Weierstrass Institute for
Applied Analysis und Stochastics

Recent Trends in Coupled Network Systems

Book of Abstracts

January
12–13
2026

Berlin

Organizers

Christian Bick (Vrije Universiteit Amsterdam)
Tiago Pereira (ICMC São Carlos)
Matthias Wolfrum (WIAS Berlin)

For more information
and registration
please visit the
workshop website

wias-berlin.de

Beyond
TheEdge

Edited by
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1 General Information

Dear Participant,

Welcome to the Weierstrass Institute for Applied Analysis and Stochastics in Berlin! We hope you enjoy your stay both at the institute and in our city.
For your convenience, please find some useful information below:

- **Building Access:** Entry to the building is granted upon showing your participant badge. Please ensure you wear it at all times when entering the premises.
- **Lectures:** All lectures will take place in the Erhard Schmidt Lecture Room, located on the ground floor.
- **Poster session & Get-Together:** This will be held on **Monday, January 12 from 6:00 PM** on the 4th floor of our building. Light refreshments, including sandwiches and drinks, will be provided.
- **Smoking Policy:** Smoking, including electronic cigarettes, is strictly prohibited inside the building. As coffee breaks will be held on the ground floor, please use this opportunity to step outside if you wish to smoke.
- **WiFi Access:** You can connect to WiFi using the personal login card provided at registration. Altenatively, Eduroam is also available throughout the building
- **Informal Dinner:** An informal dinner on a self-payment basis will take place at Maximilians Restaurant, Friedrichstr. 185-190, 10117 Berlin on **Tuesday, January 13 at 6:00 PM.**

If you have any questions or need assistance, please don't hesitate to contact a member of the organizing team.
Yours sincerely,

Organizers.

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3 Abstracts talks

Title: tba

van Strien, Sebastian
Imperial College London, United Kingdom

Abstract: tba

Selfconsistent transfer operator for heterogeneous networks

Tanzi, Matteo
King's College London, United Kingdom

We study the dynamics of large heterogeneous network dynamical systems composed of nonlocally coupled maps. These systems are modeled using graphons, describing infinite limits of dense graphs, allowing for a rigorous analysis as the network size tends to infinity. We construct suitable strong and weak functional spaces to formulate a fixed-point problem for the infinite-dimensional system and prove the existence of solutions under mild conditions. We introduced a new operator framework for infinite-dimensional dynamical systems with heterogeneous interactions. Our results establish convergence of the finite-size system to the graphon limit in a suitable norm. This work combines operator theory and graph limits tools to offer a framework for understanding emergent behaviors in complex networks.

Fibration symmetries and cluster synchronization in higher-order Kuramoto dynamics

Bertè, Margherita
IMT School for Advanced Studies Lucca, Italy

Based on recent advances in fibration symmetry theory and higher-order interactions, we investigate how structural symmetries influence synchronization in multi-body systems. We present an operational framework to identify fibres in undirected hypergraphs, that are largest sets of nodes sharing equivalent incidence relations. We compute fibre partitions algorithmically via the incidence bipartite graph, enabling the detection of structural symmetries. Building on this foundation, we analyze a Kuramoto model with two and three-body interactions with frustration parameters under anonymity conditions (identical oscillators and homogeneous initial phases), showing that synchronization clusters coincide with the fibre decomposition. Finally, we highlight how the chosen representation of interactions (hypergraph, multigraph, or simple graph) alters both fibre partitions and emergent synchronization clusters, underscoring that representational assumptions shape observable dynamics.

A parametrization-averaging method for high-order phase reduction

Rink, Bob
Vrije Universiteit Amsterdam, Netherlands

This talk presents a method for high-order phase reduction of coupled oscillator networks using the ideas of the “parametrization method”. The method works by simultaneously computing an asymptotic expansion of an embedding of a persisting normally hyperbolic invariant torus and the dynamics on it. We will also see several applications of the method, which involve remote synchronization, delay-induced bistability, heteroclinic switching and network reconstruction.
This is joint work with Chris Bick, Bengi Dönmez, Sören von der Gracht, Jose Mujica, Eddie Nijholt and Babette de Wolff.

Computing phase dynamics for delay-coupled oscillators

de Wolff, Babette
Universität Hamburg, Germany

In many real-life networks systems, couplings are time delayed, since it takes a significant time for signals to travel from node to node. For such systems, phase reduction gives a systematic way to derive equations for the phases of coupled oscillators. The resulting phase equations are finite dimensional, which makes them in particular suitable for the analysis of dynamical phenomena such as synchronisation.

In this talk, I will present a higher-order phase reduction method, allowing us to compute the dynamics of the phases with arbitrary accuracy. I will in particular discuss how one can compute such a phase reduction numerically, thus making it a starting point of further numerical analysis of synchronisation and bifurcation behaviour.

This is based upon joint work with Christian Bick (VU Amsterdam), Bob Rink (VU Amsterdam) and Kyle Wedgwood (Exeter).

Synchronizability in networks with higher-order directed interactions

De Lellis, Pietro
University of Naples Federico II, Italy

Understanding which network structures promote or obstruct coordinated behavior in coupled dynamical systems is a central challenge in network science. While pairwise interactions among identical nodes are well studied, the role of higher-order, multi-body interactions among heterogeneous nodes remains less understood.

We introduces a new definition of network synchronizability, capturing how hypergraph topologies can align trajectories even when nodes differ in their parameters. The proposed synchronizability metric is mathematically derived, strongly correlates with observed behavior, and scales effectively with network size. This scalability enables a systematic comparison between higher-order and pairwise interactions, revealing when multi-body connections enhance or hinder synchronization in nonidentical systems.

Finally, the approach is applied to opinion dynamics, showing how the metric can identify hyperedges that foster consensus within social groups.

A parametrization method for higher-order phase reduction to understand the effects of non-pairwise interactions on synchronization dynamics

Muolo, Riccardo
RIKEN, Japan

Recent studies have shown that non-pairwise interactions play a crucial role in shaping synchronization dynamics. Such interactions can have different origins. For instance, in systems with physical states $x_k, x_j, x_l \in \mathbb{R}$, a non-pairwise coupling may take the form $G(x_k, x_j, x_l) = x_k x_j x_l$, whereas in phase models with $\theta_k, \theta_j, \theta_l \in \mathbb{T}$, it may appear as $g(\theta_k, \theta_j, \theta_l) = \sin(\theta_k \theta_j - 2\theta_l)$. The link between such physical and phase-level interactions is established through phase reduction for weakly coupled oscillators, generally expressed as an asymptotic expansion in the coupling strength ε. Classical first-order phase reductions, such as the Kuramoto one, capture only pairwise interactions, but higher-order reductions, such as the León and Pazó one, reveal the emergence of non-pairwise terms. These can arise either directly from nonpairwise couplings in the physical variables or at higher orders even when the physical coupling is pairwise. Here, we employ a parametrization-based method for higher-order phase reduction that captures both routes simultaneously by approximating an invariant torus in the full system phase space, providing a unified description of nonpairwise synchronization dynamics.

Second-order Kuramoto-Sakaguchi model: what can it explain?

Rosenblum, Michael
Universität Potsdam, Germany

We apply the second-order phase reduction to obtain the phase approximation for a network of nonidentical Stuart-Landau oscillators coupled pairwisely via an arbitrary coupling matrix. The derived model contains different triplet terms as well as pairwise terms for non-connected units. In contradistinction to the standard Kuramoto-Sakaguchi model, the coefficients of high-order terms depend on their frequencies. We concentrate on qualitative effects provided by the second approximation: (i) explanation of remote synchrony, (ii) reproduction of the chimera shape's dependence on the coupling strength, and (iii) synchronization and clustering in the two-group Stuart-Landau network with neutral coupling.

Simplicial emergence in adaptive higher-order networks

Murphy, Fergal
Technische Universität München, Germany

Many real-world systems have higher-order interactions whose structure adapts dynamically over time. We are interested in the properties of such systems that lead to the formation of a well-behaved structure, namely, a simplicial complex. To achieve this, we model such co-evolving higher-order networks as directed hypergraphs using time-dependent weight tensors. We split these tensors into symmetry-invariant

subspaces, enabling us to define three stable asymptotic symmetry regimes: Symmetric, Antisymmetric, and Mixed. Under suitable conditions on the dynamics, each case enables the formation of a relevant simplicial object, (un)oriented simplicial complex in the first two cases and semi-simplicial sets in the latter. This framework provides the essential theoretical foundation needed to justify the application of homology theory and other algebraic-topological tools to adaptive higher-order systems. Such tools enable the analysis of the link between the homology of Kuramoto-type systems and synchronisation, for example.
This work is joint with Christian Kuehn.

Forcing oscillators network to compute: Harnessing all Kuramoto-like systems as computational resource

de Jong, Thomas
Kanazawa University, Temple University (Tokyo Campus), Japan

Computing in silica comes with drawbacks, including high energy consumption, susceptibility to critical failures in extreme environments, such as high-radiation areas, as well as computational speed limitations which can be troublesome when processing real-time photonic data. This has sparked significant interest in discovering alternative physical systems that can overcome these limitations. Although great efforts have been made to design computer sub-components using non-traditional media, these approaches have not yet come close to building a functional device.

A framework that overcomes this is physical reservoir computing as it allows us to directly harness the computational capabilities of a physical system without requiring a specific architecture which greatly reduces engineering overhead [1]. However, it is difficult to identify what physical systems can be utilized as reservoir computers. We propose a fundamental framework for physical reservoir computing by observing that an oscillator network subject to input forcing can be used as a computational resource [2]. Here we shall mainly consider Kuramoto oscillators, but the work extends to more general models in active matter and complex networks. We show by example that it can be used to perform a large variety of computational tasks for a wide range of parameters; here given by coupling and forcing strength. Due to the omnipresence of Kuramoto-like systems we have a whole new range of systems whose computational capabilities can be investigated.

We present our Kuramoto based reservoir computer in a numerical context. We show benchmarks and a spatial extension via swarmalators. Finally, we explore its continuum limit using the so-called Ott-Antonsen Ansatz [3].

References:

[1] K. Nakajima (2020). Physical reservoir computing: an introductory perspective. Jpn. J. Appl. Phys. 59, 060501.
[2] T. de Jong, H Notsu, K, Nakajima (2025). Harnessing omnipresent oscillator networks as computational resource. arXiv:2502.04818
[3] T. de Jong. Designing learning in high dimensional oscillator networks with low dimensional read-out. arXiv:2509.00848 (up to date paper info here https://mathowl.github.io/tgdejong/publications/)

Singular basins of multiscale systems

Yanchuk, Serhiy
University College Cork, Ireland

Real-world complex systems often possess different time scales as well as multiple coexisting stable states. We show that basins of attraction in multiscale systems possess unique properties. Namely, such basins may contain singular funnels which become exponentially narrower as the timescale separation increases. These singular funnels may prevent the possibility of a reduction (e.g., adiabatic elimination or averaging) of a multiscale system for arbitrary timescale separation. One reason for this is that the funnels may induce tunneling between different states in the full system. However, in the reduced system, these singular funnels are eliminated, along with the possibility of tunneling. We call the resulting basins of attraction of multiscale systems singular basins and show that they occur robustly in different classes of systems.

Coherence properties of global modes in oscillatory networks

Pikovsky, Arkady
Universität Potsdam, Germany

Synchronization transition manifests itself as an appearance of a global oscillatory mode. In the thermodynamic limit, such a mode oscillates periodically, but for a finite system there are fluctuations. We study phase diffusion of the periodic mode and demonstrate that depending on the dynamics of an individual system, different scaling behaviors in dependence on the network size are observed.

Phase locking and multistability in the topological Kuramoto model on cell complexes

Bačić, Iva
Forschungszentrum Juelich; Institute of Physics Belgrade, Germany

The topological Kuramoto model generalizes classical synchronization models by including higher-order interactions, with oscillator dynamics defined on cells of arbitrary dimension within simplicial or cell complexes. In this article, we demonstrate multistability in the topological Kuramoto model and develop the topological nonlinear Kirchhoff conditions algorithm to identify all phase-locked states on arbitrary cell complexes. The algorithm is based on a generalization of Kirchhoff's laws to cell complexes of arbitrary dimension and nonlinear interactions between cells. By applying this framework to rings, Platonic solids, and simplexes, as minimal representative motifs of larger networks, we derive explicit bounds (based on winding number constraints) that determine the number of coexisting stable states. We uncover structural cascades of multistability, inherited from both lower and higher dimensions and demonstrate that cell complexes can generate richer multistability patterns than simplicial complexes of the same dimension. Moreover, we find that multistability patterns in cell complexes appear to be determined by the number of boundary cells, hinting a possible universal pattern.

Dynamical stability of stochastic gradient descent in overparameterized neural networks

Engel, Maximilian
University of Amsterdam, Netherlands

For overparameterized optimization tasks, such as those found in modern neural networks, global minima are generally not unique. In order to understand generalization in these settings, it is vital to study to which minimum an optimization algorithm converges. The possibility of having minima that are unstable under the dynamics imposed by the optimization algorithm limits the potential minima that the algorithm on the network can find. We show how to characterize the global minima that are dynamically stable/unstable for (stochastic) gradient descent, short (S)GD. In particular, we introduce a characteristic Lyapunov exponent that depends on the local dynamics around a global minimum and rigorously prove that the sign of this Lyapunov exponent determines whether (S)GD can accumulate at the respective global minimum.
This is joint work with Dennis Chemnitz (ETH).

Coupled (hyperbolic) map lattices

Liverani, Carlangelo
University of Rome Tor Vergata, Italy

I will primarily discuss the case of globally coupled (mean-field) maps. The maps considered are expanding or hyperbolic. I will primarily discuss the case of globally coupled (mean-field) maps. The maps considered are expanding or hyperbolic. In particular, I'll focus on the possibility of phase transitions.

Hypernetworks induce stable hyperlocking

Nijholt, Eddie
Universidade de Sao Paulo & ICMC, Brazil

We present a synchronization phenomenon that is distinctive for hypernetworks, which we call hyperlocking. In more detail, we study a system of three coupled oscillators with (near) identical frequencies, interacting through a triadic hypernetwork motif where one node modulates the interaction between two others. We show that this configuration can induce a stable locking of a phase triplet, while no pairwise locking is observed. Using normal form transformations and phase reduction, we derive analytically how a specific choice of the coupling functions induces this hyperlocking. Moreover, we are able to confirm our predictions with both numerical simulations and chemical experiments.
This is based on joint work with Sagnik Chakraborty, Jürgen Kurths, István Z. Kiss, Tiago Pereira and Matthias Wolfrum.

Impact of heavy-tailed synaptic strength distributions on self-sustained activity in networks of spiking neurons.

Tönjes, Ralf
Humboldt-Universität zu Berlin, Germany

Biological neural networks are notoriously stochastic over many scales. The stochasticity is not additively imposed by the environment but largely a self-generated and state-dependent dynamic noise. Making the simplifying white noise approximation we derive self-consistent equations for the stationary firing rates in random networks of spiking neurons with Gaussian and with Cauchy distributed synaptic strengths. Critical transitions between low- and high activity regimes exist, but require fine tuning of several parameters, absence of external noise or additional symmetries to be realized.

Reconstructing networks and hypernetworks of coupled oscillators from time series

Donmez, Bengi
Vrije Universiteit Amsterdam, Netherlands

We are interested in weakly coupled Kuramoto oscillators and aim to determine their network structure from time series data. The main challenge here is that the problem is not well-posed: two different network models can produce identical time series if there's noise. As a result, it is impossible to reconstruct the exact model or network structure. To overcome this issue, rather than reconstructing the complete model, we focus on identifying the simplest form of the model that can replicate the observed dynamics. This involves using the normal form, which captures the core features of the dynamics. Our method uses least-squares fitting to achieve this. Fitting the normal form, we also don't need many data points, making the method efficient and robust. By examining the data and fitted terms, we further establish an explicit bound on the error in the reconstructed coupling coefficients. We illustrate our results with numerical simulations.

Mean-field approach to finite-size fluctuations in the Kuramoto-Sakaguchi model

Omelchenko, Oleh
Universität Potsdam, Germany

The Kuramoto-Sakaguchi model is a paradigmatic model widely used to describe synchronization phenomena in systems of interacting oscillators. Its properties are well studied in the thermodynamic limit, when the number of oscillators tends to infinity. But its behavior in the more realistic case of a finite number of oscillators remains poorly understood. In this talk, we investigate the statistical behavior of finite-size fluctuations in the Kuramoto-Sakaguchi model and propose an ab initio approach for their analytical description. Using it, we obtain explicit expressions for the covariance function of fluctuations of the complex order parameter and determine the variance of its magnitude entirely in terms of the equation parameters. Our results rely on an explicit complex-valued formula for solutions of the Adler equation. We present analytical results for both the sub- and the super-critical case. Moreover, our framework does not require any prior knowledge about the structure of the partially synchronized state. The proposed methodology is sufficiently general such that

it can be applied to other interacting particle systems.
This talk is based on joint work with Prof. Georg Gottwald (The University of Sydney, Australia).

Matrix-weighted networks for modeling multidimensional dynamics

Tian, Yu
Center for Systems Biology Dresden, MPI CBG PKS, Germany

Networks are powerful tools for modeling interactions in complex systems. While traditional networks use scalar edge weights, many real-world systems involve multidimensional interactions. For example, in social networks, individuals often have multiple interconnected opinions that can affect the different opinions of other individuals, which can be better characterized by matrices. In this talk, I will discuss a general framework that we have proposed for modeling such multidimensional interacting dynamics: matrix-weighted networks (MWNs). I will present the mathematical foundations of MWNs and discuss consensus dynamics and random walks within this context. Our results reveal that the coherence of MWNs gives rise to non-trivial steady states that generalize the notions of communities and structural balance in traditional networks.

Graph and hypergraph limits and their spectral theory

Zucal, Giulio
Max Planck Institute of Cell Biology and Genetics, Germany

Graph limit theory investigates the convergence of sequences of graphs as the number of vertices grows, providing a powerful framework for representing and analyzing large networks. Spectral graph theory, by contrast, studies graphs through matrices such as the adjacency and Laplacian matrices and their eigenvalues, offering fundamental insight into dynamical and stochastic processes on networks. Recent developments in network science have highlighted the need to model higher-order interactions, naturally leading to the study of hypergraphs. This shift has stimulated interest in both the spectral theory of hypergraphs and emerging limit theories for these structures. This talk provides an introduction to graph, multiplex network, and hypergraph limit theory, illustrates selected applications to random graphs, and examines the spectral properties of the resulting limit objects. These developments aim to furnish new tools for analyzing mean-field limits of coupled dynamics on hypernetworks.

4 Abstracts posters

Random walk based snapshot clustering for detecting community dynamics in temporal networks

Blaskovic, Filip
Zuse institute Berlin, Germany

The evolution of many dynamical systems that describe relationships or interactions between objects can be effectively modeled by temporal networks, which are typically represented as a sequence of static network snapshots. Here, we introduce a novel random walk-based approach that can identify clusters of time-snapshots in which network community structures are stable. This allows us to detect significant structural shifts over time, such as the splitting or merging of communities or their births and deaths. We also provide a low-dimensional representation of entire snapshots, placing those with similar community structure close to each other in the feature space. To validate our approach, we develop an agent-based algorithm that generates synthetic datasets with the desired characteristic properties, enabling thorough testing and benchmarking. We further demonstrate the effectiveness and broad applicability of our technique by testing it on various social dynamics models and real-world datasets and comparing its performance to several state-of-the-art algorithms. Our findings highlight the strength of our approach to correctly capture and analyze the dynamics of complex systems.

Multistability in gradient osciillator model for frustrated spin system

Burylko, Oleksandr & Hrabovets Anastasiia
Humboldt-Universität zu Berlin & NAS of Ukraine, Germany

We propose a gradient oscillator model to study the collective behavior of frustrated spin networks. The system is defined on a ring with attractive and repulsive couplings between nearest and next-nearest neighbors. Starting from a complex spin network, we reduce the model to a gradient-type Kuramoto system in terms of the angular coordinates with a circulant interaction matrix. We study identical oscillators, identifying symmetries, invariant manifolds and analyzing the stability of equilibria. For any number of oscillators, synchronization, splay states, and π-states are observed, along with more complex regimes.The system has high multistability, which varies significantly with parameters and changes as a result of regular and degenerate bifurcations.We study how the number and parity of oscillators, as well as the strength of the interaction between them, affect the change in energy of a frustrated system. Future work includes interpreting the results in terms of energy optimization and extending the model to two-dimensional spin networks.

Dynamic link switching induces stable synchronized states in sparse networks

Eser, Muhittin Cenk
Freie Universität Berlin, Germany

The flow of information in networked systems composed of multiple interacting elements strongly depends on the level of connectivity among these elements. Sparse connectivity often hinders the emergence of states where information is globally shared, such as fully synchronized states. In this context, dynamically switching the existing network links among the system elements can facilitate the onset of synchronization. However, determining the optimal rate at which links should be switched to ensure asymptotically stable synchronized behavior remains an open question. Here, we address this issue in a double-layer network of FitzHugh-Nagumo oscillators with sparse inter-layer connectivity. Specifically, we demonstrate that faster switching of the inter-layer links, which sweeps through a more significant number of oscillators, is more effective in establishing inter-layer synchronization than maintaining links on the identical oscillators for extended durations. We also evaluate the effectiveness of fast-switching links as the layer size increases. In a reduced system, we introduce smooth square-wave functions to emulate link switching, eventually introducing discontinuities into the system dynamics. This approach enables the assessment of the transverse stability of synchronized states induced by switching links.

Phase and gain stability for adaptive dynamical networks

Kastendiek, Nina
Potsdam Institute for Climate Impact Research, Germany

In adaptive dynamical networks, both the nodes and the connections between them evolve over time, which may give rise to complex dynamics and self-organization. Analyzing the stability of equilibria in these systems is fundamental for understanding their long-term behavior and response to perturbations. However, classical linear stability analysis based on the eigenvalues of a system's Jacobian matrix is challenging in large and adaptive networks, whereas alternative methods often rely on homogeneity assumptions or coarse-grained approximations. This talk introduces a new method for linear stability analysis in adaptive dynamical networks, drawing on recent advances in control theory and linear algebra. The method treats adaptive networks as a closed feedback loop between node and edge dynamics and provides local sufficient stability conditions in terms of node-wise and edge-wise properties. This reduces the global analysis to local conditions that are largely independent of the network topology. The proposed conditions recover state-of-the-art results and provide new insights in paradigmatic Kuramoto models and a multi-species predator-prey model. A key contribution is the derivation of novel sufficient stability conditions for ensuring small-signal stability in power grids with highly heterogeneous mixes of grid-forming inverters.

Binary and fuzzy logic with networks of excitable neurons

Krijgsheld, Henrieke
University of Groningen, Netherlands

Understanding how networks of complex nonlinear dynamical systems such as neurons can perform computations is key to understanding how the brain functions and using that for brain-inspired computing. By computations we mean here a desired input-output relation of such a network. While certain behaviors such as synchronization are more commonly studied analytically, a thorough understanding of dynamics performing this type of computation is less explored. To bridge that gap, we study networks of a general class of two-dimensional slow-fast biologically inspired neurons (including models such as FitzHugh-Nagumo and Morris-Lecar) coupled with chemical synapses. Supported by formal analysis, we provide a methodology for creating biologically inspired neuron networks that perform binary and fuzzy logic operations. The basic boolean gates are realized by a single processing neuron, and more complicated operations are built by composing these. On the other hand, to implement fuzzy logic operations (MIN/MAX), we propose a network of less than ten processing neurons. In this context, we further show how network adaptation improves the accuracy of the computations.

Systematic construction of hierarchical connection structures in phase space

Lohse, Alexander & von der Gracht, Sören
Universität Hamburg & Universität Paderborn
Germany

We provide a method to systematically construct vector fields that possess excitable transitions corresponding to a desired hierarchical connection structure. The structure is given as a finite set of digraphs $G_1, \ldots, G_N$ (the lower level), together with another digraph Γ on the set of nodes $1, \ldots, N$ (the top level). The dynamic realizations of $G_1, \ldots, G_N$ are heteroclinic networks and they can be thought of as individual connection patterns on a given set of states. Connections in Γ correspond to transitions between these different connection patterns. In our construction, the connections given through Γ are not heteroclinic, but excitable with zero threshold: such a connection exists between two sets S, S' if in every δ-neighbourhood of S there is at least one initial condition such that its ω-limit is contained in S'. In this sense, we prove a theorem that allows the systematic creation of hierarchical networks that are excitable on the top level, and heteroclinic on the lower level. Our results modify and extend the simplex method by Ashwin & Postlethwaite, which is one of several existing techniques for the construction of vector fields that possess a desired heteroclinic network.

Learning collective variables for time-evolving networks

Nagel, Sören
Zuse Institute Berlin, Germany

We address the challenge of model reduction for time-evolving networks by identifying collective variables for stochastic rewiring processes driven by opinion homophily. [Lücke et al., Phys. Rev. E 109, L022301 (2024); Djurdjevac Conrad et al., Chaos 34, 093116 (2024)]. Utilizing the textittransition manifold framework, we identify a simple consensus measure as a collective variable for an ergodic and a non-ergodic model, and learn the dynamics of the projected system. We show that the learned model reduction can be obtained from the corresponding graphon process in the case of large and not too sparse graphs with uniformly distributed opinions. Our data-driven approach successfully identifies the collective variables in more general cases, highlighting the possibility to study low-dimensional model reductions in systems that have not been understood theoretically.

Learning spatiotemporal patterns from mean-field data

Roque Dos Santos, Edmilson
Max Planck for the Physics of Complex Systems, Germany

Networks of coupled dynamical systems are fundamental models across the sciences, from physics to neuroscience. Despite their success, the governing equations of such systems are often unknown, limiting our ability to predict and control their dynamics. A major current effort is to learn these governing equations directly from data. However, existing approaches typically require access to the time series of all node states, which is rarely available outside controlled experiments. In most realistic scenarios, only aggregate or mean-field data, such as linear combinations of node states, can be measured. In this case, learning the governing equations from mean-field data inevitably becomes a secondary goal, since one must first learn the network trajectory that generated the observed measurements. This task is inherently challenging because distinct network states can yield identical macroscopic observations. Here, we address the problem of learning the network trajectory from random mean-field measurements. We show that the reconstruction becomes possible when the network exhibits structured spatiotemporal patterns, such as traveling waves. By representing these patterns sparsely in the Fourier domain, we leverage compressive sensing theory to formulate a convex optimization problem that robustly reconstructs the network trajectory. Moreover, we determine the minimum number of mean-field measurements required for exact reconstruction. We illustrate our findings using a unidirectional ring of coupled Stuart–Landau oscillators.

Origin of frequency clusters in globally coupled Kuramoto oscillators with inertia

Schöhs, Yannick
Technische Universität München, Germany

Over the past few years, the Kuramoto model with inertia has received increasing attention ? not only due to its applications in power grids and its correspondence to an adaptively coupled oscillator model, but also because of its rich dynamical behavior. Our focus lies on the formation of frequency clusters, where distinct groups oscillate at different mean frequencies. We investigate their occurrence in identical, globally coupled Kuramoto oscillators with inertia. To uncover the underlying mechanisms, we first perform a bifurcation analysis for a system with four oscillators and identify the origin of two distinct frequency clusters. Extending this approach to the thermodynamic limit, we analyze the dynamics in the invariant cluster subspaces. Finally, we investigate the emergence of three frequency clusters in a system of seven oscillators by means of a numerical bifurcation analysis. These states exhibit a locking of two mean-frequency differences, giving rise to a triplet synchrony state.

What is the right limit?

Sclosa, Davide
King's College London, United Kingdom

Large dynamical networks involve 1) a graph, 2) a phase space, 3) a transformation, 4) some observables. The limits of 1), 2), 3), 4) might be incompatible, or might not exist at all. What governs the dynamics?

Early-warning and control of burst synchronization via silence in coupled neural systems

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Abrupt transitions in coupled dynamical networks often emerge from subtle changes in the interaction structure and collective states, and neuronal systems are no exception. In this work, we show that the mean silence time-a simple population-level measure of inactivity-acts as an effective early-warning indicator of a forthcoming synchronization burst in a strongly coupled network. Using biophysical network simulations with slow modulatory dynamics, we find that the system systematically enters an extended, network-wide quiescent phase before transitioning into a highly synchronized up-state. As coupling-induced interactions push the system toward this critical transition, the mean silence time grows steadily and crosses a well-defined threshold, enabling accurate short-term prediction of the impending synchronized event. A Random Forest classifier trained solely on lagged silence metrics reliably identifies these transitions, underscoring the predictive power embedded in the temporal structure of collective inactivity. Moreover, a coupling-based control strategy-triggered when the silence threshold is crossed and implemented via brief, localized perturbations-significantly reduces the duration of the subsequent synchronized episode. Importantly, prolonged pre-transition quiescence consistent with these model predictions is also observed in intracranial recordings from individuals with epilepsy, suggesting that the phenomenon is not model-specific but rather a generic feature of strongly interacting networks approaching a synchronization burst. Mechanistically, the extended silent interval reduces slow recovery currents and adaptation, leaving the coupled system more susceptible to rapid, global synchronization. Overall, our results identify the mean silence time as a robust and physiologically accessible predictor of critical transitions in coupled network systems and highlight its potential as a control target for mitigating pathological synchronization.

Bimodal amplitude patterns in globally coupled heterogeneous oscillatory media

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Experiments on anodic electrochemical silicon dissolution reveal a surprising collective state: the medium splits into two amplitude domains, yet the entire system oscillates at a single common frequency. To reproduce this phenomenon, we analyze a heterogeneous ensemble of globally coupled Stuart–Landau oscillators. Writing the locked state in polar form yields coupled algebraic balance equations for amplitude and phase. These findings reveal that global coupling enables each oscillator to shift its amplitude off the unit circle, thereby compensating for its intrinsic frequency mismatch. As the coupling is varied, the implicit amplitude equation undergoes saddle-node bifurcations, producing a bimodal stationary amplitude distribution while full frequency entrainment is preserved. This bifurcation structure is reminiscent of the organization of the cluster singularity, known from identical oscillators, indicating that its "ghost" persists under realistic heterogeneity.

Stable time rondeau crystals in coupled dissipative systems

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Driven systems offer the potential to realise a wide range of non-equilibrium phenomena that are inaccessible in static systems, such as discrete time crystals. Time rondeau crystals with a partial temporal order have been proposed as a distinctive prethermal phase of matter in systems driven by structured random protocols. Yet, heating is inevitable in closed systems and time rondeau crystals eventually melt. We introduce dissipation to counteract heating and demonstrate it stable time rondeau crystals that persist indefinitely in a coupled dissipative system. The presence of coupling competes with synchronisation and a desynchronisation phase transition occurs at a finite interaction strength. This transition is well captured via a linear stability analysis of the underlying stochastic processes.
[Phys. Rev. B 112, L140301 (2025)]

Synchronization transitions and spike dynamics in a higher-order Kuramoto model with Lévy noise

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Synchronization in various complex networks is significantly influenced by higher-order interactions combined with non-Gaussian stochastic perturbations, yet their mechanisms remain mainly unclear. In this paper, we systematically investigate the synchronization and spike dynamics in a higher-order Kuramoto model subjected to non-Gaussian Lévy noise. Using the mean order parameter, mean first-passage time, and basin stability, we identify clear boundaries distingusihing synchronization and incoherent states under different stability indexes and scale parameters of Lévy noise. For fixed coupling parameters, synchronization weakens as the stability index decreases, and even completely disappears when the scale parameter exceeds a

critical threshold. By varying coupling parameters, we find significant dynamical phenomena including bifurcations and hysteresis. Lévy noise smooths the synchronization transitions and requires stronger coupling compared to Gaussian white noise. Furthermore, we define spikes and systematically investigate their statistical and spectral characteristics. The maximum number of spikes is observed at small scale parameter. A generalized spectral analysis further reveals burst-like structure via an edit distance algorithm. Moreover, a power-law distribution is observed in the large inter-window intervals of spikes, showing great memory effects. These findings deepen the understanding of synchronization and extreme events in complex networks driven by non-Gaussian Lévy noise.

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