DY 20: Data analytics for dynamical systems I (Focus Session joint with DY and BP) (joint session SOE/DY/CPP/BP)

Data analytics is often focussed on (generalized) regression to create models of the structure of complex systems. Here we focus on data-driven approaches of data analytics for complex systems that take into account their intrinsic nonlinear dynamics. Applications to natural and human-made systems, from cardiac dynamics to human mobility, illustrate recent progress and current methodological challenges. (Session organized by Marc Timme)

Time: Tuesday 9:30–13:15 Location: GÖR 226

Topical Talk DY 20.1 Tue 9:30 GÖR 226

One model to rule them all — •Jens Timmer — Institute of Physics, University of Freiburg, Germany

A major goal in systems biology is to reveal potential drug targets for cancer therapy. A common property of cancer cells is the alteration of signaling pathways triggering cell-fate decisions resulting in uncontrolled proliferation and tumor growth. However, addressing cancer-specific alterations experimentally by investigating each node in the signaling network one after the other is difficult or even not possible at all. Here, we use quantitative time-resolved data from different cell lines for non-linear modeling under L1 regularization, which is capable of detecting cell-type specific parameters. To adapt the least-squares numerical optimization routine to L1 regularization, subgradient strategies as well as truncation of proposed optimization steps were implemented. Likelihood-ratio tests were used to determine the optimal penalization strength resulting in a sparse solution in terms of a minimal number of cell-type specific parameters that is in agreement with the data. The uniqueness of the solution is investigated using the profile likelihood. Based on the minimal set of cell-type specific parameters experiments were designed for improving identifiability and to validate the model. The approach constitutes a general method to infer an overarching model with a minimum number of individual parameters for the particular models.

DY 20.2 Tue 10:00 GÖR 226

Volatility and Fractionality in Power-Grid Frequency — •Leonardo Rydin Gorjão[1,2], Anton Yurchenko-Tytarenko[3], and Dirk Witthaut[1,2] — [1]Forschungszentrum Jülich, Institute for Energy and Climate Research - Systems Analysis and Technology Evaluation (IEK-STE), 52428 Jülich, Germany — [2]Institute for Theoretical Physics, University of Cologne, 50937 Köln, Germany — [3]Department of Mathematics, University of Oslo, P.O. Box 1053 Blindern, N-0316 Oslo

Power-grid frequency is a key indicator of stability in power grids. The trajectory of power-grid frequency embodies several processes of different natures: the control systems enforcing stability, the trade markets, production and demand, and the correlations between these. In this article, we study power-grid frequency from Central Europe, the United Kingdom, and Scandinavia under the umbrella of fractional stochastic processes. We introduce an estimator of the Hurst index for fractional Ornstein–Uhlenbeck processes. We show that power-grid frequency exhibits time-dependent volatility, driven by daily human activity and yearly seasonal cycles. Seasonality is consistently observable in smaller power grids, affecting the correlations in the stochastic noise. The United Kingdom displays daily rhythms of varying volatility, where the noise amplitude consistently doubles its intensity, and displays bi- and tri-modal distributions. Both the Scandinavian and United Kingdom power-grids exhibit varying Hurst indices over yearly scales. All the power grids display highly persistent noise, with Hurst indices above $H > 0.5$.

Topical Talk DY 20.3 Tue 10:15 GÖR 226

Gaming the system - Analyzing Uber price data reveals anomalous supply shortages — •Malte Schröder[1], David Storch[1], Philip Marszal[1], and Marc Timme[1,2] — [1]Chair for Network Dynamics, Institute for Theoretical Physics and Center for Advancing Electronics Dresden (cfaed), TU Dresden — [2]Lakeside Labs, Klagenfurt

Dynamic pricing schemes are ubiquitously employed across industries to balance demand and supply. One well-known example is the ride-hailing platform Uber and their *surge pricing* intended to incentivize drivers to offer their service during times of high demand. However, recent reports [WJLA, Uber, Lyft drivers manipulate fares at Reagan National causing artificial price surges (2019)][Möhlmann and Zalmanson, ICIS 2017 Seoul (2017)] indicate that this surge pricing may instead cause demand-supply imbalances by incentivizing drivers to switch off their app to increase their revenue. Analyzing price estimate time series for trips from 137 locations in 59 urban areas across six continents, we identify locations with strong, repeated price surges. Correlations with demand patterns demonstrate that the observed price surges are indeed driven by supply anomalies instead of demand fluctuations. Moreover, we capture the minimal incentives driving the supply dynamics in a simple game-theoretic model, illustrating that such incentives constitute generic consequences of dynamic pricing schemes.

DY 20.4 Tue 10:45 GÖR 226

Estimation of Langevin equations with correlated noise for signals of complex systems — •Clemens Willers and Oliver Kamps — Institut für Theoretische Physik, Westfälische Wilhelms-Universität Münster, Germany

Over the last years, the estimation of stochastic evolution equations of complex systems has been applied in many scientific fields ranging from physics to biology and finance. Especially, Langevin models with delta-correlated noise terms, which realize a Markovian dynamic, have been used successfully in this context [1]. However, many real world data sets exhibit correlated noise and a non-Markovian dynamic, for example data sets from turbulence [2].

To tackle this problem, we use Langevin models containing an added hidden component which realizes a driving correlated noise. We develop two methods for the systematic estimation of the drift- and diffusion functions, parameterized through spline functions. The first method is based on a likelihood function which is constructed by a short-time propagator for the measured values of the visible component. For the second method, we use a comparison of transition probabilities via Jensen-Shannon divergence. Both methods are demonstrated using real world data sets as the turbulent air flow of a free jet [3], stock market prices [4] and wind energy production [5].

[1] Friedrich et al., Phys. Rep. 506, 87 (2011) [2] Friedrich et al., Phys. Rev. Lett. 78, 863 (1997) [3] Renner et al., J. Fluid Mech. 433, 383 (2001) [4] Nawroth et al., Eur. Phys. J. B 50, 147 (2006) [5] Kamps, in Wind Energy-Impact of Turbulence, Springer 2014, p. 67.

DY 20.5 Tue 11:00 GÖR 226

Hyper-Parameter Optimization for Identification of Dynamical Systems — •Tobias Wand[1], Alina Steinberg[1], Tim Kroll[2], and Oliver Kamps[2] — [1]Institut für Theoretische Physik, Universität Münster, Deutschland — [2]Center for Nonlinear Science, Universität Münster, Deutschland

In recent years, methods to identify dynamical systems from experimental or numerical data have been developed [1,2]. In this context, the construction of sparse models of dynamical systems has been in the focus of interest and has been applied to different problems. These data analysis methods work with hyper-parameters that have to be adjusted to improve the results of the identification procedure. If more than one hyper-parameter has to be fine-tuned, simple methods like grid search are computationally expensive and due to this, sometimes not feasible. In this talk, we will introduce different approaches to optimally select the hyper-parameters for the identification of sparse dynamical systems.

[1] Brunton et al. Proceedings of the National Academy of Sciences, 2016, 113, 3932-3937
[2] Mangan et al. Proceedings of the Royal Society A, 2017, 473, 20170009

Topical Talk DY 20.6 Tue 11:15 GÖR 226

Data driven modelling of spatio-temporal chaos in extended dynamical systems — •Ulrich Parlitz[1,2], Sebastian Herzog[1,3], Florentin Wörgötter[3], Roland S. Zimmermann[1,2], Jonas Isensee[1,2], and George Datseris[1] — [1]Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany — [2]Institut für Dynamik komplexer Systeme, Georg-August-Universität Göttingen, Germany — [3]Drittes Physikalische Institut, Georg-August-Universität Göttingen, Germany

Many spatially extended nonlinear systems, an example being excitable media, exhibit complex spatio-temporal dynamics. We shall present machine learning methods to predict the temporal evolution of these systems or estimate their full state from limited observations. The applied techniques include Reservoir Computing [1] and a combination of a Convolutional Autoencoder with a Conditional Random Field [2,3], whose perfomance will be compared to Nearest Neighbours Prediction based on dimension reduced local states [4]. Examples for demonstrating and evaluating the methods employed include the Lorenz-96 model, the Kuramoto-Sivashinsky equation, the Barkley model, and the Bueno-Orovio-Cherry-Fenton model, describing cardiac (arrhythmia) dynamics.

[1] R. S. Zimmermann and U. Parlitz, Chaos 28, 043118 (2018)
[2] S. Herzog et al., Front. Appl. Math. Stat. 4, 60 (2018)
[3] S. Herzog et al., Chaos (to appear) (2019)
[4] J. Isensee, G. Datseris, U. Parlitz, J. of Nonlinear Sci. (2019)

DY 20.7 Tue 11:45 GÖR 226

Predicting Spatio-Temporal Time Series Using Dimension Reduced Local States — •Jonas Isensee[1,2], George Datseris[1,2], and Ulrich Parlitz[1,2] — [1]Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany — [2]Institut für Dynamik komplexer Systeme, Georg-August Universität Göttingen, Germany

Understanding dynamics in spatially extended systems is central to describing many physical and biological systems that exhibit behaviour such as turbulence and wave propagation. Correctly predicting dynamics is advantageous in experimental settings and data-driven approaches are useful, particularly when no adequate mathematical models are available. We present an approach to iterated time series prediction of spatio-temporal dynamics based on local delay coordinate states and local modeling using nearest neighbour methods [1]. A crucial step in this process is to find predictive yet low-dimensional descriptions of the local dynamics . We discuss how imposing symmetries on the dynamics can be used to increase the predictiveness of our approach. The efficacy of this approach is shown for (noisy) data from a cubic Barkley model, the Bueno-Orovio-Cherry-Fenton model.

[1] J. Isensee, G. Datseris, U. Parlitz, J. of Nonlinear Sci. (2019)

Topical Talk DY 20.8 Tue 12:00 GÖR 226

Limits to predictability of complex systems dynamics — Jonathan Brisch and •Holger Kantz — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

Motivated by the challenges of weather forecasting and the well known fact that atmospheric dynamics takes place on many temporal and spatial scales, we discuss the possibility of scale dependent error growth and its consequences for predictions. In case that the growth rate of small errors depends on the error magnitude as an inverse power law, we can explain why forecasts of macroscopic observables can be successful on time scales which are orders of magnitude longer than the (estimated) Lyapunov time, and at the same time we find a strictly finite prediction horizon even for arbitrary accuracy of the initial condition. We propose a hierarchical model class, which is able to generate such an error growth behaviour, and finally we re-analyze published data of error-growth in a numerical weather forecast system to present evidence that the error growth rate there is indeed consistent with a power law with diverging growth rate for infinitesimal errors. It is plausible that the same mechanism is active in other complex phenomena which live on a variety of spatial and temporal scales.

DY 20.9 Tue 12:30 GÖR 226

Network inference from event sequences: Disentangling synchrony from serial dependency — •Reik Donner[1,2], Forough Hassanibesheli[2,3], Frederik Wolf[2,3], and Adrian Odenweller[4,5] — [1]Magdeburg-Stendal University of Applied Sciences, Magdeburg — [2]Potsdam Institute for Climate Impact Research — [3]Department of Physics, Humboldt University, Berlin — [4]Center for Earth System Research and Sustainability, University of Hamburg — [5]Max Planck Institute for Meteorology, Hamburg

Inferring coupling among interacting units or quantifying their synchronization based on the timing of discrete events has vast applications in neuroscience, climate, or economics. Here, we focus on two prominent concepts that have been widely used in the past - event synchronization (ES) and event coincidence analysis (ECA). Numerical performance studies for two different types of spreading processes on paradigmatic network architectures reveal that both methods are generally suitable for correctly identifying the unknown links. By further applying both concepts to spatiotemporal climate datasets, we demonstrate that unlike ECA, ES systematically underestimates linkages in the presence of temporal event clustering, which needs to be accounted for in network reconstruction from data. In turn, for spike train data from multi-channel EEG recordings (with relatively narrow inter-event time distributions), the obtained results are practically indistinguishable. Our findings allow deriving practical recommendations for suitable data preprocessing in the context of network inference and synchronization assessment from event data.

DY 20.10 Tue 12:45 GÖR 226

Reconstruction of nonlinear correlations and dynamical laws — Mirko Rossini, Konstantin Schmitz, and •Jürgen Stockburger — ICQ, Ulm University, Germany

Time series taken from a stationary process may feature dependencies far more subtle than linear correlations. We introduce a method based on non-linear feature extraction which can uncover and quantify such dependencies. Its utility is demonstrated using both synthetic and real-world data.

DY 20.11 Tue 13:00 GÖR 226

Collective Response of Reservoir Networks — •Arash Akrami, Fabio Schittler Neves, Xiaozhu Zhang, Malte Schröder, and Marc Timme — Chair for Network Dynamics, Institute for Theoretical Physics and Center for Advancing Electronics Dresden (cfaed), TU Dresden

Reservoir Computing constitutes a paradigm of bio-inspired machine learning relying on dynamical systems theory, that exploits high dimensionality of a large network of processing units (reservoir). However, as the collective dynamics of artificial neural networks is far from understood, their learning outcome is hardly predictable or transparent.

In Reservoir Computing systems, learning occurs exclusively in a read-out layer, with the intrinsic reservoir dynamics freely evolving.

Here we study reservoirs of processing units with linear activation functions, i.e., linear reservoirs and analytically predict the dynamic responses of all network units as a function of general, distributed and time-dependent input signals. These insights may help identifying nodes especially suitable for receiving input signals, and finding minimal reservoirs capable of performing a given task.