DY 30: Poster - Complex nonlinear systems

Time: Tuesday 18:15–21:00 Location: Poster C

DY 30.1 Tue 18:15 Poster C

A stochastic individual-based model of the progression of atrial fibrillation — Eugene Chang[1], •Yen Ting Lin[2], Tobias Galla[2], Richard Clayton[1], and Julie Eatock[3] — [1]The University of Sheffield, Sheffield, UK — [2]The University of Manchester, Manchester, UK — [3]Brunel University London, Uxbridge, Middlesex, UK

Atrial fibrillation (AF) is one of the most common rhythm disorders in the heart, and it progresses through several stages. While mechanistic models of AF exist at cellular level, there is no systematic framework with which to connect these to population-level models of AF progression. In this work we propose a stochastic individual-based model of the progression of AF. The outputs of the model are times when the patient is in normal rhythm and AF. We carry out a population-level analysis of the statistics of disease progression. While the model is stylised at present and not directly predictive, future improvements are proposed to tighten the gap between existing mechanistic models of AF, and epidemiological data, with a view towards model-based personalised medicine.

DY 30.2 Tue 18:15 Poster C

From Number Theory to dynamics of ac+dc driven Frenkel-Kontorova model — •Jovan Odavic — Aachen University

The Frenkel - Kontorova (FK) model is widely used to describe systems where competition between length scales determines the ground state energy. Dissipative FK model has been often used as one of the most suitable models for description of different kinds of phenomena in many fields of physics, such as charge or spin density wave systems, vortex lattices, Josephson-junction arrays biased by external currents and in recent years even superconducting nanowires. Main feature of the model is the appearance of a step-like (or staircase) behaviour in the response function which are due to dynamical mode-locking (synchronization) of the internal frequency with the applied external one. We will explore these step-like features and their connection to some number theory results.

Key reference: - J. Odavic, P. Mali, J. Tekic, Farey sequence in the appearance of subharmonic Shapiro steps, Phys. Rev. E 91, 052904 - J. Odavic, P. Mali, J. Tekic, M. Pantic, M. Pavkov Hrvojevic, Application of largest Lyapunov exponent analysis on the studies of dynamics under external forces, pre-print: http://arxiv.org/abs/1510.07267

DY 30.3 Tue 18:15 Poster C

Frustrated magnetic clutches – do they really work? — •Simeon Völkel and Ingo Rehberg — Experimentalphysik V, Universität Bayreuth, 95440 Bayreuth, Germany

It has been proposed to construct new types of couplings and gears based on the interaction of magnetic multipoles. These couplings exploit a continuous degenerate ground state for the chosen arrangement of the multipoles.[1]

We study experimentally the structural stability of the most basic realization of such a coupling consisting in two magnetic dipoles, where each of them is mounted perpendicularly to its dipole moment on a shaft that allows for rotation around this fixed axis. While the first magnet is driven by a motor, the second magnet rotates freely. Depending on the relative arrangement, co-rotating, counterrotating and chaotic regimes are found.

[1] Johannes Schönke, Smooth teeth: Why multipoles are perfect gears, to be published in Phys. Rev. Appl.

DY 30.4 Tue 18:15 Poster C

A novel measure to distinguish limit cycles and chaotic attractors — •Hendrik Wernecke, Bulcsú Sándor, and Claudius Gros — Institut für Theoretische Physik, Goethe-Universität Frankfurt am Main, Germany

In many dissipative dynamical systems exhibiting chaos there are parameter regions, where it is hard to distinguish between regular and chaotic motion. Then the attractors do not 'fill-up' the phase space, but the motion is bound to narrow areas. Furthermore, the maximum Lyapunov exponent can become arbitrary small in these regions, so that the standard classification can be difficult to interpret.

In the present work we describe a novel method that is able to draw a discrete distinction between limit cycles and chaotic attractors. Therefore we use the long-term distance between two trajectories starting close-by in the vicinity of the attractor and how this distance scales with the initial distance of trajectories. For the regular motion of a limit cycle one finds a linear scaling, while for the chaotic attractor the long-term distance is only correlated to the size of the attractor and therefore constant.

Furthermore, we propose a new classification of chaotic states in dissipative systems. We introduce the term 'weak dissipative chaos' for those chaotic attractors that can be distinguished from others by there topology. This classification is also indicated by the order of magnitude of the maximum Lyapunov exponent.

DY 30.5 Tue 18:15 Poster C

Nonlinear waves in biological membranes — •Julian Kappler and Roland R. Netz — Institut für Theoretische Physik, Freie Universität Berlin, 14195 Berlin, Germany

We present a theory for nonlinear waves in biological membranes. We compare predictions of this theory to recent measurements and find that our model is able to reproduce key experimental features, such as an abrupt increase in both range and velocity as the external driving amplitude is increased.

DY 30.6 Tue 18:15 Poster C

Evolution of random Boolean networks by a hill-climbing process under selection for robust functioning — •Lara Becker, Isabella-Hilda Bodea, and Barbara Drossel — TU Darmstadt, Germany

Gene regulatory networks (GRNs) play a vital role in the control of cellular processes, including differentiation, the cell cycle and metabolism. Like other biological systems, they are subject to noise, which can manifest itself e.g. as thermodynamic fluctuations. In order to maintain their functioning under stochastic influences, GRNs need to be robust, i.e. they must tolerate perturbations that would otherwise impair their funcionality.

We use Boolean threshold networks as a simple model for GRNs and subject individual networks to an evolutionary process, accepting only those mutations that do not reduce the fitness of the network. The fitness is evaluated based on the ability to display a predetermined dynamical behavior in the presence of noise. Stochastic influences are implemented through random changes in the state of nodes. A mutation modifies either the connections or update functions. We examine the change in structural as well as dynamical properties of the networks during the evolutionary process in dependence of the model parameters, and we relate them to the developing functional robustness.

DY 30.7 Tue 18:15 Poster C

Evolution of a population of Boolean threshold networks for a targeted expression pattern — •Isabella-Hilda Bodea, Lara Becker, and Barbara Drossel — TU Darmstadt, Germany

We study the evolution of a population of Boolean threshold networks under selection for dynamical robustness of a predefined expression pattern to noise.

Random Boolean networks were introduced in 1969 by S. Kauffman as a simple model for gene regulatory networks. The nodes of these networks represent genes that can only be in two different states, “on” (expressed) or “off” (not expressed). In spite of their simplicity, Boolean models are able to reproduce the essential dynamical steps of real developmental processes, where the network switches from one expression pattern to another one. Such switching processes must function reliably in the presence of mutations and dynamical noise.

In order to investigate the evolution of such gene regulatory networks in the presence of noise, we introduce stochasticity by perturbing the states of randomly chosen nodes. The evolutionary process proceeds with discrete generations, where the fitter part of the population become the parents of the next generation. While mutations act on the genotype, i.e. the connections between the nodes and the update functions, selection is based on the phenotype, i.e. the dynamical behaviour of a network. We investigate the mutational and dynamical robustness of the population as a function of time for different noise levels and mutation rates, as well as the dynamical properties of the evolved networks.

DY 30.8 Tue 18:15 Poster C

Leaf-to-leaf distances in ordered Catalan tree graphs — Andrew M. Goldsborough, John M. Fellows, Matthew Bates, S. Alex Rautu, George Rowlands, and •Rudolf A. Römer — University of Warwick, Coventry, CV4 7AL, UK

We study the average leaf-to-leaf path lengths on ordered Catalan tree graphs with n nodes and show that these are equivalent to the average length of paths starting from the root node. We give an explicit analytic formula for the average leaf-to-leaf path length as a function of separation of the leaves and study its asymptotic properties. At the heart of our method is a strategy based on an abstract graph representation of generating functions which we hope can be useful also in other contexts.

DY 30.9 Tue 18:15 Poster C

Autonomous learning in networks of heterogeneous relaxation oscillators — •Enrico Fengler, Jan F. Totz, and Harald Engel — Institut für Theoretische Physik, TU-Berlin, Berlin

Recently, networks of coupled phase oscillators with intrinsic time-delayed feedback have been trained to exhibit a desired level of partial synchronization adjusting their adjacency matrix accordingly [1]. We extend this model in two directions. First, we replace a single by a multi-valued target state. Second, instead of adapting the connection weights between the links in one network, we introduce linking probabilities between two nodes and study the performance of an ensemble of networks. Finally, in numerical simulations with a modified ZBKE model [2], we analyze numerically synchronization patterns in a network of heterogeneous Belousov-Zhabotinsky chemical oscillators [3].

[1] P. Kaluza, A.S. Mikhailov, Autonomous learning by simple dynamical systems with delayed feedback, Phys. Rev. E 90(R), 030901 (2014). [2] A. M. Zhabotinsky, F. Buchholtz, A. B. Kiyatkin, and I. R. Epstein, Oscillations and waves in metal-ion-catalyzed bromate oscillating reactions in highly oxidized states, J. Phys. Chem. 97, 7578 (1993). [3] J. F. Totz, R. Snari, D. Yengi, M. R. Tinsley, H. Engel, and K. Showalter, Phase-lag synchronization in networks of coupled chemical oscillators, Phys. Rev. E 92, 022819 (2015).

DY 30.10 Tue 18:15 Poster C

Feedback control in evolutionary dynamics: controlling the coexistence state — •Jens Christian Claussen — Computational Systems Biology, Jacobs University Bremen

Evolutionary dynamics in the frameworks of Lotka-Volterra systems and replicator equations in evolutionary game theory can include fixed points and cycles which can be neutrally stable, repelling or attracting. Of particular interest is the case where a coexistence state loses stability due to non-zero-sum payoffs, corresponding to dissipative interactions. Here I introduce a general ansatz of feedback control where an additive control term is implemented in the payoff matrix which is chosen proportional to an observable of the system which is suitably chosen to reflect the distance from the fixed point. This feedback control is implemented for the Rock-Paper-Scissors system which has applications in biology and in socio-economic systems, and for which the loss of stability depending on payoffs and population size has been recently discussed [J. Claussen and A. Traulsen, PRL 100, 058104 (2008)]. As the discretization stochasticity in a finite population additionally destabilizes coexistence, here I discuss also an implementation by a pairwise comparison process to demonstrate that the control scheme is applicable in a finite population.

DY 30.11 Tue 18:15 Poster C

Reservoir computing simulated by using the Lang Kobayashi laser equations with time delayed feedback — •David Schicke, André Röhm, and Kathy Lüdge — Institut f. Theo. Physik, Sekr. EW 7-1, Technische Universität Berlin, Hardenbergstr. 36, 10623Berlin, Germany

Reservoir computing has the potential to outperform traditional van-Neumann architectures in terms of swiftness as well as accuracy. Traditionally achieved by a system consisting of about 200-1000 physical nodes which are connected to each other, reservoir computing can also be performed by a single node with time delayed self feedback. Physical nodes are simulated as virtual nodes along the delay line. To achieve different coupling strength between virtual nodes, the input also has to be masked. Two different non-linearities are compared, one being the Ikeda nonlinearity, already discussed in e.g. [1], [2] and the other the Lang Kobayashi differential equation describing laser dynamics with linewidth enhancement and optical feedback. Their computing capability will be tested with the NARMA10 task, their performance expressed by the normalized root mean square error.

[1] Larger, L. et al., Photonic information processing beyond turing: an optoelectronic implementation of reservoir computing, *Optics Express* **20**, 3241-3249 (2012).

[2] Hermans, M. et al., Photonic Delay Systems as Machine Learning Implementations, *arXiv:* 1501.02592v1 [cs.NE] (2015)

DY 30.12 Tue 18:15 Poster C

Optimal demand control in a decentralized smart grid — •Sabine Auer[1,2], Kirsten Kleis[3], Paul Schulzu[1,2], Frank Hellmann[1], Jobst Heitzig[1], and Jürgen Kurths[1,2,4,5] — [1]Potsdam Institute for Climate Impact Research, 14412 Potsdam, Germany — [2]Department of Physics, Humboldt University Berlin, 12489 Berlin, Germany — [3]Oldenburg University, Germany — [4]Institute of Complex Systems and Mathematical Biology, University of Aberdeen, Aberdeen AB24 3FX, UK — [5]Department of Control Theory, Nizhny Novgorod State University, 606950 Nizhny Novgorod, Russia

The questions to what extent increasing shares in variable renewable energy sources influence power grid stability and whether additional costs will accrue at power markets are subject to a controversial public debate. Due to the broad scope of these questions, we show how conceptional models are built to test for the necessary model features for such a power system. To investigate grid stability, we test for the necessary model details for power grids [1] and the corresponding resilience measures. As a concept of cost efficient power balancing, we propose the optimal control of distributed generators and consumers based on a novel decentral smart grid approach [2]. Attempts how to incorporate market dynamics into such power grid models will be discussed [3, 4].

[1] S. Auer et al. arXiv:1510.05640 (2015). Submitted to EPJ. [2] B. Schäfer et al. arXiv:1508.02217 (2015). Submitted to EPJ. [3] M. Mureddu et al. Green power grids (2015). arXiv:1503.02957. [4] AH Mohsenian-Rad et al., IEEE Transactions on 1.2 (2010).

DY 30.13 Tue 18:15 Poster C

Dynamical Systems Based Modeling — •Bastian Seifert and Christian Uhl — University of Applied Sciences, Ansbach, Germany

Most approaches to the analysis of multi-variate time-series either reduce the dimensionality of the embedding or try to recognize the underlying dynamics. We present with Dynamical Systems Based Modeling an approach, which does both simultaneously. Consider a multivariate time-series q, which is subject to dynamics described by a (unknown) set of ordinary differential-equations

$$\dot{x_i} = d_i(x_1, \ldots, x_N),$$

with d_i a set of e.g. polynomial functions. We show how to define a cost-function, whose global minimum yields a low-dimensional embedding of the signal q and the corresponding dynamics in form of the coefficients for the differential equation d_i.

DY 30.14 Tue 18:15 Poster C

Survivability: How Dangerous Transients Affect the Stability of Dynamical Systems — •Paul Schultz[1,2], Frank Hellmann[1], Carsten Grabow[1], Jobst Heitzig[1], and Jürgen Kurths[1,2,3,4] — [1]Potsdam Institute for Climate Impact Research, P.O. Box 60 12 03, 14412 Potsdam, Germany — [2]Department of Physics, Humboldt University of Berlin, Newtonstr. 15, 12489 Berlin, Germany — [3]nstitute for Complex Systems and Mathematical Biology, University of Aberdeen, Aberdeen AB24 3UE, United Kingdom — [4]Department of Control Theory, Nizhny Novgorod State University, Gagarin Avenue 23, 606950 Nizhny Novgorod, Russia

The notion of a part of phase space containing desired/allowed states of a dynamical system is important in a wide range of complex systems research. It has been called safe operating space, viability kernel or sunny region. Here we define *survivability*: Given a random initial condition, what is the likelihood that the transient behaviour of a deterministic system leaves the region of desirable states? In conceptual examples we show that this basic measure captures notions of fundamental for interest various systems, e.g. climate models or power grids. We also derive a semi-analytic lower bound for the survivability of linear systems with polygonal safe operating space. We then apply the concept in the case the power grid model in realistic operating regimes to assess our analytic bound. Here, the kind of stability measured by survivability is of great practical interest. Furthermore, it is not captured by stability measures based on asymptotic trajectories.

DY 30.15 Tue 18:15 Poster C

Application of reduced-order model based on cluster analysis in numerical simulation of low permeability reservoir — •Weiwei Li[1,2], Yanyu Zhang[1], and Jianghai Lv[3] — [1]Saarland University, Experimental Physics, D-66041 Saarbrücken, Germany — [2]College of Petroleum Engineering, China University of Petroleum, 266580, Qingdao, China — [3]PetroChina ChangQing Oilfield Company Oil Production No.5, 710200, Xi'an, China

A mathematical model for a two dimensional reservoir considering the influence of start-up pressure gradients is solved based on a fully implicit finite difference scheme. The reduced-order model is established by projecting the original model on the low dimension which is formed by the basis function produced from the collected snapshots. The Lloyd algorithm for centroidal Voronoi tessellation is employed for cluster analysis to tackle the potential shortcomings from collecting snapshots with same time intervals. The computational results show that the used reduced-order model based on proper orthogonal decomposition is able to effectively approximate the results of the original model. With the help of the cluster analysis, data reduction is achieved on one hand, which could create uniform snapshots in space resulting to the enhanced accuracy of reduce-order model. On the other hand, extremely limited clustering groups might lead to loss of information and thus impairing the accuracy of the final reduced-order model.

DY 30.16 Tue 18:15 Poster C

Chimera states in chemical relaxation oscillators — •Julian Rode, Jan Totz, and Harald Engel — Technische Universität Berlin, Berlin

A system of identical oscillators with an identical coupling can differentiate in a synchronized and a desynchronized part, the so called chimera state [1]. Experiments on various chemical and physical systems have confirmed its existence [2]. We study the simplest scenario first: Ideal phase oscillators on a ring network. Inspired by real world oscillators like nerve cells, we take one further step and numerically explore chimera states on relaxation oscillators, which we compare with our experimental findings.

[1] Y. Kuramoto and D. Battogtokh, "Coexistence of coherence and incoherence in nonlocally coupled phase oscillators," Nonlin. Phenom. in Complex Syst. 5, 380 (2002)

[2] M. R. Tinsley, S. Nkomo, and K. Showalte, "Chimera and phase-cluster states in populations of coupled chemical oscillators." Nat. Phys. 8, 662 (2012) ; A. M. Hagerstrom et al. "Experimental observation of chimeras in coupled-map lattices." Nat. Phys. 8, 658 (2012)