DY 45: Poster Session: Nonlinear Dynamics, Pattern Formation, Data Analytics and Machine Learning

Time: Thursday 15:00–18:00 Location: P2

DY 45.1 Thu 15:00 P2

Influence of protective measures on rare-event behavior of the dynamics of the SIR model. — •Timo Marks, Yannick Feld, and Alexander K. Hartmann — Institute of Physics, University of Oldenburg

Since the outbreak of the SARS-CoV-2 pandemic in early 2020, there has been a surge of interest in modeling disease spreading. The basis of many more complex models is the SIR model [1], in which the population is divided into a group of *Susceptible*, *Infected* and *Recovered* individuals.

Here, the SIR model is applied to a small-world ensemble that can model social interactions of a real population [2]. Using large-deviation methods and in particular the Wang-Landau algorithm, the distributions of quantities of interest can be calculated over basically the full support [3]. To include protective measures, once a predefined threshold of simultaneously infected nodes is reached, the transmission parameter is decreased. We compare the impact of these measures with unrestrained disease spreading on the level of the full probability distributions, which were obtained down to probabilities such as 10^{-50}. We thereby observe significant changes in the shape of the distributions.

[1] W. O. Kermack and A. G. McKendrick, Proc. R. Soc. Lond. A **115**, 700*721 (1927)
[2] S. Milgram, Psychology Today **1**, 60*67 (1967)
[3] Y. Feld, A. K. Hartmann, PhysRevE.105.034313 (2022)

DY 45.2 Thu 15:00 P2

Pattern Formation in non-ideal systems: From Turing patterns to active droplets — •Lucas Menou and David Zwicker — Max Planck Institute für dynamik und selbstorganisation, Göttingen, Germany

Turing's seminal reaction-diffusion model explains how patterns form in non-equilibrium systems. Typical Turing models assume ideal diffusion, which implies dilute or ideal systems. In contrast, active droplets use chemical reactions to control phase separation emerging in strongly interacting systems. We unite both theories by combining the classical Cahn-Hilliard model, which describes non-ideal solutions, with the typical non-linear reactions responsible for Turing patterns. We find that interactions can promote or suppress the emergence of periodic patterns. Interestingly, patterns can form even when all species have equal diffusivity, which is impossible in traditional Turing models. Taken together, our theory shows a rich behavior that interpolates between the traditional Turing patterns and active droplets.

DY 45.3 Thu 15:00 P2

Chaotic Diffusion in Delay Systems: Giant Enhancement by Time Lag Modulation — •Tony Albers, David Müller-Bender, Lukas Hille, and Günter Radons — Institute of Physics, Chemnitz University of Technology, Chemnitz, Germany

We consider a typical class of systems with delayed nonlinearity, which we show to exhibit chaotic diffusion. It is demonstrated that a periodic modulation of the time-lag can lead to an enhancement of the diffusion constant by several orders of magnitude. This effect is the largest if the circle map defined by the modulation shows mode locking and more specifically, fulfills the conditions for laminar chaos. Thus we establish for the first time a connection between Arnold tongue structures in parameter space and diffusive properties of a delay system. Counterintuitively, the enhancement of diffusion is accompanied by a strong reduction of the effective dimensionality of the system.

Details can be found in: T. Albers, D. Müller-Bender, L. Hille, and G. Radons, Phys. Rev. Lett. **128**, 074101 (2022)

DY 45.4 Thu 15:00 P2

Bistable vortices formed by active particles with retarded interactions — Xiangzun Wang[1], •Pin-Chuan Chen[2], Klaus Kroy[2], Viktor Holubec[3], and Frank Cichos[1] — [1]Peter Debye Institute for Soft Matter Physics, Leipzig Univeristy, Leipzig, Germany — [2]Institute for Theoretical Physics, Leipzig University, Leipzig, Germany — [3]Department of Macromolecular Physics, Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic

In recent experiments done in the Molecular Nanophotonics Group in the Peter Debye Institute, thermophoretic microswimmers are observed to self-assemble into bi-stable rotational modes due to retarded attractive interactions.

For the particular case where a single swimmer is attracted to an immobilized target, we show how we can analytically understand such non-linear stochastic time-delayed system. This could be achieved by Taylor expanding the equation for small time delay. The system can then be described by an overdamped Langevin equation with a potential determined by time delay, and the transition in between the two stable modes is well predicted by Kramers' escape rate. However, expanding the delayed term in Taylor series is actually not as trivial as it seems to be, as instability would occur if we keep derivatives up to arbitrarily high orders.

For the case where multiple swimmers are present, the swimmers form a cluster with co-rotating and counter-rotating shells. We further discuss the competition between the time-delay and hydrodynamic effects, which result in this phenomenon.

DY 45.5 Thu 15:00 P2

Synchronizing Cells Based on Local Interactions — •Stephan Kremser, Mareike Bojer, and Ulrich Gerland — Physics Department, Technical University of Munich

Tissue-wide temporal synchronization of cellular processes is a desirable property for many systems in synthetic and developmental biology. Here, we look at a setting were cells have only limited information about the behavior of neighboring cells, receiving new information only after these neighbors change their internal state. Under these assumptions, we ask if global synchronization can be reached based on local (e.g. direct contact) interactions. We develop a conceptual model of the synchronization process and explore it computationally for different dimensions and interaction network topologies of the tissue. We show that temporal corrections to cellular processes based on magnitude ('proportional feedback control') or sign ('on-off feedback control') of local time differences are enough to conserve local synchronization and bound global asynchrony by a constant independent of time for a long period of time. This allows us to establish a link to the physics of growing surfaces and to investigate the interplay of patterning and synchronization dynamics.

DY 45.6 Thu 15:00 P2

Network complexity versus network synchronicity: A case study of the Kuramoto model on complex networks — Archan Mukhopadhyay and •Jens Christian Claussen — University of Birmingham, UK

During the last two decades, complexity measures for graphs and networks have gained significant attention (see [1] for a comparison), especially in the aim to distinguish "complex" topologies from regular lattices as well as random structures. However, what is the influence of topology on dynamics? Here we specifically analyze synchronization in a network of Kuramoto oscillators where the topology (between a high-complexity graph and a random graph) is parameterized by a complexity measure, as Offdiagonal Complexity [2] or one of the other graph complexity measures. This approach may provide a new light on both the influence of complexity on synchronization, as well as the complexity measures and which aspects of dynamical complexity these may predict.

[1] J. Kim, T. Wilhelm, Physica A 387, 2637 (2008)
[2] Jens Christian Claussen, Physica A 375, 365 (2007)

DY 45.7 Thu 15:00 P2

Quantum synchronization in a network of dissipatively coupled oscillators — •Juan Nicolas Moreno, Christopher w. Wächtler, and Alexander Eisfeld — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

Synchronization in classical systems has a long history and by now is a very well understood phenomenon. However, the question whether the classical notions of synchronization can be extended to the quantum regime has only recently been addressed in investigations of classically inspired models like quantum Van der Pol oscillators as well as models without classical analog. Inspired by the theoretical prediction that two-level atoms are able to synchronize even without interacting directly [1], we investigate a network of dissipatively coupled quantum harmonic oscillators. Within a mean-field approximation we find that the network is able to synchronize. For the fully quantum system described in terms of a Lindblad master equation we analyze various measures that have been proposed in the literature. Additionally, we investigate the Liouvillian spectrum in order to draw connections between the spectrum and the synchronization measures.

[1] PRA 101, 042121 (2020)

DY 45.8 Thu 15:00 P2

Neural Network-Based Approaches for Multiscale Modelling of Topological Defects — •Kyra Klos[1], Karin Everschor-Sitte[2], and Friederike Schmid[1] — [1]Johannes Gutenberg University, Mainz, Germany — [2]University of Duisburg-Essen, Duisburg, Germany

Topological defects and their dynamics are a heavily researched topic in a wide range of physics fields [1].

Due to the multiscale character of those defect structures, numerically simulating a large number of them in full microscopic detail gets highly computationally expensive, as the large size of associated deformation fields around each core leads to a complex interaction pattern.

To give a possible insight into the connection between the macroscopic (particle) description of a model with topological defects and the underlying microscopic structure, we propose the use of neural networks. With a spin-dynamic simulated microscopic model as training data, we use a conditional generative adversarial network system [2] with Wasserstein-loss [3] to generate reasonable spin-configurations from given defect configuration inputs. To guarantee the generation of realistic spin configuration, we also include additional physical constraints into our generator.

[1] Mermin N. D., Rev. Mod. Phys. 51, 591, (1979)
[2] Mirza M. ; Osindero S., arXiv:1411.1784v1, (2014)
[3] Arjovsky M. et al., ICML, PMLR 70, 214, (2017)
[4] Goodfellow I. et al., NeurIPS, (2014)

DY 45.9 Thu 15:00 P2

Characterizing quasicrysalline patterns with neural networks — •Jonas Buba and Michael Schmiedeberg — Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany

There exist multiple ways to generate two dimensional quasicrystal patterns such as superpositions of plane waves [1-3] or projection methods [4], each using different parametrisations. A deep convolutional Autoencoder is utilized to determine whether an artifical neural network is capable of finding sufficient parametrisations for these patterns.

Furthermore another neural network was used to classify them by symmetry. Finally, deep dream methods [5] are employed to analyze which features the artificial intelligence bases its symmetry classification on. Currently we are trying to find out how the deep dream approach can be applied to modify existing patterns by enhancing features corresponding to specific symmetries.

[1] D.S. Rokhsar, N.D. Mermin, and D.C. Wright, Acta cryst. A44, 197 (1988). [2] S.P. Gorkhali, J. Qi, and G.P. Crawford, J. Opt. Soc. Am. B 23, 149 (2005). [3] M. Schmiedeberg and H. Stark, J. of Phys.: Cond. Matter 24(28), 284101 (2012). [4] M. Duneau and A. Katz, Phys. Rev. Lett. 54, 2688 (1985). [5] A. Mordvintsev, C. Olah, and M. Tyka, "Inceptionism: Going Deeper into Neural Networks", Google AI Blog (2015).

DY 45.10 Thu 15:00 P2

Influence of delay-times on photonics reservoir computing performance — •Lina Jaurigue and Kathy Lüdge — Institut f. Physik, Technische Universität Ilmenau, Weimarer Str. 25, 98684 Ilmenau, Germany

Reservoir computing is a machine learning approach that utilises the non-linear responses of dynamical systems to perform computational tasks. Due to the relative simplicity of this approach the implementation in hardware is practicable, particularly the delay-based reservoir computing paradigm. Delay-based reservoirs use a single non-linear node subject to self-feedback. The high-dimensional dynamics that arise due to the feedback are utilised by driving the reservoir with time-multiplexed inputs. There have been a number of successful implementations of delay-based reservoirs in electronic, opto-electronic and photonic systems, among others. However, a challenge that remains is the efficient optimisation of a reservoir for performance on a variety of tasks. To this end we explore the influence of the delay-time on the performance of time-series prediction tasks and compare the computational performance of different methods of including task specific delay-timescales in a photonic reservoir setup.

DY 45.11 Thu 15:00 P2

Reservoir computing with memory cells: Impact of perturbations and phase effects — •Noah Jaitner[1], Elizabeth Robertson[3], Lina Jaurigue[2], Janik Wolters[3], and Kathy Lüdge[2] — [1]Institute of Theoretical Physics, Technische Universität-Berlin, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Institut f. Physik, Technische Universität Ilmenau, Weimarer Str. 25, 98684 Ilmenau, Germany — [3]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Insitut für Optische Sensorsysteme, Rutherfordstr. 2, 12489 Berlin, Germany

Reservoir computing is a versatile, fast-trainable approach for machine learning that utilities the capabilities of dynamical systems. The common approach is to use a nonlinear element and a delay line to construct a virtual network. These virtual networks have limited topology. By utilizing cesium cells as coherent optical memory cells to create a hybrid architecture [1] the limitations of topology can be overcome and a more dynamically versatile virtual network can be created. The optical memory used in the corresponding experiment performs well in memory bandwidth but experiences high noise levels. [2] The dynamics and noise resistance of this approach is examined to find an optimal approach for different time series prediction tasks.

[1] L. C. Jaurigue, E. Robertson, J. Wolters and K. Lüdge Entropy **23**, 1099-4300 (2021).
[2] L. Esguerra, L. Meßner, E. Robertson, N. V. Ewald, M. Gündoan and J. Wolters arXiv:2203.06151.

DY 45.12 Thu 15:00 P2

Reconstructing spatiotemporal chaos in three-dimensional excitable media based on surface data — •Inga Kottlarz[1,2], Sebastian Herzog[1,3], Roland Stenger[1,2], Baltasar Rüchardt[1,4], Stefan Luther[1,4,5], and Ulrich Parlitz[1,2,4] — [1]Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany — [2]Institute for Dynamics of Complex Systems, Georg-August-Universität Göttingen, Göttingen, Germany — [3]Department for Computational Neuroscience, Third Institute of Physics - Biophysics, University of Göttingen, Göttingen, Germany — [4]German Center for Cardiovascular Research (DZHK), partner site Göttingen, Robert-Koch-Str. 42a, 37075 Göttingen, Germany — [5]Institute of Pharmacology and Toxicology, University Medical Center Göttingen, Robert-Koch-Str. 40, 37075, Göttingen, Germany

The cardiac muscle is an excitable medium that can exhibit complex dynamics, including spatiotemporal chaos associated with (fatal) cardiac arrhythmias. While mechanical motion within the myocardium can be observed with ultrasound, there are no noninvasive techniques (to date) to measure the electrical state within the tissue. To overcome this limitation of observable quantities, we address the task of predicting the electrical state inside the heart from surface data using data-driven reconstruction by means of artificial neural networks. We study the feasibility of this approach in a homogenous and isotropic excitable medium with spatiotemporal dynamics in three spatial dimensions, applying and comparing different deep learning methods (i.e. LSTM, Convolutional Autoencoder, ...).

DY 45.13 Thu 15:00 P2

Ordinal Patterns as Robust Biomarkers in Multichannel EEG Time Series — •Inga Kottlarz[1,2], Sebastian Berg[1], Diana Toscano-Tejeida[3], Iris Steinmann[3], Mathias Bähr[4], Stefan Luther[1,5,6], Melanie Wilke[3,7], Ulrich Parlitz[1,2,6], and Alexander Schlemmer[1,6] — [1]Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany — [2]Institute for Dynamics of Complex Systems, Georg-August-Universität Göttingen, Göttingen, Germany — [3]Department of Cognitive Neurology, University Medical Center Göttingen, Göttingen, Germany — [4]Department of Neurology, University Medical Center Göttingen, Göttingen, Germany — [5]Institute of Pharmacology and Toxicology, University Medical Center Göttingen, Göttingen, Germany — [6]German Center for Cardiovascular Research (DZHK), Partner Site Göttingen, Göttingen, Germany — [7]German Primate Center, Leibniz Institute for Primate Research, Göttingen, Germany

Neurobiological changes in healthy and pathological aging and their electrophysiological correlates (EEG) are still an important topic in the neuroscience community. We extract ordinal patterns and frequency-domain based features from multichannel EEG time series to differentiate between two age groups and also between individuals, using functional connectivity and single channel features. We analyse the separation of EEG features from different age groups and individuals and demonstrate that ordinal pattern-based measures yield results comparable to frequency-based measures applied to preprocessed data, and outperform them if applied to raw data.