SOE 16: Networks - Statistics and Dynamics (joint with BP and DY)

Time: Wednesday 15:00–18:45 Location: ZEU 118

SOE 16.1 Wed 15:00 ZEU 118

Chimera states: spontaneous symmetry-breaking in dynamical networks — •Eckehard Schöll — Institut für Theoretische Physik, TU Berlin, Hardenbergstr 36, 10623 Berlin, Germany

Systems of nonlocally coupled identical oscillators can exhibit symmetry-breaking in the form of complex spatiotemporal patterns, called chimera states, which consist of coexisting domains of spatially coherent (synchronized) and incoherent (desynchronized) dynamics. We describe the scenario leading from complete coherence to complete incoherence via chimera states [1,2], and present a general analytical calculation of the critical coupling strength at the onset of the chimera states.

[1] I. Omelchenko, Y. Maistrenko, P. Hövel, and E. Schöll: Loss of coherence in dynamical networks: spatial chaos and chimera states, Phys. Rev. Lett. 106, 234102 (2011).

[2] A. Hagerstrom, T.E. Murphy, R. Roy, P. Hövel, I. Omelchenko, and E. Schöll: Experimental observation of chimeras in coupled-map lattices. Nature Physics 8, 658 (2012)

Work in collaboration with A. Hagerstrom, P. Hövel, K. Krischer, Y. Maistrenko, T.E. Murphy, I. Omelchenko, O.E. Omel'chenko, R. Roy, A. Zakharova.

SOE 16.2 Wed 15:15 ZEU 118

Pattern-matching via a network of phase oscillators of different frequency: A novel Architecture — •Daniel Heger and Katharina Krischer — Technische Universität München, Physikdepartment

Oscillatory networks can in principle be used for pattern recognition. Nevertheless, current architectures either lack scalability towards large numbers of oscillators or need the external input of complex time-dependent coupling functions. In our talk, we will present a novel architecture for pattern matching with oscillatory neural networks. A system of oscillators of different frequencies and coupling functions is used whose dynamics average to the dynamics of an all-to-all coupled oscillator network. In contrast to previous approaches, the necessary coupling functions are automatically generated inside the network and the output pattern can easily be read out binary. By additionally choosing a new type of coupling function, the matching mechanism is stable even for high coupling strengths and the degenerate attractive limit set containing the memorized patterns transforms to a system of seperated attractors for each memorized pattern. Although the system's dynamics do not average to the dynamics of simple coupled Kuramoto oscillators, the appealing mathematical structure permits determination of the stability of all fixed points using nonlinear stability analysis and a dynamic equation solely in pattern space can be derived.

SOE 16.3 Wed 15:30 ZEU 118

Data acquistion by vectorization of high resolution images of vascular networks — •Jana Lasser — Max-Planck-Institut für Dynamik und Selbstorganisation

Leaf vein networks form highly complex, reticulate, hierarchically organized webs that are believed to be the result of a process of gradual optimization over the course of evolutionary history. These networks form planar graphs dominated by cycles, but to this day the topological properties of such reticulate networks have not been adequately described. We analyze the hierarchical organization of the loops in transport networks from roughly 100 cleared leaf images that are converted into a weighted graph representation using custom tailor-made image analysis tools. We employ tools from statistics and topology, in particular an algorithmic way of assigning a topological tree graph to the leaf's loop graph which represents its hierarchical organization, thus allowing us to make use of specialized tree metrics to unravel the distinguishing characteristics between different network realisations. Our algorithmic tools allow us to quantitatively describe subtle differences between venation phenotypes, and compare reticulate network data with the predictions of optimisation models.

SOE 16.4 Wed 15:45 ZEU 118

Structure and Topology of Optimal Transport Networks in Plant Leaves — •Henrik Ronellenfitsch and Eleni Katifori — Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany

Efficient photosynthesis in plants crucially depends on the ability to transport water from the soil into the leaves, where it can evaporate. To this effect, plants are equipped with a network of pipe-like cells, the xylem, facilitating efficient delivery of water to all parts of the organism. In the leaf, these networks form highly complex, highly reticulate, hierarchically organized webs that are believed to be the result of a process of gradual optimization over the course of evolutionary history. Based on the assumption of functional optimization over the course of evolution, we construct models for optimal transport networks adapted to different kinds of damage (modelling herbivory, diseases, etc...) and fluctuating load (modelling the fact that the stomata, small orifices responsible for the exchange of gasses, open in patches at a time). We numerically solve the resulting optimization problem and analyze the solutions with special regard to structure and hierarchical organization of loops which arise in response to damage and fluctuations.

SOE 16.5 Wed 16:00 ZEU 118

The topology of adaptively controlled networks — •Judith Lehnert[1], Philipp Hövel[1,2], Alexander Fradkov[3,4], and Eckehard Schöll[1] — [1]Institut für Theoretische Physik, TU Berlin, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Bernstein Center for Computational Neuroscience, HU Berlin, Philippstr. 13, 10115 Berlin, Germany — [3]SPb State University, Universitetskii pr.28, St. Petersburg, 198504 Russia — [4]Institute for Problems of Mechanical Engineering, Russian Academy of Sciences, Bolshoy Ave, 61, V. O., St. Petersburg, 199178 Russia

Adaptive networks are characterized by a complicated interplay between the dynamics of the nodes and a changing topology: The topology evolves according to the state of the system, while at the same time the dynamics on the network and thus its state is influenced by that topology. Here, we present an algorithm for a changing topology that allows us to control the dynamics on the network. In particular, we control zero-lag and cluster synchronization in delay-coupled networks of Stuart-Landau oscillators.

The emerging topology of the network is modulated by the delay. If the delay time is a multiple of the system's eigenperiod, the coupling within a cluster and to neighboring clusters is on average positive (excitatory), while the coupling to clusters with a phase lag close to π is negative (inhibitory). For delay times equal to odd multiples of half of the eigenperiod, we find the opposite: Nodes within one cluster and of neighboring clusters are coupled by inhibitory links, while the coupling to clusters distant in phase state is excitatory.

SOE 16.6 Wed 16:15 ZEU 118

Hierarchical block structures and high-resolution model selection in large networks — •Tiago P. Peixoto — Universität Bremen, Germany

Many social, technological, and biological networks are composed of modules, which represent groups of nodes which have a similar role in the functioning of the network. The problem of detecting and characterizing these modules is a central one in the broad field of complex systems. However most existing methods used to obtain the modular structure of networks suffer from serious problems, such as the resolution limit on the size of communities. This phenomenon occurs for the very popular approach of modularity optimization, but also for more principled ones based on statistical inference and model selection. Here I construct a nested generative model which, through a complete description of the entire network hierarchy at multiple scales, is capable of avoiding this limitation, and enables the detection of modular structure at levels far beyond those possible by current approaches. Even with this increased resolution, the method is based on the principle of parsimony, and is capable of separating signal from noise. Furthermore, it fully generalizes other approaches in that it is not restricted to purely assortative mixing patterns, directed or undirected graphs, and ad hoc hierarchical structures such as binary trees..

References: [1] Tiago P. Peixoto, Phys. Rev. Lett. 110 14 148701 (2013); [2] Tiago P. Peixoto, arXiv: 1310.4377; [3] Tiago P. Peixoto, arXiv: 1310.4378

SOE 16.7 Wed 16:30 ZEU 118

Temporal networks: Laplacian spectra and synchroniza-

tion — •Konstantin Klemm[1,2], Naoki Masuda[3], and Victor M. Eguiluz[4] — [1]Bioinformatics, Institute of Computer Science, Leipzig University, Germany — [2]Bioinformatics and Computational Biology, University of Vienna, Austria — [3]Department of Mathematical Informatics, The University of Tokyo, Japan — [4]Instituto de Fisica Interdisciplinar y Sistemas Complejos, Palma de Mallorca, Spain

Interactions among units in complex systems occur in a specific sequential order thus affecting the flow of information, the propagation of diseases, and general dynamical processes. We investigate the Laplacian spectrum of temporal networks and compare it with that of the corresponding aggregate network. First, we show that the spectrum of the ensemble average of a temporal network has identical eigenmodes but smaller eigenvalues than the aggregate networks. In large networks without edge condensation, the expected temporal dynamics is a time-rescaled version of the aggregate dynamics. Even for single sequential realizations, diffusive dynamics is slower in temporal networks [1]. These discrepancies are due to the noncommutability of interactions. The final part of the presentation uses the calculated spectra to predict the stability of non linear-systems with diffusive temporal couplings.

[1] N. Masuda, K. Klemm, V. M. Eguiluz, Phys. Rev. Lett. 111, 188701 (2013).

15 min break

SOE 16.8 Wed 17:00 ZEU 118

Phase Transitions in Cooperative Coinfections: Simulation Results for Networks and Lattices — •Weiran Cai[1], Li Chen[2,3], Fakhteh Ghanbarnejad[2], and Peter Grassberger[4] — [1]Faculty of Electrical and Computer Engineering, Technische Universität Dresden, Germany — [2]Max Planck Institute for Physics of Complex Systems, Dresden, Germany — [3]Robert Koch-Institut P4 - Epidemiologische Modellierung von Infektionskrankheiten, Berlin, Germany — [4]JSC, FZ Jülich, D-52425 Jülich, Germany

In this talk, we study the spreading of a cooperative coinfection on different networks topologies. Previous work has shown that in a mean field approximation, the cooperativity of two diseases in the SIR framework can lead to first-order transitions, where the relative size of the infected cluster changes discontinuously with respect to control parameters. However, due to the mean field approximation, such discontinuous transitions could occur only when the initial density of infected sites is finite. Here we show that the same is true on trees, but not on other networks. On Erdős-Renyi(ER) networks, on networks with long range contacts, and lattices with dimension = 3 we find first order transitions initiated even by a single sick site, while no first order transitions are observed on 2-dimensional lattices, if the contacts are short range. The importance of loops for the presence/absence of discontinuous transitions is discussed.

SOE 16.9 Wed 17:15 ZEU 118

Stability of Boolean and continuous dynamics — •Fakhteh Ghanbarnejad[1] and Konsatntin Klemm[2,3] — [1]Max-Planck-Institut für Physik komplexer Systeme, Dresden, Germany — [2]Bioinformatics, Institute for Computer Science, University of Leipzig, Germany — [3]Institute for Theoretical Chemistry, University of Vienna, Austria

Regulatory dynamics in biology is often described by continuous rate equations for continuously varying chemical concentrations. Binary discretization of state space and time leads to Boolean dynamics. In the latter, the dynamics has been called unstable if flip perturbations lead to damage spreading. Here, we find that this stability classification strongly differs from the stability properties of the original continuous dynamics under small perturbations of the state vector. In particular, random networks of nodes with large sensitivity yield stable dynamics under small perturbations. (Phys. Rev. Lett. 107, 188701 (2011))

SOE 16.10 Wed 17:30 ZEU 118

Physiological networks studied with time-delay stability analysis — •Jan W. Kantelhardt[1], Amir Bashan[2], Ronny P. Bartsch[3], Shlomo Havlin[2], and Plamen C. Ivanov[3] — [1]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg — [2]Department of Physics, Bar-Ilan University, Israel — [3]Harvard Medical School, Boston, USA

The human organism is an integrated network where complex physiological systems, each with its own regulatory mechanisms, continuously interact, and where failure of one system can trigger a breakdown of the entire network. Identifying and quantifying dynamical networks of diverse systems with different types of interactions is a challenge. We have developed time-delay stability analysis as a framework to probe interactions among diverse systems and identified a physiological network from recorded time series data. Each physiological state is characterized by a specific network structure, demonstrating a robust interplay between network topology and function. Across physiological states, the network undergoes topological transitions associated with fast reorganization of physiological interactions on time scales of a few minutes, indicating high network flexibility in response to perturbations.

SOE 16.11 Wed 17:45 ZEU 118

Large networks have small Problems — •Helge Aufderheide[1] and Thilo Gross[2] — [1]Max-Planck Institut für Physik komlpexer Systeme — [2]University of Bristol, MV School of Engineering Mathematics

On several levels, humans depend on the functioning of complex networks, such as food webs and technical infrastructure networks. However, recent work shows that trying to stabilize a network can lead to large-scale failures. This suggests that it is important to assess not only the risk of a failure, but also its scale. Here we show that instabilities which naturally occur in large networks are typically localized, such that they affect only a relatively small part of the network directly, whereas attempts to stabilize the network can lead to a delocalization, such that instabilities are less likely but will affect a larger number of nodes when they occur. These results may explain how many natural networks can stabilize themselves by sacrificing the parts in which instabilities occur, whereas cases of delocalized systemic failure are known to occur in artificial technical or organizational networks.

SOE 16.12 Wed 18:00 ZEU 118

Outbreaks of coinfections: the critical role of cooperativity — •Fakhteh Ghanbarnejad[1], Li Chen[1], Weiran Cai[2], and Peter Grassberger[1,3] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]Faculty of Electrical and Computer Engineering, TU Dresden, Germany — [3]JSC, FZ Jülich, D-52425 Jülich, Germany

Modeling epidemic dynamics plays an important role in studying how diseases spread, predicting their future course, and designing strategies to control them. In this talk, we introduce a model of SIR (susceptible-infected-removed) type which explicitly incorporates the effect of *cooperative coinfection*. More precisely, each individual can get infected by two different diseases, and an individual already infected with one disease has an increased probability to get infected by the other. Depending on the amount of this increase, we prove different threshold scenarios. Apart from the standard continuous phase transition for single disease outbreaks, we observe continuous transitions where both diseases must coexist, but also discontinuous transitions are observed, where a finite fraction of the population is already affected by both diseases at the threshold. All our results are obtained in a mean field model using rate equations, but we argue that they should hold also in more general frameworks. (arXiv:1307.2404)

SOE 16.13 Wed 18:15 ZEU 118

Onset of self-sustained activity in a simple model of excitable dynamics on graphs — •Christoph Fretter[1,2], Annick Lesne[3], Claus C. Hilgetag[1,4], and Marc-Thorsten Hütt[2] — [1]Department of Computational Neuroscience, Universitätsklinikum Hamburg-Eppendorf, Hamburg, Germany — [2]School of Engineering and Science, Jacobs University Bremen, Germany — [3]LPTMC UMR 7600, Université Pierre et Marie Curie-Paris 6, 4 place Jussieu, F-75252 Paris, France — [4]Department of Health Sciences, Boston Uniersity, Boston, USA

Models of simple excitable dynamics on graphs are an efficient framework for studying the interplay between network topology and dynamics. This subject is a topic of practical relevance to diverse fields, ranging from neuroscience to engineering. Using a discrete excitable node model, we analyse how a single excitation propagates through a random network as a function of the excitation threshold,that is, the percentage of excitations in the neighborhood required for an excitation of a node. Using numerical simulations and analytical considerations, we can understand the onset of sustained activity as an interplay between topological cycle statistics and path statistics. Our findings are interpreted in the context of the theory of network reverberations in neural systems, which is a question of long-standing interest in computational neuroscience.

SOE 16.14 Wed 18:30 ZEU 118

Laplacian Spectrum of 2d Lattice Triangulations — •Ella Schmidt, Benedikt Krüger, and Klaus Mecke — Institut für Theoretische Physik, FAU Erlangen-Nürnberg, Staudtstr. 7, 91058 Erlangen

Triangulations are an important tool in physics for describing curved geometries. Unimodular triangulations on 2d lattices can also be considered as connected, simple, plane graphs, which allows the appliance of methods from spectral graph theory on triangulations.

We calculate the distribution and averages of eigenvalues of the Laplacian matrix for random and highly ordered unimodular triangulations. Introducing a curvature energy of triangulations we measure microcanonical and canonical averages of the eigenvalues using Monte-Carlo-Simulations. We examine the probability distributions of the spectra of the ensembles of triangulations, the dependence of the eigenvalues on energy and temperature as well as the scaling with the lattice size and compare with random graph models.

In the microcanonical ensemble we find in agreement with our analytical predicitions a linear dependence of the algebraic connectivity and the spectral radius on the energy, in the canonical ensemble we encounter quasi-critical behaviour.