DY 31: Nonlinear Dynamics, Synchronization and Chaos

Time: Wednesday 10:00–13:15 Location: H20

DY 31.1 Wed 10:00 H20

Scale-dependent Error Growth in Multi-hierarchical Systems — •Jonathan Brisch and Holger Kantz — Max-Planck-Institut für Physik komplexer Systeme, Dresden, Deutschland

Scale-dependent error growth rates can been found, e.g., in two-dimensional turbulence and global weather forecasting models. Both models mentioned admit turbulence and exhibit dynamics on different time and length scales. In this talk I will show that the latter fact is crucial to generate scale-dependent error growth. Thereby we gain insights into the dynamical mechanisms which might be responsible for the fact that real weather forecasts posses an intrinsic limit on forecast time, irrespective of the accuracy of input observations. For this, I introduce a toy-model with a hierarchical coupling between chaotic systems with different time and length scales. I will furthermore discuss the theoretical case of infinite hierarchies in the limit of vanishing perturbations in order to show that these systems have a finite range of predictability independent of the magnitude of the initial perturbation.

DY 31.2 Wed 10:15 H20

Separation of scales in a hierarchical heteroclinic network — •Maximilian Voit and Hildegard Meyer-Ortmanns — Jacobs University Bremen, Bremen, Germany

In the context of winnerless competition we consider a heteroclinic network with a structural hierarchy.[1] It contains two levels of cyclic competition. The lower level is realized by simple heteroclinic cycles between saddle equilibria. The higher level, on the other hand, consists of a heteroclinic cycle whose saddles are the lower level heteroclinic cycles. As a consequence, two different time scales emerge in this system. By a Poincaré map method we derive an analytic description of this dynamics. We thereby show how to predict the ratio between time scales depending on parameters and initial conditions.

[1] M. Voit and H. Meyer-Ortmanns (2018) to be pub. in EPJ ST

DY 31.3 Wed 10:30 H20

Memory induced slow-fast chaotic dynamics in a Chua circuit — •Tom Birkoben[1], Moritz Drangmeister[2], Finn Zahari[1], Serhiy Yanchuk[3], Philipp Hövel[4], and Hermann Kohlstedt[1] — [1]Nanoelektronik, Faculty of Engineering, Kiel University, Kiel, Germany — [2]Institute of Theoretical Physics, TU Berlin, Berlin, Germany — [3]Institute of Mathematics, TU Berlin, Berlin, Germany — [4]School of Mathematical Sciences, University College Cork, Cork, Ireland

Chaotic signatures have been observed in a wide range of different nonlinear systems. Besides the famous Lorenz-equations, which resemble atmospheric convections, the Chua circuit is another prominent representative of chaotic systems. This nonlinear electrical circuit consists of three energy-storing passive elements and a locally active resistor. The circuit allows the experimental study of chaotic phenomena within a mathematically well-described and dynamically rich environment. Here we present experimental and theoretical results on the Chua circuit compromising a memristive double barrier device. The device consists of Nb/Al/Al2O3/NbxOy/Au layers, is forming free and has a typical Roff/Ron ratio of about 100 at 0.7 V. The memory element changes the dynamics of the original system and induces transient suppressions of the intrinsic chaotic oscillations. The analysis of the extended system reveals overall slow-fast oscillations and their cause in the varying memristance.

DY 31.4 Wed 10:45 H20

Application of Machine Learning Methods to Problems in Transition State Theory — •Tobias Mielich and Jörg Main — Institut für Theoretische Physik 1, Universität Stuttgart, Germany

Machine learning algorithms are getting increasingly more popular across various fields of science. Their usage in solving physics problems has already shown them to be an effective tool to assist classical algorithms and solutions [1]. This talk aims to show different approaches of using artificial neural networks to aid in rate calculations of chemical reactions in driven systems in the realm of transition state theory. The networks can be used to approximate functions like the time-dependent dividing surface, the times when trajectories cross that surface, or even the potential parameter dependent reaction rate itself. It is important to use the correct approach during training to get optimal results. Techniques like cyclic learning rates and network ensemble predictions shall be discussed.

[1] P. Schraft et al., Phys. Rev. E 97, 042309 (2018)

DY 31.5 Wed 11:00 H20

Harmonic Oscillator Interacting with Random Ising Spins — •Paul Zech and Günter Radons — Institute of Physics, Chemnitz University of Technology, D-09107 Chemnitz, Germany

Hysteresis phenomena can be found in very different research fields, such as magnetic materials, porous materials, shape memory alloys, etc. One of the most prominent model of hysteresis is the zero-temperature Random Field Ising Model (RFIM). While the hysteretic behavior of the RFIM has been investigated in detail, not much is known about scenarios which arise if the RFIM is coupled dynamically to its environment, especially as the number of spins goes to infinity (thermodynamic limit). In this talk, we want to investigate the dynamical properties of a harmonic oscillator coupled to Ising spins in quenched random local fields. By applying established methods of dynamical systems and piecewise-smooth system theory to this hybrid system we show, how chaos emerges for two different spin set-ups. We first treat independent spins and secondly we introduce hysteretic behavior by a pairwise coupling of the spins, which results in an ensemble of spin dimers. We will show, that the approach to the thermodynamic limit results in an asymptotic nonlinearity in form of a error function and a hysteretic play operator, respectively. For an increasing number of spins we will also demonstrate, that the fractal dimensions of the chaotic attractors of the piecewise-smooth system approach those of the system in the thermodynamic limit and that both fractal dimensions are self-averaging quantities, in contrast to the time-averaged magnetization.

DY 31.6 Wed 11:15 H20

Resonant Doppler effect from delayed feedback leads to multistability and generalized laminar chaos — •Andreas Otto, David Müller, and Günter Radons — Institute of Physics, Chemnitz University of Technology, 09107 Chemnitz, Germany

Delayed feedback or aftereffects can be found in many dynamical systems ranging, for example, from population dynamics to metal cutting. We show that the effect of a delay variation in such time delay systems is similar to the Doppler effect with self-feedback. We distinguish between the non-resonant and the resonant Doppler effect corresponding to the known dichotomy between conservative and dissipative delays [1]. The non-resonant Doppler effect leads to a quasiperiodic frequency modulation of the signal but the qualitative properties of the solution are the same as for constant delay systems.

In contrast, for the resonant Doppler effect the solutions are characterized by alternating low and high frequency phases. For large delays these phases are clearly separated, which is equivalent to time-multiplexed dynamics. This allows the design of well-defined multistable solutions or periodic temporal switching between different chaotic and periodic dynamics. We systematically study such kind of dynamics and present the most interesting examples. Finally, we show that the recently found laminar chaos [2] is only the zeroth-order case of a bigger class of chaos, which we call generalized laminar chaos.

[1] Otto, Müller, and Radons, Phys. Rev. Lett. 118, 044104 (2017).
[2] Müller, Otto, and Radons, Phys. Rev. Lett. 120, 084102 (2018).

15 min. break

DY 31.7 Wed 11:45 H20

Temperature dependence of butterfly effect in a classical many-body system — •Thomas Bilitewski[1], Subhro Bhattacharjee[2], and Roderich Moessner[1] — [1]Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Str. 38, 01187 Dresden, Germany — [2]International Centre for Theoretical Sciences, Tata Institute of Fundamental Research, Bengaluru 560089, India

We study the chaotic dynamics in a classical many-body system of interacting spins on the kagome lattice. We characterise many-body chaos via the butterfly effect as captured by an appropriate out-of-time-ordered correlator. Due to the emergence of a spin liquid phase, the chaotic dynamics extends all the way to zero temperature. We thus determine the full temperature dependence of two complementary aspects of the butterfly effect: the Lyapunov exponent, μ, and the butterfly speed, v_b, and study their interrelations with usual measures of spin dynamics such as the spin-diffusion constant, D and spin-autocorrelation time, τ. We find that they all exhibit power law behaviour at low temperature, consistent with scaling of the form $D \sim v_b^2/\mu$ and $\tau \sim T^{-1}$. The vanishing of $\mu \sim T^{0.48}$ is parametrically slower than that of the corresponding quantum bound, $\mu \sim T$, raising interesting questions regarding the semi-classical limit of such spin systems.

DY 31.8 Wed 12:00 H20

Bifurcation scenarios in ensembles of two-dimensional excitatory units with global repulsive coupling — •Robert Ronge and Michael Zaks — Humboldt-Universität zu Berlin

We study systems of identical two-dimensional models of neurons with repulsive all-to-all coupling, focusing on the active rotator model with adaptation and the Morris-Lecar model. Parameters are chosen such that for the decoupled case each neuron is at rest, close to the border of class I excitability. Under the action of sufficiently strong repulsion, the collective equilibrium loses stability and is replaced by different form of oscillations. Two main type are oscillations in clusters and the state in which the neurons spike one-by-one in turn. We investigate transitions between these two regimes.

DY 31.9 Wed 12:15 H20

Synchronization of excitable oscillators by matrix-mediated viscoelastic coupling — •Florian Spreckelsen[1,2], Stefan Luther[1,2,3,4,5], and Ulrich Parlitz[1,2,4] — [1]Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany — [2]University of Göttingen, Institute for Nonlinear Dynamics, Göttingen, Germany — [3]University Medical Center Göttingen (UMG), Institute of Pharmacology and Toxicology, Göttingen, Germany — [4]DZHK (German Center for Cardiovascular Research), Partner Site Göttingen, Germany — [5]Department of Physics and Department of Bioengineering, Northeastern University, Boston, USA

Individually contracting cardiomyocytes mechanically linked by an extracellular matrix belong to the class of viscoelastically coupled excitable oscillators. They exhibit an interesting range of synchronization patterns due to the interplay of autonomous oscillation and refractory period following an excitation, together with the delay introduced by the viscoelaticity. We study numerically the synchronization patterns occuring in mechanically coupled excitable oscillators depending on the viscoelastic properties of the coupling matrix.

DY 31.10 Wed 12:30 H20

Divergence of predictive model output as indication of phase transitions — •Frank Schäfer and Niels Lörch — Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland

We introduce a new method to identify phase boundaries in physical systems. It is based on training a predictive model such as a neural network to infer a physical system's parameters from its state. The deviation of the inferred parameters from the underlying correct parameters will be most susceptible and diverge maximally in the vicinity of phase boundaries. Therefore, peaks in the divergence of the model's predictions are used as indication of phase transitions. Our method is applicable for phase diagrams of arbitrary dimension and without prior information about the phases. Application to both the two-dimensional Ising model and the dissipative Kuramoto-Hopf model show promising results.

DY 31.11 Wed 12:45 H20

Correlations and hyperuniformity in the avalanche size of the Oslo model — •Rosalba Garcia-Millan[1], Gunnar Pruessner[1], Luke Pickering[2], and Kim Christensen[2] — [1]Department of Mathematics, Imperial College London - London SW7 2AZ, UK — [2]Department of Physics, Blackett Laboratory, Imperial College London - London SW7 2AZ, UK

Certain random processes display anticorrelations resulting in local Poisson-like disorder and global order, where correlations suppress fluctuations. Such processes are called hyperuniform. Using a map to an interface picture we show via analytic calculations that a sequence of avalanche sizes of the Oslo model is hyperuniform in the temporal domain with the minimal exponent $\lambda = 0$. We identify the conserved quantity in the interface picture that gives rise to the hyperuniformity in the avalanche size. We further discuss the fluctuations of the avalanche size in two variants of the Oslo model. We support our findings with numerical results.

DY 31.12 Wed 13:00 H20

Field-theoretic approach to the universality of branching processes — •Johannes Pausch, Rosalba Garcia-Millan, Benjamin Walter, and Gunnar Pruessner — Department of Mathematics, Imperial College London, UK

Branching processes are widely used to model phenomena from networks to neuronal avalanching. In a large class of continuous-time branching processes, we study the temporal scaling of the moments of the instant population size, the survival probability, expected avalanche duration, the so-called avalanche shape, the n-point correlation function and the probability density function of the total avalanche size. Previous studies have shown universality in certain observables of branching processes using probabilistic arguments, however, a comprehensive description is lacking. We derive the field theory that describes the process and demonstrate how to use it to calculate the relevant observables and their scaling to leading order in time, revealing the universality of the moments of the population size. Our results explain why the first and second moment of the offspring distribution are sufficient to fully characterise the process in the vicinity of criticality, regardless of the underlying offspring distribution. This finding implies that branching processes are universal. We illustrate our analytical results with computer simulations.