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

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Overview of Invited Talks and Sessions

(Lecture halls MA 001, TC 006, and PTB; Poster D)

Invited Talks

SOE 2.1	Mon	9:30–10:00	MA 001	**Collective emotions and polarization on social media** — •Kristina Lerman
SOE 5.1	Mon	16:15–16:45	MA 001	**Radical Complexity and Bounded Rationality** — •jean-philippe bouchaud
SOE 11.1	Wed	9:30–10:00	MA 001	**Urban scaling laws arise from within-city inequalities** — •Marc Keuschnigg
SOE 20.1	Thu	15:00–15:30	MA 001	**A closer look at the multiple scales of armed conflict** — •Edward Lee
SOE 22.1	Fri	9:30–10:00	MA 001	**Resilience of power grids against extreme events** — •Mehrnaz Anvari

Invited Talks of the joint Symposium SKM Dissertation Prize 2024 (SYSD)

See SYSD for the full program of the symposium.

SYSD 1.1	Mon	9:30–10:00	H 1012	**Nonequilibrium dynamics in constrained quantum many-body systems** — •Johannes Feldmeier
SYSD 1.2	Mon	10:00–10:30	H 1012	**Controlled Manipulation of Magnetic Skyrmions: Generation, Motion and Dynamics** — •Lisa-Marie Kern
SYSD 1.3	Mon	10:30–11:00	H 1012	**Interactions within and between cytoskeletal filaments** — •Charlotta Lorenz
SYSD 1.4	Mon	11:00–11:30	H 1012	**Field theories in nonequilibrium statistical mechanics: from molecules to galaxies** — •Michael te Vrugt
SYSD 1.5	Mon	11:30–12:00	H 1012	**Lightwave control of electrons in graphene** — •Tobias Weitz

Invited Talks of the joint Symposium Diversity and Equality in Physics (SYDE)

See SYDE for the full program of the symposium.

SYDE 1.1	Tue	9:30–10:00	PTB HS HvHB	**Workplace cultures in physics as a game changer for equal opportunities** — •Martina Erlemann
SYDE 1.2	Tue	10:00–10:30	PTB HS HvHB	**Science on the Web: How networks bias academic communication online** — •Agnes Horvat
SYDE 1.3	Tue	10:30–11:00	PTB HS HvHB	**Citation inequity and gendered citation practices in contemporary physics** — •Erin Teich, Jason Kim, Christopher Lynn, Samantha Simon, Andrei Klishin, Karol Szymula, Pragya Srivastava, Lee Bassett, Perry Zurn, Jordan Dworkin, Dani Bassett
SYDE 1.4	Tue	11:15–11:45	PTB HS HvHB	**The Diversity-Innovation Paradox in Science** — •Bas Hofstra
SYDE 1.5	Tue	11:45–12:15	PTB HS HvHB	**Gender and retention patterns among U.S. faculty** — •Aaron Clauset

Invited Talks of the joint Symposium Statistical Physics of Economic and Financial Systems (SYEF)

See SYEF for the full program of the symposium.

SYEF 1.1	Thu	9:30–10:00	H 0105	**Economic Complexity Theory and the General Economic Theory: Applying Synergetics** — •Wei-Bin Zhang
SYEF 1.2	Thu	10:00–10:30	H 0105	**Opinion Formation in the World Trade Network** — •Dima Shepelyansky
SYEF 1.3	Thu	10:30–11:00	H 0105	**Transfer Entropy in financial stock markets** — •Leonidas Sandoval
SYEF 1.4	Thu	11:15–11:45	H 0105	**Statistical-Physics Theory of the Long Memory in Market-Order Flows and its Empirical Validation in the Tokyo Stock Exchange** — •Kiyoshi Kanazawa
SYEF 1.5	Thu	11:45–12:15	H 0105	**Ergodicity Economics and the Insurance Problem** — •Benjamin Skjold, Ole Peters, Colm Connaughton

Invited Talks of the joint Symposium New Trends in Nonequilibrium Physics: Conservation Laws and Nonreciprocal Interactions (SYNP)

See SYNP for the full program of the symposium.

SYNP 1.1	Thu	15:00–15:30	H 0105	**Universality classes of nonequilibrium phase transitions with conservation constraints** — •Walter Zimmermann
SYNP 1.2	Thu	15:30–16:00	H 0105	**The many faces of living chiral crystals** — •Nikta Fakhri
SYNP 1.3	Thu	16:00–16:30	H 0105	**Non-reciprocal pattern formation of conserved fields** — •Fridtjof Brauns, M Cristina Marchetti
SYNP 1.4	Thu	16:45–17:15	H 0105	**Phase transitions and fluctuations of nonreciprocal systems** — •Sarah A.M. Loos
SYNP 1.5	Thu	17:15–17:45	H 0105	**Chiral matters** — •William Irvine

Sessions

SOE 1.1–1.3	Sun	16:00–18:15	H 1012	**Tutorial: Dynamics of Economic and Financial Systems (joint session SOE/TUT)**
SOE 2.1–2.8	Mon	9:30–12:00	MA 001	**Focus Session: Machine Learning for Complex Socio-economic Systems**
SOE 3.1–3.2	Mon	12:15–12:45	MA 001	**Machine Learning**
SOE 4.1–4.4	Mon	15:00–16:00	MA 001	**Collective Dynamics**
SOE 5.1–5.2	Mon	16:15–18:00	MA 001	**Award Session: Young Scientist Award for Socio- and Econophysics (YSA)**
SOE 6.1–6.3	Mon	15:00–16:30	PTB HS HvHB	**Transformation Processes in Scientific Publishing – A Discussion (joint session AGI/SOE/AKjDPG)**
SOE 7.1–7.17	Mon	18:00–20:30	Poster D	**Poster**
SOE 8.1–8.13	Tue	9:30–13:00	BH-N 243	**Machine Learning in Dynamics and Statistical Physics II (joint session DY/SOE)**
SOE 9.1–9.1	Tue	10:00–12:00	MAR 0.011	**Physics Information Services (joint session AGI/SOE)**
SOE 10.1–10.4	Tue	13:15–14:15	PTB HS HvHB	**Sociophysics Approaches to Diversity and Equality (Accompanying Session to the Symposium Diversity and Equality in Physics)**
SOE 11.1–11.1	Wed	9:30–10:00	MA 001	**Urban Scaling**
SOE 12.1–12.4	Wed	10:00–11:00	MA 001	**Urban Systems and Traffic Flow**
SOE 13.1–13.6	Wed	9:30–12:25	MAR 0.011	**Hacky Hour I (joint session AGI/SOE/AKjDPG)**
SOE 14.1–14.6	Wed	11:15–13:05	MA 001	**Focus Session: Dynamics of Socio-ecological Systems**
SOE 15.1–15.2	Wed	15:00–15:30	MA 001	**Concept Transfer between Sciences**
SOE 16.1–16.9	Wed	15:30–18:00	MA 001	**Social Systems, Opinion and Group Dynamics**
SOE 17.1–17.13	Wed	15:00–18:30	TC 006	**Networks: From Topology to Dynamics (joint session SOE/DY)**
SOE 18.1–18.5	Wed	15:00–18:00	MAR 0.011	**Hacky Hour II (joint session AGI/SOE/AKjDPG)**
SOE 19	Wed	18:30–20:00	TC 006	**Members' Assembly**
SOE 20.1–20.4	Thu	15:00–16:45	MA 001	**Focus Session: Statistical Physics of Political Systems**
SOE 21.1–21.4	Thu	17:00–18:00	MA 001	**Computational Social Science**

SOE 22.1–22.1	Fri	9:30–10:00	MA 001	**Power Grids (joint session SOE/DY)**
SOE 23.1–23.9	Fri	9:30–12:15	BH-N 128	**Networks: From Topology to Dynamics (joint session DY/SOE)**
SOE 24.1–24.3	Fri	10:00–10:45	MA 001	**Financial Markets and Risk Management**
SOE 25.1–25.3	Fri	11:00–11:45	MA 001	**Economic Networks**
SOE 26.1–26.2	Fri	11:45–12:15	MA 001	**Mobility**
SOE 27.1–27.2	Fri	12:15–12:45	MA 001	**Sports Studies: Football/Soccer**

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

Wednesday 18:30–20:00 TC 006

- Bericht
- Zukunft und Perspektiven des Fachverbands SOE
- Verschiedenes

SOE 1: Tutorial: Dynamics of Economic and Financial Systems (joint session SOE/TUT)

This tutorial is aimed to introduce concepts and illustrate latest developments on the dynamics of economic and financial systems: non-stationary dynamics of correlations in financial markets, interpretable machine learning applied to electricity price dynamics in the context of transitioning to sustainable energy sources, and financial concepts connecting statistical physics and financial markets.

Participants are invited to continue the deep dive into the above topics at the symposium "Statistical Physics of Economic and Financial Systems (SYEF)" on Thursday at 9:30 (Audimax).

Organized by Eckehard Olbrich (Max Planck Institute for Mathematics in the Sciences, Leipzig, Germany), Fakhteh Ghanbarnejad (Potsdam Institute for Climate Impact Research, Potsdam, Germany), and Philipp Hövel (Saarland University, Germany)

Time: Sunday 16:00–18:15 Location: H 1012

Tutorial SOE 1.1 Sun 16:00 H 1012

Non-Stationary Dynamics of Correlations in Financial Markets — •Anton J. Heckens — Universität Duisburg-Essen, Lotharstr. 1, 47048 Duisburg

Financial markets are strongly correlated complex systems. The internal processes in the markets constantly change, and the external effects on the markets do change as well. This implies that there is no form of equilibrium whatsoever, rather, the financial markets are highly non-stationary. This has a large impact also on the correlations of stock prices. Here, I focus on the non-stationarity of the correlation structure that the market as a whole shows. Obviously, systemic risk and its management are severely affected. However, the non-stationarity itself has a structure because quasi-stationary states emerge, disappear, reemerge. They are the different operational modes of the market, reflecting various changes and restructurings. I will give an overview of data-driven research in this field of econophysics for a general audience interested in complex systems, not exclusively for experts.

Tutorial SOE 1.2 Sun 16:45 H 1012

Exploring electricity price dynamics with interpretable machine learning — •Benjamin Schäfer[1] and Dirk Witthaut[2] — [1]Karlsruhe Institute of Technology (KIT) — [2]Research Center Jülich (FZJ)

Mitigation of climate change requires a fundamental transformation of our energy system. Power plants based on fossil fuels must be replaced by renewable power sources, such as wind and solar power. This energy transition (Energiewende) towards a sustainable energy system raises numerous complex challenges, as power generation becomes more uncertain, while simultaneously more operational data becomes available. Hence, data-driven approaches have become feasible and even necessary to fully understand the energy systems of today and tomorrow across all scales.

Machine learning and artificial intelligence can handle these enormous amounts of data but need to do so in a transparent way. Obtaining classifications or forecasts without explanations limits their use severely.

Within this tutorial, we will discuss the uses of machine learning in energy systems and review approaches to make initial 'black box' models transparent. As an application, we will consider electricity markets and price dynamics.

Tutorial SOE 1.3 Sun 17:30 H 1012

Rien ne va plus: Seemingly perfect bets and optimal portfolios, broken ergodicity, washed-out stylized facts and financial death by Black-Scholes option pricing — •Jan Nagler — Centre for Human and Machine Intelligence, Frankfurt

Let's walk the line, together, in this tutorial: From Kelly-optimal bets, blindfolded trading, volatility drag, and ergodicity, to universal power laws in financial markets. On the electronic blackboard, we will develop concepts in statistical physics suited for our guaranteed financial ruin, chasing a fundamental understanding of some concepts and how they are linked together.

SOE 2: Focus Session: Machine Learning for Complex Socio-economic Systems

The intersection of physics and machine learning presents a promising avenue for investigating the structure and dynamics of complex socio-economic systems, e.g., by processing vast and diverse datasets. By incorporating physics-based insights and approaches into machine learning algorithms, a more comprehensive understanding of the underlying mechanisms that drive economic and social phenomena can be achieved, paving the way for more informed policy decisions, risk assessments, and the identification of emergent patterns critical for navigating the complexities of modern societies.
With this focus session, we aim to highlight recent results and discuss trends in this interdisciplinary field.

Organized by Ingo Scholtes (Universität Würzburg, Germany) and Philipp Hövel (Saarland University, Germany)

Time: Monday 9:30–12:00 Location: MA 001

Invited Talk SOE 2.1 Mon 9:30 MA 001

Collective emotions and polarization on social media — •Kristina Lerman — USC Information Sciences Institute

Social media has linked people on a global scale, transforming how we communicate and interact by sharing not only ideas, but also emotions and feelings. The massive interconnectedness created new vulnerabilities in the form of societal conflict, mistrust and deteriorating mental health. I describe the tools my group developed to recognize emotions in online discussions at scale and show how they help study collective social phenomena. One such phenomenon is affective polarization, which means that political factions not only disagree on policy issues but also dislike and distrust each other. I show that affective polarization exists in online interactions, with same-ideology users, e.g., liberals or conservatives, expressing warmer feelings toward each other than to opposite-ideology users. I also show that emotions structure social networks: interactions between users who are close to each other within the network elicit positive emotions, while more distant interactions have more anger and disgust. These findings are consistent across diverse datasets and languages, spanning discussions on topics such as the Covid-19 pandemic, abortion, and the 2017 French Election. Our research provides new insights into the complex social dynamics of collective emotions with implications for political discourse.

SOE 2.2 Mon 10:00 MA 001

Collaboration, not polarization: A Relational Graph Convolutional Network (RGCN) model to disentangle active

and passive cosponsorship in the U.S. Congress — •Frank Schweitzer — Chair of Systems Design, ETH Zurich, Switzerland

Public coverage fuels the impression of increasing elite polarization and paralysis in the U.S. Congress. The other half of the truth is the fact that, e.g., more than 15.000 bills were introduced to the 115th U.S. Congress (2017-2019). Legislators from both parties cosponsor these bills actively, e.g. by drafting the bill, or passively, by their signature. To identify their motivation, we have curated and analyzed a large data set containing bill texts, legislator speeches, and cosponsorship data for all bills from the 112th to 115th U.S. Congress. We use Natural Language Processing to obtain contextual embeddings of bills and speeches and to extract a citation network between legislators. We then develop and train a RGCN to predict active and passive cosponsorship relations. Our results demonstrate that the two types of cosponsorship are driven by two different motivations: the backing of political colleagues and the backing of the bill's content.

Reference: G. Russo, C. Gote, L. Brandenberger, S. Schlosser, F. Schweitzer: Helping a Friend or Supporting a Cause? Disentangling Active and Passive Cosponsorship in the U.S. Congress, Proc. 61st Ann. Meeting Assoc. Comput. Linguistics, Vol. 1: Long Papers, pp. 2952-2969 (2023) doi:10.18653/v1/2023.acl-long.166

SOE 2.3 Mon 10:15 MA 001

Inferring the Utility from Optimal Behaviour in an Epidemic using Neural Networks — •Mark Lynch[1], Matthew Turner[2], John Molina[3], Simon Schnyder[4], and Ryoichi Yamamoto[3] — [1]Mathematics of Systems CDT, University of Warwick, Coventry, CV4 7AL, UK — [2]Department of Physics, University of Warwick, Coventry, CV4 7AL, UK — [3]Department of Chemical Engineering, Kyoto University, Kyoto 615-8510, Japan — [4]Institute of Industrial Science, The University of Tokyo, Tokyo 153-8455, Japan

Many dynamical systems can be represented as differential games, where different interacting individuals are each seeking to simultaneously maximise their own utility function by modifying their behaviour. Here we consider rational individuals socially distancing in an epidemic. Given a specified form of utility, one can solve the related constrained optimal control problem to derive optimal system dynamics that result in the maximal utilities for each individual.

We seek to use Machine Learning techniques to solve the inverse problem, that of inferring some unknown utility function that is being optimised by given system dynamics. Usually this has been solved by assuming some fixed form of the utility. We propose a more ambitious machine learning framework that is able to infer this hidden utility assuming no knowledge of the form of this function. The main issue to address is how to perform the learning of such a function without knowledge of the hidden variables required to define the underlying constrained optimization problem (i.e., the Lagrange multipliers).

Topical Talk SOE 2.4 Mon 10:30 MA 001

Prediction of processes on networks — •Piet Van Mieghem — Delft University of Technology, Delft, The Netherlands

I will talk about two related, but different problems in network science in ref 1 and ref 2 below. First (ref 1), given the nodal states of a process (e.g. a spreading process) on a fixed network over a time interval $[0, T]$, can we predict that process at the time $t > T$? Can we unravel the topology of the fixed network? Second (ref. 2), we consider a temporal network that has evolved over a time, defined by a sequence of consecutive graphs $\{G_1, G_2, \ldots, G_T\}$. We present a linear system identification method that is able to exactly emulate the sequence $\{G_1, G_2, \ldots, G_T\}$. Thus, our method reproduces the same outcomes of the process that determined the temporal graph at times in the past. Can our method predict the temporal graph at G_t with $t > T$?

References: 1) Prasse, B. and P. Van Mieghem, 2022, "Predicting network dynamics without requiring the knowledge of the interaction graph", Proceedings of the National Academy of Sciences (PNAS), Vol. 119, No. 44, e2205517119. (DOI:pnas.2205517119) 2) Shvydun, S. and P. Van Mieghem, 2023, "System Identification for Temporal Networks", IEEE Transactions on Network Science and Engineering, to appear. (DOI:10.1109/TNSE.2023.3333007)

10 min. break

SOE 2.5 Mon 11:00 MA 001

Towards a complex systems theory of attention? — •Claudius Gros — Institute for Theoretical Physics, Goethe University Frankfurt

The attention mechanism is at the core of the current AI hype. It powers transformers and hence all modern large language models, such as GPT or LLaMA. Classical deep learning model are optimized for information processing, whereas attention allows for information routing. It is argued, that the modeling techniques used complex systems theory and physics can contribute to an understanding of what is going on inside transformers. On this background an introduction to attention is presented.

SOE 2.6 Mon 11:15 MA 001

Using Causality-Aware Graph Neural Networks to Predict Temporal Centralities in Dynamic Graphs — •Franziska Heeg and Ingo Scholtes — Julius-Maximilians-Universität Würzburg, Chair of Machine Learning for Complex Networks, CAIDAS

Node centralities play a pivotal role in network science, social network analysis, and recommender systems. In temporal data, static path-based centralities like closeness or betweenness can give misleading results about the true importance of nodes in a temporal graph. To address this issue, temporal generalizations of betweenness and closeness have been defined that are based on the shortest time-respecting paths between pairs of nodes. However, a major issue of those generalizations is that the calculation of such paths is computationally expensive. Addressing this issue, we study the application of De Bruijn Graph Neural Net- works (DBGNN), a causality-aware graph neural network architecture, to predict temporal path-based centralities in time series data. We experimentally evaluate our approach in 13 temporal graphs from biological and social systems and show that it considerably improves the prediction of both betweenness and closeness centrality compared to a static Graph Convolutional Neural Network.

SOE 2.7 Mon 11:30 MA 001

How much do nodes in socioeconomic networks rely on their neighborhood? — •Nimrah Mustafa and Rebekka Burkholz — Stuhlsatzenhaus 5, 66123 Saarbrücken, Germany.

A fundamental question in complex network science is to which degree a node's state is determined by network effects, as interactions with network neighbors may change the node's state. To model the associated process that evolves on the network, Graph Attention Networks (GATs) provide a flexible approach to learning heterogeneous dependencies from data. In practice, however, we find that GATs are limited in their ability to represent such processes due to constrained trainability and failure to recognize the relevance of the neighborhood for a node's state in a task-adaptive manner. We identify the root cause for these phenomena by deriving a conservation law that follows from Noether's theorem. Based on this law, we show how constraints on parameter norms that lead to conditions unfavorable for learning can be mitigated by an initialization scheme and architectural variation of GAT that instead facilitate better trainability. This, in turn, enables us to leverage GATs to identify the degree to which nodes in socioeconomic networks rely on their neighborhood. From a technical perspective, this also allows us to model long-range dependencies and more complex, nonlinear interactions between nodes via deeper GATs.

SOE 2.8 Mon 11:45 MA 001

The Map Equation Goes Neural — •Chester Tan[1], Christopher Blöcker[1], and Ingo Scholtes[1,2] — [1]Chair of Machine Learning for Complex Networks, Center for Artificial Intelligence and Data Science, Julius-Maximilians-Universität Würzburg, Germany — [2]Data Analytics Group, Department of Informatics, Zürich University, Switzerland

Community detection has a long history in network science, but typically relies on optimising objective functions with custom-tailored search algorithms, not leveraging recent advances in deep learning, particularly from graph neural networks. In this paper, we narrow this gap between the deep learning and network science communities. We consider the map equation, an information-theoretic objective function for unsupervised community detection. Expressing it in a fully differentiable tensor form that produces soft cluster assignments, we optimise the map equation with deep learning through gradient descent. The reformulated map equation is a loss function compatible with any graph neural network architecture, enabling flexible clustering and graph pooling that clusters both graph structure and data features in an end-to-end way, automatically finding an optimum number of clusters without explicit regularisation by following the minimum description length principle. Our results show that our approach achieves competitive performance against baselines, naturally detects overlapping communities, and avoids over-partitioning sparse graphs.

SOE 3: Machine Learning

Time: Monday 12:15–12:45 Location: MA 001

SOE 3.1 Mon 12:15 MA 001

Mapping news sharing on Twitter: A bottom-up approach based on network embeddings — •Felix Gaisbauer[1], Armin Pournaki[2,3], and Jakob Ohme[1] — [1]Weizenbaum-Institut für die vernetzte Gesellschaft e.V. — [2]Max-Planck-Institut für Mathematik in den Naturwissenschaften — [3]medialab, Sciences Po

News sharing on digital platforms is a crucial activity that determines the digital spaces millions of users navigate. Yet, we know little about general patterns of news sharing. We utilize a combination of three data sources - which we combine via network embedding methods and automated text analysis - to elucidate the extent to which sharing patterns of certain political user groups consist of specific outlets/topics/articles or have unknown diversity.

We collected all tweets which contained a link to one of 26 legacy or alternative news outlets for March 2023 (2.5M tweets). The full texts of the articles were crawled if available (30K texts); articles were assigned topics with a paragraph-based BERTopic model. The follower network of German MPs was also collected. This was used to embed followers and MPs in a latent political space using correspondence analysis.

This allows to investigate which types of articles are shared in which political region(s) of the latent space. To explore this systematically, we apply measures of collective sharing breadth and depth in the embeddings with respect to specific outlets, topics or single news events. All in all, this enables a previously unexplored bottom-up view on news sharing on Twitter.

SOE 3.2 Mon 12:30 MA 001

Enhancing Chronic Disease Management through machine learning-based analysis of population Data — •Anna Nitschke[1], Carlos Brandl[1], Jannis Demel[1], Jonathan Berthold[1], Carola Behr[1], Till Bärnighausen[2], and Matthias Weidemüller[1] — [1]Physikalisches Institut, Heidelberg University, Germany — [2]Heidelberg Institute of Global Health (HIGH), Heidelberg University, Germany

To achieve decisive progress in diagnosis and treatment of non-infectious chronic diseases, focusing on significant conditions like diabetes, we employ machine learning techniques on publicly available census data. Together with the Heidelberg Institute for Global Health, our aim is to make precise and reliable predictions about which people in which region are likely to be affected by these diseases. Using machine learning allows us to analyse individual needs and healthcare requirements. We exemplify this for India on a publicly available census dataset and will present how those predictions can help us to extract valuable insights from social and medical perspectives. Additionally they enable early identification of high-risk groups and regions, as well as improved utilisation of scarce healthcare resources.

SOE 4: Collective Dynamics

Time: Monday 15:00–16:00 Location: MA 001

SOE 4.1 Mon 15:00 MA 001

Resetting random walks may underlie movements of foraging ants — •Valentin Lecheval[1,2,4], Elva JH Robinson[3], and Richard P Mann[4] — [1]Institute for Theoretical Biology, Department of Biology, Humboldt Universität zu Berlin, Berlin, Germany — [2]Science of Intelligence, Research Cluster of Excellence, Berlin, Germany — [3]Department of Biology, University of York, York, UK — [4]School of Mathematics, University of Leeds, Leeds, UK

Animals that carry resources back to a particular site are called central place foragers, and they generally have a nest to which they bring resources. Many ant species are central place foragers, living in a nest and exploiting the surrounding environment. It is however unclear how their exploration behaviour relates to the emerging exploited area. Ants are a great opportunity to study the emergence of foraging territory from individual movements, given the potentially large number of scouting workers involved. Here, we introduce a resetting random walk model to depict ant exploration movements. We investigate various resetting mechanisms by varying how the probability to return to the nest changes with the number of foraging trips. We compare the macroscopic predictions to laboratory and field data. This reveals that the probability for scouting ants to return to their nest decreases as the number of foraging trips increases, resulting in scouts going further away as the number of foraging trips increases. Our findings highlight the importance of resetting random walk models for central place foragers and nurtures novel questions regarding the behaviour of ants.

SOE 4.2 Mon 15:15 MA 001

Impact of Temperature Change on Malaria Outbreaks — Morteza Afraz[1] and •Fakhteh Ghanbarnejad[2] — [1]Sharif University of Technology, Tehran, Iran — [2]Potsdam Institute for Climate Impact Research, Potsdam, Germany

Malaria, a vector-borne disease, remains a critical global health concern, particularly amid shifting climate patterns. This research delves into the intricate interplay between temperature variations and the dynamics of malaria transmission through an extensive analysis of deterministic mathematical models such as Ross-MacDonald and Parham and Michael models. Thus, we study the impact of temperature change on models' predictions, specifically the outbreak of malaria within populations. We explore fixed points, assessing their stability across varying temperature regimes, gauging the disease's sensitivity to temperature fluctuations, conducting bifurcation analyses, and elucidating phase transitions observable within these models. We employ empirical field data for temperature dependency and discuss which model's output aligns better with observed epidemiological trends. Finally, we present our predictions for the landscape of malaria transmission in the face of climate variations for different regions.

SOE 4.3 Mon 15:30 MA 001

Context-dependent self-tuning of distance to criticality in large fish shoals — •Yunus Sevinchan[1,2], David Bierbach[1,3], Carla Vollmoeller[1,2], Korbinian Pacher[3], Jens Krause[1,3], and Pawel Romanczuk[1,2] — [1]Science of Intelligence, TU Berlin — [2]Institute for Theoretical Biology, HU Berlin — [3]Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Berlin

Collective biological systems – such as animal groups or neuronal networks – are presumed to operate at or near critical points at which they exhibit maximal sensitivity towards environmental cues.

We have studied large fish shoals of sulphur mollies (*Poecilia sulphuraria*) in their natural ecosystem in Southern Mexico, which perform collective diving cascades as a response to predation resulting in wave-like patterns on the water surface. We previously found these shoals to operate close to criticality. However, it remains an open question by which mechanisms they adapt to variations in their biotic and abiotic environment while balancing the trade-off between sensitivity and robustness towards external cues.

By analyzing a large video dataset of surface waves originating in response to synthetic stimuli or bird attacks, we relate wave characteristics to the macroscopic state of the shoal and its environment (e.g. physico-chemical water parameters). With these empirical observations informing an agent-based model, we further study possible mechanisms for self-tuning of distance to criticality. Our results help to better understand how changes in individual-level behavior enable collective-level adaptations to varying ecological contexts.

SOE 4.4 Mon 15:45 MA 001

Epidemic processes on self-propelled particles — •Jorge P. Rodríguez[1], Matteo Paoluzzi[2], Demian Levis[2,3], and Michele Starnini[4,5] — [1]Instituto de Física Interdisciplinar y Sistemas Complejos (IFISC), CSIC-UIB, Palma de Mallorca (Spain) — [2]Departament de Física de la Matèria Condensada, Universitat de Barcelona, Barcelona, Spain — [3]Universitat de Barcelona Institute of Com-

plex Systems (UBICS), Barcelona, Spain — [4]CENTAI, Torino, Italy — [5]Departament de Física, Universitat Politécnica de Catalunya, Barcelona, Spain

Spreading processes often require spatial proximity between agents. The stationary state of spreading dynamics in a system of mobile agents thus depends on the interplay between the time and length scales involved in the spreading and the movement dynamics. We analyze the steady properties resulting from such interplay in a simple model describing epidemic spreading (Susceptible-Infected-Susceptible) on self-propelled particles (Run-and-Tumble). Proximity between particles shapes interactions, with the particle movement modifying the relative distances in the system. We analyze this problem from a continuum description of the system, validating those results by numerical simulations of an agent-based model. Focusing our attention on the diffusive long-time regime, movement changes qualitatively the nature of the epidemic transition. Indeed, the transition becomes of the mean-field type for agents diffusing in one, two and three dimensions, while, in the absence of motion, the epidemic outbreak depends on the dimension of the underlying static network.

SOE 5: Award Session: Young Scientist Award for Socio- and Econophysics (YSA)

Time: Monday 16:15–18:00 Location: MA 001

Invited Talk SOE 5.1 Mon 16:15 MA 001
Radical Complexity and Bounded Rationality — •Jean-Philippe Bouchaud — CFM, 23 rue de l'Université, 75007 Paris

Traditional economic theory assumes that agents are rational, or at least that they learn to be after interacting with their environment. As a schematic model of the complexity economic agents are confronted with, we introduce the "SK-game", a discrete time binary choice model inspired from mean-field spin-glasses. We show that even in a completely static environment, agents are unable to learn collectively optimal strategies. This is either because the learning process gets trapped by a sub-optimal fixed point, or because learning never converges and leads to a never ending evolution of agents intentions. Contrarily to the hope that learning might save the standard rational expectation framework in economics, we argue that complex situations are generically unlearnable and agents must do with "satisficing" solutions, as argued long ago by Herbert Simon.

Presentation of the Award to the Awardee

Prize Talk SOE 5.2 Mon 17:00 MA 001
Information and Infections Dynamics in Social Networks — •Viola Priesemann — Max Planck Institute for Dynamics and Self-Organization — Georg August University Göttingen

Both information and misinformation spread impact societal dynamics. However, the mechanisms and extent are unclear. To study the impact of information spread on contact behavior, the recent pandemic provided a prime data set. In a model, we show that complex, even chaotic infection dynamics can emerge if one assumes that the population reacts to high case numbers by mitigating the spread of the disease, and vice versa. Interestingly, this novel, complex endemic regime can optimize the cost of mitigation and infections, pointing to its relevance for endemic disease dynamics. In addition, we analyzed the information spread in our Telegram dataset (2.4 billion messages). The different channels were clearly clustered, and the topics and message frequencies showed pronounced relations to pandemic events. Together, these studies provide a novel window into the entangled dynamics of information spread, opinion and human behavior.

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

SOE 6: Transformation Processes in Scientific Publishing – A Discussion (joint session AGI/SOE/AKjDPG)

Time: Monday 15:00–16:30 Location: PTB HS HvHB

Invited Talk SOE 6.1 Mon 15:00 PTB HS HvHB
The future of scientific publishing, for and by scientists — •Roderich Moessner — Deutsche Physikalische Gesellschaft — MPIPKS Dresden

The landscape of scientific publishing has been very dynamic in recent years, in large part driven by a desire to transition into open access publication formats. This has raised, or refocused attention on, a number of broader issues concerning how we as scientists would like to interact with each other, and with the outside world.

In a position paper on the subject, the DPG has attempted to take stock of where we stand, what the issues are, and what the options for a way forward may be. This talk aims to introduce and give an overview over what we believe are the central issues from the point of view of practising scientists.

Invited Talk SOE 6.2 Mon 15:15 PTB HS HvHB
On the status of Open Access publishing in Germany — •Gerard Meijer — Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin

In the framework of the DEAL-project, the scientific community in Germany is pursuing the goal of transforming the academic publishing system from a subscription-based system, in which publications are locked behind a paywall, to a system where there is Open Access to scientific publications. OA increases the visibility of the published research, which is of direct benefit to the authors who want their research findings to be known and acknowledged. In OA publishing the copyrights remain where these belong, namely with the authors. Openly accessible publications can be read, reviewed and used more widely by other researchers. This increases the quality of research and accelerates scientific progress. OA makes scientific knowledge more widely available outside of the scientific community and lowers the threshold for various transfer activities. This increases the social effectiveness of (publicly funded) research.

In spite of all these advantages, which are apart from the cost-savings for Germany as a whole, the DEAL-project is viewed upon critically by many. In this short entrance statement, I will therefore focus on the factual achievements.

Discussion SOE 6.3 Mon 15:30 PTB HS HvHB
The Future of Our Publication System — •Uwe Kahlert[1], Vivienne Leidel[2], Roderich Moessner[3], and Gerard Meijer[4] — [1]RWTH Aachen University — [2]DPG — [3]DPG, MPIKS Dresden — [4]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin

Over the last two decades discussions continued on how the scientific publication system should and could be transformed to better reflect the demands of scientists. The national DEAL initiative negotiated agreements with three major publishers to initially advance this transformation at a national level. After a short introduction on these topics by representatives of the DPG and DEAL in the previous talks we want to discuss with them what changes this means for scientists and how the transformation can or should continue.

SOE 7: Poster

Time: Monday 18:00–20:30 Location: Poster D

SOE 7.1 Mon 18:00 Poster D

Bayesian Detection of Mesoscale Structures in Pathway Data on Graphs — •Vincenzo Perri[1], Luka V. Petrović[2], and Ingo Scholtes[1] — [1]University of Würzburg, Würzburg, Germany — [2]University of Zürich, Zürich, Switzerland

Mesoscale structures are an integral part of the abstraction and analysis of complex systems. For example, they can represent communities in social or citation networks, roles in corporate interactions, or core-periphery structures in transportation networks. Many methods to detect mesoscale structures are founded on the assumption that the interactions are independent. However, when complex systems are dynamic, the dynamics of interactions can invalidate this assumption and jeopardize the analysis. In this work, we derive a Bayesian approach that simultaneously models the optimal partitioning of nodes in groups and the optimal higher-order network dynamics between the groups. This model can capture mesoscale structures with higher-order patterns, which allows us to coarse grain pathway data, and analyse them at the level of groups of nodes. In synthetic data, we show that our method can recover both standard static patterns and dynamic patterns invisible to baselines. In empirical data, we find higher-order patterns at group levels, underlying the practical importance of our method. Finally, we demonstrate the interpretability of our method in an application on a language corpus and detection of vowel-consonant dynamics. From a broader perspective, our approach allows interpretable analysis of a complex system and facilitates our understanding of its structural and temporal patterns.

SOE 7.2 Mon 18:00 Poster D

Describing the Urban Heat Island effect with every-pair interactions — Yunfei Li[1], Fabiano L. Ribeiro[2], Bin Zhou[3], and •Diego Rybski[1] — [1]Potsdam Institute for Climate Impact Research (PIK), P.O. Box 601203, 14412 Potsdam, Germany — [2]Department of Physics (DFI), Federal University of Lavras (UFLA), Lavras MG, Brazil — [3]Faculty of Medicine, University of Augsburg, Augsburg, Germany

At the macroscopic scale, city size represents the most important determinant of the urban heat island (UHI) intensity. We propose an every-pair-interaction model, which incorporates urban form in a meaningful manner, to characterize the UHI intensity. We extract surface UHI intensity estimates from remote sensing data and employ the fractal dimension (obtained from urban land cover data) to characterize the urban form. Fitting the every-pair-interaction model to the data, we find that it performs better than a simple linear combination of logarithmic size and fractal dimension. Interestingly, the every-pair-interaction model represents a generalization as it includes (a) power-law, (b) logarithmic, and (c) saturating size dependence. Our theoretical framework indicates that the UHI intensity saturates with size at least for the considered surface temperature data.

SOE 7.3 Mon 18:00 Poster D

Rank dynamics in compartmental voter model — •Justas Kvedaravicius[1] and Aleksejus Kononovicius[2] — [1]Vilnius university, Faculty of Physics, Vilnius, Lithuania — [2]Vilnius university, Institute of Theoretical Physics and Astronomy, Vilnius, Lithuania

Traditional approaches to modelling opinion dynamics focus on temporal evolution of the system. While this approach is easy to model, it proves difficult to validate using empirical data, as it is more detailed in spatial resolutions rather than temporal ones. Statistics of data at various resolutions (scales) can reveal regularity and randomness in the spatial distributions. Attempts to define spatial and temporal dynamics have been suggested in [1, 2].

For models imbued with spatial distributions rank-size description is preferable to the timeseries point of view. We employ a generalization of rank-size description [3] to analyze dynamics of the compartmental voter model and approximate the dynamics using Fokker-Planck equation.

[1] Kononovicius, J. Stat. Mech. 2019: 073402 (2019). [2] Fernandez-Gracia et al., Phys. Rev. Lett. 112: 158701 (2014). [3] Iniguez et al., Nat. Commun. 13: 1646 (2022).

SOE 7.4 Mon 18:00 Poster D

Quantifying Tipping Risks in Power Grids and beyond — •Martin Hessler[1,2] and Oliver Kamps[2] — [1]University of Münster, Institute of Theoretical Physics, Germany — [2]Center for Nonlinear Science, Münster, Germany

Critical transitions, ubiquitous in nature and technology, necessitate anticipation to avert adverse outcomes. While many studies focus on bifurcation-induced tipping, where a control parameter change leads to destabilization, alternative scenarios are conceivable, e.g. noise-induced tipping by an increasing noise level in a multi-stable system. Although the generating mechanisms can be different, the observed time series can exhibit similar characteristics. Therefore, we propose a Bayesian Langevin approach (BL-estimation), implemented in an open-source tool, which is capable of quantifying both deterministic and intrinsic stochastic dynamics simultaneously. We analyse two bus voltage frequency time series of the historic North America Western Interconnection blackout on 10th August 1996. Our results unveil the intricate interplay of changing resilience and noise influence. A comparison with the blackout's timeline supports our frequency dynamics Langevin model, with the BL-estimation indicating a permanent grid state change already two minutes before the officially defined triggering event. A tree-related high impedance fault or sudden load increases may serve as earlier triggers during this event, as suggested by our findings. This study underscores the importance of distinguishing destabilizing factors for a reliable anticipation of critical transitions, offering a tool for better understanding such events across various disciplines.

SOE 7.5 Mon 18:00 Poster D

Inclusion of Social Norms and Groups in a Stylised Social-Ecological Multilayer Network Model restructures safe operating spaces in renewable resource management — •Max Bechthold and Jonathan Donges — Potsdam Institute for Climate Impact Research, Telegrafenberg A 31, 14473 Potsdam

Social norms are a main socio-cultural influence on human behaviour, one of the primary drivers of climate change in the Anthropocene. As a potential social tipping element, they are suggested to play a pivotal role in politics and governance and thus form a possible intervention point for global-scale collective action problems in the World-Earth system. This contribution presents a multi-level network framework for conceptualised social norms. It focuses on a complex contagion process that mimics the presence of social norms, which are further divided into the sub-concepts of descriptive and injunctive norms. The framework also incorporates social groups as an important feature. This allows to capture cases in which, for example, social groups may include norms into their identity, accelerating or slowing down the uptake of new social norms in their members. Building upon this framework, a model with coupled social-ecological dynamics and a closed feedback loop is constructed in the copan:CORE framework for world-Earth modelling. The results of computational investigation of the influence of social norms, social groups and social inertia in the model and the resulting safe operating spaces for management of a renewable resource are presented in this contribution.

SOE 7.6 Mon 18:00 Poster D

Forecasting confidence regions for marine animal movement with machine learning. — •Jorge M. Hernandez[1], Jorge P. Rodriguez[1], Ana M. M. Sequeira[2], and Victor M. Eguiluz[3] — [1]Institute for Cross-Disciplinary Physics and Complex Systems - IFISC (UIB-CSIC) — [2]Australian National University (ANU) — [3]Basque Centre for Climate Change (BC3)

Oceans, the largest ecosystems and crucial climate regulators, are environments where a diversity of human activities threaten marine life. To achieve effective conservation, it is crucial to comprehend the movement patterns of these animals. Home to around 36,000 species among marine mammals, fish, birds, and penguins, these habitats present a scientific challenge in movement forecasting.

Our study harnesses the Temporal Fusion Transformer (TFT) to predict marine animal movements, leveraging a dataset of 13,000 trajectories from over 100 species. Unlike traditional methods aiming for precise location prediction, our model determines a confidence region where an animal is likely to be, using quantiles and the quantile loss function. We emphasize model explainability. The analysis of the attention mechanism to understand data influence, shows a focus on recent and five-day prior data. SHAP values reveal key environmental

factors like bathymetry, temperature, and wave characteristics influencing predictions.

This research aids in understanding animal movement, improving navigation safety, and enriching ecological research. Future developments aim to create more accurate elipsoidal confidence regions.

SOE 7.7 Mon 18:00 Poster D

Disaggregating temporal properties of individual income dynamics using first passage under resetting approach — •Petar Jolakoski[1,2], Arnab Pal[3,4], Trifce Sandev[1,5,6], Ljupco Kocarev[1], Ralf Metzler[5,7], and Viktor Stojkoski[6,8] — [1]Macedonian Academy of Sciences and Arts, Skopje, Macedonia — [2]Brainster Next College, Skopje, Macedonia — [3]The Institute of Mathematical Sciences, Chennai, India — [4]Homi Bhabha National Institute, Mumbai, India — [5]Institute of Physics & Astronomy, Potsdam, Germany — [6]Ss. Cyril and Methodius University in Skopje, Macedonia — [7]Asia Pacific Centre for Theoretical Physics, Pohang, Republic of Korea — [8]Center for Collective Learning, ANITI, University of Toulouse, France

A comprehensive understanding of individual income dynamics is crucial for addressing the question of whether it is possible to improve one's income status over the course of a typical working life. This central question essentially involves observing an individual's status and its transition between two points: the current income and the desired income. These temporal changes are usually studied by using income transition matrices which only provide *aggregated quantities* for the time properties of income. As a result, we are unable to differentiate the fortunes of workers that are members of the same quantile. To bridge this critical gap, we build an analytical framework for *disaggregating* the MFPT to the *level of an individual worker* in the economy. We exploit the properties of an established stochastic process used for modelling income dynamics namely the geometric BM with resetting.

SOE 7.8 Mon 18:00 Poster D

Ising model of binary election with a split society phase — Olivier Devauchelle[1], Piotr Szymczak[2], and •Piotr Nowakowski[3,4] — [1]Université Paris Cité, Institut de Physique du Globe de Paris, Paris, France — [2]Institute of Theoretical Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland — [3]Group for Computational Life Sciences, Division of Physical Chemistry, Ruđer Bošković Institute, Zagreb, Croatia — [4]Max Planck Institute for Intelligent Systems, Stuttgart, Germany

In modern democracies, the outcome of elections and referendums is often remarkably tight. To explain this phenomenon we propose a simple model of binary elections based on an Ising model of voters with ferromagnetic coupling of the neighbors and an additional weak antiferromagnetic coupling of every voter to the opinion poll. The model exhibits a new split society phase which properties seems to resemble those observed in some real binary elections: the voters are geographically separated into two groups (domains) with opposite opinions, the total result is close to 50%-50%, and an interface between the domains is located along the lines where the coupling between neighboring voters is reduced (like borders of cities, natural barriers, or historical borders between countries). We discuss the physical properties of our model and study the conditions necessary for the system to be in the split society phase. By analyzing the results of binary elections in various countries we are able to roughly estimate the values of the parameters describing our model.

SOE 7.9 Mon 18:00 Poster D

Emergent inequalities in a primitive agent-based good-exchange model — •Nirbhay Patil[1,2], Jean-Pierre Nadal[1,3], and Jean-Philippe Bouchaud[2,4] — [1]Ecole Normale Superieure, Paris — [2]Chair Econophysix, Ecole Polytechnique, Massy-Palaisseau — [3]École des hautes études en sciences sociales, Paris — [4]Capital Fund Management, Paris

Rising inequalities around the globe bring into question our economic systems, and the source of these inequalities. Here we try to understand the economy using an agent-based model where each entity is simultaneously producing and consuming goods, like a farmer or a firm.

To optimize utility, agents buy products in decreasing order of utility per unit price till they buy everything they can. Utilities are drawn from random distributions to reflect personal tastes and convenience. To optimise sales, agents adjust prices by comparing supply and demand. This is a complete description of the model, which we then simplify in various ways to make it analytically tractable. We come up with ways to find the stability of the resulting system that constitutes a new ensemble of random matrices not studied before.

We find that the system exhibits a phase transition between states of equality and strong inequalities based on the production capacity of each person. For higher production values this society becomes extremely unequal. We explore ways to alleviate poverty in this model and whether they have real life significance.

SOE 7.10 Mon 18:00 Poster D

Predicting the Dynamics of Behavioral Contagion in Human Groups with an Increment Drift-Diffusion Model — •Maryam Karimian[1,2,3], Fabio Reeh[1,2], and Pawel Romanczuk[1,2,3] — [1]Institute for Theoretical Biology, Humboldt-Universität zu Berlin — [2]Science of Intelligence, Research Cluster of Excellence, Berlin — [3]Bernstein Center for Computational Neuroscience, Berlin

Behavioral contagion is an interesting topic for cognitive science and collective behavior. While studies in Cognitive science overlook the impact of collective dynamics on decision processes, collective behavior studies mainly focus on simplified models of social interactions and neglect the cognitive complexity of individual agents. Hence, there is a gap in studying behavioral contagion, which incorporates not only complex individual decision processes but also concurrent social interactions that influence and are influenced by individual decisions. To address this gap, we employ a computational model to simulate virtual reality experiments (VR), unifying cognitive intricacies with collective dynamics. In this model, interaction networks are defined based on visual occupancy of agents from a first-person perspective. We aim to simulate VR experiments to explore how virtual agents responding to environmental signals influence human participants. Decision processes of participants are modeled using an extended drift-diffusion model, considering real-time updates in response to changing environmental and social signals. Our work investigates how network characteristics and temporal patterns of decision-making by virtual agents affect contagion dynamics.

SOE 7.11 Mon 18:00 Poster D

Opinion Dynamics of Interacting Large Language Models — •Vincent Brockers, David Ehrlich, Andreas Schneider, and Viola Priesemann — Max-Planck-Institute for Dynamics and Self-Organization

Classical models of opinion dynamics rely on purely symbolic representations of arguments, claims and reasons, potentially oversimplifying certain aspects of complex human behavior. This complexity can better be captured with recent Large Language Models (LLMs), as these possess the ability to mimic sophisticated human-like interactions with semantic meaning. However, how these new tools can be effectively utilized to improve on classical models remains an open research question.

Our research focuses on the interactions of LLM agents with different personality types and opinions in discussion scenarios as seen as on social media platforms. We use the Big Five personality traits to define the LLMs character and assign an initial opinion for one certain topic. Letting agents discuss for multiple rounds allows us to measure their individual influence-response-functions, which give insights about the process of opinion change, depending on the agents agreeableness, initial opinion and discussion topic.

In our simulations we find similar mechanisms of opinion reinforcement as seen as in symbolic models and that the strength can be controlled via the agreeableness trait. These findings and further analysis, especially how such agents behave in larger networks, are crucial to assess the applicability of LLMs in this research area.

SOE 7.12 Mon 18:00 Poster D

Modeling the Interplay of Awareness and Epidemics: A Mean-Field Approach with Twitter Data Analysis on COVID-19 Dynamics — Sara Shabani[1,2], Sahar Jafarbegloo[1], Sadegh Raeisi[1], and •Fakhteh Ghanbarnejad[1,3] — [1]Sharif University of Technology, Tehran, Iran — [2]Virginia Tech, Blacksburg, USA — [3]Technical University of Dresden, Dresden,Germany

The recent exploration of the reciprocal impact between awareness and disease introduces notable challenges. The preventive actions individuals take and their awareness levels can significantly shape the dynamics of disease spread, while disease outbreaks can influence awareness. We propose an initial null model that couples two Susceptible-Infectious-Recovered (SIR) dynamics, employing a mean-field approach for analysis. We then explore the parameter space to quantify the mutual influence on various observables. Utilizing this null model, we empirically analyze Twitter data related to COVID-19 and confirmed cases

in American states.

Our findings reveal that in specific parameter space, increasing awareness can suppress the epidemic, leading us to investigate phase transitions. Moreover, our model showcases the ability to shift the dominant population group by adjusting parameters during the outbreak. Applying the model, we assign parameters to each state, unveiling changes at different pandemic peaks. Notably, a robust correlation emerges between states' Twitter activity and immunity parameters assigned using our model, emphasizing the crucial role of sustained awareness in disease progression from initial to subsequent peaks.

SOE 7.13 Mon 18:00 Poster D

Analysis of COVID-19 Related Misinformation Spread in Telegram Communities — •Roman David Ventzke, Sebastian Bernd Mohr, Andreas Schneider, and Viola Priesemann — Max-Planck-Institut für Dynamik und Selbstorganisation, Göttingen

To effectively combat the proliferation of misinformation in online social media, it is important to understand content spread in social networks. We therefore investigate the dynamics of (mis)information propagation via the Telegram messaging app, with the aim to improve quantitative understanding of dissemination processes in self-organized social network settings.

As a basis for this study, we employ a novel large dataset of messages from Telegram group chats and channels. This dataset comprises more than 2.3 billion messages from more than 150,000 different chats and focusses on COVID-19-related content during the time of the pandemic.

We track and analyze information avalanches propagating in this network of chats to quantify their spreading dynamics and compare the spreading processes of information from trustworthy news sources and misinformation. We also examine the impact of potentially spread-influencing factors such as content-fostered emotional engagement. Finally, we investigate through the lens of statistical physics whether the observed information avalanches within the telegram communities constitute an (almost) critical process.

SOE 7.14 Mon 18:00 Poster D

Information parity: a measure to quantify the influence of nodes in a network — Aline Viol[1] and •Philipp Hövel[2] — [1]Scuola Internazionale Superiore di Studi Avanzati di Trieste (SISSA), Italy — [2]Saarland University, Germany

A growing interest in complex networks theory results in an ongoing demand for analytical tools. In order to quantify the functional, statistical symmetries between nodes in a complex network, we propose *information parity* as an insightful measure. Unlike the usual approach to quantitative network analysis that considers only local or global scales, information parity instead quantifies pairwise statistical similarities over the entire network structure. Based on the statistics of geodesic distances, information parity assesses how similarly a pair of nodes can influence and be influenced by the network.

Relating to neuroscience, for instance, we find an increase in the average information parity on brain networks of individuals under psychedelic influences. Notably, the information parity between regions from the limbic system and frontal cortex is consistently higher for all the individuals while under the psychedelic influence. These findings suggest that the resemblance of statistical influences between pair of brain regions activities tends to increase under Ayahuasca effects. This could be interpreted as a mechanism to maintain the network functional resilience.

[1] A. Viol et al. J. Phys. Complexity 4, 01LT02 (2023).
[2] A. Viol et al. Physica A 561, 125233 (2021).

SOE 7.15 Mon 18:00 Poster D

The diffusion map technique and its application to political regime types in the 20th century — •Sönke Beier[1], Paula Pirker-Diaz[1], Matthew Charles Wilson[2], and Karoline Wiesner[1] — [1]Institute of Physics and Astronomy, University of Potsdam, Germany — [2]Department of Political Science, University of South Carolina, U.S.

The V-Dem project provides a dataset of dozens of characteristics of political systems, such as press freedom or independence of electoral authorities, for almost all countries and years of the 20th century. But can these high-dimensional data be meaningfully represented in 2- or 3 dimensions and can such a representation help to get insight into the dynamics of political systems?

We have found that the non-linear dimension reduction method "diffusion map" is able to identify a meaningful representation of the data on a 2- dimensional manifold, which is robust over a large parameter range. It sorts countries from autocratic to democratic, also some sub-forms can be recognized. We clarify the influence of the diffusion-map parameters in general, providing insights that are relevant for the application of the technique to other real-word datasets.

In a next step we will use this visualization to analyse different dynamics, such as democratization processes, backsliding, or major disruptive changes.

SOE 7.16 Mon 18:00 Poster D

Transformer neural networks for the detection of artefacts in energy market data — •Henrike von Hülsen[1,2], Ulrich Oberhofer[2], Benjamin Schäfer[2], Oliver Lauwers[3], and Gust Verbruggen[4] — [1]50Hertz Transmissions GmbH, Berlin, Germany — [2]Institute for Automation and Applied Informatics, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany — [3]Elia Group, Brussels, Belgium — [4]Microsoft, Brussels, Belgium

Participants in the Belgian electricity market are permitted to deviate from their scheduled production or consumption, if the deviation counteracts a current imbalance in the market. The interpretation of the emerging data on schedule deviations is disturbed by artefacts caused by ramping times of different assets.

Drawing inspiration from the success of transformer architectures in handling 1D imaging data, the hypothesis is that transformers can efficiently process the underlying time series data to identify and subsequently eliminate these artefacts. Removing the artefacts will directly contribute to the efficiency of the capacity market in Belgium.

We propose a method from the evolving filed of transformer applications in diverse data domains, that will reliably detect and remove ramping artefacts without diminishing the quality of the signal.

SOE 7.17 Mon 18:00 Poster D

An Open Source toolbox for Complex Systems Science: The 'pyunicorn' package — •Fritz Kühlein[1,2], Lukas Röhrich[1,3], and Jonathan Donges[1,4] — [1]Potsdam Institute for Climate Impact Research, Germany — [2]Martin-Luther-University Halle-Wittenberg, Germany — [3]Humboldt-University of Berlin, Germany — [4]Stockholm Resilience Center, Sweden

Pyunicorn is shorthand for the Python Unified Complex Network and Recurrence Analysis Toolbox. First developed at the Potsdam Institute for Climate Impact Research and published by Donges et al. (2015), it has since been under active further development as an open source project. Pyunicorn facilitates the innovative synthesis of methods from both network theory and nonlinear time series analysis in order to develop novel integrated methodologies. Such methodologies can be applied in various disciplines, such as climatology, neuroscience, social science, infrastructure or economics. Features of Pyunicorn include the construction and analysis of climate networks, interacting networks, recurrence networks and visibility graphs to name just a few, as well as event series analysis tools among the more recently included. The modular, object-oriented structure of Pyunicorn makes it highly versatile and intuitive to use. As we have been working on the latest revised version release of Pyunicorn, we primarily aim to present the package's features and applications in its current state, but also to share retrospective insight on the fruits and pitfalls of managing an open source project over almost a decade.

SOE 8: Machine Learning in Dynamics and Statistical Physics II (joint session DY/SOE)

Time: Tuesday 9:30–13:00 Location: BH-N 243

SOE 8.1 Tue 9:30 BH-N 243

Pareto-Based Selection of Data-Driven Ordinary Differential Equations — •Gianmarco Ducci, Karsten Reuter, and Christoph Scheurer — Fritz-Haber-Institut der MPG, Berlin

Data-driven approaches enable the approximation of governing laws of physical processes with parsimonious equations. However, they face challenges due to inherent noise in data, which impacts the sparsity of the result. While a great effort over the last decade has been made in this field, data-driven approaches generally rely on the paradigm of imposing a fixed base of library functions. In order to promote sparsity, finding the optimal set of basis functions is a necessary condition but a challenging task to guess in advance.

In this work, we propose an alternative approach which consists of optimizing the very library of functions while imposing sparsity. The robustness of our results is not only evaluated by the quality of the fit of the discovered model, but also by the statistical distribution of the residuals with respect to the original noise in the data. The model selection is then chosen from a subset of optimal models obtained in a Pareto fashion. We illustrate how this method can be used as a tool to derive microkinetic equations from experimental data.

SOE 8.2 Tue 9:45 BH-N 243

Accurate Memory Kernel Extraction from Discretized Time-Series Data — •Lucas Tepper — Department of Physics, Freie Universität Berlin

Memory effects emerge whenever the dynamics of complex many-body systems are projected onto low-dimensional observables. Accounting for memory effects using the framework of the generalized Langevin equation (GLE) has proven efficient, accurate and insightful, particularly when working with high-resolution time series data. However, in experimental systems, high-resolution data is often unavailable, raising questions about the effect of the data resolution on the estimated GLE parameters. Using molecular dynamics (MD) data of a small, alpha-helix-forming peptide, I demonstrate that the direct memory extraction remains accurate when the discretization time is below the memory time. For discretization times exceeding the memory time, I show that a Gaussian Process Optimization (GPO) scheme estimates accurate memory kernels by minimizing the deviation of discretized two-point correlation functions between MD and GLE simulations. The GPO scheme stays accurate for discretization times below the longest time scale in the data, typically the barrier crossing time.

SOE 8.3 Tue 10:00 BH-N 243

Coarse-graining non-equilibrium systems with machine learning: from conceptual challenges to new approaches — •Patrick Egenlauf[1,2] and Miriam Klopotek[2] — [1]University of Stuttgart, Interchange Forum for Reflecting on Intelligent Systems, IRIS3D project, Stuttgart, Germany — [2]University of Stuttgart, Stuttgart Center for Simulation Science, SimTech Cluster of Excellence EXC 2075, Stuttgart, Germany

Machine learning (ML) was previously shown to effectively coarse-grain configurations of many-body systems. We want to investigate ML applications to address the dynamic coarse-graining of non-equilibrium many-body systems. Our research aims to advance ML methods while avoiding conventional assumptions. The focus is on time-dependent datasets and their broader implications for understanding causality. We introduce innovative techniques by incorporating general theory, including the time-dependent generalized Langevin equation [1], for building and interpreting time-dependent learning techniques [2]. This provides a distinctive ML perspective that extends to various applications for dynamical systems beyond equilibrium states. This study offers new ways to improve our understanding and manipulation of complex non-equilibrium many-body dynamics using ML.

[1] Schilling, T. (2022). Coarse-grained modelling out of equilibrium. *Physics Reports*, 972, 1-45.
[2] Nakajima, K., and Fischer, I. (2021). *Reservoir Computing*. Springer Singapore.

SOE 8.4 Tue 10:15 BH-N 243

Statistical criteria for the prediction of dynamical clustering in granular gases — •Sai Preetham Sata[1,2], Dmitry Puzyrev[2], and Ralf Stannarius[1,2] — [1]Institute of Physics, Otto-von-Guericke University, Magdeburg, Germany — [2]Department of Microgravity and Translational Regenerative Medicine and MARS, Otto von Guericke University, Magdeburg, Germany

Granular gases excited by external forces can undergo transitions from the homogeneous to a dynamical cluster state [1, 2], depending on filling fraction, excitation parameters and container geometry. We compare two statistical criteria for the clustering transition, viz. the Kolmogorov-Smirnov Test (KS-Test) on the particle number density profile and the so-called caging-effect based on the local packing fraction [2]. Both criteria are evaluated for various combinations of system parameters in the VIP-Gran experiment [3] and combined into one dataset. This allows us to compare existing clustering criteria and tune them to provide matching clustering thresholds. The aim is to develop improved threshold criteria. Machine learning models are trained with this dataset to predict whether particular parameters lead to homogeneous or dynamical cluster states.

This study is supported by DLR projects VICKI and EVA II(50WM2252 and 50WK2348)

References: [1] É. Falcon et al., Phys. Rev. Lett., 83:440-443, 1999 [2] E. Opsomer et al., Europhys. Lett., 99:40001, 2012 [3] S. Aumaître et al., Rev. Sci. Instr., 89, 2018.

SOE 8.5 Tue 10:30 BH-N 243

Excitability and Memory in a Time-Delayed Optoelectronic Neuron — •Jonas Mayer Martins[1], Svetlana V. Gurevich[1], and Julien Javaloyes[2] — [1]Institute for Theoretical Physics, University of Münster, Wilhelm-Klemm-Str. 9 and Center for Nonlinear Science (CeNoS), University of Münster, Corrensstrasse 2, 48149 Münster, Germany — [2]Departament de Física and IAC-3, Universitat de les Illes Balears, C/ Valldemossa km 7.5, 07122 Mallorca

We study the dynamics of an optoelectronic circuit composed of a nanoscale resonant-tunneling diode (RTD) in the excitable regime driving a nanolaser diode (LD) coupled via time-delayed feedback. Using a combination of numerical path-continuation methods and time simulations, we demonstrate that the RTD-LD system can serve as an artificial neuron, generating pulses in the form of temporal localized states (TLSs) that can be employed as memory for neuromorphic computing. In particular, our findings reveal that the prototypical delayed FitzHugh–Nagumo model previously employed to model the RTD-LD resembles our more realistic model qualitatively only in the limit of a slow RTD. We show that the RTD time scale plays a critical role in how the RTD-LD can be used as memory because it governs a shift in pulse interaction forces from repulsive to attractive, leading to a transition from stable to unstable multi-pulse TLSs. Our theoretical analysis uncovers novel features and challenges, including the multistability of TLSs and attractive interaction forces, stemming from the previously neglected intrinsic dynamics of the laser. These dynamics are crucial to consider for the memory properties of the RTD-LD.

SOE 8.6 Tue 10:45 BH-N 243

Anisotropic diffusion analysis in confined geometries — •Kevin Höllring[1], Andreas Baer[1], Nataša Vučemilović-Alagić[2], David M. Smith[2], and Ana-Sunčana Smith[1,2] — [1]PULS Group, Friedrich-Alexander Universität Erlangen-Nürnberg (FAU), 91058 Erlangen, Germany — [2]Group of Computational Life Sciences, Ruđer Bošković Institute, 10000 Zagreb, Croatia

In various systems, liquid and particle transport are of major importance to the viability of chemical like catalysis or adsorption. Most of these systems involve interfaces and confined geometries, where the prerequesites for the application of classical analysis techniques like the Einstein/MSD or the Green-Kubo/ACF approach are not fulfilled. To facilitate the resolution of diffusion coefficients in such system, we propose a novel approach built around the analysis of time statistics of particles in subspaces of the system using the Smoluchowski equation. For simple point-like particles, we propose a explicit analytic formula to link mean lifetimes and diffusivity, with an extension to account for the impact of locally induced drift as a consequence of complex effective interaction potentials. For more complex particles like in ionic liquids, we provide an extended technique able to resolve the impact of internal degrees of freedom, through which we can not only analyze the evolution of transport but also characteristic changes

in the conformational behavior of particles close to interfaces. Overall, this approach can be used to demonstrate a characteristic oscillatory behavior of particle diffusivity in confinement close to interfaces so far not reported in literature.

SOE 8.7 Tue 11:00 BH-N 243

Data assimilation of cardiac dynamics by means of adjoint optimization — •Inga Kottlarz[1,2,3,4], Sebastian Herzog[2,4,5], Patrick Vogt[2,3], Stefan Luther[1,2,4], and Ulrich Parlitz[2,3,4] — [1]Institute for Pharmacology and Toxicology, UMG Göttingen, Germany — [2]MPI for Dynamics and Self-Organization, Göttingen, Germany — [3]Institute for the Dynamics of Complex Systems, University of Göttingen, Germany — [4]German Center for Cardiovascular Research, Partner Site Niedersachsen, Göttingen, Germany — [5]III. Institute of Physics, University of Göttingen, Germany

Cardiac muscle tissue is an excitable medium that can exhibit a range of dynamics of different complexity, from planar waves to spiral waves to spatiotemporal chaos, the latter being associated with (fatal) cardiac arrhythmia.

Both the prediction of such high dimensional chaotic time series, as well as the reconstruction of their (not yet fully observable) complete dynamical state are ongoing challenges. In recent years, machine learning approaches have gained popularity for solving these problems, which can be advantageous if we do not have much knowledge about the dynamical system in question, but are limited by the large amounts of training data that is needed and often not available for biological systems. We present adoptODE, an adjoint optimization framework for estimating model parameters and unobserved variables. We showcase the adjoint method*s effectiveness in optimizing high-dimensional problems with thousands of unknowns, serving as a valuable tool for bridging the gap between empirical data and theoretical models.

15 min. break

SOE 8.8 Tue 11:30 BH-N 243

Collective Variables for Neural Networks — •Konstantin Nikolaou[1], Samuel Tovey[1], Sven Krippendorf[2], and Christian Holm[1] — [1]Institute for Computational Physics, University of Stuttgart, Germany — [2]Arnold Sommerfeld Center for Theoretical Physics, Ludwig-Maximilians-Universität, Germany

Neural Networks have witnessed extensive integration across diverse domains within physics. However, our focus shifts towards the inverse problem: How can neural networks benefit from physics? Learning with a neural network involves algorithmically assimilating information into a model. Nevertheless, the process of neural learning remains largely elusive, given the challenge of understanding how to extract information from its dynamics. Analogous to dynamical systems in statistical physics, describing neural network training involves an extensive number of degrees of freedom, which appears to benefit from a description through macroscopic quantities. To that end, we introduce Collective Variables for neural networks, tracing out microscopic degrees of freedom to describe and analyze the learning process at every stage. We investigate the initial state as well as the learning dynamics of the network in the context of the Collective Variables. We find a correlation between the initial network state and the generalization of the model computed after training. Moreover, we use the collective variables to identify and analyze stages arising in the dynamics of the learning process.

SOE 8.9 Tue 11:45 BH-N 243

Fluctuating weight dynamics and loss landscape in deep linear networks — •Markus Gross — DLR, Institute for AI Safety and Security, Germany

Understanding how weights fluctuate during training of neural networks and how this impacts the loss landscape is key to optimizing training processes and performance. We investigate this dynamics in (deep) linear networks within the continuum limit of stochastic gradient descent. For a two-layer network, we highlight the role of the inter-layer coupling and analytically derive from first principles a recently discovered key relation between weight fluctuations and loss landscape. The uncovered behaviors are rooted in general statistical properties of the network architecture und training data.

Reference: https://arxiv.org/abs/2311.14120

SOE 8.10 Tue 12:00 BH-N 243

Loss is More: Exploring the weight space of a perceptron via enhanced sampling techniques — •Margherita Mele[1], Roberto Menichetti[1], Alessandro Ingrosso[2], and Raffaello Potestio[1] — [1]Physics Department, University of Trento, via Sommarive, 14 I-38123 Trento, Italy — [2]The Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy

Understanding how input data properties influence the learning process in artificial networks is crucial. The assumption of Gaussian i.i.d. inputs has long been foundational, yet questioning its constraints is now essential. Our approach utilises enhanced sampling methods from soft matter physics to exhaustively explore the loss profile and reconstruct the density of states of networks with discrete weights, addressing optimization in highly rugged landscapes even in simple architectures. These methods, effective in real datasets, enable exploration of data dimensionality and structure impact.

Employing benchmarks (e.g. MNIST, FashionMNIST) and in silico datasets, our study investigates the role of various input-data properties, including class imbalance, separation, item mislabelled, and input-output correlation. Our findings bridge theoretical and applied aspects, shedding light on the limitations and extensions of Gaussian i.i.d. assumptions. This work provides pivotal insights into the interplay between input data properties and network learning, advancing our understanding of how artificial networks adapt to different information contexts.

SOE 8.11 Tue 12:15 BH-N 243

Emergent oscillating dimensionality transformations in deep learning — •Pascal de Jong, Felix J. Meigel, and Steffen Rulands — Arnold Sommerfeld Center for Theoretical Physics, Department of Physics, Ludwig- Maximilians-Universität, München, Germany

Artificial intelligence relies on deep neural networks (DNNs), which comprise a large set of nonlinear nodes connected by weights. The functioning of DNNs and their ability to generalize to unseen data are examples of complex behavior, which due to their highly nonlinear nature is poorly understood. Here, we show that training DNNs universally leads to oscillating weight topologies that alter the embedding dimensions of hidden data representations in different layers. Specifically, using a path representation of DNNs, we derive equations for the time evolution of the weights. We show that training leads to a structure, in which weights are focused on a subset of nodes, and the degree of focusing oscillates across layers. We empirically confirm these findings by studying the training dynamics of large DNNs on different data sets. Finally, we show that these structures imply a repeated dimensional decrease and increase of the hidden data representations. Our results highlight that emergent dynamics during training can lead to universal network topologies with implications for their function.

SOE 8.12 Tue 12:30 BH-N 243

Investigating the Evolution of Fisher Information for Neural Network Dynamics — •Marc Sauter, Samuel Tovey, Konstantin Nikolaou, and Christian Holm — Institute for computational physics, Stuttgart, Germany

Machine learning has proven to be a powerful tool with remarkable effectiveness for various physical applications. Even though Neural Networks offer great potential for solving complex tasks, their black-box nature limits the information obtainable about the underlying mechanisms they employ. Especially in physics, where the exact methodologies of solving tasks are just as important as finding solutions itself, advances in interpretable machine learning promise to aid the applicability of Neural Networks task-solving capabilities greatly. The Fisher Information Matrix (FIM) is a statistical measure known for its ability to identify second order phase transitions in physical systems. It can also be used for analyzing learning dynamics, where it expresses correlations between influences of parameters in Neural Networks. However, because of its size, computation of the FIM is currently intractable for Neural Networks used in common problem settings. As a way of obtaining parts of the information contained in the FIM, we introduce a novel mathematical relationship between the trace of the FIM and the Neural Tangent Kernel, a smaller observable of neural network training. We apply this approach for simple test models and discuss arising research topics.

SOE 8.13 Tue 12:45 BH-N 243

Near-zero-cost post-training uncertainties for deep learning architectures — •Filippo Bigi, Sanggyu Chong, Michele Ceriotti, and Federico Grasselli — Laboratory of Computational Science and Modeling (COSMO), IMX, École Polytechnique Fédérale

de Lausanne, Switzerland

Over the last decade, deep learning models have shown impressive performance and versatility on an extremely wide range of tasks. However, their probability estimates are unreliable, especially outside of the training distribution, with neural networks often returning overconfident results when queried on unfamiliar data. Although several uncertainty quantification schemes are available, their practical downsides hinder their widespread adoption. We propose a novel method for estimating the predictive uncertainties of deep learning architectures based on the interpretation of the last layer of neural networks as a linear Gaussian process. Contrary to previous methods, the proposed approach is simple, scalable, does not involve modification of the architecture or the training procedure, can be applied to trained models *a posteriori*, and generates uncertainty estimates with a single forward pass at negligible additional cost. We demonstrate the accuracy and practicality of our scheme on a wide range of machine learning datasets.

SOE 9: Physics Information Services (joint session AGI/SOE)

Time: Tuesday 10:00–12:00 Location: MAR 0.011

Discussion SOE 9.1 Tue 10:00 MAR 0.011

From Particles to Portals: A World Café on Physics Information Services — •Holger Israel, Julia Hoffmann, and Esther Tobschall — TIB (Leibniz Information Centre for Science and Technology and University Library)

The worldwide volume of scientific literature is rapidly increasing and has been estimated to double every five to twelve years. When searching the literature for specific information, scientists are faced with an ever-steeper challenge to pick out their signal from the growing information noise. Hence, researchers should be equipped with new technologies and capabilities to retrieve knowledge from the available information.

TIB Leibniz Information Center for Science and Technology, together with partners at Physikalisch-Technische Bundesanstalt (PTB) and INP Leibniz Institute for Plasma Science and Technology are going to propose a "Fachinformationsdienst (FID) Physik", a specialized information service for physics. This infrastructure supporting research aims to facilitate researchers to access specialized literature and research-specific information and to provide services based on high quality physics metadata.

This is where we need your help. What would make your everyday (physical) working life easier? Which tool have you always dreamed of using? What access to information and products do you need for your research? Come and talk to us during our workshop, where we would like to exchange ideas with you. We are going to hold the workshop in the "world café" format: Participants can choose between 3 to 5 tables. At each table, the groups discuss a different question and make note of their ideas. After a given time, participants can rotate between the tables, allowing them to contribute to all of the topics, and for all of the participants to exchange ideas. At the end of the workshop, the results are summarized in a short overview. We would like to incorporate your suggestions and comments as a part of our community survey into our proposal for the FID Physics.

SOE 10: Sociophysics Approaches to Diversity and Equality (Accompanying Session to the Symposium Diversity and Equality in Physics)

Time: Tuesday 13:15–14:15 Location: PTB HS HvHB

SOE 10.1 Tue 13:15 PTB HS HvHB

The Centrality of Minorities under Triadic Closure and Homophily — Jan Bachmann[1], Lisette Espín-Noboa[1,2], •Samuel Martin-Gutierrez[1], Nicola Cinardi[1,4], and Fariba Karimi[1,3] — [1]Network Inequality Group, Complexity Science Hub, 1080 Vienna, Austria — [2]Department of Network and Data Science, Central European University, 1100 Vienna, Austria — [3]Institute of Interactive Systems and Data Science, TU Graz, 8010 Graz, Austria — [4]Departmen of Complex Systems, Institute of Computer Science of the Czech Academy of Sciences, Praha, Czech Republic

Link formation in social networks is governed by various well-known social mechanisms, such as preferential attachment and homophily. Triadic closure, on the other hand, describes the formation of triangles when people connect to friends-of-friends. Some works in the litearure have found that triadic closure amplifies the segregating effect of homophily, while others come to the opposite conclusion. In a system composed of two social groups of different sizes, these mechanisms are known to cause disparities in visibility and can force one group to the network's periphery. In this work, we develop PATCH, a network growth model with **p**referential **a**ttachment, **t**riadic **c**losure and **h**omophily, to disentangle their effect on the structural placement of a minority group. Our analyses suggest that triadic closure reduces the representation disparity between the majority and minority in the heterophilic setting, but it does not mitigate the under-representation of the minority group in the homophilic regime.

SOE 10.2 Tue 13:30 PTB HS HvHB

Toward Fairness in Network Algorithms: Rankings by Biased Random Walks — •Elisabetta Salvai[1], Jacob Aarup Dalsgaard[2,3], Giovanni Petri[4,5,6], and Roberta Sinatra[2,3,7,8] — [1]University of Turin — [2]SODAS, University of Copenhagen — [3]IT University of Copenhagen — [4]Network Science Institute, Northeastern University London — [5]CENTAI Institute — [6]IMT Lucca Institute — [7]ISI Foundation — [8]Complexity Science Hub

Ranking algorithms play a significant role in ordering information in networks and identifying important and influential nodes. In this study, we investigate the fairness of the widely used PageRank algorithm in networks of nodes with binary attributes. We propose a new fairness definition rooted in demographic parity in the top-ranked positions, where the observer's attention is predominantly concentrated. This definition is based on the idea that a fair ranking has the same proportion of attributes in the top-ranked positions as in the whole network. To improve the fairness of rankings, we then study a modification of the PageRank algorithm where we add a parameter that biases the random walk exploration at the core of the algorithm. This parameter changes the choice probability of the random walkers based on the degree of the neighbouring nodes. We study this biased PageRank algorithm, in both synthetic and real-word networks, for different values of the bias parameter. We analyze the degree-attribute correlations to explore how the structure of networks impacts the biased random walk ranking. We can forecast the most suitable biased parameter value by comprehending network structures.

SOE 10.3 Tue 13:45 PTB HS HvHB

The Role of Prestige on the Visibility of Underrepresented Groups in Physics Citation Rankings: International Mobility, Nationality and Gender — •Ana Maria Jaramillo[1] and Fariba Karimi[1,2] — [1]NetIn Group, CSH Vienna, Austria — [2]Institute of Interactive Systems and Data Science, TU Graz, Austria

AI-powered academic engines using citation rankings reinforce scientific biases, underrepresenting certain groups. We aim to understand how international mobility has influenced top-ranking positions in Physics by researchers who face intersecting forms of oppression (such as women from low-income countries). We study the gender and geographical representation of researchers in top-ranked positions across the Physics literature. There is small participation across different career stages for women, with an average of 0.26 and a concentration of researchers from East Asia & Pacific and Europe & Central Asia, with many affiliations in North America. Regarding mobility, Italian, German, and Chinese researchers have the highest affiliations with their

respective countries, while the United States attract researchers from various nationalities. Notably, researchers from East Asia & Pacific countries are underrepresented in the citation rankings. When examining the intersection of nationality, affiliation, and gender, women are disproportionately underrepresented in top-ranking positions across all countries except for Turkey. Future analysis should investigate how the co-authorship networks of the researchers impact the mobility of researchers and consequently impact the representation in top-ranking positions of citations based on nationality and gender.

SOE 10.4 Tue 14:00 PTB HS HvHB

Gender Disparities in Brokerage of Scientific Collaboration — •Jan Bachmann[1,2], Lisette Espín-Noboa[1,2], Gerardo Iñiguez[2,3,4,5], and Fariba Karimi[1,6] — [1]Complexity Science Hub, Vienna, Austria — [2]Dep. of Network and Data Science, Central European University, Vienna, Austria — [3]Dep. of Computer Science, Aalto University, Aalto, Finland — [4]Faculty of Information Technology and Communication Sciences, Tampere University, Tampere, Finland — [5]Centro de Ciencias de la Complejidad, Universidad Nacional Autonóma de México, Ciudad de México, Mexico — [6]TU Graz, Graz, Austria

In the scientific community, structural gender inequalities persist, leaving women disadvantaged in how many papers they publish, how their work is recognized and how likely they are to drop out of academia early. Although collaboration disparities contribute to these inequalities, little is known about differences in how new collaborations emerge and how this affects career success. Therefore, we conceptualise tertius iungens brokerage to study who introduces who to whom. We analyse the initial formation of triangles among physicists in the collaboration network across APS journals. Our results establish that early career brokerage leads to higher productivity (publications) and impact (citations). Moreover, this effect increases over career stages: early brokerage stimulates more brokerage later, exacerbating potential early career differences between men and women. We plan to identify these differences and further disentangle the role of gender in brokerage and whether both women and men can profit equally.

SOE 11: Urban Scaling

Time: Wednesday 9:30–10:00 Location: MA 001

Invited Talk SOE 11.1 Wed 9:30 MA 001

Urban scaling laws arise from within-city inequalities — •Marc Keuschnigg — Institute of Sociology, Leipzig University — Institute for Analytical Sociology, Linköping University

Theories of urban scaling have demonstrated remarkable predictive accuracy at aggregate levels. However, they have overlooked the stark inequalities that exist within cities. Human networking and productivity exhibit heavy-tailed distributions, with some individuals contributing disproportionately to city totals.

Here we use micro-level data from Europe and the United States on interconnectivity, productivity and innovation in cities. We find that the tails of within-city distributions and their growth by city size account for 36-80% of previously reported scaling effects, and 56-87% of the variance in scaling between indicators of varying economic complexity. Providing explanatory depth to these findings, we identify a city size-dependent cumulative advantage mechanism that constitutes an important channel through which differences in the size of tails emerge.

Our findings demonstrate that urban scaling is in large part a story about inequality in cities, implying that the causal processes underlying the heavier tails in larger cities must be considered in explanations of urban scaling. This result also shows that agglomeration effects benefit urban elites the most, with the majority of city dwellers partially excluded from the socio-economic benefits of growing cities.

SOE 12: Urban Systems and Traffic Flow

Time: Wednesday 10:00–11:00 Location: MA 001

SOE 12.1 Wed 10:00 MA 001

Analytical and numerical treatment of the every-pair-interaction problem — Fabiano L. Ribeiro[1], Yunfei Li[2], Stefan Born[3], and •Diego Rybski[2] — [1]Department of Physics (DFI), Federal University of Lavras (UFLA), Lavras MG, Brazil — [2]Potsdam Institute for Climate Impact Research (PIK), P.O. Box 601203, 14412 Potsdam, Germany — [3]Technische Universität Berlin, Chair of Bioprocess Engineering and Institute of Mathematics, Strasse des 17. Juni 135, 10623 Berlin, Germany

We systematically treat every-pair interactions (a) that exhibit power-law dependence on the Euclidean distance and (b) act in structures that can be characterized using fractal geometry. We analytically derive the mean interaction field of the cells and find that (i) in a long-range interaction regime, the mean interaction field increases following a power-law with the size of the system, (ii) in a short-range interaction regime, the field saturates, and (iii) in the intermediate range it follows a logarithmic behavior. For long-range interactions, the theoretical calculations align closely with the numerical simulations. For short-range interactions, we observe that discreteness significantly affects the results, which requires an expansion that substantially improves the accuracy of the analytical expression. We conclude with applications. Early version of the respective manuscript: https://arxiv.org/abs/2307.07783

SOE 12.2 Wed 10:15 MA 001

Coherent Economic Paths in Urban Systems Development — •Simone Daniotti — Complexity Science Hub, A-1090 Vienna, Austria

Diversity is pivotal for local economic development, shielding economies from sector-specific shocks and fostering innovation. However, maintaining diversity requires a widening capability base in cities. While economic geography literature explores the consequences of urban diversity, limited research addresses the constraints on diversity. This paper aims to address this gap by introducing a measure of coherence in economic activities, assessing the technological or cognitive distance between workers in a city. Examining US cities from 1850 to 1930 and recent periods (2002-2022 for occupations and patents, and 1980-2020 for technological specializations), the study reveals that, despite rapid specialization changes, the average coherence across urban systems remains stable. Interestingly, coherence falls by 4% with city size, regardless of the dataset or period, indicating a consistent correlation between city size and distinctive developments. While the reasons for this pattern remain unclear, the findings emphasize the significant relationship between city size and the observed extent of distinctiveness or dissimilarity in their specialized developments.

SOE 12.3 Wed 10:30 MA 001

Fast & Furious: Extreme events and non-Gaussian velocities in urban car traffic — Moritz Piepel[1], •Malte Schröder[1], Angelika Hirrle[2], and Marc Timme[1,3] — [1]Chair for Network Dynamics, Institue for Theoretical Physics and Center for Advancing Electronics, TUD Dresden University of Technology — [2]Chair of Traffic Process Automation, Institute of Traffic Telematics, TUD Dresden University of Technology — [3]Lakeside Labs, Klagenfurt

The majority of traffic flow models and observations focus on traffic dynamics on highways, assuming Gaussian velocity distributions typically observed in time-aggregated measurements. Here, we analyze individual velocity measurements in urban car traffic based on 145 induction loop detectors throughout the city of Dresden, observing over 340 million vehicle velocities in total. We find that velocity distributions in urban traffic are non-Gaussian, with frequent extreme velocities, independent of the local speed limit. Gaussian distributions significantly underestimate the frequency of extreme velocities and their consequences. For example, the number of speeding viola-

tions observed in the data would be valued in fines of 800 million Euros annually, more than 300 times the actual fines collected in Dresden. These observations seem to be generic and are confirmed by data on speeding violations in the city of Cologne. Our findings shed a new light on urban traffic modeling and may have implications for road safety regulations, the design of road infrastructure, and speed limits to ensure safe urban mobility.

SOE 12.4 Wed 10:45 MA 001

Electrical potential mapping of urban human flow: a river basin validation study — •Yohei Shida[1,2], Hideki Takayasu[2,3], and Misako Takayasu[3] — [1]University of Tsukuba, Tsukuba, Japan — [2]Tokyo Institute of Technology, Yokohama, Japan — [3]Sony Computer Science Laboratories, Tokyo, Japan

We conduct a thorough investigation to assess the accuracy and validity of our previously proposed GPS-based human flow potential model, which assembles human mobility using imaginary electric circuits. In contemporary urban studies, a notable approach has emerged, wherein human flow patterns are elucidated through the concept of potential. Despite the initial promise of this approach and similar methodologies, studies are yet to undergo through comprehensive validation.

By employing the river basin analysis approach, we confirm that our potential model adheres to the universal scaling law of human flow. To validate these assertions, we apply river basin analysis to human flow potentials in various Japanese metropolitan areas, utilizing high-resolution human flow data from smartphone users.

The human flows regenerated from the potentials retain the information content of the original human flows, displaying robust agreement in terms of human flow scaling laws during the morning commuter rush, such as the 3D structure of the moving people amount and fractal transportation patterns. Furthermore, by accounting for the influence of daily fluctuations in human flow on the scaling relations, we quantitatively estimate the least number of days required to establish an empirical law for human flow.

SOE 13: Hacky Hour I (joint session AGI/SOE/AKjDPG)

In this new format, introduced by AGI and jDPG, tools are presented that can be helpful in your everyday scientific work. Whenever possible a hands-on part will be offered where the tool can be used directly preferably on your own laptop. Furthermore there will be a discussion of the tool where e.g. aspects of compatibility and extensibility can be addressed.

If installation of software is necessary in advance instructions on this and further information in general can be found at https://hacky-hour.dpg-physik.de

Time: Wednesday 9:30–12:25 Location: MAR 0.011

SOE 13.1 Wed 9:30 MAR 0.011

Get the most out of your data: Interactive Visualisation with Python and Plotly — •Christian Faber — Forschungszentrum Jülich, Jülich, Germany

Scientists have always been the experts for data. Analysing and drawing conclusions from them is our daily business, and the amount of data that scientists are confronted with is growing rapidly as time passes and computing resources increase. The challenge is to quickly deal with individual data structures for which there is usually no off-the-shelf solution. In this talk, I will tell you how you can create visualisations tailored to your data. I will show, how you can access your data interactively and thus gain maximum insight from it. The graphics are created using Python and the *pyplot* and *dash* libraries to achieve maximum customisability. The entire process is demonstrated using a sequence mutation example from biophysics, but the methods can be applied to any field involving large amounts of data.

SOE 13.2 Wed 10:00 MAR 0.011

Blender for scientific figures and animations — •Timo Doerries — Institute of Physics & Astronomy, University of Potsdam, 14476 Potsdam, Germany

Blender is a free open source 3D tool. It can be used to produce static figures for publications [1,2]. In addition to a graphical user interface it can be completely controlled using simple Python syntax. This allows creating complex animations, that can be used to illustrate simulations. I will show how to set up a simple ray-tracing image and animate a simulation from the field of statistical mechanics using the python interface.

[1] Doerries, Chechkin & Metzler, J. R. Soc. Interface.19 (2022)
[2] Doerries, Metzler & Chechkin, New J. Phys. 25 (2023)

SOE 13.3 Wed 10:30 MAR 0.011

MicMag2, an atomistic and micromagnetic simulator python package — •Thomas Brian Winkler[1], Kai Litzius[2], Hans Fangohr[3], and Mathias Kläui[1] — [1]Johannes Gutenberg-Universität Mainz 55099 Mainz — [2]Universität Augsburg, 86159 Augsburg — [3]Max Planck Institute for the Structure and Dynamics of Matter Hamburg, 22761 Hamburg

Micromagnetic simulators are one core driver of spintronic research nowadays. We present MicMag2 [1], a combined micromagnetic and atomistic simulator which can be used within a python or jupyter framework. GPU acceleration and modular program architecture allow for fast data acquisition and flexibility in implementing custom modules. In this session we will introduce the functionalities of MicMag2, advanced and less common modules, and how data analysis can be easily transferred to numpy-based [2] code or to the ubermag framework [3]. The presentation will include an introduction into the basics of micromagnetism and a tutorial on the practical use of the software. [1] https://github.com/WinklerTB/MicMag2 [2] Harris, C.R., Millman, K.J., van der Walt, S.J. et al., Nature 585, 357*362 (2020) [3] M. Beg, M. Lang and H. Fangohr, IEEE Transactions on Magnetics, vol. 58, no. 2, pp. 1-5, Feb. 2022, Art no. 7300205

SOE 13.4 Wed 11:00 MAR 0.011

Quantum Many Body Simulations with TeNPy — •Johannes Hauschild — Technical University Munich, Germany

Matrix product state (MPS) based algorithms like the density matrix renormalization group (DMRG) are established as *the* state-of-the-art method for simulations of quantum many body systems in 1D, for example Heisenberg and Hubbard type models. In fact, MPS are so successfull that they are routinely used for 2D systems as well, by mapping thin long cylinder geometries to 1D. Generalizations of MPS to natively 2D tensor network states in the form of PEPS or isoTNS provide an alternative route for competitive results, especially for cases where quantum monte carlo methods suffer from the sign problem.

I will present version 1.0 of TeNPy, the "Tensor Network Python" package that I started developing half a decade ago. The major goal has been to make MPS and tensor network simulations accessible not only to experts of the field but also new users, by excellent documentation, and balancing speed of the code with flexibility to define new models and algorithms. Indeed, TeNPy has been accepted well by the community with over 250 papers acknowledging its use and code contributions from various groups. After a (very) brief introduction to the main ideas behind the algorithms, I will show small examples for typical use cases of TeNPy. I will further discuss our ongoing efforts and first benchmarks to adapt TeNPy and the implemented algorithms to GPU-based calculations, and how we plan to incorporate the conservation of non-abelian symmetries.

15 min. break

SOE 13.5 Wed 11:45 MAR 0.011

FAILS (Fancy automated internet lecture system) — •Marten Richter — Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Technische Universität Berlin, Berlin, Germany

In theoretical physics, the conventional lecture with chalk by slowly exploring the physical formulas is still one, if not the best method. However modern expectations of lectures include electronic scripts for

students, interactive questions for student engagement, and hybrid audio/video transmission.

FAILS (Fancy Automated Internet Lecture System) is developed to meet this demand. The open source software was developed driven by the author's need to have electronic chalk on multiple projectors, interactive quizzes, chat, and also audio/video transmission in one software for lectures in theoretical physics, here at TU Berlin. All features are highly automated and designed to reduce the distraction of the lecturer. After initially being used in our institute it is now university-wide deployed in our moodle learning management system ISIS with support from innoCampus. This talk gives a short hands-on demonstration of the abilities of the FAILS software (cf. https://github.com/fails-components/compositions and https://www.youtube.com/@fails-components).

SOE 13.6 Wed 12:05 MAR 0.011

Hacky teaching — •Yoav G. Pollack[1,2], Anas Hussin[1], Jaskaran Singh[1], and Komal Bhattacharyya[1] — [1]University of Göttingen, Göttingen, Germany. — [2]Max Planck Institute for Dynamics and Self-Organization (MPI-DS), Göttingen, Germany.

I examine hackathons, imported from the world of software startups, as a motivating teaching method. In December 2023, a 2-day hackathon was held for the CYTAC Research Training Group in the University of Göttingen, on the topic of simulating cytoskeleton with the Cytosim software package[by Nédélec Group]. The aims of this venture were 1) to promote initiation of collaborations by students from different research groups spanning several disciplines, 2) to encourage experiment-oriented students to do computational work, 3) to encourage theory-oriented students to consider the biological context of their theoretical research, 4) to make learning fun. I will report on the outcomes of this hackathon that managed to attract students from diverse computational backgrounds and scientific backgrounds and showcase selected proof-of-concept projects from the teams.

SOE 14: Focus Session: Dynamics of Socio-ecological Systems

The focus session addresses work on the complex and nonlinear dynamics arising from interactions between social systems and the Earth system with a specific focus on human-made climate change. This includes topics regarding the risks of tipping cascades in the climate system, implications of social inequality for Earth system stability and resilience, or the impact of extreme weather events on public attitudes on climate change

Organized by Jonathan Donges (PIK Potsdam) and Eckehard Olbrich (MPIMiS Leipzig)

Time: Wednesday 11:15–13:05 Location: MA 001

SOE 14.1 Wed 11:15 MA 001

Humans in the loop? Open questions for modelling the Anthropocene — •Malte Vogl and Gesine Steudle — Max Planck Institute of Geoanthropology, Jena, Germany

The Anthropocene is characterized by the fact that the sphere of socio-cultural-technical evolution and the sphere of natural processes can no longer be clearly separated. This stresses the importance of understanding the dynamics of socio-ecological systems, e.g. when it comes to forecasting the effects of climate adaptation and mitigation and their social impacts. A future prognosis as well as an explanation of past events (or back-casting) for such coupled systems depends on various feedback mechanisms.

In this contribution we will present food for thought on how to address this challenges with agent-based modelling. In particular we investigate what essential memory mechanisms and feedback loops are necessary to describe niche-construction-like effects, for example due to the build-up of infrastructure. Here, infrastructure is seen not only in a technical context but can also refer to knowledge structures.

We present work in progress on projects ranging from modelling mobility decisions to build-up of historical archives and discuss their similarities.

SOE 14.2 Wed 11:35 MA 001

Cascading climate tipping events and can society prevent them? — •Nico Wunderling[1,2,3], Saverio Perri[3], Johan Rockström[1,2], Michael Oppenheimer[3], Amilcare Porporato[3], Jonathan F. Donges[1,2,3], Simon A. Levin[3], Elke U. Weber[3], and Wolfram Barfuss[1,4] — [1]Potsdam Institute for Climate Impact Research — [2]Stockholm Resilience Centre — [3]Princeton University — [4]Transdisciplinary Research Area: Sustainable Futures, University of Bonn

Several climate tipping elements such as the Amazon rainforest or the large ice sheets on Greenland and Antarctica are showing increasing signs of dramatic change in response to human-made global warming. While dangerous tipping risks can be reduced by keeping strict temperature guardrails set by international agreements, so far, such agreements have prompted only moderate emission cuts due to socio-political challenges. Here, we couple a conceptual model of interacting climate tipping elements to a simplified social model outlining an energy-production transition toward clean energy. Using this coupled model, we find that three ingredients are required for a fast sustainability transition, achieving a safe sustainability transition without triggering tipping events or cascades: (i) Strong political incentives to invest in clean energies, (ii) high societal pressure to avoid crossing climate tipping thresholds, and (iii) scientific guidance leading to sufficiently small uncertainties in tipping points. If these conditions are met, we reveal that tipping risks can be reduced strongly in particular when uncertainties in tipping element thresholds are reduced

SOE 14.3 Wed 11:50 MA 001

Low-complexity model of climate change, wealth and energy transition to capture political cost of energy policies — •Diana L. Monroy and Frank Hellmann — Potsdam Institute for Climate Impact Research (PIK)

The energy transition is a pathway toward transformation of the global energy sector from fossil-based to zero-carbon technologies. In this context, devising policies that facilitate a transition to low-carbon energy systems requires an understanding of the political and economic costs of energy and climate policy formulation, both in the short and long-term to contribute to a better description of the challenges and determinants of policy choices that impact energy supplies, markets, and consumption.

This work proposes an alternative approach of modelling environmental and socioeconomic dynamics in presence of policy choices using Complex Systems. The objective is to capture the political and economical cost of energy policies based on the main assumption that there is a high political cost of redistributing economic activity.

The model is based in the AYS low-complexity model of climate change, wealth and energy transition incorporating energy policies to mitigate climate change. In the extended model we propose, the co-evolution of the natural and socio-economic system is effected by two main policies: (i) Research Program for Renewable Knowledge and (ii) Carbon Taxation. We use this model to optimize over time the parameters associated to the CCPs.

5 min. break

SOE 14.4 Wed 12:15 MA 001

A modeling framework for World-Earth system resilience: exploring social inequality and Earth system tipping points — •Jonathan F. Donges[1,2], J. Marty Anderies[3], Wolfram Barfuss[1,4,5], Ingo Fetzer[2], Jobst Heitzig[1], and Johan Rockström[1,2] — [1]Potsdam Institute for Climate Impact Research, Potsdam, Germany — [2]Stockholm Resilience Centre, Stockholm University, Stockholm, Sweden — [3]School of Sustainability and School of Human Evolution and Social Change, Arizona State University, Tempe, USA — [4]Transdisciplinary Research Area: Sustainable Futures, University of Bonn, Bonn, Germany — [5]Center for Development

Research (ZEF), University of Bonn, Bonn, Germany

The Anthropocene is characterized by the strengthening of planetary-scale interactions between the biophysical Earth system (ES) and human societies. This increasing social-ecological entanglement poses new challenges for studying possible future World-Earth system (WES) trajectories and World-Earth resilience defined as the capacity of the system to absorb and regenerate from anthropogenic stresses. We develop a framework within which to conceptualize World-Earth resilience. Because conventional system concepts of stability and resilience are hampered by the rapid and open-ended social, cultural, economic and technological evolution of human societies, we focus on the notion of pathway resilience, i.e. the relative number of paths that allow the WES to move from the currently occupied transitional states towards a safe and just operating space in the Anthropocene.

SOE 14.5 Wed 12:30 MA 001

The complex dynamics of collective reinforcement learning — •Wolfram Barfuss — University of Bonn

Cooperation at scale is critical for achieving a sustainable future for humanity. However, achieving collective, cooperative behavior – in which intelligent actors in complex environments jointly improve their well-being – remains poorly understood. Complex systems science (CSS) provides a rich understanding of collective phenomena, the evolution of cooperation, and the institutions that can sustain both. Yet, much of the theory in this area fails to consider individual-level complexity and environmental context — largely for the sake of tractability and because it has not been clear how to do so rigorously. These elements are, however, well-captured in multi-agent reinforcement learning (MARL), which has recently put focus on cooperative (artificial) intelligence. However, typical MARL simulations can be computationally expensive and challenging to interpret.

In this talk, I propose that bridging CSS and MARL affords new directions. By treating MARL as a dynamical system, we can study the complex dynamics of collective cooperation emerging from cognitive agency in a given environmental context.

SOE 14.6 Wed 12:50 MA 001

Complex Contagion in Socio-Ecological Network Systems — •Lukas Röhrich[1,2], Fritz Kühlein[1], and Jonathan Donges[1,3] — [1]Potsdam Institute for Climate Impact Research, Germany, EU — [2]Humboldt University of Berlin, Germany, EU — [3]Stockholm Resilience Center, Sweden

The acceptance of the Anthropocene as the current geological epoch opens up new areas to our understanding of the influence of a social "world" system on the ecological "earth" system. As a highly evolved species, for example, we humans are capable of especially complex behavioral patterns. Evidently, these behaviors are influenced by and influence the ecosystem around us. A modern tool for investigating this feedback between the world and the earth system is complex contagion analysis on socio-ecological networks. This approach describes social systems as adaptive networks where the vertices, representing households, cities, etc., and edges, representing social circles, cultural exchange, etc., are influenced by their social environment as well as their biophysical environment. In this talk we want to present the tool of complex contagion analysis together with two application examples. First, the general Dodds-Watts model which brings complexity to contagion simulations by incorporating individual memory of exposure, variable magnitudes of exposure and heterogeneity in the susceptibility of individuals (P.Dodds and D.Watts, 2005). Second, the more applied MayaSim model, which aims to identify candidate features of resilient versus vulnerable socio-ecological systems, using the ancient Maya as an example (S.Heckbert, 2013).

SOE 15: Concept Transfer between Sciences

Time: Wednesday 15:00–15:30 Location: MA 001

SOE 15.1 Wed 15:00 MA 001

System Science in Physics of socio-economic Systems — •Juergen Mimkes — Physics Department Paderborn University

In Physics of socio-economic systems four different fields deal with the same problem: physics, mathematics, economics and social science. Apparently the four fields have the same logic: all systems know order and disorder and the Lagrange law, L = O + T ln P -> max! In physics we have energy and entropy, in materials: solid and liquid, in society: collective and individual, in politics: autocracy and democracy, in all systems: ideal and real. The logic structure: Society * Math * Physics is replaced by more familiar systems e.g., by Society * Water. Both systems follow the same Lagrange law. The knowledge of water is used as system theory, like Empedocles did 2500 years ago: *Friends mix like water and whine, enemies separate like water and oil*. System science is easy to understand and can be applied to solve modern social problems: the integration of refugees in Europe compares to dissolving sugar in tea. The Ukrainian war between autocracy and democracy reflects the problems of ice floating on water. And system science leads to real solutions, as probability ln P looks into the future.

SOE 15.2 Wed 15:15 MA 001

Maxwell-Gleichungen der Psychologie — •Karl Hosang — Onckenstraße 12, 12435 Berlin

Was sind die dynamischen Zusammenhänge der menschlichen Psyche? Die Tiefenpsychologische Psychotherapie bezeichnet sich auch als Psychodynamik - und hat eine gewissen logische Struktur darin.

Aber wie könnte eine theoretische Reife erreicht werden wie in der Physik? Das Vorbild sind die Maxwell-Gleichungen, die in ästhetischer Knappheit ein komplexes Themengebiet, die Elektrodynamik, nur 4 Formeln gießt.

Ich möchte einen theoretischen Ansatz vorstellen, der analog die Variablen und Zusammenhänge der tiefen- und sozialen Psychologie in eine formelle Form bringt.

SOE 16: Social Systems, Opinion and Group Dynamics

Time: Wednesday 15:30–18:00 Location: MA 001

SOE 16.1 Wed 15:30 MA 001

Modelling opinion dynamics under the impact of influencer and media strategies — •Natasa Djurdjevac Conrad[1], Christof Schütte[1,2], Luzie Helfmann[1], and Philipp Lorenz-Spreen[3] — [1]Zuse Institute Berlin, Berlin, Germany — [2]Freie Universität Berlin, Berlin, Germany — [3]Max Planck Institute for Human Development, Berlin, Germany

In this talk, we will propose a novel agent-based model (ABM) that aims to model how individuals (agents) change their opinions under the impact of media and influencers. We will study the rich behavior of this ABM in different regimes and explore how different opinion formations can emerge, e.g. consensus and fragmentation. This framework allows for mean-field approximations by partial differential equations, which reproduce the dynamics and allow for efficient large-scale simulations when the number of individuals is large. Based on the mean-field model, we will show how strategies of influencers can impact the overall opinion distribution and that optimal control strategies allow other influencers (or media) to counteract such attempts and prevent further fragmentation of the opinion landscape.

SOE 16.2 Wed 15:45 MA 001

The dynamics of public and private opinions as interacting complex contagions — •Barbara Kaminska[1], Arkadiusz Jedrzejewski[2], and Katarzyna Sznajd-Weron[1] — [1]Wrocław University of Science and Technology — [2]CY Cergy Paris Université

Human decision-making and the process of opinion formation are inherently complex. This process involves two distinct levels: the external, where opinions are openly expressed, and the internal, where beliefs are privately held. These levels are shaped by a dynamic interplay between independent choices, social interactions as well as their mutual impact, akin to the concept of interacting complex contagions. Previous research, grounded in agent-based modeling, has explored this interplay primarily by considering how publicly expressed views depend on private beliefs. In this work, we extend this investigation to consider mutual interactions between opinions at the public and private levels. The main objective of this study is to assess the impact of self-confirmation and the desire to reduce cognitive dissonance, the misalignment between internal and external opinions. This also means exclusion of self-anticonformity, a factor present in our previous work. Through Monte Carlo simulations and analytical analysis, we demonstrate that a model without self-anticonformity supports the emergence of social hysteresis, a form of collective memory closely linked to delays in responding to changing external conditions. The results obtained in this work show also that self-anticonformity can foster agreement among agents, aligning with similar results from various other models.

SOE 16.3 Wed 16:00 MA 001

Accelerated consensus and stable dissent in projected argument-based opinion dynamics — •Sven Banisch and Joris Wessels — Karlsruhe Institute for Technology

This contribution reports on a first exercise to project an opinion model with psychologic depth onto continuous opinion dynamics. In the argument model, agents exchange arguments, or beliefs, and form their opinion based on evaluations of them. In continuous opinion dynamics, agents have only opinions that adapt in interaction with other opinions. Here we study which dynamics are implied by explicit argument exchange with confirmation bias on the space of continuous models. We were surprised by this exercise, because some things we had not anticipated emerged. While it was expected that consensus forms quickly in the projected, but not in the explicit model, we did not expect that the meta-stable state of polarization would stabilize after projection. Qualifying model outcomes by their convergence properties may capture differences between models more than their phenomenological similarities. With psychological depth, the transient becomes relevant. We discuss implications for coupled models, in which opinion dynamics is included in a disease or climate model, and where reducing model complexity is highly desirable for computational reasons as well as for a systematic understanding of different model classes.

SOE 16.4 Wed 16:15 MA 001

Instability Cycles in an Adaptive Network Model of Society — •Alexander Jochim and Stefan Bornholdt — Institute for Theoretical Physics, University of Bremen

Political instability and violence, enduring phenomena throughout history, pose complex challenges for societies. Recent research has uncovered compelling quantitative evidence of common patterns across various societies in history. Proxy variables for average well being and societal elites have been utilized to calculate political stress [1]. However, the transition from microscopic interactions to macroscopic behavior remains poorly understood, with only qualitative theories as a guidance.

We here study an agent based toy model of society, exhibiting cycles of instability and inequality as emergent patterns resulting from simple micro interactions. This may improve our understanding of political instability by bridging the gap between qualitative theories and quantitative agent based modeling.

[1] P. Turchin, Ages of discord (Beresta Books, 2016).

SOE 16.5 Wed 16:30 MA 001

Rigorous Agent-Based Modeling is critical: Modeling the diffusion of green products and practices — •Angelika Abramiuk-Szurlej, Mikołaj Szurlej, and Katarzyna Sznajd-Weron — Wrocław University of Science and Technology, 50-370 Wrocław, Poland

Agent-based modeling (ABM) is gaining popularity in the field of managing pro-environmental behavior change. In the field of ecology, it is a well-established and rigorous scientific method. However, within social sciences, it is often criticized for its lack of rigor. We demonstrate how best practices from ABM in ecology can be applied to the study of pro-environmental social change. We argue that the two stages of ABM, namely description and verification, are fundamental for establishing ABM as a rigorous research method. Therefore, we provide a practical illustration of how to effectively execute these stages using an example of a model introduced in 2016 to study the diffusion of green products and practices. We describe the model using the ODD (Overview, Design concepts, Details) protocol. Furthermore, we present two different approaches to model analysis borrowed from the theory of complex systems to ensure rigorous model verification. We also clarify the circumstances under which the agent-based model can be reduced to an analytical model and when such reduction is not feasible. Finally, we present new results for the model that have not been previously reported. Specifically, we demonstrate that the model effectively replicates patterns observed in the real diffusion of innovations, including the S-shaped curve and the concept of critical mass.

15 min. break

SOE 16.6 Wed 17:00 MA 001

Poll-delayed immitation in the noisy voter model — •Aleksejus Kononovicius[1], Rokas Astrauskas[2], Marijus Radavicius[2], and Feliksas Ivanauskas[2] — [1]Institute of Theoretical Physics and Astronomy, Vilnius University, Vilnius, Lithuania — [2]Faculty of Mathematics and Informatics, Vilnius University, Vilnius, Lithuania

Noisy voter model is driven by two mechanisms: exploration and peer pressure. Exploration corresponds to the independent noisy flipping of individual agent states. Peer pressure on the other hand encourages the agents to copy the state of their peers (i.e., imitate their behavior). Here we consider an extension of the noisy voter model in which the peer pressure is exerted via the polling mechanism. As typical in the real world polling information is at least somewhat delayed. We show that when delay is comparatively short, the poll-delayed model is statistically identical to the original model. As delays become longer, oscillatory behavior emerges, but the model still converges to a steady state distribution. The effect of polling mechanism is explored both analytically and numerically.

SOE 16.7 Wed 17:15 MA 001

Individual bias and fluctuations in collective decision making: From algorithms to Hamiltonians. — Petro Sarkanych[1], Yunus Sevinchan[2,3], Mariana Krasnytska[1], Luis Alberto Gomez-Nava[4], Abi Tenenbaum[5], Yurij Holovatch[1], and •Pawel Romanczuk[2,3] — [1]Institute for Condensed Matter Physics of the National Academy of Sciences of Ukraine, Lviv, Ukraine — [2]Dep. of Biol-

ogy, Humboldt Universität zu Berlin, Germany — [3]Excellence cluster "Science of Intelligence", Berlin, Germany — [4]Laboratoire Matière et Systèmes Complexes, Université Paris Cité, France — [5]Yale University, USA

We investigate a spin model proposed by [Hartnett et al., Phys. Rev. Lett. 116 038701 (2016)] for understanding collective decision-making in higher organisms. The model uses opinion and bias variables to represent agents' states, interpreting decision-making as an approach to equilibrium in a nonlinear voter model with social pressure. We extend the model by introducing noise, and push the statistical physics interpretation further by deriving the Hamiltonian and calculating the partition function, revealing two possible Hamiltonian formulations based on different considerations on social interactions. Exact solutions for thermodynamics on complete graphs are obtained and validated through simulations. Further, we explore the impact of system size and initial conditions on collective decision-making. We also analyze the spin model on Erdos-Renyi random graphs, discussing susceptibility, critical points, and the network's response to a periodic external field.

SOE 16.8 Wed 17:30 MA 001

Consensus, Polarization and Hysteresis in the Three-State Noisy q-Voter Model with Bounded Confidence — •Maciej Doniec, Arkadiusz Lipiecki, and Katarzyna Sznajd-Weron — Wroclaw University of Science and Technology

In this work, we address the question of the role of influence group size on the emergence of various collective social phenomena, such as consensus, polarization, and social hysteresis. To answer this question, we study the three-state noisy q-voter model with bounded confidence, in which agents can be in one of three states: two extremes (leftist and rightist) and centrist. We study the model on a complete graph within the mean-field approach and show that depending on the size q of the influence group, saddle-node bifurcation cascades of different length appear and different collective phenomena are possible. In particular, for all values of $q > 1$ social hysteresis is observed. Furthermore, for small values of $q \in (1, 4)$ disagreement, polarization and domination of centrists (a consensus understood as the general agreement, not unanimity) can be achieved, but not domination of extremists. The latter is possible only for larger groups of influence. Finally, by comparing our model to others, we discuss how a small change in rules at the microscopic level can dramatically change the macroscopic behavior of the model.

SOE 16.9 Wed 17:45 MA 001

Homophily-Based Social Group Formation in a Spin Glass Self-Assembly Framework — •Jan Korbel — Section for the Science of Complex Systems, CeMSIIS, Medical University of Vienna, Spitalgasse 23, A-1090, Vienna, Austria — Complexity Science Hub Vienna, Josefstädterstrasse 39, A-1080, Vienna, Austria

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 (intragroup homophily), and opinions between individuals belonging to different groups tend to be different (intergroup heterophily). We compute the associated nontrivial phase diagram by solving a self-consistency equation for magnetization(combined average opinion). Below a critical temperature, there exist two stable phases: one ordered with nonzero magnetization and large clusters, the other disordered with zero magnetization and no clusters. The system exhibits a first-order transition to the disordered phase. We analytically derive the group-size distribution that successfully matches empirical group-size distributions from online communities.

SOE 17: Networks: From Topology to Dynamics (joint session SOE/DY)

Time: Wednesday 15:00–18:30 Location: TC 006

SOE 17.1 Wed 15:00 TC 006

Implicit models, latent compression, intrinsic biases, and cheap lunches in community detection in networks — •Tiago Peixoto — Central European University, Vienna, Austria

The task of community detection, which aims to partition a network into clusters of nodes to summarize its large-scale structure, has spawned the development of many competing algorithms with varying objectives. Some community detection methods are inferential, explicitly deriving the clustering objective through a probabilistic generative model, while other methods are descriptive, dividing a network according to an objective motivated by a particular application, making it challenging to compare these methods on the same scale. In this talk I present a solution to this problem that associates any community detection objective, inferential or descriptive, with its corresponding implicit network generative model. This allows us to compute the description length of a network and its partition under arbitrary objectives, providing a principled measure to compare the performance of different algorithms without the need for ground truth labels. Our approach also gives access to instances of the community detection problem that are optimal to any given algorithm, and in this way reveals intrinsic biases in popular descriptive methods, explaining their tendency to overfit. Using our framework, we compare a number of community detection methods on artificial networks, and on a corpus of over 500 structurally diverse empirical networks.

[1] Tiago P. Peixoto, Alec Kirkley, Phys. Rev. E 108, 024309 (2023)

SOE 17.2 Wed 15:15 TC 006

ESABO Co-Abundance Analysis: cases where the binarization threshold matters — •Devi Chandran and Jens Christian Claussen — School of Computer Science University of Birmingham, UK

Population dynamics including their complex interactions lead, in societies and microbial populations, to rich co-abundance patterns, and often only the (co)abundance pattern data is measured – whereby the precise interactions remain unknown. Here, ESABO [1] has been introduced to grasp interactions that remain unseen especially for low-abundant species. In [1], using ESABO we have recovered positive and negative interactions between agents (or species) within the population based on co-abundance data. However, in the medium abundance region, instead of a binarization threshold of 1, might it be worth to consider larger binarization thresholds? We investigate, based on two datasets, whether higher thresholds can lead to a higher information gain (in the sense of ESABO), and demonstrate cases of higher information gain for higher thresholds, but also confirm that the original threshold of 1 can be optimal for other datasets.

[1] J.C.Claussen at al., PlosCB (2017) 13(6): e1005361.

SOE 17.3 Wed 15:30 TC 006

Interplay of synchronization and cortical input in models of brain networks — •Eckehard Schöll[1,2,3] and Jakub Sawicki[2] — [1]Technische Universität Berlin — [2]Potsdam Institute for Climate Impact Research (PIK) — [3]Bernstein Center for Computational Neuroscience (BCCN) Berlin

It is well known that synchronization patterns and coherence have a major role in the functioning of brain networks, both in pathological and in healthy states. In particular, in the perception of sound, one can observe an increase in coherence between the global dynamics in the network and the auditory input. In this work, we show that synchronization scenarios are determined by a fine interplay between network topology, the location of the input, and frequencies of these cortical input signals [1]. To this end, we analyze the influence of an external stimulation in a network of FitzHugh-Nagumo oscillators with empirically measured structural connectivity, and discuss different areas of cortical stimulation, including the auditory cortex. [1] J. Sawicki and E. Schöll: Europhys. Lett. (2024), invited Perspective.

SOE 17.4 Wed 15:45 TC 006

Neuronal avalanches in weakly coupled FitzHugh-Nagumo oscillators — Max Contreras[1], Everton Medeiros[2], Igor Franović[3], and •Philipp Hövel[4] — [1]Technische Universität Berlin, Germany — [2]Carl von Ossietzky University Oldenburg, Germany —

[3]University of Belgrade, Serbia — [4]Saarland University, Germany

The activity in the brain cortex remarkably shows a simultaneous presence of robust collective oscillations and neuronal avalanches, where intermittent bursts of pseudo-synchronous spiking are interspersed with long periods of quiescence. The mechanisms allowing for such coexistence are still a matter of an intensive debate. Here, we demonstrate that avalanche activity patterns can emerge in a rather simple model of an array of diffusively coupled neural oscillators with multiple timescale local dynamics in the vicinity of a canard transition. The avalanches coexist with the fully synchronous state where the units perform relaxation oscillations. We show that the mechanism behind the avalanches is based on an inhibitory effect of interactions, which may quench the spiking of units due to an interplay with the maximal canard. The avalanche activity bears certain heralds of criticality, including scale-invariant distributions of event sizes. Furthermore, the system shows increased sensitivity to perturbations, manifested as critical slowing down and reduced resilience.

Reference: Max Contreras, Everton S. Medeiros, Anna Zakharova, Philipp Hövel, and Igor Franović: *Scale-free avalanches in arrays of FitzHugh-Nagumo oscillators*, Chaos **33**, 093106 (2023).

SOE 17.5 Wed 16:00 TC 006

On the inadequacy of nominal assortativity for assessing homophily in networks — •Fariba Karimi[1] and Marcos Oliveira[2] — [1]Graz University of Technology — [2]Exeter University

Nominal assortativity (or discrete assortativity) is widely used to characterize group mixing patterns and homophily in networks, enabling researchers to analyze how groups interact with one another. Here we demonstrate that the measure presents severe shortcomings when applied to networks with unequal group sizes and asymmetric mixing. We characterize these shortcomings analytically and use synthetic and empirical networks to show that nominal assortativity fails to account for group imbalance and asymmetric group interactions, thereby producing an inaccurate characterization of mixing patterns. We propose the adjusted nominal assortativity and show that this adjustment recovers the expected assortativity in networks with various level of mixing. Furthermore, we propose an analytical method to assess asymmetric mixing by estimating the tendency of inter- and intra-group connectivities. Finally, we discuss how this approach enables uncovering hidden mixing patterns in real-world networks.

SOE 17.6 Wed 16:15 TC 006

Unveiling homophily beyond the pool of opportunities — •Sina Sajjadi[1,2], Samuel Martin-Gutierrez[1], and Fariba Karimi[1,3] — [1]Complexity Science Hub Vienna, Vienna, Austria — [2]Central European University, Vienna, Austria — [3]Graz University of Technology, Graz, Austria

We introduce a robust methodology for quantifying and inferring choice homophily, reflecting individuals' preferences for connecting with similar others beyond structural factors that determine the pool of opportunities. Our approach employs statistical network ensembles to estimate and standardize homophily measurements. We control for group size imbalances and activity disparities by counting the number of possible network configurations with a given number of inter-group links using combinatorics. Our framework is suitable for undirected and directed networks, and applicable in scenarios involving multiple groups. Tested on synthetic networks, our approach outperforms traditional metrics, accurately capturing generative homophily despite additional tie-formation mechanisms. Preferential attachment has no effect on our measure, and triadic closure's impact is minor, especially in homophilic scenarios. We apply our model to scientific collaboration and friendship networks, demonstrating its effectiveness in unveiling underlying gender homophily. Our method aligns with traditional metrics in networks with balanced populations, but we obtain different results when the group sizes are imbalanced. This finding highlights the importance of considering structural factors when measuring choice homophily in social networks.

15 min. break

SOE 17.7 Wed 16:45 TC 006

Nonequilibrium Nonlinear Dynamics I: Nonlinear Shift and Tipping — Julian Fleck[1], Moritz Thümler[1], Malte Schröder[1], Seungjae Lee[1], and •Marc Timme[1,2] — [1]Center for Advancing Electronics Dresden (cfaed) and Institute for Theoretical Physics, Technische Universität Dresden, 01062 Dresden, Germany — [2]Lakeside Labs, 9020 Klagenfurt am Wörthersee, Austria

The collective nonlinear dynamics and reliable function of complex networked systems fundamentally underlie our daily lives, whether in biological cells, in power grids or in ecosystems. Most complex systems from the natural and engineering sciences are externally driven, and may exhibit intrinsically nonlinear state shifts or undergo tipping that disrupt the systems* intended or desired functionality. While state-of-the-art theoretical concepts and method development have focused on linear responses suitable for weak driving signals, it is far less understood how to characterize, predict and design complex systems responding to strong perturbations, that e.g., may ultimately lead to tipping. Here we report average response offsets that scale nonlinearly at asymptotically small amplitudes. At some critical driving amplitude, responses cease to stay close to a given operating point and may diverge. Standard response theory fails to predict these amplitudes even at arbitrarily high orders. We propose an integral self-consistency condition that captures the full nonlinear response dynamics. We illustrate our approach for a minimal one-dimensional model and capture the nonlinear shift of voltages in the response dynamics of AC power grid networks.

SOE 17.8 Wed 17:00 TC 006

Nonequilibrium Nonlinear Dynamics II: Strong Perturbations — •Julian Fleck, Moritz Thümler, Malte Schröder, Seungjae Lee, and Marc Timme — Institute for Theoretical Physics, Technische Universität Dresden, 01062 Dresden, Germany

Analytical studies of driven nonlinear dynamical systems often focus on linear response theory or extensions thereof in the asymptotic limit of small driving amplitudes. However, standard perturbation series are incapable of faithfully describing driving-induced system disruptions such as driving-induced tipping. In recent work (see part I: Nonlinear Shift and Tipping), we have proposed a self-consistency condition to estimate at which driving amplitudes non-equilibrium nonlinear system dynamics may tip. Here we propose to predict the tipping point by a large-perturbation expansion evaluated inside the self-consistency condition. We compare small-amplitude with the novel large-amplitude ansatz. The approach we propose may help to quantitatively predict intrinsically nonlinear response dynamics as well as bifurcations emerging at large driving amplitudes in non-autonomous dynamical systems.

SOE 17.9 Wed 17:15 TC 006

Transport networks with dynamical metric: when noise is advantageous — •Frederic Folz[1], Kurt Mehlhorn[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Algorithms and Complexity Group, Max-Planck-Institut für Informatik, Saarland Informatics Campus, 66123 Saarbrücken, Germany

The interplay of nonlinear dynamics and noise is at the basis of coherent phenomena, such as stochastic resonance, synchronization, and noise-induced phase transitions. While the effect of noise in these phenomena has been partially analyzed, the impact of the specific form of the nonlinear dynamics on noise-induced phase transitions is unknown. In this work, we analyze transport on a noisy network where the nonlinearity enters through a dynamical metric, which depends nonlinearly on the local current. We determine network selforganization for different functional forms of the metric in a geometry of constraints simulating the network of metro stations of the city of Tokyo. We consider Gaussian noise and show that the resulting dynamics exhibits noise-induced resonances for a wide range of the model parameters, which manifest as selforganization into the most robust network with a resonant response to a finite value of the noise amplitude. We analyze in detail the specific features and perform a comparative assessment. Our study sheds light on the interplay between nonlinear dynamics and stochastic forces, highlighting the relevance of their mutual interplay in determining noise-induced coherence.

SOE 17.10 Wed 17:30 TC 006

Crossword puzzle percolation — •Alexander K. Hartmann — University of Oldenburg, Germany

Games are a popular subject, also for physicists. Many games have a lattice or network representation. A crossword puzzle consists of *black* (blocked) and *white* sites, the latter can be *empty* or *occupied* with letters. A word is *known* in the puzzle if a complete horizontal or vertical segment of white sites, usually between two black sites, is occupied (periodic boundary conditions are used, words may also take

a full column or row).

Here the crossword puzzle is considered as percolation problem: Two known words are *connected* if they are perpendicular to each other and share one occupied site. A configuration is considered as *percolating* if there exists a path of connected words around the system, in either direction.

Numerical simulations for two-dimensional crosswords up to size 1000×1000 are performed. For uncorrelated occupation with probability p for the white sites, percolation transitions at critical thresholds p_c, depending on the fraction of black sites, are found. The results are analyzed by finite-size scaling and indicate that the problem is in the universality class of standard two-dimensional percolation. This changes, when the real game case is considered where full words are known with a probability $p_w(x)$ which depends on the fraction x of already known letters in the word, introducing correlations. The universality class depends on the shape of $p_w(x)$.

SOE 17.11 Wed 17:45 TC 006

Network percolation provides early warnings of abrupt changes in coupled oscillatory systems: An explanatory analysis — Noémie Ehstand[1], •Reik V. Donner[2,3], Cristóbal López[1], and Emilio Hernández-García[1] — [1]IFISC, Palma de Mallorca, Spain — [2]Magdeburg-Stendal University of Applied Sciences, Magdeburg, Germany — [3]Potsdam Institute for Climate Impact Research, Potsdam, Germany

Functional networks are powerful tools to study statistical interdependency structures in spatially extended or multivariable systems. In particular, percolation properties of correlation networks have been employed to identify early warning signals of critical transitions. Here, we further study the potential of percolation measures for the anticipation of different types of sudden shifts in the state of coupled irregularly oscillating systems. For a ring of diffusively coupled noisy FitzHugh-Nagumo oscillators that are nearly completely synchronized, the percolation-based precursors successfully provide very early warnings of the rapid switches between the two states of the system. We clarify the mechanisms behind the percolation transition by separating global trends given by the mean-field behavior from the synchronization of individual stochastic fluctuations. We then apply the same methodology to real-world data of sea surface temperature anomalies during different phases of the El Niño-Southern Oscillation. This leads to a better understanding of the factors that make percolation precursors effective as early warning indicators of incipient El Niño and La Niña events. [N. Ehstand et al., Phys. Rev. E, 108, 054207, 2023]

SOE 17.12 Wed 18:00 TC 006

Bond percolation and tree decompositions of real-world networks — •Konstantin Klemm — IFISC (CSIC-UIB), Palma de Mallorca, Spain

Percolation is a class of models with numerous applications in spreading processes including epidemics and social interactions. For most real-world and model-generated networks, percolation studies rely on Monte-Carlo sampling or approximate calculations such as (heterogeneous) mean-field. The present contribution introduces a method for exact numerical estimates of expected cluster sizes in bond percolation. The method is efficient on networks with a narrow tree-decomposition, a property shared by empirical networks of interest [Klemm, Journal of Physics: Complexity 1, 035003 (2020)]. Generalization of the approach to other processes in statistical physics are discussed [Klemm, arXiv:2111.04766].

SOE 17.13 Wed 18:15 TC 006

Between mechanisms and behaviors in higher-order systems — •Thomas Robiglio[1], Davide Coppes[2], Cosimo Agostinelli[2], Matteo Neri[3], Maxime Lucas[4], Federico Battiston[1], and Giovanni Petri[4,5] — [1]Department of Network and Data Science, Central European University, Vienna, Austria — [2]Department of Physics, University of Turin, Via Pietro Giuria 1, 10125 Turin, Italy — [3]Institut de Neurosciences de la Timone, Aix Marseille Université, UMR 7289 CNRS, 13005, Marseille, France — [4]CENTAI, Corso Inghilterra 3, 10138 Turin, Italy — [5]NPLab, Network Science Institute, Northeastern University London, London, UK

Mechanism and behavior are the two fundamental facets of the study of the dynamical properties of complex systems. Mechanism describes how a system is structured and what the microscopic rules governing its dynamic are while behavior accounts for its emergent properties.

Using tools from information theory, we systematically explore the relationship between higher-order (i.e. beyond pairwise) mechanisms and higher-order behaviors. Considering two dynamical models with group interactions -a simplicial Ising model and the simplicial model of social contagion- we find a region of the parameter space in which higher-order synergistic behaviors and group mechanisms co-occur.

We also apply higher-order information theoretical metrics to characterize the behavior of the stock market across time and show that we can identify periods of economic crisis that are overseen by the corresponding low-order metrics.

SOE 18: Hacky Hour II (joint session AGI/SOE/AKjDPG)

In this new format, introduced by AGI and jDPG, tools are presented that can be helpful in your everyday scientific work. Whenever possible a hands-on part will be offered where the tool can be used directly preferably on your own laptop. Furthermore there will be a discussion of the tool where e.g. aspects of compatibility and extensibility can be addressed.

If installation of software is necessary in advance instructions on this and further information in general can be found at https://hacky-hour.dpg-physik.de

Time: Wednesday 15:00–18:00 Location: MAR 0.011

SOE 18.1 Wed 15:00 MAR 0.011

Controlling experiments and recording FAIR data with NOMAD CAMELS — •Alexander D. Fuchs[1,2], Johannes A. F. Lehmeyer[1,2], Heiko B. Weber[1], and Michael Krieger[1] — [1]Lehrstuhl für Angewandte Physik, Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany. — [2]Physics Department and CSMB, Humboldt-Universität zu Berlin, Germany

NOMAD CAMELS (Configurable Application for Measurements, Experiments and Laboratory Systems) [1] is an open-source measurement software that records FAIR and fully self-describing measurement data. It enables the definition of measurement protocols via a graphical user interface without requiring programming knowledge or deeper understanding of instrument communication. Coming from the field of experimental physics, CAMELS provides the flexibility of controlling a large variety of measurement instruments in frequently changing experimental setups. The user-defined measurement protocols are translated into stand-alone executable Python code, providing full transparency of the actual measurement sequences.

This Hacky Hour contribution starts with a brief overview of CAMELS followed by a hands-on session on setting up CAMELS and performing measurements (to follow bring your own laptop if possible).
[1] https://fau-lap.github.io/NOMAD-CAMELS

SOE 18.2 Wed 15:45 MAR 0.011

Streamlining Data Management in Laser Plasma Experiments with Python-Flask WebApps — •Kristin Tippey, Hans-Peter Schlenvoigt, and Thomas Kluge — Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Bautzner Landstraße 400, 01328 Dresden, Germany

In the complex field of laser plasma experiments, managing data efficiently and effectively is crucial. The goal of our team is to establish a standardized, efficient, and user-friendly system that adheres to FAIR principles, with ambitions to enhance the research and analysis capabilities of the teams at Helmholtz Zentrum Dresden-Rossendorf (HZDR). We are creating an integrated ecosystem comprising of a set of Python-Flask WebApps, each playing a role in the process of log-

ging and managing data in these specialized experiments. The current collection of applications include features for the direct capture of manually entered parameters, software trigger and ID distribution, generic data collection, and experiment actuator logging. Additionally, scripts are being devised to collect metadata from a selection of simulation input styles for upload to SciCat for eventual cross-referencing of simulations with experiments. The effective cataloging of data and metadata not only benefits our machine learning team but also promises to enrich experimental analysis and decision-making processes. Additionally, our software can serve as a reference model for similar systems or be adapted for deployment in other environments, extending and augmenting existing systems as appropriate.

15 min. break

SOE 18.3 Wed 16:30 MAR 0.011

elabFTW as one building block of our FAIR data exchange — •Sebastian T. Weber, Eva Walther, Martin Aeschlimann, Bärbel Rethfeld, and Georg von Freymann — Department of Physics and Research Center OPTIMAS, RPTU Kaiserslautern-Landau

The basis of a FAIR data management is a well-described and detailed documentation of every single step of the experiment and data analysis. In recent decades, however, the focus has shifted from analog measuring instruments and analytical calculations to computer-based experiments and simulations. This has lead to a large increase in the numbers of measurements and observed quantities and therefore in the amount of data generated.

We use electronic lab notebooks (ELNs) to store, index, search and retrieve a large amount of entries within our collaborative research center CCR/TRR173 Spin+X. Here, it is particularly challenging to exchange data between scientists with different background and location. In this presentation, we introduce our ELN 'elabFTW' and give insight into our journey of establishing a joint electronic lab notebook as well as harmonizing the exchanged meta(data) to foster collaboration within our research center. We report on our experiences in the daily work of the scientists and our progress of a new infrastructure project.

SOE 18.4 Wed 17:00 MAR 0.011

Computational Notebook as a Modern Multitool for Scientists — •Kirill Vasin — Augsburg University, Augsburg, Germany

Modern computational notebooks, stemming from the 1981 Literate programming concept, are powerful tools like Mathematica, Maple, and Jupyter Notebook. Yet, popular solutions often lack traditional math input support, focusing on specific fields (business analytics, engineering or solely computer algebra) or not being open/freeware.

For physicists, OriginPro, PowerPoint, and paper are preferred, as notebook interfaces are challenging to use efficiently. To address this, we developed WLJS Notebook [https://jerryi.github.io/wljs-docs/], a scientist-designed system based on Wolfram Language. It's open, friendly for mathematicians, allows mixing code and mathematical equations, figures preparation and covers all basic tasks experimentalists need like processing raw data and interactive fitting. With built-in support for various cell types, it facilitates data-driven interactive slides, eliminating export needs of graphs to .png files and syncing data to it. Markdown and plain HTML are used as a default languages for notes and slides.

Accessibility is ensured through export to .html or .pdf. WLJS Notebook runs locally, without internet dependency, and is free.

SOE 18.5 Wed 17:30 MAR 0.011

snip: user-centered lab book — •Markus Osterhoff, Sebastian Mohr und Sarah Köster — Institut für Röntgenphysik, Friedrich-Hund-Platz 1, 37077 Göttingen

Conducting and steering complex experiments is a highly creative process, requiring not just the alignment, sample treatment, and preliminary analysis, but also real-time discussions among researchers. In the realm of traditional hand-crafted log books, there was significant freedom to combine printouts with annotations and sketches, mirroring the progress and decisions of the experiment. However, with the advent of electronic log books, the creativity in free note-keeping has been largely disregarded, with an overemphasis on formalities consuming more time. Moreover, important machine parameters, like motor positions and images from detectors and microscopes, are not easily accessible or referenced, even in facility-developed log books.

We propose "snip," a digital user-centered lab book that combines hand-crafted entries with computer-generated content. This system not only supports standard measurements but puts creative research at the forefront. Through external software (control software, detector and microscope computers, etc.), standardized "snippets" representing the experiment are created and sent. Researchers can curate these snippets, adding annotations and using a pen for quick documentation, sketching, and highlighting. The web-based software facilitates collaborative work, allowing experts worldwide to work on the document simultaneously and discuss their ideas in real-time.

The "snippets" carry essential information as metadata, like motor positions or images. Before being "glued" into the book, users can adjust the actual "view" (size, ROI, etc.), and then annotate with pen entry. This maintains the "analogue mode of operation" to a large degree, but instead of printouts, "true digital copies" are used. Furthermore, an API provides definable interfaces for third-party software (control, analysis, simulation) to submit digital versions of the traditional paper snippets, including system state printouts or graphics.

In this way, snips are not automatically or strictly chronologically added to the lab book. Instead, users creatively curate them according to the ongoing discussion, enriching the machine-readable information with sketches, highlights, and ad hoc texts. This approach not only preserves but enhances the creative and collaborative aspects of experimental research, integrating the flexibility of digital technology with the intuitive, hands-on approach of traditional scientific exploration.

SOE 19: Members' Assembly

Time: Wednesday 18:30–20:00 Location: TC 006

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

SOE 20: Focus Session: Statistical Physics of Political Systems

One of todays most pressing and consequential issues are whether democracy worldwide is in decline. Thanks to an increasing collection of quantitative data, there is a rising opportunity to develop new quantitative models on the role the economy, international armed conflicts and other events play in the stabilisation of political regime types such as democracy and autocracy. This situation invites the use of statistical physics techniques, since these processes often take place on many time and length scales, from the singular event to multi-year developments, and from local regions to continents.

Organized by Karoline Wiesner and Paula Pirker Diaz (Universität Potsdam)

Time: Thursday 15:00–16:45 Location: MA 001

Invited Talk SOE 20.1 Thu 15:00 MA 001

A closer look at the multiple scales of armed conflict — •Edward Lee — Complexity Science Hub Vienna, Vienna, Austria

Conflicts, like many social processes, are related events that span multiple scales in time, from the instantaneous to multi-year development, and in space, from one neighborhood to continents. Yet, there is little systematic work on connecting the multiple scales, formal treatment of causality between events, and measures of uncertainty for how events are related. We develop a method for extracting causally related chains of events that addresses the limitations. Our method explicitly accounts for an adjustable spatial and temporal scale of interaction for clustering individual events from a detailed data set, the Armed Conflict Event & Location Data Project. With it, we discover a mesoscale ranging from a week to a few months and tens to hundreds of kilometers, where long-range correlations and nontrivial dynamics relating conflict events emerge. Importantly, clusters in the mesoscale, while extracted from conflict statistics, are identifiable with mechanism cited in field studies. We leverage our technique to identify zones of causal interaction around hotspots that naturally incorporate uncertainties. Conflict avalanches represent systematic clusters distinct from qualitative, sociopolitical labels. We use them to identify categories of conflict and are developing techniques to leverage them for conflict prediction in concert with highly resolved data sets on geographic, climatic, and socioeconomic variables. Thus, we show how a systematic, data-driven, and scalable procedure extracts social objects for study, providing a scope for scrutinizing and predicting conflict and other processes.

SOE 20.2 Thu 15:30 MA 001

Conflict Classification Using Multinomial Mixture Models and Conflict Avalanches — •Niraj Kushwaha[1], Edward Lee[1], and Woi Sok oh[2] — [1]Complexity Science Hub Vienna — [2]Princeton University

Armed conflicts are notoriously difficult to systematically characterize and classify[1]. In a recent work, the first problem was tackled using transfer entropy-a measure of information theoretic causality-to group individual conflict events into cohesive cascading structures termed "conflict avalanches"[2]. Our focus now centers on the second problem, wherein leveraging the identified conflict avalanches, we extensively mapped each conflict avalanche to twenty variables commonly linked to armed conflicts in the existing literature. These variables span climatic, socio-economic, demographic, and geographic dimensions. Employing a multi-multinomial mixture model, a novel iteration of the well-established multinomial mixture model, we subjected the conflict avalanches to clustering based on this augmented dataset. The resulting clusters enable us to classify conflicts as compositions of distinct climatic, socioeconomic, demographic, and geographic variables. This systematic classification methodology also identifies crucial underlying determinants for each conflict type and offers insights into the influential factors underpinning each. This innovative classification framework holds promise for advancing our understanding of armed conflicts and improving predictive modeling of armed conflicts. [1] Critical issues in peace and conflict studies: Theory, practice, and pedagogy. Lexington Books, 2011. [2] Kushwaha and Lee, PNAS Nexus, 2023

SOE 20.3 Thu 15:50 MA 001

Digital Democracy: Better than Optimal?! — •Dirk Helbing — ETH Zurich, Computational Social Science — Complexity Science Hub Vienna

Societies are complex systems. This has important implications for how societies should be managed, in particular, how democracies can be upgraded. I will illustrate our insights by means of pattern formation and self-organisation phenomena in social systems as well as applications to self-governance and self-control. Furthermore, I will discuss how collective intelligence and co-creation can be supported in ways that promote favourable systemic outcomes - outcomes that are better than optimal, i.e. better than when optimisation is applied. As an application example, I will present a field study on participatory budgeting, as it has been recently carried out in Aarau, Switzerland. Specifically, I will discuss, how voting rules can be improved to promote individual and systemic benefits, such as inclusion and fairness.

SOE 20.4 Thu 16:10 MA 001

Modelling dynamics of political regime types in the 20th century — •Paula Pirker-Diaz[1], Sönke Beier[1], Matthew Wilson[2], and Karoline Wiesner[1] — [1]Universität Potsdam, Potsdam, Deutschland — [2]University of South Carolina, Columbia, USA

Can the evolution of political systems be predictable? Is there a way to define their state with a maximum of two state variables?

To answer these questions we are analysing part of the V-Dem Research Project dataset, the world*s most detailed democracy ratings. It consists of hundreds of indicators quantifying different aspects that define the democracy level of more than 170 countries, which reveals the complexity of political systems and their definition. (Wilson, Matthew et al., *The Hidden Dimension in Democracy* (2023). V-Dem Working Paper 2023:137)

We apply the dimensionality reduction method called diffusion map and identify a two dimensional manifold containing all datapoints corresponding to all countries and years available, between 1900 and 2021. Being the first coordinate strongly aligned to the Electoral Democracy Index, this novel representation distinguishes autocracies from democracies in a surprisingly clear way. We also identify regions in the manifold that are related to specific regime types and additionally, suffrage types. By fitting a Gaussian Mixture model to the temporal evolution, we detect the collective response of the system to historical events. Based on our results, we suggest a predictive model for the evolution of political systems.

15 min. for final discussion

SOE 21: Computational Social Science

Time: Thursday 17:00–18:00 Location: MA 001

SOE 21.1 Thu 17:00 MA 001

Online platforms and democracy: measuring systemic risks now and in the future — •Philipp Lorenz-Spreen[1], Lisa Oswald[1], Stephan Lewandowsky[2,3], and Ralph Hertwig[1] — [1]Center for Adaptive Rationality, Max Planck Institute for Human Development, Berlin, Germany — [2]School of Psychological Science and Cabot Institute, University of Bristol, Bristol, UK — [3]School of Psychological Science, University of Western Australia, Perth, Australia

Information and communication technology has undergone dramatic developments over the past two decades. Increased peer-to-peer connectivity has led to more self-organised public discourse, but it has also given researchers new tools to quantify precisely this systemic shift. Detailed and longitudinal data from social media allow us to measure and model their network structures and dynamics. However, to get a holistic and global picture, a recent systematic literature review has provided us with a number of dimensions of political behaviour that appear to be influenced by the use of digital media. Our findings show that, while the directions within each dimension are mostly clear, they are distributed differently globally and the mechanisms by which these dimensions are linked are still unknown. Understanding these better is crucial for civil society in democracies worldwide, and I will conclude with a methodological outlook on how we can empirically investigate these missing links in the future.

SOE 21.2 Thu 17:15 MA 001

Structure and dynamics of climate change contrarianism on Reddit — •Armin Pournaki[1,2,3], Jean-Philippe Cointet[2], Thierry Poibeau[3], Jürgen Jost[1], and Eckehard Olbrich[1] — [1]Max Planck Institute for Mathematics in the Sciences, Leipzig — [2]médialab, SciencesPo, Paris — [3]Laboratoire Lattice, Paris

Even though scientific consensus on the human effects on climate change is established, there exists a growing contrarian movement that aims to reduce the consideration of climate change for policy making. This work aims to shed light on the argumentation patterns observed in everyday discussions of climate contrarians on the social media platform Reddit. Using an existing transformer-based text classifier trained on hand-annotated paragraphs of contrarian claims (Coan et al. 2021), we show that the most frequently encountered claims against climate change in this space are 1) attacks against the climate movement, 2) attacks against climate science and 3) questioning the effect of human impact on global warming. These patterns are stable over time. Computing the entropy of users' claim distributions and embedding them into a lower-dimensional argument space, we show that many Redditors adopt a variety of (sometimes incompatible) arguments and that the above mentioned top claims constitute the main argumentative axes that divide discussions in the subreddit r/climateskeptics. Finally, we investigate the role of influencers and show that the majority of the content discussed is generated by a small number of highly active accounts who predominantly push content that directly attacks the climate movement and scientists.

SOE 21.3 Thu 17:30 MA 001

Issue and user alignment in the German Twittersphere — Armin Pournaki[1,2,3], Felix Gaisbauer[4], and •Eckehard Olbrich[1] — [1]Max Planck Institute for Mathematics in the Sciences, Leipzig — [2]médialab, SciencesPo, Paris — [3]Laboratoire Lattice, Paris — [4]Weizenbaum Institut, Berlin

The rise of social media platforms has changed the structure of the public sphere. Instead of the unidirectional one to many communication of classical mass media, social media platforms created a networked public sphere and thus networks are a natural way to study the structure of public discourse on these platforms.

This work investigates the interaction structure as well as the content of trending topics of the German Twittersphere over two years (03/2021 to 03/2023). Do users sort into similar opinion groups across different themes? Are there themes that are more polarizing than others? What is the role of certain types of users (influencers, spreaders) in driving these phenomena?

Using clusters in retweet networks as opinion clusters in the underlying debate, we measure the alignment of users across issues over and show that Twitter users have a general tendency to sort into temporally stable opinion groups, and that certain overarching themes, such as COVID, align users more strongly than others. Furthermore, we investigate the role of power users in driving this alignment and shaping the perception of public debate.

SOE 21.4 Thu 17:45 MA 001

Hierarchical Clustering and Polarization in affiliation networks — •Emanuele Cozzo[1], Adrian Fernandez Cid[2], Oriol Pujol[2], and Luce Prignano[1] — [1]Univeristat de Barcelona Institute of Complex Systems — [2]Facultat de Matematiques i Informatica, Universitat de Barcelona

Social and political polarization has long been a key subject in both academic and mainstream discussions. The key focus in polarization research is its measurement. Structural methodologies emphasize deducing polarization from the characteristics of the system's network representation. Polarization metrics necessitate explicit definitions in terms of groups, which can be identified either endogenously or exogenously. In cases involving endogenously identified groups, the challenge of measuring polarization intertwines with the task of data clustering. Commonly, data is first clustered, followed by the measurement of polarization. Yet, a more coherent approach would involve identifying clusters based on the same principles used for measuring polarization.

In our study, we investigate an axiomatic suite of polarization metrics to evaluate the polarization within the identified segments and to assist in the hierarchical clustering of social entities within the system. Our focus is particularly on affiliation networks. We demonstrate our findings using the Southern Women dataset. With the insights gleaned from our analysis of this established system, we then extend our methodology to explore contemporary, real-world situations.

SOE 22: Power Grids (joint session SOE/DY)

Time: Friday 9:30–10:00 Location: MA 001

Invited Talk SOE 22.1 Fri 9:30 MA 001

Resilience of power grids against extreme events — •Mehrnaz Anvari — Fraunhofer Institute for Algorithms and Scientific Computing, Sankt Augustin, Germany

Societies are experiencing rapid and pressing changes in the way they generate and consume energy. As part of the necessary transformation towards carbon dioxide neutral energy networks, power systems are increasingly incorporating renewable energy sources (RES) into the energy mix. However, RES such as wind and solar power are inherently uncertain and intermittent, which can result in rapid transitions from maximum power to no power in just a few seconds. These non-Gaussian characteristics, combined with fluctuations in electricity consumption, can create vulnerabilities in the power system. This will be the main topic of the first part of this talk. In addition, to exploit the surplus of RES in other sectors such as transportation and heating, their coupling with power grid will become stronger. This means that failures in the power grid, driven by uncertain RES or extreme weather events can lead to cascading failures not only in the power grid but also in other sectors, creating a domino effect. Therefore, identifying the critical components in the complex power grid whose failures lead to large cascading failures is essential to improve the grid's resilience. In the second part of this talk, the co-evolution method will be introduced as a way of identifying these critical components.

SOE 23: Networks: From Topology to Dynamics (joint session DY/SOE)

Time: Friday 9:30–12:15 Location: BH-N 128

Invited Talk SOE 23.1 Fri 9:30 BH-N 128

A simulation approach for the emerging mechanical properties of multi-network systems — •Kirsten Martens — CNRS & Univ. Grenoble Alpes

Network-forming materials are ubiquitous, from industrial products (tires, food, cosmetics...) to living organisms (e.g. in the cytoskeleton). Network-based materials often possess remarkable properties, such as high reversible deformability, light weight, optical transparency. Understanding the mechanical properties of multi-array gels at the molecular scale is essential to improve the quality of these new macromolecular architectures.

In this talk I will present a coarse grained numerical model for elastomer materials to address the question how these systems deform and fracture. Our double networks are characterised by a first pre-streched network that is close to failure coupled to a second floppy one that only breaks at later stages. We show that depending on the preparation protocol we can control the ductility of the double network depending on the volume fraction of the second network. Further we have direct access to the local bond breaking dynamics. We show that in single networks bond breaking events are strongly correlated in space and lead to brittle failure, whereas in double networks the damage is more delocalised promoting ductile failure. We show that this is the effect of a two stage process that can be controlled by the densities in the initial preparation protocol of the double network.

SOE 23.2 Fri 10:00 BH-N 128

Topological data analysis applied to networks modeling porous media transport — •Lou Kondic[1], Matt Illingworth[1], Binan Gu[2], and Linda Cummings[1] — [1]New Jersey Institute of Technology, Newark, NJ, USA — [2]Worcester Polytechnic University, Worcester, MA, USA

We model porous medium as a random pore network and focus on the influence of the medium internal structure on its flow and adsorptive behavior. A particular focus is modeling suspension flow, where the particles adsorb on the pore walls. We first formulate the governing equations of fluid flow on a general network. Then, we model adsorption by imposing an advection equation with a sink term on each pore and study the influence of network parameters on the flow and transport. The presentation will focus on developing a better understanding of the connection between the topology of the medium (pore network) and the flow properties. The challenging aspect of understanding and quantifying evolving pore network topology is addressed by using topological methods that allow for simplified network descriptions, both regarding their static and their dynamic properties. For this purpose, we use tools based on persistent homology. These tools allow us to connect topology, transport, and adsorption as the basic step toward designing porous media of desired properties.

SOE 23.3 Fri 10:15 BH-N 128

Stimulating self-optimisation of flow networks for transport — Julien Bouvard[1], •Swarnavo Basu[2], Charlotte Leu[3], Onurcan Bektas[2,3], Joachim Rädler[3], Gabriel Amselem[1], and Karen Alim[2] — [1]Laboratoire d'Hydrodynamique, CNRS, École polytechnique, Institut Polytechnique de Paris, France — [2]School of Natural Sciences, Technical University of Munich, Germany — [3]Soft Condensed Matter Group, Ludwig-Maximilians-Universität München, Germany

Transport of substances via fluid flow in networks is ubiquitous in biology (e.g. blood vasculature) and engineering (e.g. porous media). Many biological networks can self-organise in response to stimuli by homogenising flow to achieve optimal perfusion and transport. In contrast, engineered networks of random media have heterogeneous flow velocity distributions. Self-organising engineered networks that can homogenise flow will have many applications, e.g. cooling batteries, chemical reactors and *in vitro* vasculature for perfusing tissues and implants. We show, experimentally and theoretically, that self-optimisation can be achieved in networks with eroding walls. Perfusing such a network with short pulses of an eroding agent achieves homogenisation of flow velocities across the network, thus, providing us with a framework for engineering self-optimising networks.

SOE 23.4 Fri 10:30 BH-N 128

Partial event coincidence analysis for distinguishing direct and indirect coupling in functional network construction — •Reik V. Donner[1,2] and Yong Zou[3] — [1]Magdeburg-Stendal University of Applied Sciences, Magdeburg, Germany — [2]Potsdam Institute for Climate Impact Research, Potsdam, Germany — [3]East China Normal University, Shanghai, China

Correctly identifying interaction patterns from multivariate time series presents an important step in functional network construction. In this context, the widespread use of bivariate statistical association measures often results in a false identification of links because of strong similarity originating from indirect interaction or common drivers. In order to properly distinguish such direct and indirect links for the special case of event-like data, we present a partial version of event coincidence analysis (PECA) aimed at excluding possible transitive effects of indirect couplings. Using coupled chaotic systems and stochastic processes on two generic coupling topologies, we demonstrate that the proposed methodology allows for the correct identification of indirect interactions in case of just a few coupled systems. Finally, we apply PECA to multi-channel EEG recordings to investigate possible differences in coordinated alpha band activity among macroscopic brain regions in resting states with eyes open (EO) and closed (EC) conditions. Our approach leads to a significant reduction in the number of indirect connections and thereby contributes to a better understanding of the alpha band desynchronization phenomenon in the EO state.

SOE 23.5 Fri 10:45 BH-N 128

Meta-reinforcement adds a second memory time-scale to random walk dynamics — •Gianmarco Zanardi[1,2], Paolo Bettotti[1], Lorenzo Pavesi[1], and Luca Tubiana[1,2] — [1]Physics Department, University of Trento, via Sommarive, 14 I-38123 Trento (IT) — [2]INFN-TIFPA, Trento Institute for Fundamental Physics and Applications, I-38123 Trento (IT)

Stochastic processes on networks have successfully been employed to model a multitude of phenomena. Non-Markovianity allows to account

for history, introducing a memory effect that biases the evolution. Amongst all the variations that have been developed, in the reinforced random walk (RW) the walker is attracted towards its past trajectory: this process manifests emergent memory where edge weights in the network store information on the path of the RW.

We focus on this emergent memory feature and expand the model to introduce another memory level on a longer time-scale. We extend the reinforcement dynamics to feature a bounded non-linear function and a decay mechanism to interpret weights as short-term memory. We pair this with a second dynamics that is stochastic, irreversible and adapts the reinforcement function during the RW: the walk becomes "meta-reinforced". The result is a long-term memory form on top of the short-term one.

We simulate the RW on a recurrent feed-forward network under many parameter combinations to study the ability of the system to learn and recall traversal paths of the walker.

15 min. break

SOE 23.6 Fri 11:15 BH-N 128

Exploiting memory effects to detect the boundaries of biochemical subnetworks — •Moshir Harsh[1], Leonhard Vulpius[1], and Peter Sollich[1,2] — [1]Institut für Theoretische Physik, Georg-August-Universität Göttingen, Göttingen — [2]Department of Mathematics, King's College London, London WC2R 2LS, UK

Partial measurements of biochemical reaction networks are ubiquitous and limit our ability to reconstruct the topology of the reaction network and the strength of the interactions amongst both the observed and the unobserved molecular species. Here, we show how we can utilise noisy time series of such partially observed networks to determine which species of the observed part form its boundary, i.e. have significant interactions with the unobserved part. This opens a route to reliable network reconstruction. The method exploits the memory terms arising from projecting the dynamics of the entire network onto the observed subnetwork. We apply it to the dynamics of the Epidermal Growth Factor Receptor (EGFR) network and show that it works even for substantial noise levels.

SOE 23.7 Fri 11:30 BH-N 128

Linear Stability of Adaptive Dynamical Networks — •Frank Hellmann — Potsdam Institute for Climate Impact Research

I present new stability results for heterogeneous adaptive dynamical networks. As a first application I present a universal stability condition for power grids based on the complex couplings formulation [1].

[1] https://arxiv.org/abs/2308.15285

SOE 23.8 Fri 11:45 BH-N 128

Network Science and Beyond – Can Network Measures capture Mechanisms of Desynchronization in Complex Networks? — •Christian Nauck — Potsdam Institute for Climate Impact Research, Germany

This study addresses the fundamental question of how network function emerges from topology, particularly in nonlinear oscillator networks. While traditionally network measures have been discovered, recent advances in Machine Learning (ML), notably Graph Neural Networks (GNNs), provide an alternative for predicting network function. Through a comprehensive literature review, we identify 46 network measures, integrating them with conventional ML (NetSciML) to predict dynamic stability in power grids. Our findings reveal that a complete set of measures rivals GNNs in performance on the same ensemble, offering advantages such as reduced data requirements, shorter training times, and enhanced interpretability. However, NetSciML falls short in predicting stability across varied grid sizes, suggesting that GNNs employ a distinct and potentially more mechanistic approach. This underscores GNNs' potential to overcome challenges faced by current network science-based methods, providing novel solutions for desired outcomes.

SOE 23.9 Fri 12:00 BH-N 128

Network dynamics in urban mobility: a case study of Berlin during and after COVID-19 — •Marlli Zambrano, Andrzej Jarynowski, and Vitaly Belik — Freie Universität Berlin, Berlin, Germany

In response to the urgent need for better models in the face of public health crises like the COVID-19 pandemic, this study presents a temporal network analysis of urban mobility and contact patterns in Berlin. To this end we leverage GPS mobile phone data (provided by Net Check GmbH) from 2020 and 2022, focusing on the month of November to reduce seasonal or holiday influences. The dataset encompasses 72,301 records with 14,908 nodes (persons) in 2020, and 96,844 records with 11,094 nodes in 2022. Two persons were in contact, if they spent at least 2 minutes on a 8x8 meters geolocation tile. Our approach highlights the temporal evolution of contact network clusters and community dynamics. We investigate the temporal motifs in people's movements between common locations like home and work, and the temporal heterogeneity in activity patterns. Our results indicate a significant temporal shift in mobility patterns during the pandemic, characterized by less path-like average nearest neighbor distances, as opposed to the post-pandemic period. Despite these temporal shifts, the frequency of contact motifs remained surprisingly consistent. This study not only offers a physics-focused lens on the impact of the pandemic on urban temporal networks but also paves the way for developing advanced models for urban dynamics in crisis situations.

SOE 24: Financial Markets and Risk Management

Time: Friday 10:00–10:45 Location: MA 001

SOE 24.1 Fri 10:00 MA 001

Estimating Stable Fixed Points and Langevin Potentials for Financial Dynamics — •Tobias Wand[1,2], Timo Wiedemann[3], Jan Harren[3], and Oliver Kamps[1] — [1]Center for Nonlinear Science, Universität Münster — [2]Institut für Theoretische Physik, Universität Münster — [3]Finance Center Münster, Universität Münster

The Geometric Brownian Motion (GBM) is a standard model in quantitative finance, but the potential function of its stochastic differential equation (SDE) cannot include stable nonzero prices. Under strong constraints derived from additional data, evidence has been found that additional correction terms in the SDE's drift potential should be taken into consideration [1]. Our work generalises the GBM to an SDE with polynomial drift of order q and shows via model selection that q=2 is most frequently the optimal model to describe the data without requiring any additional constraints [2]. Moreover, Markov chain Monte Carlo ensembles of the accompanying potential functions show a clear and pronounced potential well, indicating the existence of a stable price.

[1] Halperin and Dixon, Physica A: 537, 122187 (2019) [2] Wand et al., arXiv 2309.12082 (2023)

SOE 24.2 Fri 10:15 MA 001

Influence of the real economy on financial systemic risk - linking supply chain contagion with financial networks — •Jan Fialkowski[1,2], Zlata Tabachová[1], Christian Diem[1], András Borsos[1,3], and Stefan Thurner[1,2,4] — [1]Complexity Science Hub, Vienna, Austria — [2]Medical University of Vienna, Vienna, Austria — [3]Central Bank of Hungary, Budapest, Hungary — [4]Santa Fe Institute, Santa Fe, USA

The recent COVID-19 crisis has shown that supply chain disruptions may lead to contagion in the financial system. The notion of financial systemic risk (SR) arises from the interconnectivity of financial institutions, e.g. on the interbank market. A shock to this system can originate from supply chain disruptions and for a coherent picture the notion of financial SR has to be extended by including firms and supply chains. Here we explore the relevance of supply chain contagion on financial SR. We use a unique dataset comprised of firm-level data of the Hungarian economy with time resolved information on its supply chains as well as bank-firm credits as well as the interbank loans. We identify and compare the relevance of the different channels through which financial institutions are exposed and show that taking the supply chain layer into account increases the expected losses of financial institutions from interbank exposure by a factor of 2. This highlights the need for a more integrated SR assessment by linking financial risks

with dynamics of the real economy.

SOE 24.3 Fri 10:30 MA 001

Multivariate distributions of correlated returns in non-stationary stock markets — Efstratios Manolakis, •Anton J. Heckens, and Thomas Guhr — Universität Duisburg-Essen, Lotharstr. 1, 47048 Duisburg

Risk assessment for rare events is very important for understanding systemic stability. Since financial markets are highly correlated, it is essential to study multivariate distributions of stocks, i.e. the joint probability density functions. To the best of our knowledge, we are the first to empirically study multivariate distributions for a large number of correlated stocks [1]. To this end, we compare empirical distributions with the results of a random matrix model [2]. First, our model separates different time scales: smaller time intervals, so-called epochs, that are assumed to be stationary and large scales on which the non-stationarity of the market is relevant and strong. Second, our model treats nonstationary fluctuations of measured correlation matrices by averaging over random matrices.

[1] Efstratios Manolakis, Anton J. Heckens and Thomas Guhr, Analysis of Aggregated Return Distributions for Stock Markets. Available at SSRN: https://ssrn.com/abstract=4462276

[2] Thomas Guhr and Andreas Schell 2021 J. Phys. A: Math. Theor. 54 125002

SOE 25: Economic Networks

Time: Friday 11:00–11:45 Location: MA 001

SOE 25.1 Fri 11:00 MA 001

Rethinking the Lotka-Volterra equations as a model of inequality — •Fabian Aguirre Lopez — Ecole Polytechnique, Paris, France

We recast the Lotka-Volterra model as an effective model for the interaction between the wealth of agents in an economy. The model is chosen to have a single parameter that controls whether agents are competing or cooperating. And, most importantly, the agents interact through a random network with a prescribed degree distribution.

In the competitive case, the effect of the network of interactions is negative. For some agents this only means relaxing to a small value, but interestingly, for some agents with high degree it implies that they go extinct. We can calculate exactly both the critical degree for extinction and the fraction of survivors. In the cooperative case, there is no extinction, but interestingly there is a regime where the global wealth diverges. It is determined by the network structure and we refer to it as the "wealth creation regime". Amazingly, we find that in this new scaling we have relative extinctions in the system, but now for the low degrees. The meaning of these extinctions is that low enough degree nodes have a vanishing fraction of the total wealth. We can also calculate exactly both the critical degree and the fraction of survivors.

We have shown that in this minimal model, wealth creation goes hand in hand with increasing inequality, as nodes with higher number of interactions will benefit more and more as the total wealth diverges. This phenomenon is strongly dependent on the network structure as all of these results trivialize if the graph has no degree heterogeneity.

SOE 25.2 Fri 11:15 MA 001

Integrated model of B-to-B trade network reproducing all major empirical laws: from structural evolution to monetary flows — •Jun'ichi Ozaki[1], Eduardo Viegas[1,2], Hideki Takayasu[1,3], and Misako Takayasu[1] — [1]Tokyo Institute of Technology, Yokohama, Japan — [2]Imperial College London, London, United Kingdom — [3]Sony Computer Science Laboratories, Inc., Tokyo, Japan

This study presents a novel two-layered model framework designed to comprehensively capture and replicate both the statistical properties of networks and the intrinsic quantities of interacting agents. Departing from traditional isolated investigations, our framework seamlessly integrates methods associated with temporal network structures and those related to transport flows.

Our approach enables the simultaneous emergence of tent-shaped distributions in agents' growth rates and scaling properties within the network. To validate our model framework and dynamics, we apply them to the real-world context of the inter-firm trading network in Japan. Comparative analysis of statistical distributions at both network and agent levels over time is strongly consistent with seven empirical laws observed in empirical data: degree distribution, mean degree growth rate over time, age distribution of firms, preferential attachment, sales distribution in steady states, and growth rates, as well as scaling relations.

SOE 25.3 Fri 11:30 MA 001

Hysteresis of Activities of the Network of Firms During the Economic Downturns — •Ali Hosseiny — Department of Physics, Shahid Beheshti University, Tehran, Iran

During the great recession in 2008 and 2009, when Obama's administration proposed its stimulation bill, some prominent economists such as Noble laureates, Joseph Stiglitz and Paul Krugman claimed that Obama's bill might not be big enough to lead the economy to overcome the recession. Now, a question arises: Does the economy show hysteresis over recession so that a minimum size of stimulation is needed to overcome recession? To answer this question we state that the activity of firms in their trade network is correlated. If a firm decreases or increases its activity, then its trade partners are forced to do so.

It can be shown that the interaction of firms results in hysteresis. Such a hysteresis resists government stimulation of the economy. Hysteresis analysis provides a correct prediction about the outcome of the fiscal stimulation in the US and the EU. In the aftermath recession of the economic crisis of 2009, the bill imposed by Obama was greater than the hysteresis of the market and thereby successful. The European Union*s bill however was below the hysteresis of the market and unsuccessful.

SOE 26: Mobility

Time: Friday 11:45–12:15 Location: MA 001

SOE 26.1 Fri 11:45 MA 001

The phase space of shared pooled mobility — •Nora Molkenthin — Potsdam Institute for Climate Impact Research, Potsdam, Germany

In face of the climate emergency and growing challenges ranging from pollution to traffic jams, shared pooled mobility has been floated as a potential solution for less congested, low-carbon and more space-efficient urban transport. However, it is unclear under which conditions shared pooled mobility offers a beneficial alternative. Here we map out the phase space and identify line service, shared pooled mobility and taxi service as distinct regimes depending on street network topology, fleet size and request load. We then model the adoption behaviour based on economic incentives in order to predict good parameter ranges for a shared pooled mobility service.

SOE 26.2 Fri 12:00 MA 001

Influence of Complex Networks on Ride-Pooling Systems — •Alexander Schmaus — Potsdam Institute for Climate Impact Research

Ride-pooling is an efficient technique to lower negative aspects of individual traffic by cars. Ride-pooling services bundle similar rides together, implying that the number of required vehicles and the overall number of rides decreases. Since studies show that using stops is more efficient than having a door-to-door service, we work with discrete stop networks. In particular, we study, which stop networks perform the best at minimizing the average passenger travel time. To draw the most efficient networks from the infinite set of possible networks that can be created on every road network, a Markov Chain Monte Carlo algorithm (MCMC) is used. Starting from an initial network, in each step of the MCMC, a proposal network is generated from the last accepted network by pooling or splitting stops. By running a ride-pooling simulation on the created network and measuring the resulting travel time, the efficiency is determined. Here, a low travel time indicates a high efficiency. The proposed network is accepted under two conditions: It could surpass the efficiency of the last accepted network, or, to avoid a local minimum, it could be accepted with a low probability even if its less efficient than the last accepted network. From the result networks it can be derived that stops at intersections are preferred. Stops that lead to detours are ignored and the area served by the system is reduced.

SOE 27: Sports Studies: Football/Soccer

Time: Friday 12:15–12:45 Location: MA 001

SOE 27.1 Fri 12:15 MA 001

Coping with crises: a quantitative stochastic approach to determine the resilience of soccer teams — •Ralph Stömmer — Private researcher, Ottobrunn, Germany

Resilience is a crucial asset for successfully coping with crises. In the sport context, research on resilience is rather new. A quantitative model is developed to determine the resilience of soccer teams and applied to the German premier league Bundesliga.

The concept of resilience does agree with previous research and implies two conditions: (i) adversity and (ii) positive adaption despite this adversity. The quantitative model to measure resilience is a novel approach. The relative frequency of matches is determined, where a soccer team, which is initially trailing by 2 goals, finally succeeds to win the match or at least to reach a draw. The empirical data are compared with a theoretical model derived from Poisson distributions. The analysis reveals how the resilience values of leading soccer teams differ from the average, which highlights the importance of experience and grit, compared to talent and technique.

In retrospect, the method sheds some new light on the final 3:2 win of the German team in the 1954 FIFA world cup in Bern, Switzerland, generally known as the *miracle of Bern*.

SOE 27.2 Fri 12:30 MA 001

"Expected Goals" and other KPIs to characterize team performance in soccer matches: how to quantify their quality? — •Andreas Heuer[1] and Fabian Wunderlich[2] — [1]Institut für Physikalische Chemie, Universität Münster, 48149 Münster — [2]Institut für Trainingswissenschaft und Sportinformatik, Deutsche Sporthochschule Köln, 50933 Köln

A variety of so-called Key Performance Indicators (KPIs) are available to characterize the performance of teams in soccer matches. A relatively novel and very popular KPI is expected goals (xG), which is derived by weighting each shot with an empirical probability of scoring a goal from that position on the pitch. How informative are KPIs to estimate the team strength and predict future results?

This question is analysed within an appropriate statistical framework aiming to answer two questions: (i) How well does the estimation process work when the statistical noise due to finite information is absent? The associated score directly expresses how well the chosen KPI reflects the underlying team strength. (ii) How much is the estimation process affected by statistical noise? Both pieces of information can be used to construct a normalized score that is a direct measure of the overall forecast quality of a KPI.

This general formalism is applied to the five biggest European leagues for a variety of KPIs. From this analysis, the quality of xG compared to other KPIs as well as possible differences across leagues can be clearly quantified. Implications for the prediction of individual soccer match results are discussed.