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Overview of Invited Talks and Sessions

Invited Talks

SOE 1.1	Mon	9:00– 9:40	SOEa	**Mathematical modelling of COVID-19: dynamics and containment** — •Yuliya Kyrychko
SOE 1.5	Mon	11:00–11:40	SOEa	**data-driven modeling of COVID-19 pandemic** — •Yamir Moreno

Sessions

SOE 1.1–1.9	Mon	9:00–13:00	SOEa	**COVID-19 pandemics through the lens of physics (org.: Fakhteh Ghanbarnejad and Philipp Hövel)**
SOE 2.1–2.6	Mon	14:00–16:00	SOEa	**Networks and Social Dynamics**
SOE 3.1–3.8	Mon	17:30–19:30	SOEp	**Poster**
SOE 4.1–4.5	Tue	11:00–12:40	SOEa	**Data Analytics for Complex Dynamical Systems (joint SOE/DY Focus Session) (joint session SOE/DY)**
SOE 5.1–5.3	Tue	14:00–15:00	SOEa	**Financial and Economic Systems and Evolutionary Game Theory**
SOE 6	Tue	17:45–18:30	BPb	**Nationale Forschungsdateninfrastruktur (NDFI) (joint session BP/CPP/DY/SOE)**
SOE 7	Tue	19:00–19:40	SOEa	**Member's Assembly of SOE**
SOE 8.1–8.3	Wed	9:00–10:00	SOEa	**Partial Synchronization in Networks (Focus Session joint with DY and BP) (joint session SOE/DY)**
SOE 9.1–9.4	Wed	11:00–12:20	SOEa	**Opinion Formation**
SOE 10.1–10.8	Wed	13:00–15:40	SOEa	**Transport, Regional and Urban Dynamics**

Annual General Meeting of the Physics of Socio-economic Systems Division

Tue 19:00–19:40 SOEa

SOE 1: COVID-19 pandemics through the lens of physics (org.: Fakhteh Ghanbarnejad and Philipp Hövel)

Time: Monday 9:00–13:00 Location: SOEa

Invited Talk SOE 1.1 Mon 9:00 SOEa

Mathematical modelling of COVID-19: dynamics and containment — •Yuliya Kyrychko — Department of Mathematics, University of Sussex, Falmer, Brighton, United Kingdom

COVID-19 disease caused by the novel SARS-CoV-2 coronavirus has already brought unprecedented challenges for public health and resulted in huge numbers of cases and deaths worldwide. In this talk I will discuss mathematical models developed to analyse the dynamics of COVID-19 spread in some regions of the UK and Ukraine. A particular emphasis will be made on the non-exponential distribution of infection and recovery times as well as age- and location-specific contact matrices used to represented mixing patterns. I will show how the model can be used to provide an accurate short-term forecast for the numbers and age distribution of cases and deaths, as well as the effects of different lockdown scenarios [1,2].

[1] Y.N. Kyrychko, K.B. Blyuss, I. Brovchenko (2020). Mathematical modelling of the dynamics and containment of COVID-19 in Ukraine . Nature Sci. Rep., 2020;10:1-11.DOI: 10.1038/s41598-020-76710-1

[2] K.B. Blyuss, Y.N. Kyrychko, Effects of latency and age structure on the dynamics and containment of COVID-19, J.Theor.Biol. 2021; 513: 110587:DOI:10.1016/j.jtbi.2021.110587.

SOE 1.2 Mon 9:40 SOEa

An all-Ireland SIRX Network Model for the Spreading of SARS-CoV-2 — •Rory Humphries[1], Mary Spillane[1], Kiernan Mulchrone[1], Sebastian Wieczorek[1], Michael O'Riordain[1,2], and Philipp Hövel[1] — [1]School of Mathematical Sciences, University College Cork, Western Road, Cork T12 XF64, Ireland — [2]Department of Surgery, Mercy University Hospital, Grenville Place, Cork, T12 WE28, Ireland

The Republic of Ireland and Northern Ireland have been severely impacted by the recent history of the spreading of the Severe Acute Respiratory Syndrome Corona Virus 2 (SARS-CoV-2). Our work contributes to the goal of an island with zero community transmissions and careful monitoring of routes of importation in the absence of effective pharmaceutical interventions.

In the model, nodes correspond to locations or communities that are connected by links indicating travel and commuting between different locations. The network comprises 4330 nodes, which corresponds to local administrative units below the NUTS 3 regions. The local dynamics within each node follows a phenomenological SIRXD compartmental model including classes of Susceptibles, Infected, Recovered, Quarantined (X) and Deaths. We consider various scenarios including the 5-phase roadmap for Ireland, where the parameters are chosen to match the current number of reported deaths. In addition, we investigate the effect of dynamic interventions that aim to keep the number of infected below a given threshold.

SOE 1.3 Mon 10:00 SOEa

Scenario projections of the Covid-19 pandemic using a data-driven macroscopic model — •Martin Treiber — TU Dresden, Germany

Modelling the pandemic dynamics is a prime example of an interdisciplinary topic combining biology, the dynamics of social systems, and econometric data analysis. The proposed model is of the delayed SEIR type including delays caused by the infection period and the delayed effect of vaccinations. Moreover, it also includes a complete measurement model including the delay between infection and test, the number of tests, test strategies, the percentage of reported infections, and the test sensitivity and specificity.

The time varying model parameters base reproduction number R_0 and infection fatality rate are calibrated, for different countries, to the reported cases and fatalities of RKI and OWID data. Relating the R_0 values to social behavior (mask usage, distance, different stages of a "lockdown") I estimate the effect of different measures, of the season, and possibly of different virus strains, in terms of changes of R_0.

Using the interactive online tool `traffic-simulation.de`, I present projections for several timelines of social behaviour, vaccination process, and interactions with neighboring countries. As of Jan 28, the projection of the weekly incidence for the time of the Spring Meeting is, ceteris paribus, about 30 confirmed cases/week/100000 persons.

SOE 1.4 Mon 10:20 SOEa

Analyzing protests against COVID-19 mitigation strategies on the German internet — •Andrzej Jarynowski[1], Alexander Semenov[2], and Vitaly Belik[3] — [1]Interdisciplinary Research Institute, Wroclaw, Poland — [2]Herbert Wertheim College of Engineering, University of Florida, Gainesville, USA — [3]System Modeling Group, Institute of Veterinary Epidemiology and Biostatistics, Freie Universität Berlin, Berlin, Germany

In this study we quantitatively assess perception of protests agains COVID-19 mitigation strategies in Germany from the late July till the end of August 2020 in the Internet media. To this end we investigate Google searches, Twitter and Telegram posts, as well as selection of news articles collected via EventRegistry. We focus on demonstrations on August 1st and August 29th, 2020 in Berlin [1]. Although the dominant actors of the protest are on the far-right political spectrum, based on network analysis, we demonstrate that left-wing activists could both sympathize with and oppose the protest. We observe a constant interest in the protest movements in traditional media, in contrast, their popularity on social media was growing. The revealed insights shed light on social dynamics in the context of such major disruptive events as COVID-19 pandemic and could serve as a basis for optimization of risk awareness campaigns by the government.

[1] Jarynowski A., Semenov A., Belik V. (2020) In: Chellappan S., Choo KK.R., Phan N. (eds) Computational Data and Social Networks. CSoNet 2020. Springer Lecture Notes in Computer Science, vol 12575, 524 (2021) https://doi.org/10.1007/978-3-030-66046-8_43

20 min. break

Invited Talk SOE 1.5 Mon 11:00 SOEa

data-driven modeling of COVID-19 pandemic — •Yamir Moreno — Institute BIFI, University of Zaragoza, Zaragoza 50018

The new Coronavirus disease 2019 (COVID-19) has forced an unprecedented response from health authorities worldwide and the World Health Organization. Despite the adoption of drastic measures, the pandemic is still ongoing worldwide, and surges of infections are being observed in more than 188 countries. Even with vaccination campaigns starting to roll out, specific pharmaceutical interventions need to be adopted nowadays to reduce the pressure over health-care systems. Here we show results that correspond to different stages of the pandemic using data-driven modeling. Specifically, we present simulations using data-driven models tailored to mobility data from China, Spain, and the U.S. The models are used to estimate the effectiveness of customary public interventions on the spread of COVID-19 in these locations as well as to calculate heard immunity thresholds of realistic populations and vaccine coverage needed to protect them. Our main findings highlight that having a coordinated response system could be key for the containment of the spread of COVID19 and its possible eradication at the lowest possible cost.

SOE 1.6 Mon 11:40 SOEa

How to estimate the macroscopic epidemic dynamics with a random testing strategy — Yasaman Asgari[1], Sepideh Abdollahi[2], Aryana Haghjoo[2], Farnoush Farahpour[3], and •Fakhteh Ghanbarnejad[1,4] — [1]Department of Mathematics, Sharif University of Technology, Tehran, Iran — [2]Department of Physics, Sharif University of Technology, Tehran, Iran — [3]Bioinformatics and Computational Biophysics, University of Duisburg-Essen, Germany — [4]Institute for Theoretical Physics, Technical University of Dresden, Dresden, Germany

The world has suffered from epidemics and pandemics especially the most recent one: COVID-19 in many ways. Having a more precise estimation of how an epidemic evolves, can help us to make better interventions policies. Molecular and Antibody tests, not only can help the physicians for a more accurate individual diagnosis (microscopic level) but also can help to have a macroscopic picture of the spreading dynamics. However, due to some limitations, different testing strategies have to be made. In this work, we want to show how to estimate the real epidemic dynamics with random sampling at a macroscopic

level. So we developed a mathematical model based on SIR dynamics and introduced a quantitative method on how to extract information from the empirical data, i.e. daily test results. Moreover, we show the impact of daily test capacity on the estimation. Finally, we studied two empirical data, namely the daily positive PCR cases at Paris and Massachusetts, and compared our estimations with their COVID-19 wastewater analysis. Our estimations present reliable error bars.

SOE 1.7 Mon 12:00 SOEa

Discontinuous epidemic transition due to limited testing — Davide Scarselli[1], •Nazmi Burak Budanur[1], Marc Timme[2], and Björn Hof[1] — [1]Institute of Science and Technology Austria, Am Campus 1, 3400 Klosterneuburg, Austria — [2]Chair for Network Dynamics, Center for Advancing Electronics Dresden (cfaed), Institute for Theoretical Physics and Center of Excellence Physics of Life, Technical University of Dresden, 01062 Dresden, Germany

High impact epidemics constitute one of the largest threats humanity is facing in the 21st century. In the absence of pharmaceutical interventions, physical distancing together with testing, contact tracing and quarantining constitute crucial measures in slowing down epidemic dynamics. Yet, here we show that if testing capacities are limited, containment may fail dramatically because such combined countermeasures drastically change the rules of the epidemic transition: Instead of continuous, the response to countermeasures becomes discontinuous [1]. Rather than following the conventional exponential growth, the outbreak that is initially strongly suppressed eventually accelerates and scales faster than exponential during an explosive growth period. As a consequence, containment measures either suffice to stop the outbreak at low total case numbers or fail catastrophically if marginally too weak, thus implying large uncertainties in reliably estimating overall epidemic dynamics, both during initial phases and during second wave scenarios. Reference(s): [1] D. Scarselli, N. B. Budanur, M. Timme, B. Hof. Discontinuous epidemic transition due to limited testing. Under review (2021).

SOE 1.8 Mon 12:20 SOEa

A control theory approach to optimal pandemic mitigation — Prakhar Godara[1], Stephan Herminghaus[1,2], and •Knut Heidemann[1] — [1]Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany — [2]Institute for the Dynamics of Complex Systems, Georg-August-Universität Göttingen, Germany

The recent outbreak of the illness COVID-19, has resulted in a pandemic with unprecedented impact on societies all over the globe. A major focus of governments is on designing containment strategies which are as mild as possible, but substantial enough to limit the severity of the outbreak in order not to overwhelm the health service system (HSS). In the framework of homogeneous susceptible-infected-recovered (SIR) models, we use a control theory approach to identify optimal pandemic mitigation strategies [1]. We derive rather general conditions for reaching herd immunity while minimizing the costs incurred by the introduction of societal control measures (such as closing schools, social distancing, lockdowns, etc.), under the constraint that the infected fraction of the population does never exceed a certain maximum corresponding to public health system capacity. Optimality is derived and verified by variational and numerical methods for a number of model cost functions. The effects of immune response decay after recovery are taken into account and discussed in terms of the feasibility of strategies based on herd immunity.

[1] Prakhar Godara, Stephan Herminghaus and Knut M. Heidemann. "A control theory approach to optimal pandemic mitigation." arXiv preprint arXiv:2009.02513 (2020).

SOE 1.9 Mon 12:40 SOEa

Statistsiche Untersuchungen der Covid-Inzidenzzahlen des RKI — •Rainer Gottwald[1], Stefan Scheingraber[2] und Uli Spreitzer[3] — [1]Dr. Rainer Gottwald, 86899 Landsberg am Lech — [2]PD. Dr. Stefan Scheingraber, 93413 Cham — [3]Löw & Spreitzer GmbH, 92277 Hohenburg

Inzidenzzahlen für Corona-positive des RKI sind umstritten wegen der Änderungen der Teststrategie, methodische Grenzen des PCR-Testverfahrens, Meldedatenverzug u.a. Die Daten des RKI zur Inzidenz der "Coronafälle" für 2020 wurden mit mathematischen Verfahren untersucht. Zeitreihenanalyse ergaben abweichende Werte für wichtige Punkte wie Trendumkehr. Der Einfluß des weißen Rauschen wurde aufgezeigt. Korrelationsrechnungen zeigten den Einfluß geänderter Testbedingungen auf die Werte. Medizinische Analysen der Inzidenzahlen ergänzen und plausibilisieren die statistischen Erkenntnisse.

SOE 2: Networks and Social Dynamics

Time: Monday 14:00–16:00 Location: SOEa

SOE 2.1 Mon 14:00 SOEa

Degree irregularity and rank probability bias in network meta analysis — •Annabel L Davies[1] and Tobias Galla[1,2] — [1]The University of Manchester, Manchester, United Kingdom — [2]Instituto de Fisica Interdisciplinar y Sistemas Complejos, IFISC (CSIC-UIB), Palma de Mallorca, Spain

Network meta-analysis (NMA) is a statistical technique for the comparison of treatment options. The nodes of the network graph are the competing treatments and the edges represent comparisons made between the treatments in the trials. Outcomes of Bayesian NMA include estimates of treatment effects, and the probabilities that each treatment is ranked best, second best and so on. How exactly network topology affects the accuracy and precision of these outcomes is not fully understood. We conduct a simulation study and find that disparity in the number of trials involving different treatments leads to a systematic bias in estimated rank probabilities. This bias is associated with an increased variation in the precision of treatment effect estimates. Using ideas from network theory, we define a measure of 'degree irregularity' to quantify asymmetry in the number of studies involving each treatment. Our simulations indicate that more regular networks have more precise treatment effect estimates and smaller bias of rank probabilities. We also find that degree regularity is a better indicator for the accuracy and precision of parameter estimates in NMA than both the total number of studies in a network and the disparity in the number of trials per comparison. Reference: A. L. Davies, T. Galla, Research Synthesis Methods 2020, 1-17, https://doi.org/10.1002/jrsm.1454

SOE 2.2 Mon 14:20 SOEa

Revealing network size from the dynamics of a single node? — •Georg Börner, Hauke Haehne, Jose Casadiego, and Marc Timme — Chair for Network Dynamics, Institute for Theoretical Physics and Center for Advancing Electronics Dresden (cfaed), TU Dresden

Networks are ubiquitous in the natural and human-made world and their dynamics fundamentally underlie the function of a variety of systems, from gene regulation in the cell and the activity of neuronal circuits to the distribution of electric power and the transport of people and goods.

Recent work [1] introduced a method to infer the size of a network, its number of dynamical variables, from measuring times series of a fraction of the its units only. Here we demonstrate that size inference is possible even from the observed time series of a single unit. We state mathematical conditions required for such inference in principle and show that, in practice, the success depends strongly on numerical constraints as well as on experimental decisions. We illustrate successful size inference for systems of $N = 20$ variables and point to ways for improving the reliability and power of the reconstruction. We briefly comment on how the success of the approach depends on the quality and quantity of collected data and formulate some general rules of thumb on how to approach the measurement of a given system.

[1] H. Haehne et al., Detecting Hidden Units and Network Size from Perceptible Dynamics Phys. Rev. Lett. 122:158301 (2019).

SOE 2.3 Mon 14:40 SOEa

Blind identification of stochastic block models from dynamical observations — •Michael Schaub — RWTH Aachen University, Aachen, Germany

In many applications we are confronted with the following system identification problem: we observe a dynamical process that describes the state of a system at particular times. Based on these observations we want to infer the (dynamical) interactions between the entities we observe. In the context of a distributed system, this typically corre-

sponds to a "network identification" task: find the edges of the graph of interconnections.

However, often the number of samples we can obtain from such a process are far too few to identify the edges of the network exactly. Can we still reliably infer some aspects of the underlying system?

Motivated by this question we consider the following identification problem: instead of trying to infer the exact network, we aim to recover a (low-dimensional) statistical model of the network based on the observed signals on the nodes. More concretely, here we focus on observations that consist of snapshots of a diffusive process that evolves over the unknown network. We model the (unobserved) network as generated from an independent draw from a latent stochastic block-model (SBM), and our goal is to infer both the partition of the nodes into blocks, as well as the parameters of this SBM. We present simple spectral algorithms that provably solve the partition and parameter inference problems with high-accuracy. We further discuss some possible variations and extensions of this problem setup.

SOE 2.4 Mon 15:00 SOEa

Detection and Analysis of Fake News on Twitter — Zahra Ghadiri, Sima Hashemi, Milad Ranjbar, •Fakhteh Ghanbarnejad, and Sadegh Raeisi — Sharif University of Technology, Tehran, Iran

Fake news on social media has become a major problem that impacts many aspects of our lives. In this work, we try to combine ideas from complex systems and networks with techniques from natural language processing (NLP) to develop intelligent agents that can distinguish real and fake news. Our approach is based on the intuition that one of the more effective ways to detect fake news is to cross-check with reliable sources such as well-established news agencies. To this end, first we collect tweets from the Twitter accounts of official news agencies which are posted around the posting time of the target tweets. We use clustering algorithms to cluster tweets based on the topic and content. Next we identify the cluster that best matches the target tweet. Then we extract features from our tweets and train a classifier that based on the comparison with the corresponding cluster would identify fake tweets. This provides a NLP tool that enables us to check a posted tweet with news from news agencies or any other reliable source of information based on the content. We also build and investigate the evolution/dynamic trees of retweets. We analyze the topological features of the trees as well as the dynamical properties. We should note that there are challenges associated with the reconstruction of the network and dynamics of a tweet on Twitter that could potentially influence our results and conclusion.

SOE 2.5 Mon 15:20 SOEa

A physics of governance networks: critical transitions in contagion dynamics on multilayer adaptive networks with application to the sustainable use of renewable resources — •Jonathan Donges[1,2], Fabian Geier[1], Wolfram Barfuss[1,3], and Marc Wiedermann[1] — [1]Potsdam Institute for Climate Impact Research, Potsdam, Germany — [2]Stockholm Resilience Centre, Stockholm University, Stockholm, Sweden — [3]School of Mathematics, University of Leeds, Leeds, United Kingdom

Adaptive network models are promising tools to analyze complex interactions in coupled human-economy-nature systems in the context of climate change mitigation and sustainability transformations. Here, we focus on a three-layer adaptive network model, where a polycentric governance network interacts with a social network of resource users which in turn interacts with an ecological network of renewable resources. We uncover that sustainability is favored for slow interaction timescales, large homophilic network adaptation rate (as long it is below the fragmentation threshold) and high taxation rates. We also observe a trade-off between an eco-dictatorship and the polycentric governance network of multiple actors. In the latter setup, sustainability is enhanced for low but hindered for high tax rates compared to the eco-dictatorship case. These results highlight mechanisms generating emergent critical transitions in contagion dynamics on multilayer adaptive networks and show how these can be understood and approximated analytically, relevant for understanding complex adaptive systems from various disciplines ranging from physics to epidemiology.

SOE 2.6 Mon 15:40 SOEa

Public goods games on networks: endogeneous reference groups — •Adrian Fessel[1], Martin Kocher[2], and Hans-Günther Döbereiner[1] — [1]Institute for Biophysics, University of Bremen, Bremen, Germany — [2]Department of Economics, University of Vienna, Vienna, Austria

Public goods games are a paradigm for understanding cooperative behavior within some reference group, whereas the field of complex networks provides powerful frameworks for modeling the dynamics and structure of interactions between individual agents. Combining these approaches, we study the formation and evolution of endogeneous reference groups in a network model. Between iterations of public goods games played within each connected component, the model evolves by edge addition or removal based on expected utility. In simulations, we observe fragmented or percolated states depending on the set of parameters, as well as dynamical solutions characterized by oscillations of the network structure.

SOE 3: Poster

Time: Monday 17:30–19:30 Location: SOEp

SOE 3.1 Mon 17:30 SOEp

Effective curvature of street networks — •David Bantje, Stephan Herminghaus, and Knut M. Heidemann — Max-Planck Institute for Dynamics and Self-Organization, Am Fassberg 17, 37077 Göttingen, Germany

Demand responsive ride pooling (DRRP) could contribute significantly to the transition towards sustainable mobility. In mean-field theories of DRRP [1], such systems are currently modelled in the Euclidean plane. We investigate if by assigning an effective Gaussian curvature, the metric properties of the street network can be incorporated into the existing theoretical framework. This poster illustrates the calculation scheme of effective curvature and presents results for model and real street networks.

[1] S. Herminghaus (2019). Mean field theory of demand responsive ride pooling systems. Transportation Research Part A: Policy and Practice, 119. https://doi.org/10.1016/j.tra.2018.10.028

SOE 3.2 Mon 17:30 SOEp

Persistence length of ride-sharing bus trajectories — •Steffen Mühle and Helge Heuer — Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany

On-demand ride-sharing services have the potential to drastically decrease urban traffic, mobility costs, carbon emissions and the need for owning a private car. While the benefits of a well-coordinated bus fleet capable of serving live incoming transport requests are compelling, predicting the spatio-temporal dynamics even of single buses is far from trivial. Typically, a bus' trajectory does not originate in isolation but emerges from its interplay with incoming requests, the street network, other buses and fleet-wide policies.

Given the latter, namely the maximally allowed detour an accepted request may entail, $\delta_{\max}$, we treat bus trajectories as random walks and inspect them from the perspective of polymer theory. To this end, we generate random walks purely geometrically, and also run full-scale ride-sharing simulations using MatSim. In both cases, we observe that for long times a bus' trajectory becomes diffusive, which allows us to assign a persistence length to them.

This creates a quantitative link between the (tunable) parameter $\delta_{\max}$ and the (observed) typical length scale on which a bus changes its direction, enabling us to predict e.g. how much time a bus spends in a certain district or how far it travels over the course of one day.

SOE 3.3 Mon 17:30 SOEp

Evaluation of demand responsive ride pooling on real life taxi data — •Michael Sternbach[1,2,3], Felix Jung[1], Puneet Sharma[1,2], Stepahn Herminghaus[1,2], and Knut Heidemann[1,2] — [1]Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany — [2]Institut for Dynamics and Complex Systems, University of Göttingen, Germany — [3]Campus Institute for Dynamics of Biological Networks, Göttingen, Germany

Climate change caused by human greenhouse gas (GHG) emissions is

one of the vital challenges of humankind. Passenger cars contribute significantly to human GHG emissions. To reduce this effect, more eco-friendly transport modes are needed. Demand responsive ride pooling (DRRP) offers door-to-door service similar to taxi or personal car while pooling customers with similar routes on the same vehicle, thereby reducing emissions and the number of cars needed. In this study, we measure the performance of a DRRP system on real life taxi request data and evaluate under which conditions e. g. request rate, number of vehicles, allowed detour or waiting time DRRP can operate more efficiently than taxi service at a reasonable service quality. We compare our results to a mean field description of DRRP [1] to analyze the effect of road network structure and spatial request distribution. Our results provide significant insight on the prerequisites for ecological and economic feasibility of DRRP.

[1] Herminghaus, S. (2019). Mean field theory of demand responsive ride pooling systems. Transportation Research Part A: Policy and Practice, 119, 15-28.

SOE 3.4 Mon 17:30 SOEp

Bi-modal demand responsive ride pooling — •Puneet Sharma, Helge Heuer, Stephan Herminghaus, and Knut Heidemann — Max Planck Institute for Dynamics and Self-Organization, Goettingen

Commuting is an indispensable part of modern human lives. While modern cities offer various modes of transportation, considered separately, none of them is both efficient, i.e., sustainable, and convenient. A taxi service is convenient, in a sense, due to door-to-door service, but is inefficient since it usually serves one customer only. Demand responsive ride pooling (DRRP) with minibuses is more efficient, but leads to undue competition with line services (LS), which provide even better pooling (average number of passengers per vehicle) but are less convenient due to fixed routes and stops. A combination of both modes, DRRP and LS, may provide an ideal solution but is challenging to organize. Here we derive conditions for efficient and convenient transportation for a bi-modal service based on a simple square-grid geometry. We relate the optimal mesh size, i.e., distance between stations, to external parameters like passenger density and traveling behavior. We also compare the carbon footprint of the bi-modal service with private cars so as to measure it*s efficiency.

SOE 3.5 Mon 17:30 SOEp

Numerical study of phase transition in the bipartite *z*-matching — •Till Kahlke[1], Martin Fränzle[2], and Alexander K. Hartmann[1] — [1]Institut of Physics, University of Oldenburg, Germany — [2]Institut of Computer Science, University of Oldenburg, Germany

We study numerically [1] the many-to-one bipartite *z-matching*, a generalisation of the matching problem. It can be used, e.g., to model a wireless communication network of users and servers, where z denotes the maximum number of users a server can treat at one time. Within a bipartite graph representation, there are links from each user to all servers which are feasible, e.g., close enough. The maximum matching capacity of this graph is the largest total number of users all servers can serve. After mapping to standard maximum matching, we use a numerically *exact algorithm* (Edmonds blossom shrinking) to solve the z-matching problem. First, we compare it with previous analytic results [2]. Next, we look at the saturation probability as order parameter and *observe phase transitions* when varying the average number of neighbors. We describe these transitions by their critical points and an universal critical exponent. When comparing the matchings of the exact algorithm with a commonly used matching *heuristic*, we observe that the heuristic starts to differ from the optimal solution right at the critical point.

[1] A.K. Hartmann, *Big Practical Guide to Computer Simulations* (World Scientific, 2015).
[2] E. Kreačić and G. Bianconi, Europhys. Lett. **126**, 28001 (2019).

SOE 3.6 Mon 17:30 SOEp

Burstiness and accuracy of collective decision-making — •Mariko Ito — Rikkyo University, Tokyo, Japan

In the decision-making of an individual, others' opinions can significantly affect when and what he/she states. Kurvers et al. [1] empirically showed that informative individuals tend to answer earlier than the others when each individual in a group is allowed to answer any time for a binary choice problem. They also exhibited that the group performance is high in the collective decision-making with such self-organised orders compared to that in the case where individuals make decisions independently. Here my interest is whether the distribution of the interval between statements has any information about the quality of their collective decision-making as well as the order of the statements.

I analysed the data in Kurvers et al. and derived the burstiness parameter B, the strength of burstiness [2]. Burst is the phenomenon where events, i.e., statements in our case, frequently occur in short periods while that rarely occur in long periods. I found that the greater is B, the higher is the group performance. The value of B was positively correlated with the group performance even when individuals made decisions independently. These results suggest that individuals with stronger confidence can cause a more bursty sequence of their statements.

[1] Kurvers et al., R. Soc. Open Sci., 2015. [2] Goh and Barabási, EPL, 2008.

SOE 3.7 Mon 17:30 SOEp

Cascade dynamics in Reddit communities — •Joao Pinheiro Neto and Knut Heidemann — Max Planck Institute for Dynamics and Self-Organization

Social media has a large role in modern society, making studying its dynamics fundamental to understand social and political events. Reddit is one of the biggest social media platforms in the world, and individual subcommunities (called "subreddits") have been involved in some of the biggest events in recent times. Discussions in Reddit happen in threads that follow a tree structure, with each comment spawning a new branch. This has been modeled with directed percolation-like models such as the Hawkes process, and it has been shown that the probability distributions of both thread size and total score follow power-laws [1,2]. Here we explore how these distributions and other observables vary across different subreddits. In particular, we show that i) subreddits can display both power-laws and non-power-law distributions, and ii) that the measured power-law exponents can vary considerably. We relate that to subreddit features such as the type of content and size of the userbase.

References

1. Medvedev, A. N., Delvenne, J. C., Lambiotte, R., & Cherifi, H. (2018). Journal of Complex Networks, 7(1), 67*82

2. Medvedev, A. N., Lambiotte, R., & Delvenne, J.-C. (2019) In Springer Proceedings in Complexity (pp. 183*204).

SOE 3.8 Mon 17:30 SOEp

Dirac Algebra Generalized Matrix Inverses — •Martin Erik Horn — IUBH - Internationale Hochschule, Campus Berlin

More and more introductory business mathematics textbooks present generalized matrix inverses as elementary part of the foundations of mathematical economics. Therefore Moore-Penrose generalized matrix inverses as the scalar part of Pauli Algebra generalized matrix inverses had been discussed at the DPG spring meeting 2018 of the Physics of Socio-economic Systems Division in Berlin in a geometric way.

As this geometry is based on the Euclidean structure of space, it is quite reasonable to ask, what happens if generalized matrix inverses are constructed in pseudo-Euclidean, hyperbolic spacetimes. This will be discussed in this poster presentation: Spacetime generalized matrix inverses are constructed as the scalar part of Dirac Algebra generalized matrix inverses. And again the algebraic reasoning of textbooks will be completed by analyzing the geometry it is based on.

SOE 4: Data Analytics for Complex Dynamical Systems (joint SOE/DY Focus Session) (joint session SOE/DY)

Time: Tuesday 11:00–12:40 Location: SOEa

SOE 4.1 Tue 11:00 SOEa

Network inference from event sequences: Disentangling synchrony from serial dependency — •Reik Donner[1,2], Adrian Odenweller[2], Frederik Wolf[2], and Forough Hassanibesheli[2] — [1]Magdeburg-Stendal University of Applied Sciences, Magdeburg, Germany — [2]Potsdam Institute for Climate Impact Research (PIK) - Member of the Leibniz Association, Potsdam, Germany

Inferring coupling among interacting units or quantifying their synchronization based on the timing of discrete events has vast applications in neuroscience, climate, or economics. Here, we focus on two prominent concepts that have been widely used in the past: event synchronization (ES) and event coincidence analysis (ECA). Numerical performance studies for two different types of spreading processes on paradigmatic network architectures reveal that both methods are generally suitable for correctly identifying the unknown links. By further applying both concepts to spatiotemporal climate datasets, we demonstrate that unlike ECA, ES systematically underestimates linkages in the presence of temporal event clustering, which needs to be accounted for in network reconstruction from data. In turn, for spike train data from multi-channel EEG recordings (with relatively narrow inter-event time distributions), the obtained results are practically indistinguishable. Our findings allow deriving practical recommendations for suitable data preprocessing in the context of network inference and synchronization assessment from event data.

SOE 4.2 Tue 11:20 SOEa

Identification of Stochastic Differential Equations from Data — •Tobias Wand[1] and Oliver Kamps[2] — [1]Westfälische Wilhelms-Universität Münster — [2]Center for Nonlinear Science Münster

In recent years, methods to identify dynamical systems from experimental or numerical data have been developed [1, 2]. In this context, the construction of sparse models of dynamical systems has been in the focus of interest and has been applied to different problems. These data analysis methods work with hyper-parameters that have to be adjusted to improve the results of the identification procedure. Nondeterministic systems require a refined identification algorithm. In this talk, we will introduce an approach to optimally select hyperparameters for the identification of sparse differential equations from non-deterministic data.

[1] Brunton et al. Proceedings of the National Academy of Sciences, 2016, 113, 3932-3937

[2] Mangan et al. Proceedings of the Royal Society A, 2017, 473, 20170009

SOE 4.3 Tue 11:40 SOEa

Data-driven analysis of the power grid frequency — •Benjamin Schäfer[1], Christian Beck[1], Leonardo Rydin Gorjão[2,3], Johannes Kruse[2,3], and Dirk Witthaut[2,3] — [1]School of Mathematical Sciences, Queen Mary University of London, London E1 4NS, United Kingdom — [2]Forschungszentrum Jülich, Institute for Energy and Climate Research-Systems Analysis and Technology Evaluation (IEK-STE), Jülich, Germany — [3]Institute for Theoretical Physics, University of Cologne, Köln, Germany

The Paris conference 2015 set a path to limit climate change to "well below 2°C". To reach this goal greenhouse gas emissions have to be reduced and renewable generators, electrical mobility or smart grids are integrated into the existing power system.

The introduction of these new technologies raises several questions about control, stability and operation and therefore requires a solid understanding of existing and future systems and new conceptional approaches.

Here, we use data-driven approaches to work towards a quantitative understanding of the power grid with a particular focus on the power grid frequency. We analyse time series from various synchronous areas such as Continental Europe, Great Britain but also two US areas and several European islands.

We highlight significant deviations from Gaussianity in several regions, scaling laws and spatio-temporal dynamics. Finally, we discuss how past information may be used to forecast the frequency.

SOE 4.4 Tue 12:00 SOEa

Tipping and transition paths in high-dimensional agent-based models — •Luzie Helfmann[1,2,3], Peter Koltai[1], Jobst Heitzig[3], and Christof Schütte[2,1] — [1]Freie Universität Berlin — [2]Zuse Institute Berlin — [3]Potsdam Institute for Climate Impact Research

Agent-based models are a popular choice for modeling complex social systems. Here, we are concerned with studying noise-induced tipping between relevant subsets of the agent state space, e.g., in order to understand drastic opinion changes in a population of agents. Due to the large number of interacting individuals, agent-based models are usually very high-dimensional. We therefore apply Diffusion Maps, a non-linear dimension reduction, to reveal the intrinsic low-dimensional structure of the model dynamics. We will characterize the tipping behavior by means of Transition Path Theory, a theory for gaining statistical understanding of the tipping paths (e.g., their density, flux, rate). We will illustrate our approach on two examples, both exhibiting a multitude of tipping pathways.

SOE 4.5 Tue 12:20 SOEa

Quasi-stationary states in temporal correlations for traffic systems: Cologne orbital motorway as an example — •Shanshan Wang, Sebastian Gartzke, Michael Schreckenberg, and Thomas Guhr — Fakultät für Physik, Universität Duisburg–Essen, Lotharstraße 1, 47048 Duisburg, Germany

Traffic systems are complex systems that exhibit non-stationary characteristics. Therefore, the identification of temporary traffic states is significant. In contrast to the usual correlations of time series, here we study those of position series, revealing structures in time, i.e. the rich non-Markovian features of traffic. Considering the traffic system of the Cologne orbital motorway as a whole, we identify five quasi-stationary states by clustering reduced-rank correlation matrices of flows using the k-means method. The five quasi-stationary states with nontrivial features include one holiday state, three workday states and one mixed state of holidays and workdays. In particular, the workday states and the mixed state exhibit strongly correlated time groups shown as diagonal blocks in the correlation matrices. We map the five states onto reduced-rank correlation matrices of velocities and onto traffic states where free or congested states are revealed in both space and time. Our study opens a new perspective for studying traffic systems. This contribution is meant to provide a proof of concept and a basis for further study.

SOE 5: Financial and Economic Systems and Evolutionary Game Theory

Time: Tuesday 14:00–15:00 Location: SOEa

SOE 5.1 Tue 14:00 SOEa

Uncovering the Dynamics of Correlation Structures Relative to the Collective Market Motion — •Anton J. Heckens, Sebastian M. Krause, and Thomas Guhr — Universität Duisburg-Essen, Lotharstr. 1, 47048 Duisburg

Complex systems are characterized by a variety of interactions and often produce a strong correlated behavior of their system components. Stock markets are particularly well-suited as examples of such complex systems due to their abundance of data for the analysis of correlated phenomena. Münnix et al. [1] used correlation matrices over short time horizons, in order to analyze their dynamics with respect to their non-stationarity. Using a cluster procedure, it became apparent that there are quasi-stationary periods, so-called market states. They emerge, disappear or reemerge, but they are dominated by the collective motion of all stocks. To extract more refined information, we present a new approach by clustering correlation matrices which

are free from the collective market motion [2]. The resulting dynamics is remarkably different, and the corresponding market states are quasi-stationary over a long period of time.

[1] M. C. Münnix, T. Shimada, R. Schäfer, F. Leyvraz, T. H. Seligman, T. Guhr and H. E. Stanley, Identifying States of a Financial Market, Scientific Reports 2, 644 (2012), arXiv:1202.1623

[2] A. J. Heckens, S. M. Krause, T. Guhr, Uncovering the Dynamics of Correlation Structures Relative to the Collective Market Motion J. Stat. Mech. 2020, 103402 (2020), arXiv:2004.12336

SOE 5.2 Tue 14:20 SOEa

Explosive amortization times in the dynamics of photovoltaic implementation? — •Raoul Schmidt, Malte Schröder, and Marc Timme — Chair for Network Dynamics, Institute for Theoretical Physics and Center for Advancing Electronics Dresden (cfaed), TU Dresden

To combat climate change, renewable energy supply such as through photovoltaics (PV) becomes increasingly important. The amortization time of a single PV unit relates the energy (and CO2) expended for production, transport and installation of a unit to its electric power generation (and thus potential savings in CO2 emissions). Here, we analyze the CO2 budgeting dynamics of many PV units continuously added by new installations [1,2]. Intriguingly, the resulting systemic amortization time necessarily is substantially larger than that of a single unit. We demonstrate analytically that already at constant installation rate, it already is twice the amortization time of a single unit, whereas at an exponentially increasing rate, it may be arbitrarily much larger, with resulting relevant time scales in between 10 and more than 30 years - potentially beyond the life time of a PV unit. Intriguingly, evaluating installation data of the past two decades indicates an exponential installation rate on the global scale that may cause such explosive increase of CO2 budget amortization times.

[1] N. von der Heydt, DPG Spring Meeting Berlin (2018). [2] R. Schmidt et al., in prep. (2021).

SOE 5.3 Tue 14:40 SOEa

Should the government reward cooperation? Insights from an agent-based model of wealth redistribution — Frank Schweitzer, Luca Verginer, and •Giacomo Vaccario — ETH, Zurich, Switzerlan

In our multi-agent model agents generate wealth from repeated interactions for which a prisoner's dilemma payoff matrix is assumed. Their gains are taxed by a government at a rate α. The resulting budget is spent to cover administrative costs and to pay a bonus to cooperative agents, which can be identified correctly only with a probability p. Agents decide at each time step to choose either cooperation or defection based on different information. In the local scenario, they compare their potential gains from both strategies. In the global scenario, they compare the gains of the cooperative and defective sub-populations. We derive analytical expressions for the critical bonus needed to make cooperation as attractive as defection. We show that for the local scenario the government can establish only a medium level of cooperation, because the critical bonus increases with the level of cooperation. In the global scenario instead full cooperation can be achieved once the cold-start problem is solved, because the critical bonus decreases with the level of cooperation. This allows to lower the tax rate, while maintaining high cooperation.

SOE 6: Nationale Forschungsdateninfrastruktur (NDFI) (joint session BP/CPP/DY/SOE)

Time: Tuesday 17:45–18:30 Location: BPb

Details will be published in a programme update.

SOE 7: Member's Assembly of SOE

Time: Tuesday 19:00–19:40 Location: SOEa

Online Member's Assembly. The ordinary Annual Member's Assembly will be held in September.

SOE 8: Partial Synchronization in Networks (Focus Session joint with DY and BP) (joint session SOE/DY)

Time: Wednesday 9:00–10:00 Location: SOEa

SOE 8.1 Wed 9:00 SOEa

Partial synchronization as a model for uni-hemispheric sleep — •Jakub Sawicki[1], Lukas Ramlow[1,2], and Eckehard Schöll[1,3] — [1]Institute of Theoretical Physics, Technische Universität Berlin, Germany — [2]Humboldt University of Berlin, Berlin, Germany — [3]Potsdam Institute for Climate Impact Research, Potsdam, Germany

Uni-hemispheric slow-wave sleep is a dynamical state of the brain where one hemisphere is asleep while the other remains awake. This state can also be characterized by simultaneous but spatially separated occurrence of high and low degree of synchronization in the sleeping and the awake hemisphere, respectively. Therefore, this real world phenomenon can be described in terms of partial synchronization characterizing patterns of coexistence of synchronized and desynchronized parts of a network. Here we investigate the occurrence of partial synchronization patterns in empirical structural connectivities of the human brain. The connectivities consist of ninety regions of interest using the Automated Anatomical Labeling (AAL) Atlas, and were derived by magnetic resonance imaging (MRI) based probabilistic diffusion tractography. The local dynamics is modeled by FitzHugh-Nagumo oscillators. We demonstrate under which conditions partial synchronization patterns with respect to the brain hemispheres can be found.

SOE 8.2 Wed 9:20 SOEa

Effect of Topology upon Relay Synchronization in Triplex Neuronal Networks — •Fenja Drauschke, Iryna Omelchenko, Rico Berner, Jakub Sawicki, and Eckehard Schöll — Institute of Theoretical Physics, Technische Universität Berlin

Complex networks consisting of several interacting layers allow for remote synchronization of distant layers via an intermediate relay layer. We investigate relay synchronization in a three-layer neuronal network and study the effect of the topology of the layers upon the synchronization scenarios. Introducing random topologies either in the outer layers or in the middle (relay) layer leads to an increase of the range of inter-layer coupling strength for which the relay-synchronized state is preserved, compared with regular nonlocal coupling topologies.

SOE 8.3 Wed 9:40 SOEa

Complexified Kuramoto model – synchrony in the weak coupling regime — •Moritz Thümler, Sheshagobal Srinivas, Malte Schroeder, and Marc Timme — TU Dresden, Dresden, Germany

Networks of Kuramoto oscillators constitute paradigmatic models for the emergence of temporal patterns – foremost synchrony – across oscillatory systems. Here we extend the Kuramoto model to complex dynamical variables. We uncover a transition from traditional synchrony emerging for sufficiently large coupling strengths to a second type of synchrony that exists in the weak coupling regime, i.e. below the coupling required for the real-variable model to synchronize. The new type of synchrony state is known from systems that are not

dissipative but conservative, compare [1,2] for relations of the two system types. We introduce a novel, two dimensional order parameter for networks of N oscillators that enables us to consistently quantify synchrony.

[1] D. Witthaut and M Timme, Phys. Rev. E 90:032917 (2014)
[2] D. Witthaut et al., Nature Comm. 8:14829 (2017)

SOE 9: Opinion Formation

Time: Wednesday 11:00–12:20 Location: SOEa

SOE 9.1 Wed 11:00 SOEa

Social nucleation: From physics to group formation and opinion polarization — •Georges Andres and Frank Schweitzer — Chair of Systems Design, ETH Zurich, Weinbergstrasse 58, 8092 Zurich, Switzerland

Individuals form groups, which subsequently develop larger domains via competition and coalescence. How much have these social processes in common with established mechanisms of phase transitions in physics? Are nucleation in metastable systems or spinodal decomposition of thermodynamic phases or percolation in porous media suitable paradigms for modeling the emergence of large social groups? We answer this challenging question by providing an agent-based model that combines group formation and opinion dynamics in a novel manner. Opinion formation is a fast process and determines the formation of groups. On a slower time scale, groups can form larger clusters of various numbers, density and stability. These clusters can merge, split or rearrange, to develop either compact phases, networks of high modularity, or quasistable cluster distributions. Dependent on the choice of parameters for opinion dynamics and social influence, our model can reproduce social phenomena such as consensus, weak or strong polarization, social networks of various densities or stable minorities.

SOE 9.2 Wed 11:20 SOEa

Ideological differences in engagement in public debate on Twitter — •Felix Gaisbauer, Armin Pournaki, Sven Banisch, and Eckehard Olbrich — Max Planck Institute for Mathematics in the Sciences, Inselstrasse 22, 04103 Leipzig

We analyse public debate on Twitter via network representations of retweets and replies. We show that through the interplay of the two networks, it is possible to identify ideological differences in activity patterns between different opinion groups on the platform. The method is employed to observe public debate about two events: The Saxon state elections and violent riots in the city of Leipzig in 2019. We show that in both cases, (i) opinion groups differ in their propensities to get involved in debate, and therefore have unequal impact on public opinion. Users retweeting far-right parties and politicians are significantly more active, hence their positions are disproportionately visible. (ii) Said users act significantly more confrontational, as becomes visible in the local assortativity distribution of the reply network, while other opinion groups tend to debate largely amongst themselves.

SOE 9.3 Wed 11:40 SOEa

Modeling Opinion Formations in Europe: A new Perspective — •Martin Gestefeld, Jan Lorenz, Nils Henschel, and Klaus Boehnke — Jacobs University Bremen, Bremen, Deutschland

In recent years, politics and especially election results appear to be more polarized than in the years before. Empirical evidence for opinion polarization has been found regarding specific topics but there is still a lack of evidence for a general trend in society. The presented work compares the characteristics of various polarization measurements and determines similarities between them in empirical data. In an exploratory data analysis of the European Social Survey, individual responses are analyzed on the left-right political self-placements and similar attitudes. By applying a new model, we demonstrate that people who placed their opinions on a 0 to 10 scale can be split up into five distinct groups. In addition to this model, we are able to decompose a formal measurement and provide detailed information on the degree of polarization in each of our distinct groups. Over the complete data set, cross-topic, cross-country, and time-trends are analyzed and compared to establish an overview and new perspective on polarization in Europe.

SOE 9.4 Wed 12:00 SOEa

Opinion Formation in distributed topologies: the voter model on hierarchical networks — •Kateryna Isirova[1,2], Oleksandr Potii[2], and Jens Christian Claussen[1] — [1]Department of Mathematics, Aston University, Birmingham, UK — [2]V. N. Karazin Kharkiv National University, Ukraine

The voter model is a paradigmatic stochastic model that has been widely employed especially for modeling of emergent social phenomena as opinion formation. Consensus formation protocols however also occur in the dynamics of computer networks, where the verification of nodes may become time-critical in large networks, and depend on the network topology. In society, consensus is formed (or not) via messages to neighbours in the network and likewise depends on the network structure. Here, we investigate the average time to consensus in a variety of different hierarchical and other network topologies, namely, small-world networks, various tree structures and hierarchical networks. For hierarchical networks, we consider the straightforward generalization where influencing a node occurs with different probability depending on the direction of hierarchy. Systemeatic Monte-Carlo simulations show that the average time to consensus in hierarchical networks is considerably larger than in regular graphs and small-world networks.

SOE 10: Transport, Regional and Urban Dynamics

Time: Wednesday 13:00–15:40 Location: SOEa

SOE 10.1 Wed 13:00 SOEa

Adaptive Stop-Pooling for Sustainable Shared Mobility? — •Charlotte Lotze, Malte Schröder, and Marc Timme — Chair for Network Dynamics, Institute for Theoretical Physics and Center for Advancing Electronics Dresden (cfaed), TU Dresden

Ride-sharing – the bundling of simultaneous trips of several people in one vehicle – may help us to reduce the carbon footprint of human mobility [1,2]. Ride-sharing trades reduced total route traveled by vehicles for increased passenger travel times. Yet standard door-to-door ride sharing services come with the burden of many stops and detours to pick up individual passengers. Requiring some passengers to walk to nearby shared stops may reduce detours yet may become inefficient if spatio-temporal demand patterns do not well fit the stop locations. Here, we present a simple model of adaptive, on-demand stop pooling and analyze its influence on the performance of ride-sharing services. We find counteracting effects of stop pooling on the number of and distance between stops, inducing a roughly constant route length despite stop pooling benefits. Intriguingly, however, stop pooling also reduces the average travel time although passengers walk parts of their trip. Stop pooling may thus break the trade-off between route lengths and travel times. We conclude, that dynamic stop pooling could enable higher sustainability and service quality simultaneously, potentially also in real world ride sharing systems. References: [1] Molkenthin et al., Scaling Laws of Collective Ride-Sharing Dynamics, Phys. Rev. Lett. 125:248302 (2020); [2] Storch et al., Incentive-driven discontinuous transition to high ride-sharing adoption, arXiv:2008.11079 (2020).

SOE 10.2 Wed 13:20 SOEa

The future of traffic jams: Forward propagating congestion in electric vehicle charging infrastructure — •Philip Marszal[1], Malte Schröder[1], and Marc Timme[1,2] — [1]Chair for Network Dynamics, Center for Advancing Electronics and Institute for Theoretical Physics, Technical University of Dresden, Dresden, Germany — [2]Lakeside Labs, Klagenfurt, Austria

Individual motorized mobility is becoming increasingly electrified. The unique properties of electric vehicles promise to give rise to new collective traffic flow dynamics, which are largely unexplored as of now. Here we demonstrate a new type of congestion in the utilization of charging infrastructure, emerging solely from correlations in driver's charging dynamics due to queue-avoidance behavior on long range trips. We explain the formation of forward-propagating congestion waves as phase separation of the traffic flow into free and congested phases, occurring already before the system reaches its theoretical capacity limit. While current numbers of electric vehicles compared to available charging stations are far below the onset of congestion, these results reveal collective dynamics that may influence how future infrastructure supporting sustainable modes of mobility will be built.

SOE 10.3 Wed 13:40 SOEa

Towards Optimal Bikeability of Urban Mobility Networks — •Christoph Steinacker, David-Maximilian Storch, Marc Timme, and Malte Schröder — Chair for Network Dynamics, Institute for Theoretical Physics and Center for Advancing Electronics Dresden (cfaed), TU Dresden

Individual transport in cities is most commonly enabled by private cars, an unsustainable status quo both ecologically and socially. On typical urban distance scales, bicycling constitutes a more sustainable alternative that is broadly accessible. Yet, insufficient and poorly designed bike path networks often hinder more prevalent bike use. Here, we propose an optimisation scheme for bike path networks that enables smooth and safe bicycle travel in cities. Evaluating bike-sharing data on millions of city trips, we estimate bike travel demand and find greatly bike-friendly network topologies. Interestingly, a reverse percolation process that starts from a complete bike path network covering all streets and systematically lowers the number of bike paths by eliminating least used bicycle paths yields topologies much more suitable than a forward process with optimised iterative addition of paths. Even just a small number of bike paths, if chosen wisely, may result in a bike-friendly network. These results may support the planning of sustainable mobility networks, strongly improving urban bikeability.

SOE 10.4 Wed 14:00 SOEa

Purely fluctuation-induced congestion in street traffic — •Verena Krall[1], Max Burg[2,3], Malte Schröder[1], and Marc Timme[1] — [1]Chair for Network Dynamics, Center for Advancing Electronics Dresden (cfaed) and Institute of Theoretical Physics, Technical University Dresden, Germany — [2]Institute for Theoretical Physics and Centre for Integrative Neuroscience, University of Tübingen, Germany — [3]Bernstein Center for Computational Neuroscience, Tübingen, Germany

Traffic congestions may emerge spontaneously - out of nowhere. Statistical physics studies provide both qualitative and quantitative insights, yet so far they focused on the consequences of external factors such as street bottlenecks or human behavioral imperfections. Here we present a simple model of traffic flow on a street segment in which congestion spontaneously emerges purely due to fluctuations in the number of incoming vehicles [1]. Agent-based simulations and analytical estimates indicate that this instability exists even in regimes where mean field theory predicts stable traffic flow. Our results thus underline the limitations of mean field analysis for predicting the collective nonlinear dynamics of mobility systems.

[1] V. Krall et al., Number Fluctuations Induce Persistent Congestion, Transport Findings, December 2020. https://doi.org/10.32866/001c.18154.

SOE 10.5 Wed 14:20 SOEa

On the relation between transversal and longitudinal scaling in cities — •Fabiano L. Ribeiro — Universidade Federal de Lavras, Lavras, Brazil

Empirical evidence has been shown that some urban variables scale non-linearly with the city population size. More specifically, some socio-economic variables, such as the number of patents, wages and GDP, show a super-linear behaviour with the population of the city. On the other hand, infrastructure variables, such as the number of gas stations and length of streets, scale sub-linearly with the city population, generating a scale economy. However, does this scaling properties observed in a system of cities (transversal scaling) also work for individual cities in different stages of their growth process (longitudinal scaling)? The answer to this question has important policy implications, but the lack of suitable data has so far hindered rigorous empirical tests. The work that will be presented was developed looking at the evolution of two urban variables, GDP and water network length, for over 5500 cities in Brazil. It will be shown that longitudinal scaling exponents are city-specific, however they are distributed around an average value that approaches the transversal scaling exponent provided that the data is decomposed to eliminate external factors, and only for cities with a sufficiently high growth rate. This result adds complexity to the idea that the longitudinal dynamics is a micro-scaling version of the transversal dynamics of the entire urban system.

SOE 10.6 Wed 14:40 SOEa

Bimodal Transport: Combining Demand Responsive and Public Transport — •Helge Heuer, Puneet Sharma, Stephan Herminghaus, and Knut M. Heidemann — Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany

Bimodal Transport describes the combination of traditional Public Transport (PT), also called Fixed Route Transport (FRT), and Demand Responsive Transport (DRT). In many of the existing DRT services there is the option to share the rides with other customers to reduce the price and increase the ecological efficiency of the individual rides. Bimodal Transport aims to combine the flexibility of DRT services with the efficiency of classical line services. An advantage of shared mobility in general is the comparably low carbon footprint and less general pollution, resulting from the reduction of active vehicles in comparison to unshared transportation.

Here we study bimodal transport via simulations on a square lattice. We analyze the performance of the system under various parameter settings and identify under which conditions the overall ecological footprint can be minimized while maintaining satisfactory customer service. Simulations are compared to an effective analytical theory.

SOE 10.7 Wed 15:00 SOEa

Policy and Innovation Spreading on the Global City Network — •Niklas Kitzmann[1], Jonathan Donges[1], Xuemei Bai[2], Pawel Romanczuk[3], and Ricarda Winkelmann[1] — [1]Potsdam Institute for Climate Impact Research, Germany — [2]Fenner School of Environment & Society, Australian National University, Australia — [3]Institute for Theoretical Biology, Humboldt University of Berlin, Germany

In the much-needed global sustainability transformation, cities may play an important role. Being among the prime drivers of GHG emissions, as well as of sustainable policy innovation and adoption, cities are known to learn from each other to reduce, prepare for and react to the coming environmental changes. In this way, they can be conceptualized as nodes in a globe-spanning learning network, potentially yielding insights into the social tipping dynamics that are so urgently needed to control the human impacts on the Earth System.

Here, we aim to identify whether network-based contagion effects are dominant in sustainability policy adoption by cities. An attempt is made to approximate the inter-city innovation spreading network using empirical data of the global air traffic network and other city-to-city connections. We analyze the spreading of several municipal policies and innovations related to sustainability, such as the implementation of Bus Rapid Transit public transport systems, as contagion processes on these inter-city networks. Surrogate data methods and a dose-response-contagion approach are used to identify network-spreading-correlations. We then investigate the nature of the spreading process by attempting to reproduce it using generative models.

SOE 10.8 Wed 15:20 SOEa

Indication of correlations between urban scaling and Zipf's exponent — Haroldo V. Ribeiro[1], Milena Oehlers[2], Ana I. Moreno-Monroy[3], Jürgen P. Kropp[2,4], and •Diego Rybski[2,5] — [1]Departamento de Fisica, Universidade Estadual de Maringa, PR 87020-900, Brazil — [2]Potsdam Institute for Climate Impact Research - PIK, Member of Leibniz Association, P.O. Box 601203, 14412 Potsdam, Germany — [3]OECD Centre for Entrepreneurship, SMEs, Regions and Cities, Honorary Associate, Geography and Planning Department, University of Liverpool, 2 rue Andre-Pascal, 75016 Paris, France — [4]Institute for Environmental Science and Geography, University of Potsdam, 14476 Potsdam, Germany — [5]Department of Environmental Science Policy and Management, University of California Berkeley, 130 Mulford Hall #3114, Berkeley, CA 94720, USA

Zipf's law and urban scaling are two fundamental paradigms researched in urban science. They have mostly been investigated independently and are perceived as disassociated matters. Here we present a large scale investigation about the connection between these two laws using population and GDP data from 96 countries. We empirically demonstrate that both laws are tied to each other and derive an expression

relating the exponents, capturing the main tendency of the empirical relation. Simulations yield very similar results to the real data after accounting for fluctuations. Our research puts forward the idea that urban scaling of GDP does not solely emerge from intra-city processes.