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.