Sawicki, J., Berner, R., Löser, T., and Schöll, E., Front. Netw. Physiol. 1, 730385 (2022). [2] Berner, R., Sawicki, J., Thiele, M., Löser, T. and Schöll, E., Front. Netw. Physiol. 2, 904480 (2022).

SOE 20.4 Fri 10:15 ZEU 250

Automated chemical reaction network discovery for the simulation of long-timescale degradation of materials — •Joe Gilkes[1], Mark Storr[2], Reinhard J. Maurer[1], and Scott Habershon[1] — [1]University of Warwick, United Kingdom — [2]AWE plc, United Kingdom

Degradation of organic materials such as polymers occurs over time scales of years and involves rare reaction events over an expansive network of elementary processes. Building such networks in order to predict the degradation pathways of these materials requires tackling combinatorially large chemical spaces, and propagating these networks in time becomes considerably more difficult as network size increases. Predicting overall rates by which materials break down requires accurate calculations of the energetic barriers of thousands of elementary reaction steps, which also comes with a substantial computational cost. We present a software framework written in the Julia language for automatically traversing chemical reaction space with an approach that iteratively expands the reaction network through successive re-evaluation of degradation products. We couple this with a machine learning model to predict activation energies. The result is a workflow that can swiftly sample reaction space to create computationally efficient molecular breakdown networks, and then run simulations to predict the long-term stability of these species under a range of environmental conditions. We demonstrate this approach for the example of polyethylene degradation.

15 min. break

SOE 20.5 Fri 10:45 ZEU 250

Exact statistical mechanics of spin models on networks — •Konstantin Klemm — IFISC (CSIC-UIB), Mallorca, Spain

Biological, social, and technical systems are modeled as discrete entities interacting through a network. Predicting these systems' behaviour thus involves the computationally difficult task of solving dynamics on a given complex network. Although networks of interest typically have an abundance of short cycles influencing dynamics, existing computational methods build on the assumption that short cycles are small structural corrections, thus making a *locally tree-like* approximation. Here we show that exact and efficient prediction, exemplified by the Ising and spin glass models, is possible for many networks. We exploit *globally tree-like* structure in the sense of small tree-width. The

full manuscript is available at https://arxiv.org/abs/2111.04766 .

SOE 20.6 Fri 11:00 ZEU 250

Network meta-analysis: A statistical physics perpective — Annabel L. Davies[1] and •Tobias Galla[2] — [1]Bristol Medical School, University of Bristol, Bristol BS8 2PS, UK — [2]IFISC, Instituto de Física Interdisciplinar y Sistemas Complejos (CSIC-UIB), Campus Universitat de les Illes Balears, 07122 Palma de Mallorca, Spain

Network meta-analysis (NMA) is a technique used in medical statistics to combine evidence from multiple medical trials. In particular it allows one to compare treatments that have not been tested directly against each other in a trial. NMA defines an inference and information processing problem on a network of treatment options and trials connecting the treatments. In this talk I will briefly outline the 'NMA problem', and I will then describe how statistical physics can offer useful ideas and tools for this area, including from the theory of complex networks, stochastic modelling and simulation techniques [1]. In particular I will present an analogy we recently established between NMA and random walks on networks [2], and which improves existing algorithms for the estimation of 'proportion contributions' – that is the importance of any one element in the network for the comparison of any two given treatment options. One main aim of the talk is to attract physicists to this timely, interesting and worthwhile area of research.

[1] Annabel L Davies and Tobias Galla, J. Stat. Mech. (2022) 11R001

[2] Annabel L Davies, Theodoros Papakonstantinou, Adriani Nikolakopoulou, Gerta Rücker, Tobias Galla, Statistics in Medicine, 41 (2022) 2091

SOE 20.7 Fri 11:15 ZEU 250

Controlling the coarsening dynamics of ferrogranular networks by means of a vertical magnetic field — •Oksana Bilous[1], Pedro Sánchez[1], Matthias Biersack[2], Ali Lakkis[2], Reinhard Richter[2], and Sofia Kantorovich[1] — [1]University of Vienna — [2]University of Bayreuth

In nature, phase transitions of various nature are significant and often lead to abrupt changes in the macroscopic properties of the material. Here, we address the question if a viscoelastic phase separation (VPS), proposed in 2000 by Hajime Tanaka for dynamically asymmetric mixtures, scales up for a shaken mixture of steel and glass spheres, i.e. for a so-called ferrogranulate when an external magnetic field is applied perpendicular to the plane in which the system is confined. In this contribution we focus on computer simulation. We calculated magnetization, dipolar and steric energies, radial distribution functions, the average number of neighbours and the efficiency of the emerging networks as functions of the simulation time and the values of the external vertical magnetic fields. Our results demonstrate that the network formation can be inhibited by the field perpendicular to the sample via dipole-dipole repulsion the field. These results are qualitatively confirmed by the experimental data.

SOE 20.8 Fri 11:30 ZEU 250

Controlling the coarsening dynamics of ferrogranular networks by means of a vertical magnetic field — •Oksana Bilous[1], Pedro Sánchez[1], Matthias Biersack[2], Ali Lakkis[2], Reinhard Richter[2], and Sofia Kantorovich[1] — [1]Computational and Soft Matter Physics, Faculty of Physics, University of Vienna, 1090 Vienna, Austria — [2]University of Bayreuth, Experimental Physics V, 95447 Bayreuth, Germany

In nature, phase transitions of various nature are significant and often lead to abrupt changes in the macroscopic properties of the material. Here, we address the question if a viscoelastic phase separation (VPS), proposed in 2000 by Hajime Tanaka for dynamically asymmetric mixtures, scales up for a shaken mixture of steel and glass spheres, i.e. for a so-called ferrogranulate when an external magnetic field is applied perpendicular to the plane in which the system is confined. In this contribution we focus on computer simulation. We calculated magnetization, dipolar and steric energies, radial distribution functions, the average number of neighbours and the efficiency of the emerging networks as functions of the simulation time and the values of the external vertical magnetic fields. Our results demonstrate that the network formation can be inhibited by the field perpendicular to the sample via dipole-dipole repulsion the field. These results are qualitatively confirmed by the experimental data.

SOE 21: Financial Markets and Risk Management I

Time: Friday 9:30–10:00 Location: ZEU 260

Invited Talk SOE 21.1 Fri 9:30 ZEU 260

Marginal Stability and Excess volatility in firm networks — •Jean-Philippe Bouchaud — CFM — Academie des Sciences

Will a large economy be stable? Building on Robert May's original argument for large ecosystems, we conjecture that evolutionary and behavioural forces conspire to drive the economy towards marginal stability. We study networks of firms in which inputs for production are not easily substitutable, as in several real-world supply chains. We argue that such networks generically become dysfunctional when their size increases, when the heterogeneity between firms becomes too strong, or when substitutability of their production inputs is reduced. At marginal stability and for large heterogeneities, we find that the distribution of firm sizes develops a power-law tail, as observed empirically. Crises can be triggered by small idiosyncratic shocks, which lead to avalanches of defaults characterized by a power-law distribution of total output losses. This scenario would naturally explain the well-known small shocks, large business cycles puzzle, as anticipated long ago by Bak, Chen, Scheinkman, and Woodford.

SOE 22: Financial Markets and Risk Management II

Time: Friday 10:00–10:45 Location: ZEU 260

SOE 22.1 Fri 10:00 ZEU 260

Microscopic origin of the persistent order flows: microscopic data analysis — Yuki Sato[1] and •Kiyoshi Kanazawa[2] — [1]University of Tsukuba, Tsukuba, Japan — [2]Kyoto University, Kyoto, Japan

In financial markets, it is a stylised fact that the order flow exhibits persistence (or called the long-range correlation, LRC): if you observe a buy (sell) order, you will likely observe a buy (sell) order even in future. This character can be quantified as the power-law decay of the order-sign autocorrelation function $C(\tau) \propto \tau^{-\gamma}$. In explaining the origin of the LRC, the order-splitting hypothesis was proposed as a promising theory. Further, Lillo, Mike, and Farmer proposed a minimal stochastic model of order-splitting traders in 2005, showing a quantitative prediction connecting the relationship between the microscopic and macroscopic behaviour. However, the LMF quantitative prediction has not yet been verified in the lack of appropriate microscopic datasets. In this talk, we solve this long-standing econophysics problem by analysing a huge microscopic dataset in the Tokyo Stock Exchange market. We apply a strategy clustering to identify the set of splitting traders and then measure the power-law exponent α in the metaorder-length distribution for splitting traders. We finally verify the quantitative prediction of the LMF model ($\gamma = \alpha - 1$) by providing the scatterplot between α and γ.

SOE 22.2 Fri 10:15 ZEU 260

Collective Effects Relative to the Collective Market Motion in Financial Markets — •Anton J. Heckens and Thomas Guhr — Universität Duisburg-Essen, Lotharstr. 1, 47048 Duisburg

Financial markets are usually non-stationary and their dynamics is dominated by strong collective effects. We introduce new measures for collectivity derived from covariance and correlation matrices [1]. The largest eigenvalue of covariance and correlation matrices corresponds to the collective motion of the whole system. By removing the collective motion of the system as a whole, we detect a remaining collectivity which corresponds to the industrial sectors. We use risk-phase diagrams to compare the remaining collectivity with the market collectivity. The time evolution of the remaining collectivity shows a remarkable property as a potential precursor for the Lehman crash in 2008. As of 2015/2016 the collectivity in the US stock markets changed fundamentally. It is connected to trend shifts from smaller mean covariances or correlations to larger ones, especially in recent years. Hence, this new kind of collectivity is connected to systemic instabilities which appear more often in recent years according to our new measures.

[1] A. J. Heckens and T. Guhr, New Collectivity Measures for Financial Covariances and Correlations, Physica A: Statistical Mechanics and its Applications 604, 127704 (2022), arXiv:2202.00297.

SOE 22.3 Fri 10:30 ZEU 260

Quantifying the exposure of banking system to the propagation of supply chain shocks in large scale firm-level production networks — •Zlata Tabachová[1], Christian Diem[1], András Borsos[1,2], and Stefan Thurner[1] — [1]Complexity Science Hub Vienna, Josefstädter Strasse 39, A-1080 Vienna, Austria — [2]Central Bank of Hungary, Szabadság tér 9, 1054 Budapest, Hungary

The credit risk assessment is core to sound banking business and financial stability. Traditional credit risk and macro-prudential stress testing models using solely node-level financial information can not take the risk of supply chain (SC) contagion into account, leading to potential underestimation of risks. Recent crises such as pandemic or natural disasters have drastically revealed that the propagation of shocks along SCs can potentially lead to large financial losses of firms. Based on a unique country wide dataset, we simulate how an initial failure of firms spread along the SC leading to additional firm defaults and losses to banks. We first define a financial systemic risk index (FSRI) of a firm that measures financial losses due to the SC disruptions caused by failure of that firm. We show that a small fraction of firms pose sizeable risks to the financial system, affecting up to 16% of overall bank equity. Second, we calculate expected losses, value at risk and expected shortfall of banks with and without supply network contagion. Our simulations show that these risk measures can be underestimated by a factor of 4. This indicates that it is crucial for regulators financial systemic risk assessment to monitor SC shock propagation.

SOE 23: Economic Models

Time: Friday 11:00–12:00 Location: ZEU 260

SOE 23.1 Fri 11:00 ZEU 260

Stochastics in action: how to generate profit by exploiting the inefficiencies of the soccer betting market — •Ralph Stömmer — Private researcher, Ottobrunn, Germany

In economy, markets are denoted as efficient when it is impossible to systematically generate profits which outperform the average. In the past years, the concept has been tested in other domains such as the growing sports betting market. Surprisingly, despite its large size and its level of maturity, sports betting shows traits of inefficiency. The anomalies indicate the existence of strategies which slightly shift betting from a game of chance towards a game of skill.

This presentation shows an example for an inefficiency detected in the German soccer betting TOTO 13er Wette, which is operated by state-run lottery agencies. Gamblers have to guess the outcome (win, draw, loss) of 13 soccer matches listed on a lottery tip. Applying stochastic methods, a recipe is presented to determine tendencies for single match outcomes, currently resulting in hit rates $> 47{,}7\%$. More important, the recipe provides the number of lottery tips required to achieve a specific number of strikes (number of correct match forecasts per lottery tip) for a given level of safety (for instance 99,9%). As additional benefit, a useful approximation is derived with Stirling*s formula to cope with large numbers in hypergeometric distributions, valid under certain constraints.

Overall, the strategy does lead to price expectations exceeding the aggregated lottery fees, resulting in consistent profits.

SOE 23.2 Fri 11:15 ZEU 260

Assessing the impact of extreme weather events on the global market for staple food — •Nkongho Ayuketang Arreyndip[1] and Ebobenow Joseph[2] — [1]Institute of Applied Geosciences, Technical University of Darmstadt, Darmstadt, Germany — [2]Physics Department, University of Buea, Cameroon.

The impacts of increasing extreme weather events under future warming may exacerbate global food insecurity. Assessing the economic impact of these disasters in the agricultural sector is critical for early mitigation planning. We model the impacts of extreme weather events by perturbing the agricultural sectors of some breadbasket regions (USA, EU, and China) with a uniform forcing for both single and concurrent extreme weather event scenarios. We consider forcing data from the 2018 Summer European heatwave. This heatwave simultaneously affected multiple Northern-hemisphere mid-latitude locations. We compute and compare the production and consumption value losses in the corn, rice, wheat, soybean, and other agricultural sectors using the FAO data and an agent-based economic model Acclimate. We show that simultaneous extreme weather events can exacerbate the loss of value of agricultural production relative to single extreme weather events. The highest global repercussion is felt in the rice sector compared to other sectors under study for concurrent extreme events scenarios involving China. Moreover, the global commodity market is hardest hit when regions that are major producers of that commodity are affected by extreme weather events such as corn for the USA, wheat for Europe, rice for Southeast Asia, and soybean for Brazil.

SOE 23.3 Fri 11:30 ZEU 260

Forecasting power grid frequency using transformers — •Hadeer El Ashhab and Benjamin Schäfer — Institute for Au-

tomation and Applied Informatics, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany

The power grid frequency is the central observable in power system control, as it measures the balance of electrical supply and demand. A reliable frequency forecast can facilitate rapid control actions and may thus greatly improve power system stability. Here, we develop a forecasting model based on transformers and investigate its performance on data recorded in different power grids.

SOE 23.4 Fri 11:45 ZEU 260

Measuring the Robustness of Production Networks — •Tobias Reisch[1], Georg Heiler[1,2], Christian Diem[1], Peter Klimek[1,3], and Stefan Thurner[1,3,4] — [1]Complexity Science Hub Vienna, Vienna, Austria — [2]Institute of Information Systems Engineering, TU Wien, Vienna, Austria — [3]Section for Science of Complex Systems, CEMSIIS, Medical University of Vienna, Vienna, Austria — [4]Santa Fe Institute, Santa Fe, NM, USA

In modern economies manufacturing happens typically along supply chains. These supply chains intersect and overlap, forming complex networks of production. The failure of single firms in production networks can cause large disruptions. To assess the robustness of economic networks, we develop a firm-level shock spreading model that takes node-specific production functions into account. We define the Economic Systemic Risk Index (ESRI) of a firm as the size of the production interruptions the firm's initial failure causes. First, we apply the new index to the empirical production network of Hungary based on VAT data. Second, we use mobile phone data to reconstruct the production network of a second country that cannot be disclosed. For both countries we find a core of less than 100 high-systemic risk firms that can affect more than 20% of the respective economy. The high-systemic risk core cannot be identified by firm-size. We discuss the network properties that give rise to the observed patterns of systemic risk. Our results contribute to the broader field of network resilience with the introduction of node specific shock spreading dynamics.