DY 48: Nonlinear Dynamics and Time-Delay Systems

Time: Thursday 9:30–11:00 Location: ZEU/0118

DY 48.1 Thu 9:30 ZEU/0118

From Case Counts to Contact Networks: Inferring Epidemic Coupling in Space and Time — •Adrian Pelcaru and Dirk Brockmann — Center Synergy of Systems (SynoSys), TUD Dresden University of Technology, Dresden, Germany

Inferring spatio-temporal transmission structure from incidence data alone is a central problem in epidemic modelling, with implications for real-time surveillance and for how we interpret mobility and contact information. We analyse discrete-time renewal SIRS models on a network of metapopulations that incorporate infection-age structure, seasonality, mobility between regions, and time-varying local contact rates. In the analysis, these ingredients are combined into an effective spatio-temporal contact kernel that quantifies how cases in region m at a given infection age contribute to new infections in region n one day ahead. Stacking multi-region incidence histories across lags into a delay-embedded state, the renewal dynamics define a map on this reconstructed space whose local Jacobian is the convolution operator determined by the contact kernel and the susceptibles. Aggregating the kernel over infection age with suitable weights yields a time-dependent effective contact matrix and associated effective distances that summarise how infections propagate between regions. This construction provides a transparent link between mechanistic assumptions about mobility and varying infection rates and the resulting effective couplings in space and time, and identifies a natural operator that can, in principle, be compared to reconstructions from incidence data to detect systematic deviations from mobility-based expectations.

DY 48.2 Thu 9:45 ZEU/0118

Beyond the Balance: A Minimal Model Unifying Regime Shifts, Long Transients, and Critical Transitions — •Misha Chai and Holger Kantz — Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Str. 38, D 01187, Germany

By the late 20th century, ecologists recognized that classical equilibrium views — nature is deterministic and always converges to a single, stable state — often fail to capture real-world dynamics. A nonequilibrium perspective emerged: ecological systems are frequently dominated by long transients that can persist over a super-long periods of time, with recurrent cyclic and chaotic behavior, until a sudden regime shifts changes the dynamics and transitions the system to an unpredictable new state.

However, models that integrate these key features — alternative stable states, stochastic drivers, long transients, and critical transitions — while also quantifying stability via resilience, remain rare.

We propose a minimal model that encapsulates these key properties of nonequilibrium ecology, while remaining amenable to theoretical analysis.

DY 48.3 Thu 10:00 ZEU/0118

Anticipated synchronization in systems with distributed delay — •David Ortiz, Tobias Galla, and Raúl Toral — Instituto de Física Interdisciplinar y Sistemas Complejos IFISC (CSIC-UIB), Campus UIB, 07122 Palma de Mallorca, Spain

Anticipated Synchronization (AS) describes counterintuitive situations in which a system synchronizes with the future state of another, even though the coupling between the systems is perfectly causal. Thus, the driven system 'forecasts' the driver. Common setups include two identical copies of a system, coupled with a fixed delayed interaction. AS has been reported in chaotic, excitable and spatially extended systems.

We extend AS to linear and nonlinear systems coupled with distributed delay. This models situations with uncertainty on the delay, or systems in which there are multiple distinct delay channels. The damped harmonic oscillator can be studied analytically, and shows stable AS provided the coupling strength and mean delay are not too large. We compute the anticipation time, and show that the driven system amplifies the oscillations in the driver. Our theoretical predictions are confirmed by numerical simulations. Numerically, we also investigate nonlinear chaotic and excitable systems. We confirm that AS can occur in the presence of distributed delay. Similar to the case of linear systems, we again find instances of signal enhancement.

DY 48.4 Thu 10:15 ZEU/0118

Dynamics of Temporal Localized States in an Injected Resonant Saturable Absorber Mirror — •Martin P. Szymiczek[1], Elias R. Koch[1], Julien Javaloyes[2], and Svetlana V. Gurevich[1,2,3] — [1]Institut für Theoretische Physik, Universität Münster — [2]Universitat de les Illes Balears, Palma — [3]Center for Data Science and Complexity, Universität Münster

We are interested in the dynamical behaviour of temporal localized states (TLS) and corresponding frequency combs in an injected microcavities subjected to a strong time-delayed feedback. A nonlinear optical system consist of a short injected microcavity with a thin slice of a saturable absorber, coupled to a long external cavity introducing a time delay and closed by a feedback mirror. We disclose sets of multistable bright TLSs coexisting on their respective bistable homogeneous backgrounds and show that they are mainly generated through the locking of domain walls leading to a collapsed snaking structure. The results provide insights into the control and design of emission in delay-coupled micro-resonator systems.

DY 48.5 Thu 10:30 ZEU/0118

FPGA-integrated analog simulations of time-delayed differential equations — •Matthias Hering[1], Julien Javaloyes[2], and Svetlana V. Gurevich[1,2,3] — [1]Institute of Theoretical Physics, Münster, Germany — [2]Departament de Física and IAC[3], Universitat de les Illes Balears, Spain — [3]Center for Data Science and Complexity, Münster, Germany

Real-world complex systems can be strongly influenced by time-delays due to unavoidable finite signal propagation speeds and time-delayed dynamical systems (TDSs) have proven to be a fertile framework for the modeling of nonlinear phenomena. However, they are difficult to study experimentally due to the need for precise delay elements. We present a hybrid implementation by integrating a digital feedback loop powered by an FPGA into an analog circuit to realize a damped harmonic oscillator with a piecewise nonlinear, delayed restoring force. Operating at 125 MS/s enables the FPGA to enable a clean reconstruction of the system*s dynamics up into the MHz regime without digital artifacts. The experiment not only reproduces the expected Turing bifurcation in the long delay limit, but also reveals the formation of robust localized states and square-waves patterns.

DY 48.6 Thu 10:45 ZEU/0118

Experimental realisation of thermalisation in a nonlinear non-Hermitian optical lattice — •Julia Görsch[1], Joshua Feis[1], Andrea Steinfurth[1], Sebastian Weidemann[1], Georgios G. Pyrialakos[2], Matthias Heinrich[1], Mercedeh Khajavikhan[2], Alexander Szameit[1], and Demetrios N. Christodoulides[2] — [1]Institute of Physics, University of Rostock, Rostock, Germany — [2]Ming Hsieh Department of Electrical and Computer Engineering, University of Southern California, Los Angeles, California, USA

Optical thermodynamics has emerged as an efficient framework for describing and predicting the dynamics of strongly multimode, nonlinear systems. Yet, in non-Hermitian settings, many of the theoretically predicted effects have remained experimentally unexplored. Here, we report the first experimental observation of thermalisation in a nonlinear, non-Hermitian optical lattice using a platform based on coupled optical fiber loops. This arrangement emulates light propagation in a one-dimensional lattice by coupling two fiber loops of unequal length via a beam splitter, thereby mapping pulse evolution onto a doubly discrete (1+1)D lattice. Within this system, we engineer a pseudo-Hermitian lattice whose non-Hermiticity arises from anisotropic nearest-neighbor coupling, implemented via a tunable beam-splitting ratio combined with amplitude modulation. Following excitation with a superposition of eigenmodes, the system undergoes a clear thermalisation process - despite its intrinsic non-Hermiticity - revealing a previously inaccessible regime of non-Hermitian optical thermodynamics and opening the door to further experimental investigations.