DY 33: Poster: Nonlinear Dynamics, Pattern Formation and Networks

Time: Wednesday 15:00–18:00 Location: Poster C

DY 33.1 Wed 15:00 Poster C

Force networks in granular experiments: From topology to dynamics — •Lou Kondic — New Jersey Institute of Technology, Newark, NJ, USA

We will discuss force networks that spontaneously form in particulate-based systems. These networks, most commonly known as ‘force chains’ in granular systems, are dynamic structures of fundamental importance for revealing the underlying causes of many physical phenomena involved in the statics and dynamics of particulate-based systems. While the networks emerging from discrete element simulations have been analyzed extensively, the analysis of networks found in physical experiments is far less developed. The presentation will focus on applications of algebraic topology, particularly persistent homology (PH) to analysis of such networks. PH allows for a simplified representation of complex interaction fields in both two and three spatial dimensions in terms of persistent diagrams (PDs) that are essentially point clouds. These point clouds could be compared meaningfully, allowing for the analysis of the underlying systems’ static and dynamic properties. The presentation will focus on applications of topological data analysis of such networks found in photoelastic experiments involving an intruder moving in a stick-slip fashion through a 2D granular domain. We will particularly focus on exploring the predictability potential of the considered topological measures.

DY 33.2 Wed 15:00 Poster C

Resonant Velocity Tuning of Solitary States in Complex Networks — •Jakob Niehues[1,2,3], Serhiy Yanchuk[1,2,4], Rico Berner[2], Jürgen Kurths[1,2], Frank Hellmann[1], and Mehrnaz Anvari[1,5] — [1]Potsdam Institute for Climate Impact Research (PIK), Member of the Leibniz Association, P.O. Box 60 12 03, D-14412 Potsdam, Germany — [2]Humboldt-Universität zu Berlin, Department of Physics, Newtonstraße 15, 12489 Berlin, Germany — [3]Technische Universität Berlin, ER 3-2, Hardenbergstrasse 36a, 10623 Berlin, Germany — [4]University College Cork, School of Mathematical Sciences, Western Road, Cork, T12 XF62, Ireland — [5]Fraunhofer Institute for Algorithms and Scientific Computing, 53757 Sankt Augustin, Germany

Partially synchronized solitary states occur frequently when a synchronous system of networked oscillators is perturbed locally. Remarkably, several asymptotic states of different frequencies can coexist at the same node. Here we uncover the mechanism underlying this multistability. The resonant back-reaction of the networks’ modes on the solitary oscillator can lead to large energy transfer between them. The frequency adaptation of the oscillator can tune the system to this resonance. We provide a full analytic analysis of this mechanism, and show which network structures enable its presence.

DY 33.3 Wed 15:00 Poster C

Wave Digital Model of a Relaxation Oscillator with Optical Memsensor — •Sebastian Jenderny[1], Rohit Gupta[2], Roshani Madurawala[3], Maik-Ivo Terasa[3], Franz Faupel[2], Sören Kaps[3], Rainer Adelung[3], Alexander Vahl[2], and Karlheinz Ochs[1] — [1]Ruhr-University Bochum, Chair of Digital Communication Systems, Bochum, Germany — [2]Christian-Albrechts University Kiel, Chair for Multicomponent Materials, Kiel, Germany — [3]Christian-Albrechts University Kiel, Functional Nanomaterials Chair, Kiel, Germany

Biological neuronal networks, besides their increased energy-efficiency, are especially interesting due to their learning and adaption abilities. To come up with new designs for circuits adapting to new tasks in a self-organizing fashion, it is important to transfer findings on the biological wiring and rewiring mechanisms to electrical circuits. Up to now, the wiring mechanisms are typically associated with the change of synaptic weights and are often implemented by memristors. Growth in real neuronal networks, however, strongly depends on the integration of sensory information from their surroundings. For this purpose, in this work, we report on the use of memsensors. We specifically introduce a relaxation oscillator that includes an optical sensor as well as a memristor. The oscillator acts as an optical memsensor displaying basic neuronal behavior. To be able to evaluate the usage of this memsensor in larger circuit setups, we develop a corresponding wave digital model on the basis of experimental data of the memsensor.

DY 33.4 Wed 15:00 Poster C

Kirman’s herding model with stochastic resetting — •Pece Trajanovski[1], Petar Jolakoski[1], Arnab Pal[2], Ljupco Kocarev[1,3], and Trifce Sandev[1,4] — [1]Macedonian Academy of Sciences and Arts, Skopje, Macedonia — [2]Institute of Mathematical Sciences, Chennai, India — [3]Ss. Cyril and Methodius University in Skopje, Macedonia — [4]University of Potsdam, Germany

Kirman’s herding model with stochastic resetting extends the seminal Kirman*s ants model by incorporating stochastic resetting, which mimics sharp external influences on the system. The dynamics are characterized by two essential parameters b and a, the first representing the strength of agents influence to convert others, and other signifying the likelihood of spontaneous preference alteration by each agent. The resetting rate (r) introduces a pivotal interplay, yielding unexpected outcomes in the mean first passage time to a specific binary choice.

Our approach enhances Kirman’s model by introducing exogenous factors, resulting in a more realistic herding/recruiting model adaptable to diverse behavioral scenarios. The analysis provides a comprehensive understanding, including the derivation of the probability distribution function solution, the distribution for the stationary case, and the mean first passage time distribution using the backward master equation. This exploration contributes valuable insights into the nuanced dynamics of collective decision-making and population configurations within complex systems, enriching our understanding of the Kirman’s herding model.

DY 33.5 Wed 15:00 Poster C

Nature of the volcano transition in the fully disordered Kuramoto model — •Axel Prüser, Sebastian Rosmej, and Andreas Engel — Carl von Ossietzky University Oldenburg, Institut für Physik, D26111 Oldenburg, Germany

Randomly coupled phase oscillators may synchronize into disordered patterns of collective motion. We analyze this transition in a large, fully connected Kuramoto model with symmetric but otherwise independent random interactions. Using the dynamical cavity method we reduce the dynamics to a stochastic single oscillator problem with self-consistent correlation and response functions that we study analytically and numerically. We clarify the nature of the volcano transition and elucidate its relation to the existence of an oscillator glass phase.

DY 33.6 Wed 15:00 Poster C

A novel cutoff criterion for spectral derivatives in the context of ordinary differential equation model estimation — •Oliver Strebel — Angelstr. 17, 75392 Deckenpfronn

After the advent of SINDy-methods [1] estimation of ordinary differential equation models involves typically the numerical calculation of derivatives for noisy data. This contribution presents a novel determination method concerning the cutoff parameter for spectral derivatives. The method is benchmarked against 60 differential equations and estimation methods of reference [2].

It is compared to numerical differentiation methods like finite differences, derivatives using the Friedrichs mollifier and weak differentiation using this mollifier. The hyperparameters of all these methods are optimized against the test set of these equations at a fixed noise level. Then the resilence against larger noise or fewer data points per time interval is examined. It turns out that the novel method is overall superior to the other methods.

[1] Steve L. Brunton, PNAS 113 (2016): https://doi.org/10.1073/pnas.1517384113

[2] Oliver Strebel, Nonlinear Dynamics 111 (2023): https://doi.org/10.1007/s11071-023-08242-y

DY 33.7 Wed 15:00 Poster C

Reliability of Numerical Solutions in Transient Chaos — Ali Goodarzi[1], Maryam Rahimi[1], Mohammadjavad Valizadeh[2], and •Fakhteh Ghanbarnejad[3] — [1]Institute of Physics, EPFL, Lausanne, Switzerland — [2]Department of Mathematics, Simon Fraser University, Burnaby, Canada — [3]Chair of Network Dynamics, Institute for Theoretical Physics and Center for Advancing Electronics Dresden (cfaed), Technical University of Dresden, 01062 Dresden, Germany

In dealing with nonlinear systems, it is common to use numerical solutions. Unlike the careful behavior towards the numerical results in chaotic regions, the validity of numerical results in regions of tran-

sient chaos might not always be taken into consideration. This article demonstrates that using numerical methods to solve systems undergoing transient chaos can be challenging and sometimes unreliable.

To illustrate this issue, we use the Lorenz system in the region of transient chaos as an example. We show how the result of the computation might completely change when using different mathematically equivalent expressions. This raises the question of which result should be relied on. To answer this question, we propose a method based on the Lyapunov exponent to determine the reliability of the numerical solution and apply it to the provided example. In fact, this method checks a necessary condition for the validity of the numerical solution. Then, by increasing the precision to the extent suggested by our method, we show that the result of our studied case passes this test. In the end, we briefly discuss the scope and limits of our method.

full article: arXiv:2310.13155

DY 33.8 Wed 15:00 Poster C

A Study of complex Kuramoto Agents in Small-World Networks — Toni Sollfrank[1], Sibylle Gemming[1], and •Jeffrey Kelling[1,2] — [1]Institut für Physik, TU Chemnitz, Chemnitz, Germany — [2]Helmholtz-Zentrum Dresden - Rossendorf, Dresden, Germany

Synchronization is a phenomenon frequently observed or employed in natural or engineered systems. Swarms of animals can show synchronized behavior which has been qualitatively modeled as dynamic networks of Kuramoto oscillators. We propose a model for networks of complex agents, where each agent is a small sub-network which is only very sparsely coupled to other agents via designated input-output nodes. The internal structure of each agent gives rise to complex response to stimuli from the external network. Here, we present a study of the dynamical synchronization behavior on these, by construction, hierarchical graphs. A range of defined agent sub-network types are considered connected by small-world networks Barabási–Albert, Erdös–Rényi or Watts–Strogatz types.

DY 33.9 Wed 15:00 Poster C

Minimal thermal and thermoelectric rectifiers — •José Balduque[1] and Rafael Sánchez[1,2] — [1]Departamento de Física Teórica de la Materia Condensada, Universidad Autónoma de Madrid, Madrid, Spain. — [2]Condensed Matter Physics Center (IFIMAC), and Instituto Nicolás Cabrera, Universidad Autónoma de Madrid, Madrid, Spain.

Modern electronic devices are currently operated at the nanoscale regime, where overheating becomes a problem. Controlling the undesired heat flows in a useful manner is another less explored way of improving its performance. For this, efficient thermal diodes need to be designed [1]. Usual proposals rely in nonlinear scenarios [2]; here, we identify the minimal conditions for a nanoscale device to rectify the heat and thermoelectric currents, even in the absence nonlinearities. This is achieved for asymmetric coherent conductors that allow for some local thermalization of the heat carriers. We quantify the amount of rectification achieved by this mechanism in some proposed systems composed of resonant-tunneling quantum dots and compare (and combine) it with the nonlinear scenarios. Finally, we propose feasible experimental realizations of this idea in an elastic conductor where the interplay between thermalization and nonlinearities can be controlled via quantum interference [3].

[1] G. Benenti et al., Springer International Publishing (Cham, Switzerland), 2016.

[2] B. Li et al., Phys. Rev. Lett., 93 (2004) 184301.

[3] R. Sánchez et al., Phys. Rev. B, 104 (2021) 115430.

DY 33.10 Wed 15:00 Poster C

Oscillations in SIRS model with block delay kernels — •Daniel Henrik Nevermann and Claudius Gros — Institut für Theoretische Physik, Goethe-Universität Frankfurt, Deutschland

Oscillations are an omnipresent feature of epidemic dynamics, however, the classical SIRS model with exponentially distributed dwell-times in the compartments is unable to capture stable oscillations. Models with non-exponentially distributed dwell-times, on the other hand, may exhibit periodic outbreaks in its endemic state for certain parameter values. These oscillatory solutions are already present when considering a simple normalized step function kernel, what we call a block delay kernel, for the time of immunity of a recovered individual. We investigate the resulting attractor topology and study the characteristics of the periodic outbreaks, where we use the skewness of the time series as a measure for the shape of the periodic outbreaks.

A continuous approximation to the block delay kernel is given by the normalized sum of N Erlang distributions, where the block delay kernel is recovered in the limit $N \to \infty$. We show that this finite sum may be equally represented by an upper incomplete gamma function, which simplifies the derivation of its mathematical properties. We apply the kernel series framework to recast the system with continuous block delay kernel to a set of ordinary differential equations. Using this, we study the onset of periodic outbreaks when systematically decreasing the slope of the block delay kernel. Comparing the skewness of the time series to limiting case of a fixed time in the recovered compartment, we find that the relative deviation scales as a power-law in N.

DY 33.11 Wed 15:00 Poster C

Square waves and Bykov T-points in a delay algebraic model for the Kerr-Gires-Tournois interferometer — Mina Stöhr[1], •Elias Koch[2], Julien Javaloyes[3], Svetlana Gurevich[2,4], and Matthias Wolfrum[1] — [1]Weierstrass Institute, Mohrenstrasse 39, 10117 Berlin, Germany — [2]Institute for Theoretical Physics, University of Münster, Wilhelm-Klemm-Str. 9, 48149 Münster, Germany — [3]Departament de Física & IAC-3, Universitat de les Illes Balears, C/ Valldemossa km 7.5, 07122 Mallorca, Spain — [4]Center for Nonlinear Science (CeNoS), University of Münster, Corrensstrasse 2, 48149 Münster, Germany

We study theoretically the mechanisms of square wave formation in an injected vertically emitting micro-cavity, containing a nonlinear Kerr medium and subjected to strong time-delayed optical feedback. We show that for large delays, square wave solutions of the time-delayed system can be treated as relative homoclinic solutions of an advanced argument equation. This allows the use of classical homoclinic bifurcation theory to study different types of square wave solutions. In particular, we unveil the mechanisms behind the collapsed snaking scenario of square waves and explain the formation of complex-shaped multistable square wave solutions through a Bykov T-point. Finally, we relate the position of the T-point to the position of the Maxwell point in the original time-delayed system.

DY 33.12 Wed 15:00 Poster C

Dynamics and bifurcation analysis of active mode-locked semiconductor lasers — •Elias Koch[1], Svetlana Gurevich[1,3], and Julien Javaloyes[2] — [1]Institute for Theoretical Physics, University of Münster, Wilhelm-Klemm-Str. 9, 48149 Münster, Germany — [2]Departament de Física, Universitat de les Illes Balears & IAC-3, Cra. de Valldemossa, km 7.5, E-07122 Palma de Mallorca, Spain — [3]Center for Nonlinear Science (CeNoS), University of Münster, Corrensstraße 2, 48149 Münster, Germany

We study theoretically the dynamics and bifurcations of an actively mode-locked laser by employing a delay differential equation model. This allows us to consider regimes of high gain and losses typical of semiconductor lasers. Using a combination of numerical path continuation and direct numerical simulation we find that the solution branches corresponding to higher order Hermite-Gauss modes in a modulated potential can interact leading to a complex scenario. By performing a multiple time-scale analysis close to the lasing threshold, we derive a Haus master equation which shows a good agreement with the original time-delayed model. Finally, we study the regime of multiple pulses in a cavity. There, we identify different dynamical regimes and the underlying bifurcation structure, discovering a global bifurcation scenario.

DY 33.13 Wed 15:00 Poster C

Chaotic Diffusion in Delay Systems: Transition to Anomalous Diffusion and Weak Ergodicity Breaking by Time Lag Modulation — •Tony Albers[1], Lukas Hille[1], David Müller-Bender[1], and Günter Radons[1,2] — [1]Institute of Physics, Chemnitz University of Technology, Chemnitz, Germany — [2]Institute for Mechanical and Industrial Engineering, Chemnitz, Germany

In this contribution, we show that in a typical class of time-delayed systems with linear instantaneous and nonlinear delayed term a transition from normal diffusion to anomalous diffusion and weak ergodicity breaking can be induced by a modulation of the delay time. This change is related to a transition from turbulent chaos to laminar chaos [1] and reveals a new kind of dynamical behavior consisting of a coexistence of turbulent and laminar phases alternating within one single time series. We investigate this transition in detail and its influence on the diffusive and ergodic properties of the system and the related occurrence of infinite densities. We show that some of the observed features in the system can be explained by low-dimensional iterated maps and appropriate stochastic models.

[1] David Müller, Andreas Otto, and Günter Radons, Phys. Rev. Lett. **120**, 084102 (2018)

DY 33.14 Wed 15:00 Poster C

Dynamic patterns in active particles with delayed all-to-all attractions — •Pin-Chuan Chen[1], Klaus Kroy[1], and Viktor Holubec[2] — [1]Institute for Theoretical Physics, Universität Leipzig - 04103 Leipzig, Germany — [2]Department of Macromolecular Physics, Faculty of Mathematics and Physics, Charles University 18000 Prague, Czech Republic

Time delayed effective interactions are ubiquitous in coarse-grained models of complex systems. Using Brownian dynamics simulations, we study a collection of active particles attracting each other with a time delay. In two dimensions, we find patterns similar to those reported previously [1,2] for a delayed attraction to a common center. For long delays, a more symmetric configuration arises. In three dimensions, the situation is somewhat similar, but due to the extra degree of freedom, the phenomenology is much richer. Beyond rotating crystallites, shear bands and co-orbiting satellites, conveyor belts with shapes of a tennis ball seam appear.

[1] Wang, X., Chen, P. C., Kroy, K., Holubec, V., & Cichos, F. (2023). Spontaneous vortex formation by microswimmers with retarded attractions. Nature Communications, 14(1), 56.

[2] Chen, P. C., Kroy, K. D., Cichos, F., Wang, X., & Holubec, V. (2023). Active particles with delayed attractions form quaking crystallites. Europhysics Letters.

DY 33.15 Wed 15:00 Poster C

The route to mesoscale turbulence in a model of active fluids — •Henning Reinken[1,2], Sebastian Heidenreich[3], Markus Bär[3], and Sabine H. L. Klapp[2] — [1]Otto-von-Guericke-Universität Magdeburg, Universitätsplatz 2, 39106 Magdeburg, Germany — [2]Technische Universität Berlin, Straße des 17. Juni 135, 10623, Berlin, Germany — [3]Physikalisch-Technische Bundesanstalt Braunschweig und Berlin, Abbestr. 2-12, 10587 Berlin, Germany

Suspensions of microswimmers are a paradigmatic example of active fluids and are known to develop mesoscale turbulence, a state of dynamic vortex structures characterized by the presence of a characteristic length scale. Here, we employ a minimal model for the effective microswimmer velocity field [1,2] to explore how the turbulent state develops from regular, stationary vortex patterns when the strength of nonlinear advection is increased. To this end, we perform an extended stability analysis and uncover a linear instability, which follows from the mutual excitement and simultaneous growth of multiple perturbative modes. The extended analysis allows us to calculate a critical advection strength signifying the onset of mesoscale turbulence in the active fluid model, in very good agreement with numerical results. By this we establish an analogy to a critical Reynolds number in driven flow exhibiting inertial turbulence.

[1] Wensink, Dunkel, Heidenreich, Drescher, Goldstein, Löwen, Yeomans, Proc. Natl. Acad. Sci. U.S.A. **109**, 14308 (2012)

[2] Reinken, Klapp, Bär, Heidenreich, Phys. Rev. E **97**, 022613 (2018)

DY 33.16 Wed 15:00 Poster C

Towards bacterial growth laws for shape-conserving cell wall growth: a linear stability analysis — •Paul Nemec and Ulrich Gerland — Physics Department, Technical University of Munich

Inspired by the question of how bacteria maintain their shapes during growth, we study how pressurised elastic shells may grow robustly. Specifically, we ask how cell envelope growth could depend on local observables like curvature or stress, such that perturbed spherical or spherocylindrical cells recover their shape. Within a simplistic continuum model of a growing elastic shell, general requirements like locality, isotropy and material-frame indifference provide strong constraints on local growth laws. By linearising around a growing and pressurised reference trajectory, we obtain linear stability results for different ways that growth may couple to local observables. By requiring that growth depends on local observables isotropically, the space of possible linear couplings dramatically reduces. For a sphere, we are left with a six-dimensional space of couplings, which we investigate to find that naive isotropic growth is generally unstable, but can be stabilised by additional coupling.

DY 33.17 Wed 15:00 Poster C

Experimental study of stress in force chains in granular matter — •Lukas Reiter[1], Amelie Mayländer[1], Raphael Blumenfeld[3], Clara Wanjura[2], and Othmar Marti[1] — [1]Institute of Experimental Physics, Ulm University, D-89069 Ulm — [2]Max Planck Institute for the Science of Light, Staudststr. 7, D-91058 Erlangen — [3]Gonville & Caius College, University of Cambridge, Trinity St., Cambridge CB2 1TA, UK

The properties of dense granular media are largely determined by the contact forces between particles. Experimentally, these forces become visible as interference patterns in photo-elastic particles, but, so far, their quantitative analysis from experimental data has been challenging. Using a dark field polariscope, we explore the stress dynamics of a sheared, two-dimensional granular system of photo-elastic discs forming a self-organizing many-particle contact network and observe the formation of force chains. We use a convolutional neural network (CNN) approach based on [1] to analyse the interference fringes arising in the photo-elastic particles due to strain. We train and compare different pre-trained state-of-the-art CNN models on synthetically generated 2D images of particles. The CNNs provide quantitative information on the number of forces, their magnitudes and angles at which the forces are applied.

[1] R. Sergazinov, M. Kramár. Mach. Learn.: Sci. Technol. 2 045030 (2021).