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.