Conference Programme

Nonlinear Data Analysis and Modeling: Advances, Applications, Perspectives

Potsdam, 15–17 March 2023

Contents

Abstracts

General Information

Organisational Committee

Scientific Organisation

Dr. Norbert Marwan (Potsdam Institute for Climate Impact Research)
Dr. Aneta Koseska (Max Planck Institute for Neurobiology of Behavior – caesar, Bonn)
Dr. Jobst Heitzig (Potsdam Institute for Climate Impact Research)

Local Organisation

Anja Bruhn, Till Hollmann, Anja Kliese de Souza, Gabriele Pilz, and numerous colleagues and students

General Contact

`nda23@listserv.dfn.de`

Aims

The last decade has witnessed a rapid development and extension of methods for analysing data, and modeling and predicting complex systems. Many examples represent the strong interactive and fruitful exchange between the scientific communities, which usually gather on more disciplinary and special conferences. Moreover, in the last (almost) three years the possibilities of exchange were hampered by the COVID19 pandemic. The virtual meetings are helpful to partly cover the gap but are not a suitable replacement, because the social interactions are very limited in the virtual space. Therefore, with a strong interdisciplinary focus, the conference brings together leading scientists with senior and young researchers who deal with nonlinear dynamics, complex systems, machine learning, and their applications for data analysis and modeling in different disciplines. Moreover, the conference, organised on the occasion of the 70th birthday of Prof. Jürgen Kurths, provides a platform to exchange ideas, knowledge, and new aspects on research in these fields and to allow young researchers to catch up to the frontiers in this research.

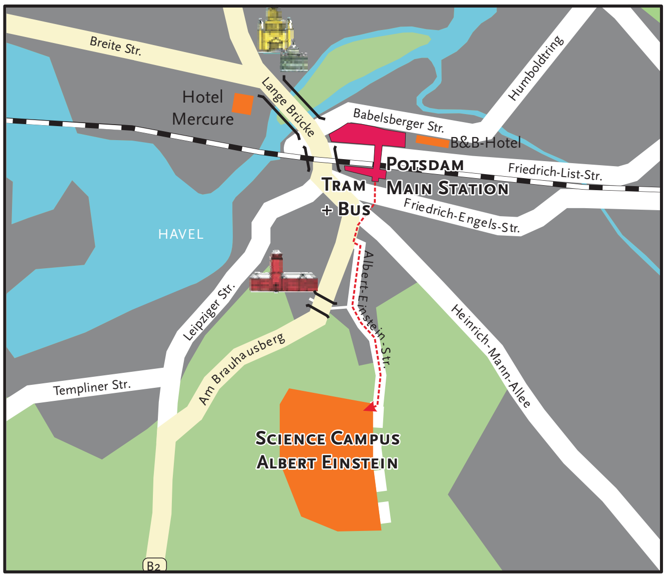
The social programme will provide an opportunity to meet former colleagues and alumni of the group of Prof. Kurths.

Location

The event will take place at the Einstein Campus in Potsdam (Telegraphenberg), close to the Potsdam Institute for Climate Impact Research (PIK), March 15 to 17, 2023. The keynote talks are in the auditorium of **building H**, the minisymposia in the auditorium and the lecture rooms 1 and 3 of the building H.

To reach the Einstein Campus from Potsdam main station, you may either *take a taxi* up the Telegrafenberg – which is recommended if you have heavy luggage to carry. Or you can *walk*, which takes about 15 minutes: From the train station take the exit “Friedrich Engels Str.”, cross the tram- and bus-station as well as the Friedrich Engels street at the traffic light, take the footpath (80 m) to the next parallel street (Heinrich Mann Allee), cross it at the traffic light and walk 50 m parallel of the street “Brauhausberg” (left and right construction area). Then turn left into “Albert-Einstein-Str.” which goes uphill and first leads you through a small residential area, then through a wooden area. Finally it ends right at the gate of the “Einstein-Wissenschaftspark”. Enter the campus and after 200 m you arrive at the building H (left).

You can also take *bus No. 691* which leaves Potsdam main station (platform 7) heading towards “Einstein-Wissenschaftspark” or “Telegrafenberg”, and get off at the final stop, “Telegrafenberg”. Departure in the morning from train main station is 8:42 (and then every 30 minutes), arriving directly at building H at 8:48.



Presentations

Presentations should be uploaded to the presentation computer in the lecture hall or seminar rooms at the earliest of your convenience but not later than the last break before the session of presentation. The time for invited talks is 25 min + 5 min discussion. The time for talks in the minisymposia will vary.

The presentation computer runs with MS Windows with standard presentation software (PowerPoint, Acrobat Reader). Only in exceptional case, you can use your own computer or presentation device, and only as long as it has the appropriate VGA or HDMI output and you are able to test the machine before the scheduled session.

Note

The symposium will adhere to the rules of good scientific and ethical practice. This means that it is not allowed to copy presentations from the presentation computer. It is also forbidden to take photographs or videos of oral presentations and presented posters without explicitly given permission of the presenter.

Social Programme

Thursday, March 16th, we have a social programme with casual, non-scientific presentations in the lecture hall in the afternoon, followed by a reception in the evening.

Lunch

Lunch meals are not included in the conference registration. The canteen in the 1stst floor of the conference building and the café Feundlich can be used to take lunch at your own expense.

Internet Access

Wireless internet access is available via Eduroam or PIK visitors WLAN (access key available onsite).

Financial Support

The conference is financially supported by the Deutsche Forschungsgemeinschaft DFG project 516567511, by the Potsdam Institute for Climate Impact Research (PIK), by the "Verein der Freunde und Förderer des PIK", and by Ambrosys GmbH.

DFG Deutsche Forschungsgemeinschaft

Suggestions for Sightseeing

The science campus at the Telegraphenberg is a famous historical site. For example, the Michelson building was the first astrophysical institute of the world (build in 1879). In its basement, the famous Michelson experiment (1881; interferometer experiment intended to detect the existence of the luminiferous aether, finally leading to Einstein's theory of special relativity) was first performed. Moreover, the first registering of seismic waves of a faraway earthquake were done (Ernst Rebeur-Paschwitz, 1889). The Great Refractor, close to the Michelson building hosts the 4th largest refracting telescope of the world (build 1899). Here, the interstellar medium (cosmic dust) was discovered first (Johannes Hartmann, 1904).

Michelson building (Foto: N. Marwan).

The Einstein tower is located behind the Great Refractor. It was the most important solar observatory in the first half of the 19th century and is a testimony of expressionist architecture (build by Erich Mendelsohn, 1921). It was built to validate Einstein's relativity theory (Erwin Freundlich, Albert Einstein). The Helmert tower was the reference point of the Prussian geodetic network and in the Helmert building the international gravitational constant (Potsdam's gravity value) was defined for long time. Close to the Süring house, a weather station collects data for one of the longest weather time series of the world (measuring since 1893 without any gaps). The campus contains also important new buildings, like the one for the PIK, which is an energetically highly innovative building, hosting a supercomputer that was one of the 400 fastest supercomputers of the world.

When coming to Potsdam for the conference, you should use this opportunity to visit some of the further wonderful places in this city.

Close to the Telegraphenberg, you can visit the Palais Barberini, a reconstructed Classicist Baroque palace. It contains temporary art exhibitions from the Old Masters to contemporary art, presenting international and famous works. If interested in former GDR art, the very recently opened new art museum "Das Minsk" should not be missed – also very close to the Telegraphenberg.

Palais Barberini (Foto: N. Marwan).

Potsdam is famous for its parks and palaces. You can start with Park Sanssouci, which contains an ensemble of several palaces of the Prussian emperors (e.g., in Neues Palais, the German emperor declared the Declaration of war which finally started the World War I). Then continue with the landscape park Babelsberg Park. You should also not miss the Park Neuer Garten which includes the historically important Schloß Cecilienhof (the place of the Potsdam Agreement in 1945 concerned on the military occupation and reconstruction of Germany).

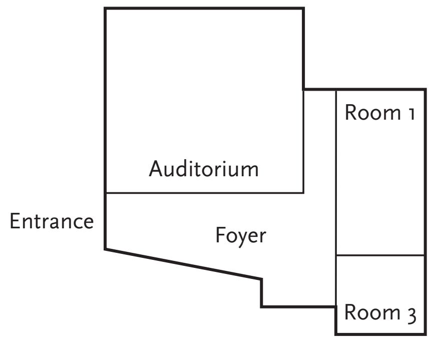
The centre of Potsdam contains some interesting buildings and quarters. For example, the Nikolaikirche, the Dutch quarter (Holländerviertel), the Russian colony Alexandrovka, or the Pfingstberg Hill.

Potsdam is the first UNESCO-Creative City of Film in Germany. It is the cradle of the German film industry. You can visit the Filmpark Babelsberg, which hosts the Babelsberg Studio (founded 1912) famous for many movies like Fritz Lang's *Metropolis* (1927) or (more recent) *The Reader* (2008) and *Inglourious Basterds* (2009).

Further information on what to visit in Potsdam can be found at Potsdam Information:
www.potsdam-tourism.com/en/.

Mill in park Sanssouci (Foto: N. Marwan).

Main Programme



Keynote lectures: auditorium
Minisymposia: auditorium, lecture rooms 1 and 3
Poster session: foyer, lecture rooms 1 and 3

Wednesday, March 15th

13:00–13:10 *Opening*

13:10–13:40 **Celso Grebogi**
Recent achievements in studying ecological networks

13:40–14:10 **Ginestra Bianconi**
The dynamics of higher-order networks: The effect of topology and triadic interactions

14:10–14:40 **Jean-Pierre Eckmann**
The predictive power of theoretical biology: An example

14:40–15:00 *Coffee break*

15:00–15:30 **Veronika Stolbova**
Complex networks in financial systems

15:30–16:00 **Kira Rehfeld**
Climate variability from the last glacial to the Anthropocene:
Knowns, unknowns and future challenges

16:00–16:30 **Matjaž Perc**
Nonlinear data analysis and the visual arts

16:30–16:50 *Coffee break*

16:50–18:20 **Minisymposium 1/I** (auditorium)
Concepts from complex systems – Networks, synchronisation, recurrence I

Minisymposium 2 (lecture room 1)
Analysis and modeling of infrastructure networks

18:20–21:00 **Poster session I** (Groups I, P, C, T) *and icebreaker*

Thursday, March 16th

9:00–10:30 **Minisymposium 3** (lecture room 3)
Adaptive and multistable networks

Minisymposium 4 (auditorium)
World-Earth system analysis

Minisymposium 5 (lecture room 1)
Cardiovascular dynamics and sleep disorders

10:30–10:45 *Coffee break*

10:45–12:15	**Poster session II** (Groups B, S, M, W)
12:15–12:45	**Ying-Cheng Lai** Deficiency of deterministic modeling and data-based causal analysis of complex dynamical systems
12:45–13:15	**Elizabeth M. Cherry**, Shahrokh Shahi Machine-learning approaches for predicting cardiac voltage dynamics
13:15–14:45	*Lunch break*
14:45–15:15	**Rajarshi Roy** Singular, dual and plural: A tale of numbers, networks and synchrony
15:15–15:45	**Sudeshna Sinha** Chaos and noise in the aid of logic
15:45–16:15	Rene van Westen, Sven Baars, **Henk A. Dijkstra** Tipping of the Atlantic Ocean Circulation
16:15–16:45	*Coffee break*
16:45–18:45	**Special birthday session**
18:45–22:00	*Reception*

Friday, March 17th

9:00–9:30	**Yong Xu** Early warning and suppression of noise-induced critical transitions
9:30–10:00	**Ulrike Feudel**, Lukas Halekotte, Sarah Schoenmakers, Anna Vanselow, Sebastian Wieczorek Multistability and tipping: Critical transitions in complex systems
10:00–10:30	**Peng Ji** Asymptotic scaling of signal propagation in complex networks
10:30–11:00	*Coffee break*
11:00–12:30	**Minisymposium 6** (auditorium) Dynamics of complex biological systems
	Minisymposium 7 (lecture room 1) Nonlinear dynamics in economics
	Minisymposium 8 (lecture room 3) Causation and prediction of weather and climate extremes
12:30–14:00	*Lunch break*
14:00–15:30	**Minisymposium 9** (lecture room 1) Tipping points
	Minisymposium 1/II (auditorium) Concepts from complex systems – Networks, synchronisation, recurrence II

15:30–15:50 *Coffee break*

15:50–16:20 **Deniz Eroglu**
Recurrences: Fingerprints of dynamics –
A journey from low dimensional systems to climate networks

16:20–16:50 **R. I. Sujith**
Complex system approach to investigate and mitigate thermoacoustic instability in turbulent combustors

16:50–17:05 *Closing*

Minisymposia

MS 1 – Concepts from complex systems – networks, synchronisation, recurrence

Convener: Sarika Jalan, Maria Carmen Romano
Room: auditorium

Wednesday, March 15th, 16:50–18:20

16:50–17:05	**G. Ambika** (online) Dynamical transitions on multiplex networks
17:05–17:20	**Sarika Jalan** Adaptation in higher-order interactions: Explosive transition to cluster synchronisation
17:20–17:35	M. Kumar, **Mihael Rosenblum** High-order phase reduction explains remote synchrony in a chain of Stuart–Landau oscillators
17:35–17:50	**Peter beim Graben**, Axel Hutt, Serafim Rodrigues Recurrence structure analysis of neurophysiological data
17:50–18:00	Steve J. Kongni, Thierry Njougouo, Patrick Louodop, Robert Tchitnga, **Hilda A. Cerdeira** Phase transition to synchronization in a system of swarmalators
18:00–18:10	**Timo Bröhl**, Klaus Lehnertz A perturbation-based approach to identifying superfluous network constituents
18:10–18:20	**Géza Ódor**, Shengfeng Deng, Bálint Hartmann, Jeffrey Kelling Non-local cascade failures and synchronization dynamics on European and US power grids

Friday, March 17th, 14:00–15:30

14:00–14:15	**Georgios Balasis** Complex systems perspectives pertaining to the research of the geospace environment
14:15–14:25	**Gorka Zamora Lopez**, Matthieu Gilson Perturbation-based graph theory: An integrative dynamical perspective for the study of complex networks
14:25–14:35	**Jose M. Amigo**, Roberto Dale, Piergiulio Tempesta Complexity-based permutation entropies: from deterministic time series to white noise
14:35–14:45	P. Haerter, **Ricardo Viana** Synchronization of phase oscillators due to nonlocal coupling mediated by the diffusion of a substance
14:45–14:55	**M. Carmen Romano**, Ian Stansfield, Pierre Bonnin, Norbert Kern, Alexander Groh, Scott Angus, Tomas Gouveia Patient flow through a hospital: A combined data-driven and modelling approach
14:55–15:05	**Oleh Omel'chenko** Periodic orbits in the Ott–Antonsen manifold
15:05–15:15	**Tamás Kovács** Exoplanetary mass constraints based on topology of interacting networks

MS 2 – Analysis and modeling of infrastructure networks

Convener: Nora Molkenthin, Dirk Witthaut
Room: lecture room 1

Wednesday, March 15th, 16:50–18:20

16:50–17:02 **Anna Büttner**, Anton Plietzsch, Mehrnaz Anvari, Frank Hellmann
A framework for synthetic power system dynamics

17:02–17:14 **Benjamin Schäfer**, Ulrich Oberhofer
Physics-inspired machine learning and stochastic models of power grid dynamics

17:14–17:26 **Bálint Hartmann**
How grid information affects the perception of vulnerability of the power grid under physical attacks

17:26–17:38 **Mehrnaz Anvari**
Hurricane-induced failures of critical transmission lines lead to huge power outages in Texas

17:38–17:50 Narges Chinichian, **Gregory Ireland**, Pierre-Francois Duc, Clara Neyrand, Philipp Blechinger
Estimating electricity demand profile of rural and peri-urban Nigerian households

17:50–18:02 **Naoya Fujiwara**
Human mobility networks and their applications

18:02–18:14 Christoph Steinacker, David-Maximilian Storch, Marc Timme, **Malte Schröder**
Demand-driven design of bicycle infrastructure networks

MS 3 – Adaptive and multistable networks

Convener: Serhiy Yanchuk, Tomasz Kapitaniak
Room: lecture room 3

Thursday, March 16th, 9:00–10:30

9:00–9:12 **Eckehard Schöll**
Partial synchronization patterns and chimera states in adaptive networks

9:12–9:24 **Celik Ozdes**, Deniz Eroglu, Norbert Marwan Tobias Braun
Multi-stable synchronization patterns and switching dynamics of paleoclimate networks

9:24–9:36 Christian Bick, **Tobias Böhle**, Christian Kühn
Bifurcations of twisted states in phase oscillator networks

9:36–9:48 **Luis Guillermo Venegas Pineda**, Hildeberto Jardón-Kojakhmetov, Ming Cao
Generating stable chimera states in adaptive networks

9:48–10:00 **Rico Berner**
Adaptivity and multi-mode-induced multistability in coupled oscillator systems

10:00–10:12 Tomasz Burzynski, **Przemyslaw Perlikowski**, Piotr Brzeski
Multistable dynamics of church bell system

10:12–10:24 A. A. Nanha Djanan, **B. R. Nana Nbendjo**
Response of mechanical structures supporting DC motors with limited power supply

10:24–10:30 **Tiago Pereira**, Carlos Fiore, Ralf Toenjes
Coherence resonance in networks

MS 4 – World-Earth system analysis

Convener: Jonathan Donges, Jobst Heitzig
Room: auditorium

Thursday, March 16th, 9:00–10:30

9:00– 9:05 **Jonathan Donges, Jobst Heitzig**
Introduction

9:05– 9:25 **Wolfram Barfuss**
Reshaping human-environment modeling

9:25– 9:40 **Alexander Makarenko**
Toward strict investigation of sustainable development of society: Formalization and models

9:40– 9:55 **Nico Wunderling**, Saverio Perri, Wolfram Barfuss, Amilcare Porporato, Michael Oppenheimer, Jonathan F. Donges Simon A. Levin, Johan Rockström
Concerted efforts of politics, society and science can effectively turn down tipping risks

9:55–10:10 **Miguel D. Mahecha**, Chaonan Ji, Guido Kraemer, Francesco Martinuzzi, David Montero, Karin Mora, Martin Reinhardt, Maximilian Söchting
Uncovering complex dynamics in the Earth system using Earth system data cubes

10:10–10:25 **Bernd Blasius**
Theoretical ecology meets marine geochemistry: Approaching the enigmatic persistence of dissolved organic matter in the oceans

10:25–10:30 **Jonathan Donges, Jobst Heitzig**
Wrap-up

MS 5 – Cardiovascular dynamics and sleep disorders

Convener: Niels Wessel, Ulrich Parlitz
Room: lecture room 1

Thursday, March 16th, 9:00–10:30

9:00– 9:15 **Thomas Penzel**
Sleep research using non-linear analysis supports the understanding of physiological brain functions

9:15– 9:30 **Dagmar Krefting**
Measuring synchronization of physiological systems in sleep – Chances and challenges

9:30– 9:45 **Beata Graff**, Grzegorz Graff, Krzysztof Narkiewicz
Assessment of cardiorespiratory variability from a clinician's perspective

9:45–10:00 **Dirk Cysarz**, Friedrich Edelhäuser
Asymmetries of heart period dynamics assessed by its cumulative accelerations and decelerations

10:00–10:15 **Thomas Lilienkamp**, Ulrich Parlitz, Stefan Luther
Adapting pulse sequences for an efficient termination of spiral wave chaos

10:15–10:30 **Flavio H. Fenton**, Uzelac Ilija, Neal Bhatia, Shahriar Iravanian, Elizabeth M. Cherry
Nonlinear dynamics in live explanted human hearts – From spiral waves to unstable periodic orbits including period three and chaos

MS 6 – Dynamics of complex biological systems

Convener: Alexey Zaikin, Aneta Koseska
Room: auditorium

Friday, March 17th, 11:00–12:30

11:00–11:15 **Alexander Auhlela**
Arnold tongues in mouse embryonic development

11:15–11:30 **Benjamin Lindner**
Fluctuation-dissipation relations for spiking neurons

11:30–11:42 **Mogens Jensen**
Oscillations, Arnold Tongues and Chaos in Cell Dynamics

11:42–11:54 **Arkady Pikovsky**, Lev Tsimring
Statistical theory of asymmetric damage segregation in clonal cell populations

11:54–12:06 Bhumika Thakur, **Hildegard Meyer-Ortmanns**
Heteroclinic dynamics as framework for cognitive processes

12:06–12:18 **Klaus Lehnertz**
Network-based approaches to prediction and control of epileptic seizures

12:18–12:30 **Axel Hutt**, Jérémie Lefebvre
Additive noise-induced stability tuning in neuronal systems

MS 7 – Nonlinear dynamics in economics

Convener: Giuseppe Orlando, Willi Semmler
Room: lecture room 1

Friday, March 17th, 11:00–12:30

11:00-11:15	**Stefan Mittnik** Modeling state-dependent dynamics
11:15-11:30	**Pu Chen**, Willi Semmler Stability in threshold VAR models
11:30-11:45	**Marek Lampart**, Alžběta Lampartová, Giuseppe Orlando On risk and market sentiments driving financial share price dynamics
11:45-12:00	Marek Lampart, **Alžběta Lampartová**, Giuseppe Orlando On extensive dynamics of a Cournot heterogeneous model with optimal response
12:00-12:15	Jian Kang, Changli He, Annastiina Silvennoinen, **Timo Teräsvirta** Long monthly European temperature series and the North Atlantic Oscillation
12:15-12:30	**Oliver Richters** Modeling the out-of-equilibrium dynamics of bounded rationality and economic constraints

MS 8 – Causation and prediction of weather and climate extremes

Convener: Bruno Merz, Jakob Runge
Room: lecture room 1

Friday, March 17th, 11:00–12:30

11:00–11:05	**Jakob Runge, Bruno Merz** Introduction
11:05–11:25	**Leonard A. Smith** *(Keynote)* A dynamical systems view of the prediction of extreme weather events in a changing climate: Insight, foresight and attribution
11:25–11:40	**Elena Surovyatkina** Forecasting tropical monsoon: Advances and opportunities
11:40–11:55	**Milan Paluš** Causality in complex systems: Multiple scales and extreme events
11:55–12:10	**Norbert Marwan**, Tobias Braun, K. Hauke Kraemer, Abhirup Banerjee, Deniz Eroglu Recurrence plots for analysing extreme events data
12:10–12:25	**Noémie Ehstand** A percolation framework to anticipate fast changes in irregular climate oscillations
12:25–12:30	**Jakob Runge, Bruno Merz** Wrap-up

MS 9 – Tipping points

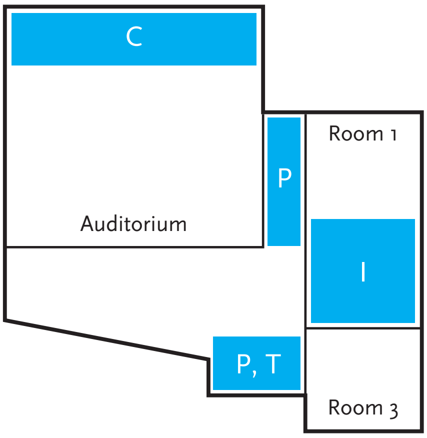
Convener: Niklas Boers, Valerio Lucarini
Room: lecture room 1

Friday, March 17th, 14:00–15:30

14:00–14:18	N. Sharafi, C. Martin, **S. Hallerberg** Critical transitions and perturbation growth
14:18–14:36	**Keno Riechers**, Georg Gottwald, Niklas Boers Glacial abrupt climate change as a multi-scale phenomenon resulting from monostable excitable dynamics
14:36–14:54	Martin Hessler, **Oliver Kamps** Bayesian on-line anticipation of critical transitions
14:54–15:12	**Induja Pavithran**, P. R. Midhun, R.I. Sujith Tipping in complex systems under fast variations of parameters
15:12–15:30	**Frank Kwasniok** Data-driven anticipation and prediction of Atlantic Meridional Overturning Circulation collapse using non-autonomous spatiotemporal dynamical modelling

Poster

Poster session 1: Wednesday, March 15th, 18:20–21:00



Group C: Concepts from complex systems – networks, synchronisation, recurrence

C1 **A. Tiganouria**, M. Pavlidou, D. Valavanis, D. Spanoudaki, Ch. Gkili, D. Sazou
Recurrence analysis of the complex dynamics of an electrochemical oscillator comprising the destabilization of iron induced by halides under current-controlled conditions

C2 **Abinesh Ganapathy**, Ankit Agarwal
Multi-scale SST-streamflow connectivity: A complex network approach

C3 **Akhilesh Nandan**, Aneta Koseska
Role of transient dynamics versus fixed points in cellular sensing and responsiveness to dynamic spatial-temporal signals

C4 **Alexander Schlemmer**, Inga Kottlarz, Baltasar Rüchardt, Ulrich Parlitz, Stefan Luther
Improving findability and reproducibility of research data using semantic data management with CaosDB

C5 Matheus Hansen, Paulo R. Protachevicz, Kelly C. Iarosz, Ibere L. Caldas, Antonio M. Batista, **Elbert E. N. Macau**
The effect of time delay for synchronisation suppression in neuronal networks

C6 **Gonzalo Contreras**, Miguel Romance, Regino Criado
Parametric control of PageRank on real network data

C7 **J. S. Armand Eyebe Fouda**, Wolfram Koepf
The permutation largest slope network: Concept and applications

C8 **Jonathan F. Donges**, Jakob Lochner, Niklas Kitzmann, Jobst Heitzig, Sune Lehmann, Marc Wiedermann, Jürgen Vollmer
Dose-response functions and surrogate data models for exploring complex social contagion and tipping dynamics

C9 **José Angel Mercado Uribe**, Jesus Mendoza Avila, Denis Efimov, Johannes Schiffer
Global synchronization analysis of acyclic networks of heterogeneous Kuramoto oscillators

C10 L. Alexandre, W. Duch, L. Furman, **K. Tolpa**
Recurrence analysis of brain neurodynamics

C11 **Matheus Palmero**, Iberê Caldas, Igor Sokolov
Recurrence analysis of chaotic trajectories: Application in tokamaks

C12 **Matheus R. Sales**, Michele Mugnaine, José D. Szezech Jr., Ricardo L. Viana, IbeIberê L. Caldas, Norbert Marwan, Jürgen Kurths
Characterizing stickiness using recurrence time entropy

C13 **Matthias Wolfrum**
Phase sensitive excitability of a limit cycle

C14 **Miwa Fukino**, Yoshito Hirata, Kazuyuki Aihara
Comparing music waveform and its MIDI by their hierarchical recurrence plots

C15 **Nils Antary** Norbert Marwan
Interpolation effects an RQA measures

C16 **Paulo R. Protachevicz**, Fernando S. Borges, Kelly C. Iarosz, Iberê L. Caldas, Antonio M. Batista, Murilo S. Baptista, Jürgen Kurths
Emergence of highly synchronized firing patterns in neuronal networks

C17 **Rubens Sautter**, Reinaldo Rosa, Luan Barauna
Characterizing nonlinear spatiotemporal dynamics by gradient pattern analysis

C18 **Shruti Tandon**, R. I. Sujith
Multilayer network analysis of turbulent thermoacoustic system

C19 **Teddy Craciunescu**, Andrea Murari
Time series analysis for fusion plasma disruption prediction

C20 **Yue Weng**, Vishnu R. Unni, R. I. Sujith, Abhishek Saha
Transition to thermoacoustic instability: Modeling order emerging in a complex system using a synchronization framework

C21 **Fred Feudel**, Ulrike Feudel
The influence of a differential rotation on bifurcations of buoyancy driven spherical shell convection

Group I: Analysis and modeling of infrastructure networks

I1 **Angeles Criado-Alonso**, David Aleja, Miguel Romance, Regino Criado
A new tool to analyze mesoscopic and centrality relationships in complex networks

I2 **Jonas Wassmer**, Bruno Merz, Norbert Marwan
Resilience of emergency infrastructure networks after flooding events

I3 **Henrik M. Bette**, Thomas Guhr
Sensitivity of principal components to changes in the presence of non-stationarity

I4 **Michael Lindner**, Christian Nauck
Graph neural networks beat network science at predicting dynamic stability of sustainable power grids

I5 **Timo Haselhoff**, Tobias Braun, Norbert Marwan, Susanne Moebus
Complex networks for the urban acoustic environment

I6 **Yunfei Li**, Deniz Ural, Caner Aydin, Celine Rozenblat, Jan W. Kantelhardt, Diego Rybski
Indication of long-range city size correlation analysis based on city networks of European countries

I7 Patrycja Jaros, Roman Levchenko, Tomasz Kapitaniak, Jürgen Kurths, **Yuriy Maistrenko**
Asymmetry induces critical desynchronization of power grids

Group P: Causation and prediction of weather and climate extremes and Nonlinear dynamics in economics

P1 **Akash Singh Raghuvanshi**, Ankit Agarwal
Linking anomalous high moisture transport to extreme precipitation

P2 **Rubens Sautter**, Reinaldo Rosa, Pablo Medina, Juan Valdivia
Characterizing extreme patterns from time series

P3 **Tobias Braun**, Sara M. Vallejo-Bernal, Dominik Traxl, Norbert Marwan, Jürgen Kurths
A spatio-temporal analysis of global atmospheric rivers

P4 **Sara M. Vallejo-Bernal**, Tobias Braun, Norbert Marwan, Jürgen Kurths
Synchronized heavy rainfall events in Europe: the role of atmospheric rivers

P5 **Shraddha Gupta**, Zhen Su, Abhirup Banerjee, Niklas Boers, Norbert Marwan, Linus Magnusson, Cristobal Lopez, Emilio Hernandez-Garcia, Florian Pappenberger and Jürgen Kurths
Spatial synchronization patterns of extreme rainfall and convection in the Asian Summer Monsoon region

P6 **Giuseppe Orlando**, Giovanna Zimatore
Is deterministic chaos present in business cycles?

P7 **Haochun Ma**, Alexander Haluszczynski, Davide Prosperino, Christoph Räth
Causalities and their drivers in financial data

P8 **Sijmen Duineveld**
Projection methods made easy

Group T: Tipping points

T1 **Ayanava Basak**, Syamal Kumar Dana, Nandadulal Bairagi
Frequency-dependent tipping in driven ecological system

T2 **Da Nian**, Sebastian Bathiany, Maya Ben-Yami, Lana Blaschke, Marina Hirota, Regina Rodrigues, Niklas Boers
Combined effects of global warming and the collapse of AMOC over South America

T3 **Giulio Tirabassi**, Cristina Masoller
Entropy-Based Early Detection of critical transitions in spatial vegetation fields

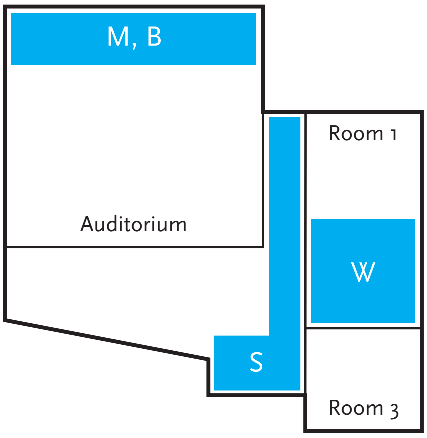
T4 **Jan Swierczek-Jereczek**, George Datseris
TransitionIndicators.jl – A high end software to accelerate research and computation of transition indicators

T5 **Reyk Börner**, Ryan Deeley, Raphael Römer, Tobias Grafke, Ulrike Feudel, Valerio Lucarini
Limits of large deviation theory in predicting transition paths of tipping events

T6 **Markus Drüke**, Boris Sakschewski, Werner von Bloh, Maik Billing, Wolfgang Lucht, Kirsten Thonicke
Fire prevents future Amazon forest recovery after large-scale deforestation

T7 **Taylor Smith**, Niklas Boers
Progress on data reliability and processing best practices for resilience estimation with satellite data

Poster session 2: Thursday, March 16th, 10:45–12:15



Group M: Methods

M1 **Alistair White**, Niklas Boers
Stabilized universal differential equations for hybrid machine learning of conservative dynamical systems

M2 **Gábor Drótos**, Emilio Hernández-García, Cristóbal Lopez
Local characterization of transient chaos on finite times in open systems

M3 **Zhen Su**, Jürgen Kurths, Henning Meyerhenke
Network sparsification via degree- and subgraph-based edge sampling

M4 **Inga Kottlarz**, Ulrich Parlitz
Ordinal pattern based complexity analysis of high-dimensional chaotic time series

M5 Matheus R. Sales, Michele Mugnaine, Ricardo L. Viana, Iberê L. Caldas, **José D. Szezech Jr.**
Uncertainty boundaries in Hamiltonian Systems

M6 **Maximilian Gelbrecht**, K. Hauke Krämer, Norbert Marwan
TreeEmbedding: Optimal state space reconstruction via Monte Carlo decision tree search

M7 **Sergio Iglesias**, Regino Criado
Combining multiplex networks, time series and machine learning: A methodology for reducing the dimensionality of data representation and making effective predictions

M8 Tushar Mitra, **Md. Kamrul Hassan**
Infinitely many conserved quantities in a weighted planar stochastic lattice and their connection to Noether's theorem

M9 **Yang Liu**, Xiaoqi Wang, Xi Wang, Zhen Wang, Jürgen Kurths
Percolation-based Evolutionary Framework for the diffusion-source-localization problem in large networks

Group B: Dynamics of complex biological systems

B1 Cedric Hameni Nkwayep, **Samuel Bowong**
Modelling, parameter and state estimation, and optimal control of COVID-19 pandemic: A study case of Cameroon

B2 **Daniel Koch**
Nonlinearity in biochemical networks resulting from protein homo-oligomerisation

B3 **Elena Adomaitienė**, Skaidra Bumelienė, Arūnas Tamaševičius
Stabilizing equilibrium in an array of the neuronal oscillators by injecting electrical current proportional to inverted mean membrane potential

B4 **Karin Mora**, Jana Wäldchen, Michael Rzanny, Guido Kraemer, Ingolf Kühn, Patrick Mäder, Miguel D. Mahecha
Dynamics of collective flora behaviour from crowd-sourced data

B5 **Michele Mugnaine**, Enrique C. Gabrick, Paulo R. Protachevicz, Kelly C. Iarosz, Silvio L. T. de Souza, Alexandre C. L. Almeida, Antonio M. Batista, Iberê L. Caldas, José D. Szezech Jr., Ricardo L. Viana
Control attenuation and second wave scenario in a cellular automata SEIR epidemic model

B6 **Yu Meng**, Ying-Cheng Lai, Celso Grebogi
The fundamental benefits of multiplexity in ecological networks

B7 **Nikita Frolov**, Liliana Piñeros, Bartosz Prokop, Lendert Gelens
Scaling relationship between nuclear density and cell cycle duration in frog egg extracts

B8 **Philipp Hövel**, Sebastian Jenderny, Karlheinz Ochs, Jorge Ruiz, Thomas Maertens
Simulating the locomotion of C. Elegans via an extended Hindmarsh-Rose model

B9 **Sabrina Hempel**, Huyen Vu, Moustapha Doumbia, Qianying Yi, David Janke, Thomas Amon
Livestock-environment-interaction in naturally ventilated housing on the example of ammonia

B10 **Shaoxuan Cui**, Fangzhou Liu, Hildeberto Jardón Kojakhmetov, Ming Cao
Modelling and analysis of the mean-field SIWS epidemic model with higher-oder interactions

B11 **Sourav Roy**, Sayantan Nag Chowdhury, Prakash Chandra Mali, Matjaz Perc, Dibakar Ghosh
Eco-evolutionary dynamics with multi-games under mutation

Group S: Cardiovascular dynamics and sleep disorders

S1 **Alondra Albarado-Ibañez**, Martha Ita-Amador, Julian Torres-Jacome
Dimorphism sexual and frequency cardiac: non-linear method analyses

S2 Chiara Barà, **Yuri Antonacci**, Luca Faes
Estimating the decomposition of the mutual information rate in short-term cardiovascular variability time series: Comparison between different discretization strategies

S3 **Daniel Suth**, Thomas Lilienkamp
From 2D to 3D: Comparing the performance of different GPU-based algorithms to simulate cardiac excitation wave dynamics

S4 **Mateusz Ozimek**, Karolina Rams, Jan Zebrowski, Teodor Buchner
Information dynamics of heart rhythm, repolarization and amplitudes time series in Long QT Syndrome

S5 **Richa Tripathi**, Rammah Abohtyra, Bruce J. Gluckman
Mechanistic neural masses for modeling seizures and spreading depolarization

S6 **Sayedeh Hussaini**, Johannes Schroeder-Schetelig, Aidai M. Kyzy, Sarah L. Lädke, Laura Diaz, Raul Q. Uribe, Vishalini Venkatesan, Claudia Richter, Annette Witt, Vadim Biktashev, Rupamanjari Majumder, Valentin Krinski, Stefan Luther
Efficient termination of cardiac arrhythmias using optogenetic resonant feedback pacing

S7 **Stefan Luther**
Spatial-temporal organisation of cardiac fibrillation: From principles to patients

Group W: World-Earth system analysis

W1 **Andrej Spiridonov**, Shaun Lovejoy, Lauras Balakauskas
Scaling of tectonics, biogeographical structures, and macroevolution

W2 **Françoise Martine Enyegue à Nyam**, Collins Djouda Paguem
Modelling the evolution of the volcanic plume height as a function of the eruption time and the seasonal climate

W3 **Gaurav Chopra**, V. R. Unni, R. I. Sujith
Spatiotemporal dynamics of the ITCZ using complex network analysis of outgoing longwave radiation

W4 **Hannah Prawitz**
Towards modelling the Anthropocene: Conception and analysis of potential planetary-scale socio-ecological feedbacks the nexus of climate change, loss of biosphere integrity and human mitigation behaviour

W5 **Leonard Schulz**, Karin Mora, Jürgen Vollmer, Miguel Mahecha
Inferring dynamical information of the Earth system by dimensionality-reduction

W6 **Markus Abel**, Thomas Seidler, Markus Quade, Fabian Emmerich
Phase transitions in machine learning

W7 **Max Bechthold**
Local resource dynamics and normative spreading of behaviour in a World-Earth model

W8 **Moritz Adam**, Kira Rehfeld
Artificial trees and sustainable development – Towards coupling decision making on carbon dioxide removal with a comprehensive Earth system modeling framework

W9 **Niklas Kitzmann**, Jonathan Donges
Assortativity and consensus: A stylized model of frontrunner cities and global sustainability action

W10 **Takahito Mitsui**, Metteo Willeit, Niklas Boers
Synchronization theory for Quaternary ice age cycles

W11 **Francesco Martinuzzi**, Miguel D. Mahecha, Karin Mora
Learning biosphere response to climate drivers using echo state observers

Abstracts

Invited keynote lectures

Recent achievements in studying ecological networks

Celso Grebogi

University of Aberdeen
grebogi@abdn.ac.uk

Long-term predictions constitute a fundamental challenge in ecology, epidemiology and climate science. Reliable forecasting is difficult because of sensitive dependence on initial conditions, noise, and incomplete data. Another obstacle to reliable prediction of ecosystems is a phenomenon known as "regime shift", where any conclusions or estimates based on the observations made before the regime shift become irrelevant after the shift. The timing of the regime shift is difficult to predict and the problem of identifying early warning signals remains largely open. Sudden regimes shift often results in a population collapse, extinction of species and biodiversity loss, making it an important issue for nature conservation and ecosystem management. Focusing on the regime shift or the tipping-point dynamics in ecological mutualistic networks of pollinators and plants constructed from empirical data, I will examine the phenomena of noise-induced collapse and noise-induced recovery, aiming at understanding the interplay between transients and stochasticity. I will discuss control strategies that delay the extinction and advances the recovery by controlling the decay rate of pollinators in a stochastic mutualistic complex network, whose control strategies are affected by Gaussian environmental and state-dependent demographic noises. Since in recent years, the concept of multilayer networks has also been adopted in ecology, I will also look at the influence of the topological structure on the control effect due to multiplexity. This is a basic notion in complex multilayer networks, where a subset of nodes belongs simultaneously to different network layers. I will argue that multiplexity also arises in multilayer ecological networks supported by mutualism and, more importantly, it has the fundamental benefits to sustaining the whole networked system and keeping it in a healthy state by delaying, often significantly, the occurrence of a catastrophic tipping point that would otherwise lead to extinction on a massive scale.

References

Y. Meng and C. Grebogi, Control of tipping points in stochastic mutualistic complex networks, Chaos 31, 023118(1-9) (2021)

C. Grebogi, Sudden regime shifts after apparent stasis: Comment on long transients in ecology, Physics of Life Reviews 32, 41 (2020)

Y. Meng, Y.-C. Lai, and C. Grebogi, Tipping point and noise-induced transients in ecological networks, J. Royal Soc. Interface 17, 20200645 (2020)

Y. Meng, Y.-C. Lai, and C. Grebogi, The fundamental benefits of multiplexity in ecological networks, J. R. Soc. Interface 19, 20220438 (2022)

The dynamics of higher-order networks: The effect of topology and triadic interactions

Ginestra Bianconi

(1) Queen Mary University of London; (2) The Alan Turing Institute
ginestra.bianconi@gmail.com

Higher-order networks capture the interactions among two or more nodes and they are raising increasing interest in the study of brain networks. Here we show that higher-order interactions are responsible for new dynamical processes that cannot be observed in pairwise networks. In this talk we will cover how topology is key to define synchronization of topological signals, i.e., dynamical signal defined not only on nodes but also on links, triangles and higher-dimensional simplices in simplicial complexes. Interesting topological synchronization dictated by the Dirac operator can lead to the spontaneous emergence of a rhythmic phase where the synchronization order parameter displays low frequency oscillations which might shed light on possible topological mechanisms for the emergence of brain rhythms. We will also reveal how triadic interactions can turn percolation into a fully-fledged dynamical process in which nodes can turn on and off intermittently in a periodic fashion or even chaotically leading to period doubling and a route to chaos of the percolation order parameter.

The predictive power of theoretical biology: An example

Jean-Pierre Eckmann

Université de Genève, Département de physique théorique et Section de Mathématiques
jean-pierre.eckmann@unige.ch

I will argue, supported by an experiment, that theoretical biology moves (very slowly) in a direction where predictions (as in theoretical physics) become possible. We start with a simple, theoretical, mechanical-genetic model of protein. Using the interpration of its spectral properties, one can formulate some predictions on the possible effects when the protein is mutated. The results suggest that only mutations at specific positions in the gene sequence can have a relevant effect on the function of the protein. These predictions have then been checked in a delicate experiment with actual mutations in the protein Guanylate kinase. A clear signal confirms the theoretical prediction.

Complex networks in financial systems

Veronika Stolbova

ETH Zurich
veronika.stolbova@gmail.com

Policymakers, investors, and firms recognize the need to assess the financial impact of climate change and climate policy on the real economy and the financial system. It is debated, that the introduction of climate policies might lead to a reevaluation of a large portion of financial assets with implications for financial stability. However, currently, there are no consistent bottom-up monetary estimates of climate change-related financial gains and losses of the economy as well as of the current exposure of the economy's financial assets to climate change. To fill this gap, we develop a framework for the assessment of climate change-related financial gains and losses building on recent developments in climate policy assessment, climate stress-testing, and risk analysis. We apply this framework to macro-level and micro-level data of financial contracts (equity holdings, bonds, and loans) between firms worldwide, estimate climate policy risks for the Euro Area, and assess implications for financial stability. We find that direct exposure of the Euro Area through financial assets to fossil-fuel, utility and energy-intensive sectors is relatively small in monetary terms across equity holdings, bonds, and loans. However, financial interconnectedness at the macro-level plays a crucial role in the assessment of climate change-related gains and losses, with noticeable consequences for insurance and pension funds sector of the Euro area.

Climate variability from the last Glacial to the Anthropocene: Knowns, unknowns and future challenges

Kira Rehfeld

Tübingen University, Germany
kira.rehfeld@uni-tuebingen.de

Substantial temperature and precipitation variability with large amplitudes occurred over the last 130,000 years, from the last Interglacial, through the last Glacial up to the last pre-anthropogenic global warming that led to the Holocene Interglacial more than 10,000 years ago. With the industrialization, human influence has overprinted natural variability of the Earth system, and the Holocene has given way to a continued warming now officially recognized as the era of the Anthropocene. Early evidence of large changes in climate variability between cold and warm Earth system states were recognized from Greenland ice core data since the late 20^{th} century. With advances in palaeoclimate data compilation, analysis and proxy modelling we gained a spatio-temporal perspective on the evolution of the climate system over the last 130,000 years. Systematic comparison to state-of-the-art global circulation models (as used in the IPCC projections) shows shortcomings in these model systems beyond the centennial timescale. The newly emerging coupled models out of the PalMod project (https://www.palmod.de) including dynamic ice sheets and solid Earth components show more promise in representing levels of variability consistent with palaeoclimate evidence. Data-model integration therefore improved our understanding of the longterm predictability of the climate system. Large unknowns in all compartments (Atmosphere, Ocean, Biosphere, Cryosphere, Anthroposphere) remain, each with significant influence on the future trajectory of the Earth system.

Nonlinear data analysis and the visual arts

Matjaž Perc

University of Maribor
matjaz.perc@gmail.com

The 20^{th} century is often referred to as the century of physics. From x-rays to the semiconductor industry, human societies today would indeed be very different were it not for the progress made in physics laboratories around the world [1,2]. What the past 100 years have been for science, the past millennium has been for the arts. From the late Byzantine and Islamic art to Renaissance, Realism and Pop art, the past 1000 years are packed with the most productive periods of our creative existence. The availability of digitized artworks allows us to perform large-scale nonlinear data analysis of the history of visual arts. We have analyzed almost 140,000 visual artworks [3], the majority of which were paintings, by more than 2,300 artists created between the years 1031 and 2016. Based on the complexity and entropy of spatial patterns in the artworks, we were able to hierarchically categorize the artworks on a scale of order-disorder and simplicity-complexity, revealing a temporal evolution of the artworks that coincides with the main historical periods of art. We also outline possibilities for similar research in other forms of art [4].

References

[1] M. Perc, Self-organization of progress across the century of physics, Sci. Rep. 3, 1720 (2013)

[2] T. Kuhn, M. Perc, and D. Helbing, Inheritance patterns in citation networks reveal scientific memes, Phys. Rev. X 4, 041036 (2014)

[3] H. Y. D. Sigaki, M. Perc, and H. V. Ribeiro, History of art paintings through the lens of entropy and complexity, Proc. Natl. Acad. Sci. U.S.A. 115, E8585-E8594 (2018)

[4] M. Perc, Beauty in artistic expressions through the eyes of networks and physics, J. R. Soc. Interface 17, 20190686 (2020)

Deficiency of deterministic modeling and data-based causal analysis of complex dynamical systems

Ying-Cheng Lai

Arizona State University
`Ying-Cheng.Lai@asu.edu`

This talk will focus on my joint papers with Jürgen in the past as well as some recent effort in climatic dynamics stimulated by Jürgen's pioneering works in this field. First, I will argue that in complex dynamical systems, there are situations such as unstable dimension variability in which deterministic modeling fails, rendering necessary to develop completely data-driven approaches. I will then discuss the challenging problem of detecting direct causation by eliminating indirect causal influences in situations where the variables of the underlying dynamical system are non-separable and are weakly coupled. I will present a model-free and completely data-driven method of partial cross mapping based on a synthesis of three known methods from nonlinear dynamics and statistics: phase-space reconstruction, mutual cross mapping, and partial correlation, and provide support from a number of real-world systems. Finally, I will discuss a recent work on detecting and quantifying the causal influence among different climate regions in the contiguous U.S. in response to temperature perturbations using the long-term (1901–2018) record of near surface air temperature. The directed causal network constructed by the convergent cross-mapping algorithm enables us to distinguish the causal links from spurious ones rendered by statistical correlation and to identify the Ohio Valley region as an atmospheric convergent zone that acts as the regional gateway and mediator to the long-term thermal environments in the contiguous U.S.

References

[1] Y.-C. Lai, C. Grebogi, and J. Kurths, Modeling of deterministic chaotic systems, Physical Review E 59, 2907–2910 (1999)

[2] H.-F. Ma, S.-Y. Leng, C.-Y. Tao, X. Ying, J. Kurths, Y.-C. Lai, and W. Lin, Detection of time delays and directional interactions based on time series from complex dynamical systems, Physical Review E 96, 012221, 1–8 (2017)

[3] S.-Y Leng, H.-F. Ma, J. Kurths, Y.-C. Lai, W. Lin, K. Aihara, and L.-N. Chen, Partial cross mapping eliminates indirect causal influences, Nature Communications 11, 2632, 1–9 (2020)

[4] X.-L. Yang, Z.-H.Wang, C.-H.Wang, and Y.-C. Lai, Detecting the causal influence of thermal environments among climate regions in the United States, Journal of Environmental Management 322, 116001, 1–9 (2022)

Machine-learning approaches for predicting cardiac voltage dynamics

Elizabeth M. Cherry, Shahrokh Shahi

School of Computational Science and Engineering, Georgia Institute of Technology
`echerry30@gatech.edu`

Disruptions to the electrical behavior of the heart caused by cardiac arrhythmias can result in complex dynamics, from period-2 rhythms in single cells to spatiotemporally complex spiral and scroll waves of electrical activity, which can inhibit contraction and may be lethal if untreated. Accurate forecasts of cardiac voltage behavior could allow new opportunities for intervention and control, but predicting complex nonlinear time series is a challenging task. In this talk, we discuss our recent work using machine-learning approaches based in reservoir computing to forecast cardiac voltage dynamics.

First, we show that a novel method combining an echo state network with automated feature extraction via an autoencoder can successfully and efficiently predict time series of synthetic and experimental datasets of cardiac voltage in one cell 20-30 action potentials in advance. Building on this work, we then demonstrate a novel method for predicting the complex spatiotemporal electrical dynamics of cardiac tissue using an echo state network integrated with a convolutional autoencoder. We show that our approach can forecast complex spiral-wave behavior including breakup several periods in advance for time series ranging from model-derived synthetic datasets to optical-mapping recordings of explanted human hearts.

Singular, dual and plural: A tale of numbers, networks and synchrony

Rajarshi Roy

University of Maryland, College Park
rroy@umd.edu

Life is full of examples where one progresses from one, to two and then to many; you can just open the Bible and realize that such thoughts have occupied us from a long time back. We will reflect on the dynamics of systems on their own, and then in twos, and finally in threes and fours and more. While creating many identical replicas is difficult (specially for nonlinear dynamical systems), we will examine situations where diversity is important and useful for networks and for synchrony. Some examples from our laboratory and beyond will illustrate these ideas at different scales of space and time. Light will play a central role in illuminating what is distinguishable and indistinguishable.

Chaos and noise in the aid of logic

Sudeshna Sinha

Indian Institute of Science Education and Research Mohali
sudeshna@iisermohali.ac.in

We discuss how understanding the nature of chaotic dynamics allows us to manipulate these complex systems to obtain versatile pattern generators that can be used for a range of applications. Specifically we will discuss the application of chaos to the design of reconfigurable dynamic logic gates. Further we indicate how one can exploit the interplay of nonlinearity and noise to obtain more consistent and robust logic operations. We also suggest how these concepts may be applied to systems ranging from electronic circuits and synthetic genetic networks, to nanomechanical oscillators.

Tipping of the Atlantic Ocean Circulation

Rene van Westen, Sven Baars, **Henk A. Dijkstra**

IMAU, Department of Physics, University of Utrecht, The Netherlands
h.a.dijkstra@uu.nl

The Atlantic Ocean Circulation, in particular its zonally averaged component called the Atlantic Meridional Overturning Circulation (AMOC), is one of the tipping elements in the climate system. The AMOC is sensitive to freshwater perturbations and may undergo a transition to a climate disrupting state within a few decades under continuing greenhouse gas emissions. The potential climate impacts of such a collapse are enormous and hence reliable estimates of the probability of its occurrence before the year 2100 are crucial information for policy makers. In his talk, an overview will be given of the current state of addressing the AMOC collapse problem and approaches to determine AMOC transition probabilities in a hierarchy of ocean-climate models.

Early warning and suppression of noise-induced critical transitions

Yong Xu

Northwestern Polytechnical University
hsux3@nwpu.edu.cn

Noise-induced critical transitions (CTs) from one dynamical state to another contrasting one are widespread in real systems. Once they take place, it is often difficult to restore a system to the previous state, and may cause some catastrophic effects on human living environment, economy and health. Therefore, early warning and suppression of noise-induced CTs have been always the hottest topics in the investigation of nonlinear stochastic dynamics. In this presentation, Gaussian white noise-induced CTs between adjacent states and Lévy noise-induced CTs between two non-adjacent states are shown, respectively. Correspondingly, a more general early-warning indicator, the parameter dependent basin of the unsafe regime (PDBUR), is proposed. This is a new and efficient tool to quantify the ranges of the parameters where Gaussian white noise or Lévy noise-induced CTs may occur. Furthermore, by an external linear augmentation method, a new perspective to suppress noise-induced critical transitions away from a desirable state to another contrasting one is presented. All of these results may provide some guidance for managers to take some measures to avoid such catastrophic noise-induced critical transitions in practical applications.

This is a joint work with Jinzhong Ma (Shanxi University) and Jürgen Kurths (Humboldt University and PIK).

Multistability and tipping: Critical transitions in complex systems

Ulrike Feudel (1), Lukas Halekotte (1,2), Sarah Schoenmakers (1), Anna Vanselow (1), Sebastian Wieczorek (3)

(1) ICBM, Carl von Ossietzky University Oldenburg, Germany; (2) Institute for the Protection of Terrestrial Infrastructures, DLR, Germany; (3) Dept. Mathematics, University College Cork, Ireland
ulrike.feudel@uni-oldenburg.de

Many systems in nature are characterized by multistabiliy, i.e., the coexistence of different stable states for a given set of environmental parameters and external forcing. Examples for such behavior can be found in different fields of science ranging from mechanical or chemical systems to ecosystem and climate dynamics. As a consequence of the coexistence of a multitude of stable states, the final state of the system depends strongly on the initial condition. Perturbations, applied to those natural systems can lead to a critical transition from one stable state to another. Such critical transitions are called tipping phenomena in climate science, regime shifts in ecology or phase transitions in physics. Such critical transitions can happen in various ways: (1) due to bifurcations, i.e., changes in the dynamics when external forcing or parameters are varied extremely slow (2) due to fluctuations which are always inevitable in natural systems, (3) due to rate-induced transitions, i.e., when external forcing changes on a characteristic time scale comparable to the time scale of the considered dynamical system and (4) due to shocks or extreme events. We discuss these critical transitions and their characteristics and illustrate them with examples from mechanical and natural systems. Moreover, we discuss the concept of resilience, which has been originally introduced by C.S. Holling in ecology, and reformulate it in terms of dynamical systems theory.

Asymptotic scaling of signal propagation in complex networks

Peng Ji

Fudan University
pengji@fudan.edu.cn

Many collective phenomena such as epidemic spreading and cascading failures in socioeconomic systems on networks are caused by perturbations of the dynamics. How perturbations propagate through networks, impact and disrupt their functions may depend on the network, the type and location of the perturbation as well as the spreading dynamics. Previous work has analyzed the retardation effects of the nodes along the propagation paths, suggesting a few transient propagation "scaling" regimes as a function of the nodes' degree, but regardless of motifs such as triangles. Yet, empirical networks consist of motifs enabling the proper functioning of the system. Here, we show that basic motifs along the propagation path jointly determine the previously proposed scaling regimes of distance-limited propagation and degree-limited propagation, or even cease their existence. Our results suggest a radical departure from these scaling regimes and provide a deeper understanding of the interplay of self-dynamics, interaction dynamics, and topological properties.

Recurrences: Fingerprints of dynamics – A journey from low dimensional systems to climate networks

Deniz Eroglu

Kadir Has University
deniz.eroglu@khas.edu.tr

Climate systems comprise parts (nodes) that interact through an intricate network, and climate events result from these unknown complex interactions. Understanding such complex systems that evolve in time is dependent on measured datasets. However, only data availability does not lead to a better understanding of a system if the interactions governing the evolution of the system's behavior remain unknown. Data analysis for the behavior characterization of dynamical systems requires sufficiently long time series, which is mostly unavailable for palaeoclimate proxies. In this talk, I will briefly overview recurrence plot based time series analysis using limited data, from characterizing low-dimensional systems to reconstructing paleoclimate networks. In the applications, topological changes in the paleoclimate networks allow the detection of climate regime switches in the past, which are the recursive events that will help to forecast oncoming climate events in large time scales.

Complex system approach to investigate and mitigate thermoacoustic instability in turbulent combustors

R. I. Sujith

Indian Institute of Technology Madras
sujith@iitm.ac.in

The onset of thermoacoustic instability leading to large amplitude self-sustained oscillations is a plaguing problem in the development of modern gas turbine and rocket engines. Thermoacoustic instability occurs as a consequence of the nonlinear interaction between the unsteady flame, the hydrodynamic field and the acoustic field in the combustor. Traditionally, this phenomenon has been modeled using a linear acoustic framework. An alternate perspective in which a thermoacoustic system in a turbulent combustor can be viewed as a complex system and its dynamics be perceived as emergent behaviors of this complex system has emerged recently. This perspective has led to strategies to forewarn and mitigate thermoacoustic instability based on complex systems theory.

MS1
Concepts from complex systems – networks, synchronisation, recurrence

(online) Dynamical transitions on multiplex networks

G. Ambika

(1) Indian Institute of Science Education and Research (IISER) Tirupati, INDIA (2) Indian Institute of Science Education and Research (IISER) Thiruvananthapuram, INDIA
g.ambika@iisertvm.ac.in

The real-world complex systems with multiple types of dynamics and multiple types of interactions among them, can be effectively modeled using the framework of multiplex networks. In this talk I will present the emergence of spatio-temporal patterns among dynamical systems connected on a multiplex framework. I will focus mainly on the transfer or selection of activity patterns between collection of neurons and emergence of stable amplitude chimeras and chimera death induced by multiplexing. The occurrence of explosive synchronization and other sudden transitions or tipping induced in a collection of systems due to multiplexing will also be presented.

Adaptation in higher-order interactions: Explosive transition to cluster synchronisation

Sarika Jalan

Indian Institute of Technology Indore
sarika@iiti.ac.in

So far, all the studies on adaptation in networks have revolved around pair wise interactions. Breaking away from the traditional approach of assuming adaptation in the pairwise coupling, we consider adaptation in higher-order couplings, and show that dynamically adaptive simplicial couplings give birth to cluster (de)synchronization. Notably, the global synchronization which is a prominent feature for non-adaptative simplicial complexes is entirely suppressed as a consequence of adaptation. We develop an analytical framework based on Ott–Antonsen approximation for coupled phase oscillators on adaptive higher order interaction networks, which fully explain the origin of abrupt cluster synchronization and desynchronization.

High-order phase reduction explains remote synchrony in a chain of Stuart-Landau oscillators

M. Kumar (1), **M. Rosenblum (2)**

(1) Purdue University; (2) Potsdam University
mros@uni-potsdam.de

Remote synchronization implies that oscillators interacting not directly but via an additional unit (hub) adjust their frequencies and exhibit frequency locking while the hub remains asynchronous. In this paper, we analyze the mechanisms of remote synchrony in a small network of three coupled Stuart-Landau oscillators using recent results on higher-order phase reduction. We analytically demonstrate the role of two factors promoting remote synchrony. These factors are the nonisochronicity of oscillators and the coupling terms appearing in the second-order phase approximation. We show a good correspondence between our theory and numerical results for small and moderate coupling strengths.

Recurrence structure analysis of neurophysiological data

Peter beim Graben (1), Axel Hutt (2), Serafim Rodrigues(3)

(1) Bernstein Center for Computational Neuroscience, Berlin, Germany; (2) Université de Strasbourg, CNRS, lnria, ICube, MLMS, MIMESIS, Strasbourg, France; (3) Ikerbasque Mathematical, Computational and Experimental Neuroscience, Basque Center for Applied Mathematics, Bilbao, Spain

peter.beimgraben@b-tu.de

Recurrence is ubiquitous in complex nonlinear systems and can be studied by means of recurrence plots (RP) and recurrence quantification analyses (RQA). Another possibility is to consider the RP as a recurrence grammar which substitutes large time indices from a time series by the smallest, recurrent ones, thereby leading to a coarse-grained representation of the system's recurrence structure through symbolic dynamics [1,2]. Under two reasonable assumptions about the distribution of the system's recurrence domains, we suggested two possible utility functions for the optimization of the RP threshold parameter. First, assuming a uniform distribution of recurrence domains and non-recurrent transients over time, we postulated a maximum entropy criterion for the symbolic sequences [1,2]. Second, regarding recurrence domains as metastable states, we derived a utility function for an optimal Markov chain model [3]. In our contribution we compare both approaches by means of numerical simulation results and neurophysiological time series from event-related brain potentials [2,4], resting state fMRI data [5] and animal local field potentials [3].

References

[1] beim Graben, P. & Hutt, A. (2013). Detecting recurrence domains of dynamical systems by symbolic dynamics. Physical Review Letters 110(15), 154101

[2] beim Graben, P. & Hutt, A. (2015). Detecting event-related recurrences by symbolic analysis: Applications to human language processing. Philosophical Transactions of the Royal Society London, A373, 20140089

[3] beim Graben, P., Sellers, K. K., Fröhlich, F. & Hutt, A. (2016). Optimal estimation of recurrence structures from time series. EPL Europhysics Letters, 114, 38003

[4] Hutt, A. & beim Graben, P. (2017). Sequences by metastable attractors: interweaving dynamical systems and experimental data. Frontiers in Applied Mathematics and Statistics, 3, 11

[5] beim Graben, P., Jimenez-Marin, A., Diez, I., Cortes, J. M., Desroches, M. & Rodrigues, S. (2019). Metastable resting state brain dynamics. Frontiers in Computational Neuroscience, 13, 62

Phase transition to synchronization in a system of swarmalators

Steve J. Kongni (1), Thierry Njougouo (1,2), Patrick Louodop (1,3), Robert Tchitnga (1) and **Hilda A. Cerdeira** (3)

(1) Research Unit Condensed Matter, Electronics and Signal Processing, University of Dschang, Cameroon; (2) Faculty of Computer Science, University of Namur, Belgium; (3) ICTP South American Institute for Fundamental Research, São Paulo State University (UNESP), Instituto de Física Teórica, Brazil.

hilda.cerdeira@unesp.br

Systems of oscillators called Swarmalators, whose phase and spatial dynamics are coupled, have been used to describe the dynamics of some living systems. Their collective behavior presents simultaneous aggregation in space and synchronization in phase which in some cases leads to explosive synchronization in a finite population as a function of the coupling parameter between the phases of the internal dynamics. We describe this phenomenon using the order parameter and the Hamiltonian formalism. Near the synchronization transition the phase energy of the particles are represented by the XY model, and they undergo a transition which can be of the first order or second depending on the distribution of natural frequencies of the internal dynamics of the swarmalators.

A perturbation-based approach to identifying superfluous network constituents

Timo Bröhl (1,2), Klaus Lehnertz (1,2,3)

(1) Department of Epileptology, University of Bonn, Germany; (2) Helmholtz Institute for Radiation and Nuclear Physics, University of Bonn, Germany; (3) Interdisciplinary Center for complex Systems, University of Bonn, Germany

timo.broehl@uni-bonn.de

Constructing networks from empirical time series data is often faced with the as yet unsolved issue of how to avoid superfluous network constituents. Such constituents can result, e.g., from spatial and temporal oversampling of the system's dynamics, and neglecting them can lead to severe misinterpretations of network characteristics ranging from the global to the local scale. We deduce deduce a perturbation-based method to identify superfluous network constituents that makes use of vertex and edge centrality concepts by investigating the influence of removing and cloning single constituents on these global and local network characteristics. We demonstrate the suitability of our approach through analyses of paradigmatic network models with adjustable built-in superfluous constituents.

Non-local cascade failures and synchronization dynamics on European and US power grids

Géza Ódor (1), Shengfeng Deng (1), Bálint Hartmann (1), Jeffrey Kelling (2)

(1) Centre for Energy Research, Institute of Materials Science and Technical Physics, Department of Complex Systems, Budapest; (2) HZDR Dresden
odor.geza@ek-cer.hu

Dynamical simulation of the cascade failures on the EU and USA high-voltage power grids has been done via solving the second-order Kuramoto equation. We show that synchronization transition happens by increasing the global coupling parameter K with meta-stable states depending on the initial conditions so that hysteresis loops occur. We provide analytic results for the time dependence of frequency spread in the large K approximation and by comparing it with numerics of $d = 2, 3$ lattices, we find agreement in the case of ordered initial conditions. However, different power-law (PL) tails occur, when the fluctuations are strong. After thermalizing the systems we allow a single line cut failure and follow the subsequent overloads with respect to threshold values T. The PDFs $p(N_f)$ of the cascade failures exhibit PL tails near the synchronization transition point K_c. Below K_c we find signatures of T-dependent PL-s, caused by frustrated synchronization, reminiscent of Griffiths effects [1]. Here we also observe stability growth following blackout cascades, similar to intentional islanding, but for $K > K_c$ this does not happen. For $T < T_c$, bumps appear in the PDFs with large mean values, known as “dragon king” blackout events. We also analyze the delaying/stabilizing effects of instantaneous feedback or increased dissipation and show how local synchronization behaves on geographic maps. We demonstrate the occurrence of non-local cascade failure events at the weak points of the networks.

References

[1] Entropy 22 (2020) 666

[2] Phys. Rev. E 106 (2022) 034311

Complex systems perspectives pertaining to the research of the geospace environment

Georgios Balasis

National Observatory of Athens
gbalasis@noa.gr

Learning from successful applications of methods originating in statistical mechanics, complex systems science, or information theory in one scientific field (e.g., atmospheric physics or climatology) can provide important insights or conceptual ideas for other areas (e.g., space sciences) or even stimulate new research questions and approaches. For instance, quantification and attribution of dynamical complexity in output time series of nonlinear dynamical systems is a key challenge across scientific disciplines. Especially in the field of space physics, an early and accurate detection of characteristic dissimilarity between normal and abnormal states (e.g., pre-storm activity vs. magnetic storms) has the potential to vastly improve space weather diagnosis and, consequently, the mitigation of space weather hazards. We provide an overview on existing nonlinear dynamical systems-based methodologies along with key results of their previous applications in a space physics context, which particularly illustrates how complementary modern complex systems approaches have recently shaped our understanding of nonlinear magnetospheric variability.

Perturbation-based graph theory: An integrative dynamical perspective for the study of complex networks

Gorka Zamora-López (1), Matthieu Gilson (2)

(1) Center for Brain and Cognition, Pompeu Fabra University, Barcelona, Spain; (2) Institut for Systems Neuroscience (INSERM-AMU), Marseille, France.
gorka@zamora-lopez.xyz

Built upon the shoulders of graph theory, the field of complex networks has become a central tool for understanding complex systems. Represented as a graph, empirical systems across domains can thus be studied using the same concepts and the same metrics. However, this simplicity is also a major limitation since graph theory is defined for a binary and symmetric description where the only relevant information is whether a link exists or not between two vertices. The adaptation of graph theory to weighted networks has been rather clumsy with approaches that typically ignore the fact that link weights are not numerical values but represent physical or statistical quantities.

Here, we propose a dynamical reformulation of graph theory that can help aleviate these limitations. First, we show that classical graph metrics are derived from a simple but common generative dynamical model (a discrete cascade) governing how perturbations propagate along the network. This finding exposes that – contrary to common belief – graph analysis is a model-based analysis method instead of a data-driven one. From the dynamical perspective graph metrics are no longer regarded as combinatorial attributes of a graph, but correspond to spatio-temporal properties of the network's response to external perturbations.

Second, we learn that many of the limitations of graph theory can be leveraged by replacing the underlying discrete cascade by other generative models which allow for the propagation of continuous variables in continuous time. In practice, our formalism consists in redefining graph metrics from the Green's function of a network. Given an adjacency matrix A we define its Green's function $\mathscr{G}(t)$ for a propagation model of choice. At each time point t', $\mathscr{G}_{ij}(t')$ is a matrix encoding the response of node j to an initial unit perturbation at node i. Last, we provide examples of how the perturbation-based analysis helps overcome common issues of graph analysis such as the definition of graph distance in weighted graphs and the comparison of networks of different size or density.

In summary, we propose a dynamical formulation of graph theory in which the underlying generative model is explicit and tunable. This allows to define metrics in which both directionality and link weights are natural – built-in – aspects of the metrics. It also provides the oportunity to calibrate network analyses by choosing generative models that are well suited for the particular system under study; thus balancing between simplicity and interpretability of results.

Complexity-based permutation entropies: From deterministic time series to white noise

José M. Amigó, Roberto Dale and Piergiulio Tempesta

Universidad Miguel Hernández (J.M.A. and R.D.) and Universidad Complutense de Madrid (P.T.)
jm.amigo@umh.es

Complexity in symbolic times series, symbols being taken from a finite alphabet, has to do with the number of different sequences (strings, words, blocks,...) of a given length L and how this number increases with L. The perhaps simplest approach consists in counting the number of such sequences. In this case, the complexity of periodic sequences is a bounded function of L, while the complexity of arbitrary sequences grows exponentially with L. Hence, taking the logarithm is a good idea to distinguish polynomial from exponential growth. Moreover, the limit of the logarithmic growth rate with increasing lengths produces a finite number that is independent of length and, hence, intrinsic to the time series.

Otherwise, if the alphabet is continuous, the situation is more complicated. Such is the case with observations from nonlinear processes and continuous-valued random processes. In this event, one usually divides the alphabet into bins or, as in the ordinal methodology, represents each block by the permutation obtained by ranking the observations in the block. The trouble with the latter option is that the growth of permutations with the length becomes super-exponential in the case of noisy and random signals, which prevents a theoretical definition of "permutation complexity" (say, the permutation entropy rate) along the standard lines sketched above. In this talk we borrow ideas from statistical physics (e.g., group entropy and extensivity) and complexity theory (e.g., complexity classes) to extend the conventional permutation entropy from the exponential class to other complexity classes (polynomial, factorial, ...) in such a way that the entropy rate of each extension is finite on the corresponding complexity class.

Synchronization of phase oscillators due to nonlocal coupling mediated by the diffusion of a substance

P. Haerter, **R. L. Viana**

Federal University of Parana, Department of Physics, Curitiba, Parana, Brazil
rlv640@gmail.com

Many systems of physical and biological interest are characterized by assemblies of phase oscillators whose interaction is mediated by a diffusing chemical. The coupling effect results from the fact that the local concentration of the mediating chemical affects both its production and absorption by each oscillator. Since the chemical diffuses through the medium in which the oscillators are embedded, the coupling among oscillators is non-local: it considers all the oscillators depending on their relative spatial distances. We considered a mathematical model for this coupling, when the diffusion time is arbitrary with respect to the characteristic oscillator periods, yielding a system of coupled nonlinear integrodifferential equations which can be solved using Green functions for appropriate boundary conditions. In this paper we show numerical solutions of these equations for three finite domains: a linear one-dimensional interval, a rectangular, and a circular region, with absorbing boundary conditions. From the numerical solutions we obtain we investigate phase and frequency synchronization of the oscillators, with respect to changes in the coupling parameters for the three considered geometries.

Patient flow through a hospital: A combined data-driven and modelling approach

M. Carmen Romano (1,2), Ian Stansfield (2), Pierre Bonnin (1), Norbert Kern (3), Alexander Groh (1), Scott Angus (1) and Tomas Gouveia (1)

(1) Institute for Complex Systems and Mathematical Biology, University of Aberdeen; (2) Institute of Medical Sciences, University of Aberdeen; (3) Laboratoire Charles Coulomb (L2C), University of Montpellier
m.romano@abdn.ac.uk

One of the biggest challenges faced by hospitals is managing elective care delivery alongside large numbers of emergency admissions, causing rapid growth of elective care waiting times. Mechanisms to improve patient flow through hospitals are urgently needed, but the uncertainty of when patients will be discharged is a major barrier to admissions planning. Hence, the development of a mathematical framework to predict patients' discharge times and optimise patient flow is crucial to identify bottlenecks and optimisation strategies to alleviate pressures on hospital staff, directly translating into improved healthcare for patients.

In this talk I will present an integrated modelling and data-driven approach to describe patient flow through a hospital and predict hospital length of stay. Based on a publicly available, extensive dataset from intensive care patients in a Boston hospital (MIMIC-III), we show how a neural network approach is able to predict hospital length of stay. Moreover, a mathematical transport model will be presented to describe patient flow through the network of wards in a hospital, taking into account key characteristics governing patient flow, such as ward capacity and state of patients.

Periodic orbits in the Ott–Antonsen manifold

Oleh Omel'chenko

University of Potsdam
omelchenko@uni-potsdam.de

In their seminal paper [Chaos 18, 037113 (2008)], E. Ott and T. M. Antonsen showed that large groups of phase oscillators driven by a certain type of common force display low dimensional long-term dynamics, which is described by a small number of ordinary differential equations. This fact was later used as a simplifying reduction technique in many studies of synchronization phenomena occurring in networks of coupled oscillators and in neural networks. Most of these studies focused mainly on partially synchronized states corresponding to equilibrium-type dynamics in the so called Ott–Antonsen manifold. Going beyond this paradigm, in this talk, I propose a new approach for the efficient analysis of partially synchronized states with non-equilibrium periodic collective dynamics. The approach is based on the observation that the Poincar'e map of the complex Riccati equation, which describes the dynamics in the Ott–Antonsen manifold, coincides with the well-known Möbius transformation. The possibilities of the proposed method are illustrated by its application to the analysis of travelling and breathing chimera states as well as moving spiral wave chimeras.

Exoplanetary mass constraints based on topology of interacting networks

Tamás Kovács

Eötvös University, Budapest, Hungary
tamas.kovacs@ttk.elte.hu

The continuously increasing number of newly discovered worlds outside of our own solar system requires as precise as possible parameter estimations such as planetary masses, orbital characteristics, bulk density, etc. Comprehensive statistical methods and inverse dynamical analyses have been worked out to obtain system parameters from astronomical observations. Nevertheless, the time domain measurements as scalar time series transformed into complex networks serve a powerful tool to investigate dynamical systems via network topology. Many recent works make significant effort to explore the causality relations and coupling directions between connected dynamical systems.

In this study a new estimation procedure of planetary masses is presented making use of eclipse time variation

in multi-planetary systems. Due to the gravitational coupling the motion of planets differs from pure Keplerian ellipse resulting in variable orbital periods. Measuring this tiny effect for nearly co-planar planets one is able to reconstruct the trajectories sharing the same phase space. Transforming then the obtained state vectors of the entangled dynamical systems into network representation, it can be shown that the coupling directions between the interacting sub-networks are related to planetary masses relative to each other.

Posters C
Concepts from complex systems – networks, synchronisation, recurrence

C1 – Recurrence analysis of the complex dynamics of an electrochemical oscillator comprising the destabilization of iron induced by halides under current-controlled conditions

A. Tiganouria, M. Pavlidou, D. Valavanis, D. Spanoudaki, Ch. Gkili, D. Sazou

Department of Chemistry, Aristotle University of Thessaloniki
alexandratiganouria@gmail.com

The potential oscillations assigned to the halide-induced destabilization of the protective iron oxide observed, under current-controlled conditions, were analyzed using recurrence plots (RPs) and recurrence quantification analysis (RQA). It was found that RQA is efficient in identifying the transitions between different states of the passivation mechanism, determined by the rate of oxide growth and its breakdown. Breakdown of the oxide is initiated by halides acting competitively to the oxide growth. At relatively low halide concentrations (<30 mM) the passive state is rapidly established, and its destabilization appears to be a relatively slow process, which at a critical moment causes a major collapse of the protective oxide film. This step occurs suddenly and leads to the transition of iron to its active state. An oxide-free surface is then exposed to the aggressive environment for a while, before its repassivation. At relatively high halide concentrations (>30 mM), full iron passivation is prevented. Instead, rhythmic passivation events now occur, depending on the localized conditions established on the iron surface. It is shown that in both cases, increasing the applied current facilitates repassivation and increases the time the system spent in the passive state. A correlation between either the instant collapse of the passive state or the instant attainment of the passive state and RQA measures was found.

In summary, this investigation shows that RQA measures may distinguish between two distinct situations associated with the stability of the iron: (i) a mostly passive state regime, with passive-active transitions, during which the active state is reached for a very short time; and (ii) a reversed behavior, with the active-passive transitions prevailing, and the iron reaching the passive state only briefly. The latter case is characterized by worse metal stability and increased metal weight loss. Finally, the greater aggressiveness of chlorides in comparison with bromides, as well as their notable effect on the stability of the iron passive state, are reflected in RQA measures.

C2 – Multi-scale SST-Streamflow connectivity: A complex network approach

Abinesh Ganapathy, Ankit Agarwal

Indian Institute of Technology Roorkee, India
abinesh_g@hy.iitr.ac.in

The current study examines the association of global SST and streamflow in Germany at different timescales, ranging from seasonal to interannual, by integrating wavelet transform and complex network techniques. Most studies exploring this connection only focus on a single timescale; however, consideration of various atmospheric and oceanic large-scale phenomena occurring at different temporal scales is important. Germany is divided into three regions, viz. Alpine, Atlantic and Continental, based on its streamflow regime. The decomposition of the time series into multiple frequency signals is carried out using wavelet transform, and the network theory is employed on these decomposed signals to identify the spatial connections based on the 99 percentile correlation coefficient. The degree centrality metric is used to evaluate the characteristics of the spatially embedded networks. Our results re-establish known SST regions that have a potential connection with the various streamflow regions of Germany. Spatial patterns that resemble the North Atlantic SST tripole-like pattern is predominant for Alpine streamflow regions at finer timescale. Equatorial Atlantic Mode re-

gions observed for Atlantic streamflow at interannual timescale and Vb weather system connected regions in the Mediterranean Sea have appeared for all the streamflow regions of Germany. Besides, continental streamflow regions exhibited combined characteristics of the Alpine and Atlantic streamflow spatial patterns. In addition to the above regions, we also identify the scale-specific patterns in the Pacific, Indian and Southern Ocean regions at different timescales.

C3 – Role of transient dynamics versus fixed points in cellular sensing and responsiveness to dynamic spatial-temporal signals

Akhilesh Nandan, Aneta Koseska

Max Planck Institute for Neurobiology of Behavior-caesar
akhilesh.nandan@mpinb.mpg.de

Under physiological conditions, cells continuously sense and migrate in response to local gradient cues which are irregular, conflicting, and changing over time and space. This suggests cells exhibit seemingly opposed characteristics, such as robust maintenance of polarized state longer than the signal duration while remaining adaptive to novel signals. However, the dynamical mechanism that enables such sensing capabilities is still unclear. Here we propose a generic dynamical mechanism based on the critical positioning of the receptor signaling network in the vicinity of saddle node of a sub critical pitchfork bifurcation (SubPB mechanism). The dynamical ghost that emerges at the critical organization gives transient memory in the polarized response, as well as the ability to continuously adapt to changes in signal localization. Using weakly nonlinear analysis, an analytical description of the necessary conditions for the existence of this mechanism in a general receptor network is provided. By using a physical model that couples signaling to morphology, we demonstrate how this mechanism enables cells to navigate in changing environments. Comparing to three classes of existing mathematical models for the polarization that operate on the principle of stable attractors (Wave pinning, Turing, and LEGI models), we show that the metastability arising from ghost in the SubPB mechanism uniquely enables sensing dynamic spatial-temporal signals in a history dependent manner.

C4 – Improving findability and reproducibility of research data using semantic data management with CaosDB

Alexander Schlemmer (1,2), Inga Kottlarz (1), Baltasar Rüchardt (1), Ulrich Parlitz (1), Stefan Luther (1)

(1) Max Planck Institute for Dynamics and Self-Organization, Göttingen; (2) IndiScale GmbH, Göttingen
alexander.schlemmer@ds.mpg.de

Semantic data management is a powerful concept for managing complex heterogeneous data. The open source project CaosDB provides a framework that is especially suited for scientific data and has been successfully applied in different fields of research. Here we would like to focus on two important aspects of data-intensive research: Findability and Reproducibility.

To allow reproducibility, it must be ensured that software, data and meta data are sufficiently documented. This documentation must also be easily findable in order to perform continued research on this data. We show how simple guidelines for creating a human- and machine-readable documentation of digital scientific workflows can lead to a high degree of reproducibility. We demonstrate, how this approach can be combined with semantic data management using CaosDB to simplify findability and interoperability.

References

Fitschen, T.; Schlemmer, A.; Hornung, D.; tom Woerden, H.; Parlitz, U.; Luther, S.: CaosDB – Research Data Management for Complex, Changing, and Automated Research Workflows. Data 2019, 4, 83

C5 – The effect of time delay for synchronisation suppression in neuronal networks

Matheus Hansen (1), Paulo R. Protachevicz (2), Kelly C. Iarosz (3), Ibere L. Caldas (2), Antonio M. Batista (4), **Elbert E.N. Macau** (1)

(1) Federal University of Sao Paulo, Brazil, (2) University of Sao Paulo, Brazil, (3) Faculdade de Telemaco Borba, Brazil, (4) State University of Ponta Grosa, Brazil
elbert.macau@unifesp.br

We study the time delay in the synaptic conductance for suppression of spike synchronisation in a random network of Hodgkin Huxley neurons coupled by means of chemical synapses. In the first part, we examine in detail how the time delay acts over the network during the synchronised and desynchronised neuronal activities. We observe a relation between the neuronal dynamics and the synaptic conductance distributions. We find parameter values in which the time delay has high effectiveness in promoting the suppression of spike synchronisation. In the second part, we analyse how the delayed neuronal networks react when pulsed inputs with different profiles (periodic, random, and mixed) are applied to the neurons. We show the main parameters responsible for inducing or not synchronous neuronal oscillations in delayed networks.

C6 – Parametric control of PageRank on real network data

Gonzalo Contreras, Miguel Romance, **Regino Criado**

Universidad Rey Juan Carlos
regino.criado@urjc.es

One of the sparks which ignited the study of complex networks of the last two decades was the invention of the PageRank algorithm in 1998 by Brin and Page. This algorithm to the Internet by storm, and soon attracted a lot of attention of attention from the network science community. Initially, a vast amount of research was poured in the understanding of the role of the damping factor α. However, one quickly realizes that the behavior of the different rankings one can obtain is highly dependent on the personalization vector $\mathbf{v}$ too. In this poster we study the extent of the control one can exert on the network centrality defined by the PageRank centrality measure. In order to present these results, we resort to a geometrical description of the PageRank algorithm, which shines a light on the problem of centrality ranking control. We later numerically examine the consequences of the proven theorems, which confirm the reliability of the PageRank algorithm as a source of trustworthy importance, and we apply this new methodology to several real network data sets.

C7 – The permutation largest slope network: Concept and applications

J. S. Armand Eyebe Fouda (1), Wolfram Koepf (2)

(1) Department of Physics, University of Yaoundé I; (2) Institut für Mathematik, Universität Kassel
efoudajsa@gmail.com

The permutation largest slope entropy (PLSE) has been shown effective to distinguish between regular and non-regular dynamics and estimate the period of limit-cycles. However, it fails to detect limit-cycles with large periods under the embedding dimension constraint. This talk presents the concept of the permutation largest slope network (PLSN) as a complementary tool for the interpretation of the entropy values. Permutation largest slopes derived from embedding vectors of the underlying time series are considered as the network nodes. The PLSN is then constructed by considering connections between the different nodes. Likewise, as the PLSE is computed from node probability, we defined the PLSN entropy (PLSNE) by considering the node edge probability. Thereby, we observed that limit-cycles are represented by a network with proportionally distributed edge weights, whereas non-regular dynamics do by randomly distributed edge weights. Some examples of applications using well-known dynamical systems are presented to show how far is enhanced the interpretation of entropy results by the network plot, hence the characterization of the underlying dynamics.

C8 – Dose-response functions and surrogate data models for exploring complex social contagion and tipping dynamics

Jonathan F. Donges (1,2), Jakob Lochner (1,3), Niklas Kitzmann (1,4), Jobst Heitzig (1), Sune Lehmann (5,6), Marc Wiedermann (1,7,8), Jürgen Vollmer (3)

(1) Potsdam Institute for Climate Impact Research; (2) Stockholm Resilience Centre, Stockholm University; (3) Institute for Theoretical Physics, University of Leipzig; (4) Institute for Physics and Astronomy, University of Potsdam; (5) Department of Applied Mathematics and Computer Science, Technical University of Denmark; (6) Center for Social Data Science, University of Copenhagen; (7) Robert Koch-Institut; (8) Institute for Theoretical Biology, Humboldt University of Berlin
donges@pik-potsdam.de

Spreading dynamics and complex contagion processes on networks are important mechanisms underlying the emergence of critical transitions, tipping points and other non-linear phenomena in complex human and natural systems. Increasing amounts of temporal network data are now becoming available to study such spreading processes of behaviours, opinions, ideas, diseases and innovations to test hypotheses regarding their specific properties. To this end, we here present a methodology based on dose-response functions and hypothesis testing using surrogate network data models that randomise most aspects of the empirical data while conserving certain structures relevant to contagion, group or homophily dynamics. We demonstrate this methodology for synthetic temporal network data of spreading processes generated by the adaptive voter model. Furthermore, we apply it to empirical temporal network data from the Copenhagen Networks Study and to study the global spreading dynamics of bus rapid transport systems, a sustainability innovation in the transport sector. The proposed methodology is generic and promising also for applications to a broader set of temporal network data sets and traits of interest.

C9 – Global synchronization analysis of acyclic networks of heterogeneous Kuramoto oscillators

José Angel Mercado Uribe (1), Jesus Mendoza Avila (2), Denis Efimov (2) Johannes Schiffer (1,3)

(1) BTU Cottbus-Senftenberg; (2) Inria, Univ. Lille; (3) Fraunhofer Research Institution for Energy Infrastructures and Geothermal Systems IEG
mercadou@b-tu.de

Global synchronization properties of acyclic networks of Kuramoto oscillators with heterogeneous coupling strengths and natural frequencies are established. To this end, we employ the Leonov function framework, which can be applied to systems whose dynamics are periodic with respect to some or all state variables. By using this approach, we construct a suitable Leonov function for the Kuramoto model and obtain sufficient conditions for almost global synchronization of the system. The result is accompanied by necessary and sufficient conditions to guarantee the existence of equilibria. The implications of the proposed conditions on the network topology as well as the oscillator's coupling strengths and natural frequencies are discussed. Furthermore, the results are illustrated via a numerical example.

C10 – Recurrence analysis of brain neurodynamics

L. Alexandre, W. Duch, **Ł. Furman**, K. Tołpa

Nicolaus Copernicus University, Toruń, Poland, and University of Beira Interior, Covilhã, Portugal
krzychtolpa@gmail.com

Dynamics of the brain states is characterized by metastable states. Brain networks may be modeled using attractor networks. Recurrence analysis is very well suited to find such states in neuroimaging or in electrophysiological EEG or MEG signals. Trajectories of simulated, as well as real brain states, show rapid transition and short (of the order of 100 ms) periods of stability. Recurrence Quantification Analysis may provide useful features for classification of EEG data, although RQA measures are better suited for the quasi-periodic than for the attractor dynamics. EEG signals are sampled at frequencies of 128 to 1000 Hz. To characterize global states of the brain cortex and compare their similarities, we have represented signals in time windows of one second by their power spectra (using STFT). Shifting these time windows by one or a few samples we get approximation to the time/frequency representation of signals. We have recently showed that this method generates useful RQA features, and that using these features in combination with EEG channels linear SVM analysis finds reduced number of electrodes/features that lead to a high accuracy classification of these complex signals. Estimating the noise level we can filter weak fluctuations, obtaining simplified signal representation. Using joint recurrence analysis of the multi-channel EEG signals we can find patterns of similar signals at different spatial positions. Distribution of such patterns shows important differences in individual brains, as well as in subgroups of people with specific mental disorders.

Identifying the same states and analyzing transition sequences between these states we get important information about specific, frequently occurring states, including their spatial locations and dominating oscillation frequency. We can create a graph showing connections between observed states and probability of transitions between them. In the oddball experiments we can also try to identify rare states. Using high-density EEG such techniques as LORETA can solve inverse problem and find the sources in the brain that generate electrode activation, leading to metastable, synchronized states. Usually only a small number of sources are active in a subnetwork that quickly switches to other networks. Such analysis facilitates interpretation of the most frequent states and probabilities of transitions to other states. It has high diagnostic value, opening new doors for neuromodulatory interventions. Some examples of analysis of the resting state EEG data for healthy people and people with mental disorders will be presented.

We are developing a BrainPulse software package to automatize such analysis.

C11 – Recurrence analysis of chaotic trajectories: Application in tokamaks

Matheus Palmero (1,2), Iberê Caldas (1), Igor Sokolov (2)

(1) Instituto de Física, Universidade de São Paulo, São Paulo, Brazil; (2), Institut für Physik, Humboldt-Universität zu Berlin, Berlin, Germany
matheuspalmero@gmail.com

In this work, we show that recurrence analysis of chaotic trajectories in non-linear Hamiltonian systems provides useful prior knowledge of their dynamical behaviour. By defining an ensemble of initial conditions, evolving them until a given maximum iteration time, and computing the recurrence rate of each orbit, it is possible to find particular trajectories that widely differ from the average behaviour. We show that orbits with high recurrence rates are the ones that experience stickiness, phenomena where the trajectories are dynamically trapped in certain regions of the system's phase space. We analyse the ergodic magnetic limiter map, or Ullmann map, a symplectic model that qualitatively describes the magnetic field lines of a tokamak assembled with an ergodic magnetic limiter, a device that periodically perturbs the magnetic configuration on the plasma edge. This selected approach is proposed as a general method for different Hamiltonian systems with diverse applications. The method is suitable to visually illustrate and characterise particular regions of the space that indicate very distinct dynamical behaviours.

C12 – Characterizing stickiness using recurrence time entropy

Matheus R. Sales (1,2,3), Michele Mugnaine (4,5), José D. Szezech Jr. (1,6), Ricardo L. Viana (4,5), Iberê L. Caldas (5), Norbert Marwan (2), Jürgen Kurths (2,7)

(1) Graduate Program in Sciences/Physics, State University of Ponta Grossa, Brazil; (2) Potsdam Institute for Climate Impact Research, Germany; (3) Institute of Mathematics, Humboldt University Berlin, Germany; (4) Department of Physics, Federal University of Paraná, Brazil; (5) Institute of Physics, University of São Paulo, Brazil; (6) Department of Mathematics and Statistics, State University of Ponta Grossa, Brazil; (7) Institute of Physics, Humboldt University Berlin, Germany
matheusrolim95@gmail.com

The stickiness effect is a fundamental characteristic of quasi-integrable Hamiltonian systems. We propose the use of an entropy-based measure of recurrence plots (RP), namely, the entropy of the distribution of the recurrence times (estimated from the RP), to characterize the dynamics of a typical quasi-integrable Hamiltonian system with coexisting regular and chaotic regions. We show that the recurrence time entropy (RTE) is positively correlated to the largest Lyapunov exponent, with a high correlation coefficient. We obtain a multi-modal distribution of the finite-time RTE and show that each mode corresponds to the motion around islands of different hierarchical levels.

C13 – Phase sensitive excitability of a limit cycle

Matthias Wolfrum

WIAS-Berlin
wolfrum@wias-berlin.de

The classical notion of excitability refers to an equilibrium state that shows under the influence of perturbations a nonlinear threshold-like behavior. Here, we extend this concept by demonstrating how periodic orbits can exhibit a specific form of excitable behavior where the nonlinear threshold-like response appears only after perturbations applied within a certain part of the periodic orbit, i.e., the excitability happens to be phase sensitive. As a paradigmatic example of this concept we employ the classical FitzHugh–Nagumo system. The relaxation oscillations, appearing in the oscillatory regime of this system, turn out to exhibit a phase sensitive nonlinear threshold-like response to perturbations, which can be explained by the nonlinear behavior in the vicinity of the canard trajectory. Triggering the phase sensitive excitability of the relaxation oscillations by noise we find a characteristic non-monotone dependence of the mean spiking rate of the relaxation oscillation on the noise level. We explain this non-monotone dependence as a result of an interplay of two competing effects of the increasing noise: the growing efficiency of the excitationand the degradation of the nonlinear response.

C14 – Comparing music waveform and its MIDI by their hierarchical recurrence plots

Miwa Fukino (1,2), Yoshito Hirata (3), Kazuyuki Aihara (4)

(1) Digital&AI Technology Center, Panasonic Holdings Corporation (2) Department of Mathematical Informatics, Graduate School of Information Science and Technology, The University of Tokyo (3) Faculty of Engineering, Information, and Systems, University of Tsukuba (4) International Research Center for Neurointelligence (WPI-IRCN), The University of Tokyo
fukino.miwa@jp.panasonic.com

We introduce a method for using a recurrence plot (Marwan et al., 2007) for music analysis. A recurrence plot is one of the important tools for analyzing the nonlinear properties behind time series data. It takes the same time series for both the vertical and horizontal axes. If the distance between the points for two times is close, a dot is plotted at the corresponding two-dimensional place. If the distance is far, a dot is not plotted there. In recurrence plots, a sampling rate of the time series is usually kept at a constant interval, and 10,000 points or less is an appropriate length to ensure the visibility of the resulting plots. In this presentation, we compare two formats of recorded musical performance data, namely sampled acoustic waveforms and MIDI (Musical Instrument Digital Interface), from the viewpoints of their time series characteristics.

First, we show an analysis method of acoustic waveforms of music. In the case of acoustic waveforms in CD, the sampling rate is 44.1 kHz, and thus a five-minute song contains $44100 \cdot 60 \cdot 5 = 13.23$ million points. That is too long to be represented in a recurrence plot. Instead, we proposed our method called Recurrence Plot of Recurrence Plots (RPofRPs) (Fukino et al., 2016), which uses recurrence plots hierarchically in two layers to solve this problem.

Next, we show how to analyze MIDI, which is a standard format for recording performance information with electronic musical instruments and computers. In MIDI, the sampling period is not constant. It is discrete data which records such as the onset time, duration, and volume (velocity) of each pitch (note number) of each timber. We describe how to calculate RPofRPs of MIDI data as a marked point process by using the edit distance for marked point processes (Suzuki et al., 2010, Hirara et al., 2012). We regard a set of onset times of MIDI as a point process, and duration, note number, and velocity as the marks of the point process.

Finally, we discuss the differences for these two types of RPofRPs obtained from the same song by varying parameters of the marked point processes and the RPofRPs.

C15 – Interpolation effects an RQA measures

Nils Antary, Norbert Marwan

Potsdam Institute for Climate Impact Research (PIK)
uw07izon@studserv.uni-leipzig.de

The recurrence plot and recurrence quantification analysis (RQA) are well established methods for the analysis of data from complex systems. They provide import insides about the nature of the dynamics, periodicity, regime changes, and many more. This method is used in different fields of research like finance, engineering, life and earth science. In order to use this method the data has usually to be uniformly sampled. This poses a difficulty for data, which is taken from palaeoclimate archives like sediment cores or stalagmite. One frequently used solution is interpolation to generate uniform time series. However, this prepossessing changes the RQA measures like DET, LAM, or the average line length. Using auto-regression processes, we systematically analyse how these measures increase when interpolating the data. For other systems which show a smoother behavior there is only an effect if the interpolation takes place on a time scale close to the characteristic timescale of the system, like the period lengths. For the Roessler system, the RQA measures decrease when approaching this timescale and show a very irregular behavior below. For real data, we show that the course of the DET measure strongly depends on the choice of interpolation.

C16 – Emergence of highly synchronized firing patterns in neuronal networks

Paulo R. Protachevicz (1), Fernando S. Borges (2), Kelly C. Iarosz (39), Iberê L. Caldas (4), Antonio M. Batista (5), Murilo S. Baptista (1), Jürgen Kurths (6,7)

(1) University of Aberdeen; (2) State University of New York; (3) University Center UNIFATEB; (4) University of São Paulo; (5) State University of Ponta Grossa; (6) Potsdam Institute for Climate Impact Research; (7) Humboldt University
protachevicz@gmail.com

In the brain cortex, excessive burst synchronization is a characteristic of epileptic activities. Such dynamical behaviour is associated with an unbalanced between excitatory and inhibitory signals. On the other hand, balanced excitatory and inhibitory signals could prevent such activities. For this reason, we investigated the emergence of highly synchronized bursts due to the conductance intensity and time delay in the communication of excitatory and inhibitory neurons in a random neuronal network connected by chemical synapses. As the main result, we found that synchronous burst activities can emerge via a first-order phase transition which is correlated to a hysteretic behaviour of the synchronization and firing pattern. In such a regime, both synchronous and non-synchronous patterns can occur depending on the initial conditions and external perturbations. In this framework, synchronized bursts are associated with epileptic activities, while non-synchronous spikes with non-epileptic ones. Besides that, we found that not only the excitatory and inhibitory balance is sufficient to avoid the highly synchronized behaviour, but also short time delays in the transmission of inhibitory signals. Our results improve the comprehension of how synchronized activities emerge in neuronal networks, pointing some routes to the appearance of epileptic activities, as well as proposing some possible treatments.

References

P. R. Protachevicz, F. S. Borges, E. L. Lameu, P. Ji, K. C. Iarosz, A. H. Kihara, I. L. Caldas, J. D. Szezech Jr, M. S. Baptista, E. E. N. Macau, C. G. Antonopoulos, A. M. Batista, J. Kurths. Bistable firing pattern in a neural network model. Front Comput Neurosci., 13:19 (2019)

P. R. Protachevicz, F. S. Borges, K. C. Iarosz, M. S. Baptista, E. L. Lameu, M. Hansen, I. L. Caldas, J. D. Szezech Jr, A. M. Batista, J. Kurths. Influence of delayed conductance on neuronal synchronization. Front Physiol., 11:1053 (2020).

C17 – Characterizing nonlinear spatiotemporal dynamics by gradient pattern analysis

Rubens Sautter, Reinaldo Rosa, Luan Barauna

Lab for Computing and Applied Math, INPE, São José dos Campos, SP, Brazil
`rubens.sautter@gmail.com`

Gradient Pattern Analysis (GPA) is a technique for identifying the dynamics of complex spatiotemporal systems by the bilateral symmetry-breaking properties of the 2D gradient field of each snapshot. The gradient field is obtained from a numerical lattice (for example, a matrix of a digital image). GPA has been of great importance for several applications with an emphasis on 2D dynamics mainly associated with coupled map lattices (CMLs) and reactive-diffusive systems. However, applying the technique and interpreting the results is not always a simple task. In this work, we propose an improvement of the technique based on the four so-called gradient moments related respectively to geometry, norms, phases and complex composition between norm and phase. New metrics are validated from the study of CMLs with symmetric initial conditions (2D Gaussian function) in different chaotic regimes. We also present an unsupervised learning approach with the Density-Based Spatial Clustering of Applications with Noise (DBSCAN) technique and Silhouette scoring to bring the analysis into the context of machine learning (unsupervised classification). The new version of GPA is capable of discriminating different mechanisms related to symmetry breaking of extended dynamical systems and segregating CML conditions that drive the system in the long term. We also discuss its usefulness in identifying extreme fluctuations from a sequence of 2D snapshots in practical applications.

C18 – Multilayer network analysis of turbulent thermoacoustic system

Shruti Tandon, R. I. Sujith

Indian Institute of Technology Madras, India
`shrutitandon97@gmail.com`

Thermoacoustic systems are complex systems that comprise acoustic, hydrodynamic and combustion subsystems. Inter-subsystem nonlinear interactions between the acoustic field, heat release rate fluctuations and the underlying turbulent flow leads to a variety of rich dynamics.

We study the spatio-temporal dynamics in a turbulent bluff-body stabilized dump combustor. The system exhibits a transition from chaotic to periodic (thermoacoustic instability) dynamics with increase in the Reynolds number of the inlet flow. Such a transition occurs via the state of intermittent spatio-temporal patterns. In order to capture the higher-order complexities in the system arising due to the interaction between the various subsystems we use multi-layered complex networks. We construct a two layered network, where one layer represents the vorticity dynamics and the other layer represents the acoustically-driven combustion subsystem. The nodes of the network are spatial locations in the combustion chamber. The inter-layer links between any two nodes is established using cross-variable short-window correlation between vorticity and thermoacoustic power fluctuations at the corresponding locations. The inter-layer node strength represents the strength of the inter-subsystem interactions. Further,

we analyze the topology of the inter-layer network using inter-layer network assortativity and link-rank distribution during various dynamical states to infer the pattern of inter-subsystem interactions.

During chaotic dynamics, the inter-subsystem interactions occur predominantly in the wake of the bluff-body in a non-localized manner. On the other hand, during periodic dynamics, the inter-subsystem interactions are intense in regions of coherent vortex shedding. Interestingly, prior to the emergence of such ordered dynamics, we obtain localized pockets of inter-subsystem interactions in the recirculation zone during the state of intermittency. These regions are identified as the hubs of the inter-layer network. The influence of interactions in such localized pockets is also spread across the entire combustion chamber as identified via disassortative network topology. Targeted attack on these hub locations using microjet secondary flow injections can cause disruption of the feedback interactions and help in mitigating the occurrence of thermoacoustic instability.

Multilayer network analysis thus reveals the rich pattern of inter-subsystem interactions and helps identify critical regions for passive control of thermoacoustic instability.

C19 – Time series analysis for fusion plasma disruption prediction

Teddy Craciunescu (1), Andrea Murari (2)

(1) National Institute for Laser, Plasma and Radiation Physics, Măgurele, Romania; (2) Consorzio RFX (CNR, ENEA, INFN, Università di Padova, Acciaierie Venete SpA), Padova, Italy
teddy.craciunescu@gmail.com

Tokamak plasmas are very complex systems, from both a technological and physical point of view. They are kept well out of equilibrium by continuous injection of matter and megawatts of power. One of the major issues on the route of a commercial tokamak reactor is the occurrence of macroscopic instabilities called disruptions, which cause a complete loss of confinement, the abrupt extinction of the discharge, high thermal loads on the plasma facing components,strong forces on the electromagnetic structures and the generation of beams of runaway electrons in the MeV range. Therefore, preventing disruptions or, at least, mitigating their detrimental effects is extremely important. A series of methods based on the time series analysis of the main plasma diagnostic signals are used to determine when significant changes in the plasma dynamics of the tokamak configuration occur, indicating the onset of drifts towards the plasma disruption. The main changes monitored are related to the embedding dimensions, the structure of the recurrence plots and the transition to chaotic dynamics. A good estimation of the intervals, in which the anomalous behaviours manifest themselves, is very useful for building significantly more appropriate training sets for various kinds of disruption predictors. Some of these methods presented may also be implemented themselves as stand-alone predictors for real time deployment.

C20 – Transition to thermoacoustic instability: Modeling order emerging in a complex system using a synchronization framework

Yue Weng (1), Vishnu R. Unni (2), R. I. Sujith (3), Abhishek Saha (1)

(1) University of California San Diego, USA; (2) Indian Institute of Technology Hyderabad, India; (3) Indian Institute of Technology Madras, India
vishnu.runni@mae.iith.ac.in

In this study, we introduce a framework based on synchronization to model the transition to thermoacoustic instability in laminar and turbulent combustors. Thermoacoustic instability, which results from the positive feedback between the acoustic field and unsteady heat release rate causes large amplitude oscillations that can damage the hardware. In turbulent conditions, the transition to thermoacoustic instability corresponds to the emergence of order from disorder. Currently, flame transfer function (FTF) and flame describing function (FDF) are used to model the onset of thermoacoustic instability. However, since FTF and FDF are forcing responses, they do not capture the mutual interaction between the flame and the acoustic field.

To address this lacuna, we introduce a model using the concept of synchronization and thus capture the complex behaviors and bifurcations observed in the experiment. We model the transition to thermoacoustic instability in a laminar and turbulent system. In the laminar case, we model the system as two damped simple harmonic oscillators that are nonlinearly coupled. With this model, we capture the bifurcation route from no oscillation to periodic oscillation, to quasi-periodic oscillation, to strange non-chaos, and chaos. For the turbulent case, we use two nonlinearly coupled ODEs to generate time series of the unsteady heat release rate from turbulent combustion. This unsteady heat release rate is then coupled to the acoustic oscillator with a variable coupling strength. As the coupling strength changes, the model replicates the transition from combustion noise to periodic oscillation through intermittency. Furthermore, the model captures multifractal characteristics and the power law corresponding to self-organization associated with the transition. We compare these two different transitions and show that the transition to thermoacoustic instability in a turbulent system is unique. That is the system transitions from low-amplitude chaos to high-amplitude periodic oscillations.

C21 – The influence of a differential rotation on bifurcations of buoyancy driven spherical shell convection

Fred Feudel (1), Ulrike Feudel (2)

(1) Universität Potsdam; (2) Universität Oldenburg
ffeudel@uni-potsdam.de

We investigate numerically the bifurcation phenomena of buoyancy driven convection in a rotating spherical shell which is heated by imposing a constant temperature difference between the inner and outer spheres, and is subject to a radially directed gravity force. Along with the overall rotation of the fluid shell the influence of a shear generated by a differential rotation between both spheres on the convection pattern is the focus of this work. This configuration is an appropriate model of convection flows in geophysical and astrophysical applications, as, e.g., in the outer cores of terrestrial planets.

Due to the imposed differential rotation of both spheres the dynamics for small Rayleigh numbers generates a nonzero basic flow which possesses features of the spherical Couette flow. Increasing the Rayleigh number the axisymmetry of the flow is broken in successive Hopf bifurcations generating new stable branches of rotating waves (RWs) and modulated rotating waves (MRWs), respectively, with an azimuthal mode number $m = 3$. However in comparison to the configuration without differential rotation, now in addition, a new RW branch with no symmetry, $m = 1$, bifurcates in a saddle node bifurcation, separated from the other branches. The stable $m = 3$ MRWs and the arising stable $m = 1$ RWs are coexisting along a certain interval of the Rayleigh numbers creating a region of bistability. We demonstrate that finally the stable $m = 3$ MRW branch collides with an unstable RW branch in an homoclinic bifurcation, and the $m = 1$ MRW branch remains in this scenario the only stable branch for larger Rayleigh numbers.

In summary, in contrast to the situation with no differential rotation in this configuration a saddle node bifurcation generates a branch with no axial subsymmetry which also enhances the heat transfer in comparison to the other branches and which forms the final attractor after the homoclinic bifurcation.

MS2
Analysis and modeling of infrastructure networks

A framework for synthetic power system dynamics

Anna Büttner, Anton Plietzsch, Mehrnaz Anvari, Frank Hellmann

Potsdam Institute for Climate Impact Research
buettner@pik-potsdam.de

As power grids are critical infrastructures their structure and functioning are largely kept confidential by grid operators. Thus there is a need for synthetic power grid models in research. A major use case is to generate large data sets of synthetic grids to investigate the dynamic stability of power grids using machine learning. So far, most machine learning projects had to resort to simple models and often homogeneous parameterization to generate large grid ensembles. I will present a modular framework to generate synthetic power grids that considers the heterogeneity of real power grids but remains simple and tractable. The synthetic grids generated are robust and show good synchronization under all evaluated scenarios, as should be expected for realistic power grids.

Physics-inspired machine learning and stochastic models of power grid dynamics

Benjamin Schäfer, Ulrich Oberhofer

Karlsruhe Institute of Technology
benjamin.schaefer@kit.edu

The operation of power systems is affected by diverse technical, economic and social factors. Social behaviour determines load patterns, electricity markets regulate the generation and weather-dependent renewables introduce power fluctuations. Thus, power system dynamics must be regarded as a non-autonomous system whose parameters vary strongly with time. However, the external driving factors are usually only available on coarse scales and the actual dependencies of the dynamic system parameters are generally unknown. Here, we propose a physics-inspired machine learning model that bridges the gap between large-scale drivers and short-term dynamics of the power system. Integrating stochastic differential equations and artificial neural networks, we construct a probabilistic model of the power grid frequency dynamics in Continental Europe. We complement this machine-learning approach with stochastic models for island power grids, such as Ireland and Iceland. We demonstrate how our models generate synthetic time series, which successfully reproduce central characteristics of the grid frequency. All in all, our work emphasises the importance of modelling power system dynamics as a stochastic non-autonomous system with both intrinsic dynamics and external drivers.

How grid information affects the perception of vulnerability of the power grid under physical attacks

Bálint Hartmann

ELKH Centre for Energy Research
hartmann.balint@ek-cer.hu

Tolerance of the power grid against physical intrusions has gained importance in the light of various attacks that have taken place around the world. To adequately prepare for such events, grid operators have to possess a deep understanding of their infrastructure, more specifically, of its weaknesses. A graph representation of the Hungarian power grid was created in a way that the vertices are generators, transformers, and substations and the edges are high-voltage transmission lines. All transmission and sub-transmission elements were considered, including the 132 kV network as well. The network is subjected to various types of single and double element attacks, objects of which are selected according to different aspects. In all cases, damage is calculated for unweighted and weighted networks as well, to enable the comparison of those two models. Comparison of the damage measured in the unweighted and the weighted network representations shows that damage to the weighted network tends to be bigger for vertex attacks, but the contrary is observed for edge attacks. Numerical differences between the two representations do not show any trend that could be generalised, but in the case of the most vulnerable elements significant differences were found in damage measures, which underlines the importance of using weighted models.

Hurricane-induced failures of critical transmission lines lead to huge power outages in Texas

Mehrnaz Anvari

(1) Fraunhofer Institute for Algorithms and Scientific Computing,(2) Potsdam Institute for Climate Impact Research
mehrnaz.anvari@scai.fraunhofer.de

Recent reports from various places indicate that electrical infrastructures are hit increasingly by extreme wind events leading to power outages in the system. The Texas electric grid in the Gulf Coast of the United States (US) is a prime example that is frequently hit by hurricanes causing widespread power outages. We here combine a probabilistic line fragility models with a network model of the Texas grid to study the wind-induced failures of transmission lines and the resulting cascading power outages from seven major historical hurricanes. We first identity the most vulnerable sections of the grid. We then show that hardening just a small fraction of critical lines would substantially increase the resilience of the grid to tropical cyclone strikes and could therefore be a viable means to adapt to the projected frequency increase of very intense hurricanes.

Estimating electricity demand profile of rural and peri-urban Nigerian households

Narges Chinichian (1,2), **Gregory Ireland** (1,3), Pierre-Francois Duc (1), Clara Neyrand (1), Philipp Blechinger (1)

(1) Off-Grid Systems unit, Reiner Lemoine Institut (RLI), Berlin, Germany (2) Theoretical Physics Department, Technical University of Berlin, Germany (3) Energy Systems Research Group, Department of Chemical Engineering, University of Cape Town, South Africa
irelandgregory@gmail.com

Reaching SDG7 (Ensure access to affordable, reliable, sustainable, and modern energy for all) in rural and peri-urban underserved communities necessitates a comprehensive understanding of the potential electricity demand of these target communities. In the scope of the PeopleSuN project (People Power: Optimizing off-grid electricity supply systems in Nigeria[1]), 3,599 Nigerian households and 1,122 small and medium-sized enterprises (SMEs) in communities with electricity access outside of urban cores across broad geographic and socioeconomic contexts of Nigeria were surveyed.

[1]PeopleSuN is a project funded by the German Federal Ministry of Education and Research (BMBF).

The surveys captured household data on socioeconomic and demographic characteristics, expenditures on different household needs, electricity access types and quality, electrical appliance ownership and usage preferences, and usage of different cooking stoves and fuels. More than half of respondents reported a low-quality national grid connection with less than 8 hours of supply per day [1]. We use this data, and its geospatial correlates, to model different archetypical electricity demand profiles at 1-minute resolution for Nigerian households and SMEs using the bottom-up stochastic RAMP model [2]. The model works by simulating the ownership of appliances, their electrical characteristics, and their usage time preferences. The demand profiles resulting from RAMP will then be made publicly available as an open-access dataset for the next steps of the project.

The final product of the project will be an online spatially explicit tool for planning and costing electricity supply solutions [on and off-grid] for non-electrified or weakly electrified areas assuming the archetypical user demands modelled here. This integrated tool is expected to be released in the second half of 2023. We would like to introduce our survey data, demand profiles, and methods to the nonlinear modelling community, receive feedback and form potential further collaborations to develop reliable and open scientific methodologies for planning energy access for underserved communities.

References

[1] Setu Pelz et al. A novel survey dataset for analysing electricity supply and use among rural and peri-urban households and small firms in Nigeria. In:(2022)

[2] Francesco Lombardi et al. Generating high-resolution multi-energy load profiles for remote areas with an open-source stochastic model. In:Energy 177 (2019), pp. 433-444.

Human mobility networks and their applications

Naoya Fujiwara

(1) Graduate School of Information Sciences, Tohoku University (2) PRESTO, Japan Science and Technology Agency
fujiwara@se.is.tohoku.ac.jp

Human mobility plays a crucial role in the human activities in cities. It represents not only our daily activities related with locations such as commuting, shopping, and long-distance travels, but also response to abnormal events such as evacuation from disasters and mobility reduction to mitigate spread of infectious diseases. By quantifying the human mobility associated with such activities, we have insights into these issues, which give us clues to better solve such problems. Development of smart phones enables us to acquire big human mobility data with high spatial and time resolution. In particular, time resolution of the mobility data can be less than minutes and duration of the data recording becomes the order of decade. This extends the possible time scales for the analysis including short-time event such as evacuation and long-time event such as migration. A wide variety of tools, which have been proposed recently, enables us to analyze human mobility based on such data much more precisely than before. There are various ways of expressing human mobility. One of the typical ways to express macroscopic flows of people is to count the number of trips between locations, which can be regarded as a network characterized by the origin-destination matrix. Therefore, network analysis is quite important, and various methods have been proposed and applied to analyze the human mobility network. Modelling techniques for reproducing human mobility patterns in various spatial and time scales have been also developed thanks to the enhanced data availability. For example, a model for the travel distance of individuals has been proposed, and some conventional models have been updated.

Here, recent developments of the data analysis, mathematical models and theories of human mobility are reviewed. Possible applications of the analysis of the human mobility networks to social problems such as understanding the change in the mobility under the intervention policies against the spread of an infectious disease are presented.

Demand-driven design of bicycle infrastructure networks

Christoph Steinacker, David-Maximilian Storch, Marc Timme, **Malte Schröder**

Chair for Network Dynamics, Institute of Theoretical Physics and Center for Advancing Electronics Dresden (cfaed), TU Dresden
malte.schroeder@tu-dresden.de

Sustainable urban transportation critically relies on a sufficiently developed infrastructure. However, designing efficient infrastructure networks constitutes a highly complex problem that requires balancing multiple, often opposing, constraints. Bike path networks in particular need to enable both safe and direct travel for all cyclists with an often strongly limited budget and strong competition for limited road space.

Here, we present a framework to create a sequence of efficient bike path networks by reversing the network formation process and iteratively removing bike paths from an initially complete bike path network. During this process, we continually update cyclists' route choices, explicitly taking into account the cyclists' demand and their safety and convenience preferences. In this way, we ensure that the networks are always adapted to the current cycling demand. The framework may thus enable the theoretical study of structural properties of efficient bike path networks across cities and quantify the inherent impact of the demand distributions and street networks on a cities bikeability.

Posters I
Analysis and modeling of infrastructure networks

I1 – A new tool to analyze mesoscopic and centrality relationships in complex networks

Angeles Criado-Alonso, David Aleja, Miguel Romance, **Regino Criado**

Universidad Rey Juan Carlos
`regino.criado@urjc.es`

The existence of interactions, connections and relationships of different and simultaneous nature between nodes and edges of a complex network (e.g., group collaborations, chemical reactions in which more than two components interact, ...) have allowed to show that hypergraphs and multilayer networks are very suitable structures for the analysis of some of these types of interactions. In this poster we present a new tool that relies on several mathematical structures such as hypergraphs, multilayer networks or the concept of derivative graph of a hypergraph to introduce a new methodology able to analyze some mesoscopic and centrality relationships in the field of complex networks. To see the scope of these ideas, we apply this methodology to a real linguistic network to computationally analyze mesoscopic relationships between words, sentences, paragraphs, chapters and texts focusing not only on a quantitative index but also on other elements and mathematical tools that allow, among other things, to analyze similarities and dissimilarities in texts.

I2 – Resilience of emergency infrastructure networks after flooding events

Jonas Wassmer (1,2), Bruno Merz (3,1), Norbert Marwan (2,4)

(1) University of Potsdam, Inst. of Environmental Science and Geography; (2) Potsdam Institute for Climate Impact Research; (3) German Research Centre for Geosciences; (4) University of Potsdam, Inst. of Geosciences
`jonas.wassmer@pik-potsdam.de`

Extreme weather events can drastically influence the dynamics and stability of networked infrastructure systems like transportation networks or power grids. Climate change is increasing the frequency of such events, making their impact on human society and ecosystems increasingly relevant. Prominent examples include damage of critical infrastructure caused by heavy rainfalls and landslides. The devastating floods that struck Germany's Ahr valley in 2021 are yet another reminder of the threat posed by such extreme events. Due to washed-out roads and further severe infrastructure damages, critical bottlenecks effectively cut off a substantial share of the population from assistance, hampering or even impeding their rescue.

In this study, we investigate the impact of flood events on transportation networks where stability is particularly important in order to ensure the accessibility of emergency services. Local changes in the underlying network dynamics can affect the whole road network and, in the worst case, cause a total collapse of the system through cascading failures. Because of the severe consequences of cascading events, we aim to recognise such spreading processes at an early stage and, in a further step, be able to prevent them. To this end, we set up a gravity model of travel to simulate the changes of the traffic load after flooding events to identify vulnerabilities in the system. We further analyse how the accessibility of emergency services is affected and if the population can be effectively reached in time.

I3 – Sensitivity of principal components to changes in the presence of non-stationarity

Henrik M. Bette, Thomas Guhr

Faculty of Physics, University of Duisburg-Essen, Duisburg, Germany
Henrik.bette@ish.de

Non-stationarity affects the sensitivity of change detection in correlated systems described by sets of measurable variables. We study this by projecting onto different principal components. Non-stationarity is modeled as multiple normal states that exist in the system even before a change occurs. The studied changes occur in mean values, standard deviations or correlations of the variables. Monte Carlo simulations are performed to test the sensitivity for change detection with and without knowledge about the non-stationarity for different system dimensions and numbers of normal states. A comparison clearly shows that the knowledge about the non-stationarity of the system greatly improves change detection sensitivity for all principal components. This improvement is largest for those components that already provide the greatest possibility for change detection in the stationary case

I4 – Graph neural networks beat network science at predicting dynamic stability of sustainable power grids

Michael Lindner, Christian Nauck

Potsdam Institute for Climate Impact Research (PIK)
michaellindner@pik-potsdam.de

A large body of work in network science studies the interplay of network topology with observables of interest. For example, several centrality measures quantify a network's vulnerability to attacks at specific nodes. Recently, Graph Neural Networks have shown great potential for network prediction tasks. They do not rely on explicitly defined network measures but implicitly learn node embeddings from the topology. We compare different predictive models of the highly nonlinear observables single node basin stability (SNBS) and survivability (SURV) in networks of inertial Kuramoto oscillator, which are paradigmatic models of power grids. We explicitly compute a large number of network measures that might be related to SNBS and SURV and provide them as inputs for a linear regression and a multi-layer perceptron. Their performance is then compared to Graph Neural Networks that only receive the network topology and the distribution of sources and sinks as inputs. We study networks of varying size as well as machine learning models with different numbers of trainable parameters and find a remarkable performance of Graph Neural Networks as compared to the more established approaches. While our methods have been developed in the context of power grids, they only rely on general features of complex networks, and may thus be applied to related nonlinear phenomena in other domains as well.

I5 – Complex networks for the urban acoustic environment

Timo Haselhoff (1), Tobias Braun (2), Norbert Marwan (2,3), Susanne Moebus (1)

(1) Institute for Urban Public Health, University Hospital Essen, 45147 Essen, Germany; (2) Complexity Science, Potsdam Institute for Climate Impact Research, 14473 Potsdam, Germany; (3) Institute of Geoscience, University of Potsdam, 14473 Potsdam, Germany
timo.haselhoff@uk-essen.de

The urban acoustic environment (AE) plays an underestimated role in the daily life of residents inhabiting metropolitan regions. The urban AE contains valuable information on complex sub-systems of urban areas, such as traffic, infrastructure and biodiversity. Associations between noise exposure and the mental or physical health of urban residents are an important subject of ongoing research. Despite the extensive information that is recorded by modern acoustic sensors, few approaches are designed to capture the rich complexity embedded in the time-frequency domain of the urban AE. The decreasing costs of acoustic sensors and rapid growth of storage space and computational power have led to an increase of acoustical data to be processed. Quantitative methods need to account for this complexity, while effectively reducing the high dimensionality of terabytes of audio data.

We take this as an opportunity to introduce complex networks to the field of urban acoustics. We use one of the world's most extensive longitudinal audio datasets from the SALVE study to systematically characterize the urban AE. SALVE is an ongoing study since 2019, in which 3-min acoustic recordings are made twice per hour at 23 locations in Bochum, Germany. The recorded acoustic samples exhibit a clear diel cycle and reveal site-dependent communities of interlinked frequencies. We demonstrate the utility of frequency-correlation matrices (FCMs) to effectively capture these communities. Based on these results, we construct (functional) networks of day time-specific 3-min audio recordings from

05.2019 to 03.2020 ($n = 319,385 = 665$ days). We show that the average shortest path length of an acoustic frequency network informs on site- and time-specific distinctiveness of frequency dynamics in the urban AE. To validate our findings, we use the land use mix around each site as a proxy for the AE, as the acoustic environment is heavily impacted by the built environment. The proposed method enables us to clearly identify 4–5 clusters of distinct urban AEs based on hourly variations in the distinctiveness of frequency dynamics. Our results indicate that complex networks represent a promising approach to analyse large-scale audio data and help to understand the time-frequency domain of the urban acoustic environment.

I6 – Indication of long-range city size correlation analysis based on city networks of European countries

Yunfei Li (1), Deniz Ural (1), Caner Aydin (1), Celine Rozenblat (2), Jan W. Kantelhardt (3), Diego Rybski (1,4,5)

(1) Potsdam Institute for Climate Impact Research; (2) Institute of Geography and Sustainability, Faculty of Geoscience, University of Lausanne; (3) Institute of Physics, Martin-Luther-University, Halle (Saale), Germany; (4) Department of Environmental Science Policy and Management, University of California Berkeley; (5) Complexity Science Hub Vienna, Vienna, Austria
yunfei.li@pik-potsdam.de

City systems are characterized by the functional organization of cities on a regional or country scale. While there is a relatively good empirical and theoretical understanding of city size distributions, insights about their spatial organization remain on a conceptual level. Here we empirically analyze the correlations between the sizes of cities (in terms of area) across long distances. Therefore, we (i) define city clusters, (ii) obtain the neighbourhood network from Voronoi cells, and (iii) apply a fluctuation analysis along all shortest paths. We find that most European countries exhibit long-range correlations but in several cases these are anti-correlations. In an analogous way we study a model inspired by Central Places Theory and find that depending on the level of disorder, both positive and negative long-range correlations can be simulated. We conclude that the interactions between cities of different sizes extend over distances reaching the country scale.

I7 – Asymmetry induces critical desynchronization of power grids

Patrycja Jaros, Roman Levchenko, Tomasz Kapitaniak, Jürgen Kurths, **Yuri Maistrenko**

Lodz University of Technology
patrycja.kuzma@p.lodz.pl

Dynamical stability of the synchronous regime remains a challenging problem for secure functioning of power grids. Based on the symmetric circular model [Nature Communication 11, 592 (2020)], we demonstrate that the grid stability can be destroyed by elementary violations (motifs) of the network architecture such as cutting a connection between any two nodes or removing a generator or a consumer. We describe the mechanism for the cascading failure in each of the damaging case and show that the desynchronization starts with the frequency deviation of the neighbouring grid elements followed by the cascading splitting of the others, distant elements and ending eventually in the bi-modal or a partially desynchronized state. Our findings reveal that symmetric topology underlines stability of the power grids, while local damaging can cause a fatal blackout.

MS3 Adaptive and multistable networks

Partial synchronization patterns and chimera states in adaptive networks

Eckehard Schöll

TU Berlin, Potsdam Institute for Climate Impact Research, Bernstein Center of Computational Neuroscience Berlin
schoell@physik.tu-berlin.de

We review partial synchronization patterns emerging in networks of adaptively coupled nonlinear oscillators. Power grids, as well as neuronal networks with synaptic plasticity, and physiological networks of the immune system and the parenchyma coupled adaptively by cytokines, describe real-world systems of tremendous importance for our daily life. This contribution provides a new perspective by demonstrating that power grids can be viewed as a special class of adaptive networks, where the coupling weights are continuously adapted by feedback of the dynamics, and both the local dynamics and the coupling weights evolve in time as co-evolutionary processes [1]. Such adaptive networks are very common in neural networks with synaptic plasticity. In terms of power grids, the power flow into the network nodes from other nodes represent pseudo coupling weights. This modelling approach allows one to transfer methods and results from neural networks, in particular the emergence of solitary states [2] and multifrequency clusters [3], which may form in a hierarchical way and destabilize the desirable completely synchronized operating state of the power grid. In this work, the relation between these two types of networks, in particular the model of Kuramoto-Sakaguchi phase oscillators with inertia (swing equation for power grids) and the model of phase oscillators with adaptivity, is used to gain insights into the dynamical properties of solitary states and multifrequency clusters in power grid networks. Furthermore, with adaptively coupled phase oscillators in a 2-layer physiological network we present functional modeling of tumor disease and sepsis [4,5].

References

[1] R. Berner, S. Yanchuk, and E. Schöll: What adaptive neuronal networks teach us about power grids, Phys. Rev. E 103, 042315 (2021)

[2] H. Taher, S. Olmi, and E. Schöll: Enhancing power grid synchronization and stability through time delayed feedback control, Phys. Rev. E 100, 062306 (2019)

[3] R. Berner, S. Vock, E. Schöll, and S. Yanchuk: Desynchronization transitions in adaptive networks, Phys. Rev. Lett. 126, 028301 (2021)

[4] Sawicki, J., Berner, R., Löser, T., and Schöll, E.: Modeling tumor disease and sepsis by networks of adaptively coupled phase oscillators, Frontiers Netw. Physiology 1, 730385 (2022)

[5] Berner, R., Sawicki, J., Thiele, M., Löser, T., and Schöll, E.: Critical parameters in dynamic network modeling of sepsis, Frontiers Netw. Physiol. 2, 904480 (2022)

Multi-stable synchronization patterns and switching dynamics of paleoclimate networks

Celik Ozdes (1), Deniz Eroglu (1), Norbert Marwan (2), Tobias Braun (2)

(1) Kadir Has University (KHAS) (2)Potsdam Institute for Climate Impact Research (PIK)
celik.ozdes@khas.edu.tr

To improve our understanding of climate dynamics, we first need to deeply understand the climate's past if we hope to mitigate and adapt to oncoming critical climate change. Understanding the past climate dynamics depends on the interpretation of paleo proxies. Blending dynamical systems theory, recurrence theorem, multistability, and synchronization with complex networks theory and machine learning techniques have become instrumental for a more profound understanding of climate dynamics in the last few decades. However, these techniques are not directly applicable to paleoclimate research since the proxy data is subject to different distortions. The paleoclimate proxy measurements carry uncertainty in nominal and temporal dimensions, and also the choice of proxy and varying effects of local and global interactions matter.

Paleoclimate proxies typically represent the climate dynamics of large spatial regions and long periods. Furthermore, the proxies contain many switching transitions between droughts and wet seasons, showing that paleoclimate dynamics have multi-stability. To mimic paleoclimate dynamics, we introduce a multi-layer network model of coupled chaotic maps where multiple chimera configurations of synchronized subsystems coexist as stable states. This multi-stable system goes through a series of critical transitions into another stable state through noise induction. We collect only the mean field of the state variables from each layer to imitate the spatial sparsity of paleoclimate measurements. Using this limited information, we developed a methodology to reconstruct paleoclimate networks and identify the critical switching of dynamical patterns.

Our paleoclimate network approach pivots around the recurrent property of climate system states. After suitable transformations, recurrence quantification analyses (RQA) of proxy series are shown to be robust indicators of the dynamical properties of represented dynamics in the form of time series. We construct a functional network from these series with nodes representing proxy sources using the time evolution of individual series. This allows us to classify the system state with respect to the visible relational dynamics between nodes. We also extended our studies to real paleoclimate datasets around Northern Africa and found the dominant dynamical patterns associated with known periods.

Bifurcations of twisted states in phase oscillator networks

Christian Bick, **Tobias Böhle**, Christian Kuehn

Technical University Munich
tobias.boehle@tum.de

The Kuramoto model provides a prototypical framework to study the dynamics of interacting particle systems. The classical heterogeneous Kuramoto model exhibits two main dynamically important states – desynchronization and partial synchronization. Depending on the parameters of the system, the long term behavior always tends to either of these states. However, when considering identical oscillators on a nearest-neighbor graph, the Kuramoto model exhibits more interesting states such as uniformly twisted states. It was discovered by Wiley, Strogatz and Girvan in 2006 that the stability of these twisted stated depends on the coupling range of the nearest-neighbor graph. Since this original analysis was published, many generalizations and variants were developed. In this talk, we will analyze the bifurcation in which these twisted states lose their stability upon varying parameters, such as the coupling range, of the system. We investigate the existence and shape of bifurcating equilibria in the infinite particle limit.

Generating stable chimera states in adaptive networks

Luis Guillermo Venegas Pineda, Hildeberto Jardón-Kojakhmetov, Ming Cao

University of Groningen
l.g.venegas.pineda@rug.nl

During the past decades, chimera states have attracted substantial attention due to their unexpected symmetry broken spatio-temporal nature, enabling the coexistence of synchronous and incoherent behaviours in complex networks under particular conditions. Despite relevant results of such unforeseen states in different physical and topological configurations have been obtained, there remain several structures and mechanisms yet to be unveiled. In this talk, I will present a novel technique for the generation of different synchronization patterns, including stable chimera states, by introducing adaptation in the coupling strengths. For this matter, we study a multilayer network composed by two populations of heterogeneous Kuramoto phase oscillators with coevolutive couplings only dependent on macroscopic quantities of the system. Moreover, due to the nature of the model and by taking the continuum limit, we derive a mean-field representation for which we employ geometric singular perturbation theory (GSPT) by including a time-scale separation between the dynamics of the nodes and their connections. Subsequently, I address two different problems, namely the coevolutive inter and intracoupling scenarios, for which I present necessary and sufficient conditions for the critical manifold to be normally hyperbolic and attracting in the entire domain of interest. Moreover, I will emphasize the effect of the selected slow adaptation rule in the formation of different synchronization patterns in the mean-field. On top of that, considering the previous conditions and the stability of the coupling dynamics, I give arguments for the preservation of such behaviors at the network level, supported by numeric results for several synchronization arrangements. Lastly, I present simulations of the non-hyperbolic case for which relaxation oscillations and canard cycles, related for the first time to breathing chimera states, have been observed.

Adaptivity and multi-mode-induced multistability in coupled oscillator systems

Rico Berner

Humboldt-Universität zu Berlin
rico.berner@physik.hu-berlin.de

Multistability, the co-emergence of collective states and synchronization patterns, plays an important role in mathematics and physics, e.g., for the modeling of climate systems or the understanding of the dynamic coordination in the brain. Different mechanisms inducing multistability in complex dynamical systems have been described. In this talk, we show how an adaptive network structure or the interplay of multiple modes in the interaction function provide the necessary flexibility for the co-stability of different dynamical states in systems of coupled phase oscillators. We identify the systems' main features leading to multistability and discuss the implications of multistability for their complex phase transitions. In particular, we present a transition phenomenon in an adaptive dynamical network that is similar to heterogeneous nucleation induced by local impurities known, e.g., from cloud formation, crystal growth or Ostwald ripening in equilibrium and nonequilibrium systems.

Multistable dynamics of church bell system

Tomasz Burzynski, **Przemyslaw Perlikowski**, Piotr Brzeski

Division of Dynamics, Lodz University of Technology, Stefanoiwsego 1/15 Lodz, Poland
przemyslaw.perlikowski@p.lodz.pl

We present how sample-based analysis can complement classical methods for the analysis of dynamical systems. We use it to detect the multistability in the non-linear, piecewise, and discontinuous system. We base on the yoke-bell-clapper system with variable geometry and adjustable excitation force. A mathematical model base on the existing device. The analysed model can reliably predict the ringing scheme of a bell and associated reaction forces in the supports. We found a wide variety of periodic and non-periodic solutions and examined the ranges of coexistence of solutions and transitions between them via different types of bifurcations.

Response of mechanical structures supporting dc motors with limited power supply

A. A. Nanha Djanan, **B. R. Nana Nbendjo**

University of Yaounde I, Cameroon
nananbendjo@yahoo.com

The present communication aims to describe the dynamics of mechanical structures such as beam and rectangular plate when they are subjected to one or more DC motors with limited power supply. For that, two main approaches have been developed with the purpose to give a good insight on vibration control and stability of the studied system. The method is rather based on the synchronization with and without delay between the external sources (DC motors) working on the structure. The phase, anti-phase or rapid and late synchronization phenomena between the motors show a big influence on the dynamics response of the system.

Coherence resonance in networks

Tiago Pereira (1,2), Carlos Fiore (1,2), Ralf Toenjes (3)

(1,2) Universidade de São Paulo, (3) Potsdam University
tiago@icmc.usp.br

Complex networks are abundant in nature and many share an important structural property: they contain a few nodes that are abnormally highly connected (hubs). Some of these hubs are called influencers because they couple strongly to the network and play fundamental dynamical and structural roles. Strikingly, despite the abundance of networks with influencers, little is known about their response to stochastic forcing. Here, for oscillatory dynamics on influencer networks, we show that subjecting influencers to an optimal intensity of noise can result in enhanced network synchronization. This new network dynamical effect, which we call coherence resonance in influencer networks, emerges from a synergy between network structure and stochasticity and is highly nonlinear, vanishing when the noise is too weak or too strong. This is a joint work with C. Fiore and Ralf Toenjes.

MS4
World-Earth system analysis

Reshaping human-environment modeling

Wolfram Barfuss

University of Tübingen
wolfram.barfuss@gmail.com

Collective action is crucial to embark on sustainable development pathways. Rapid and large-scale transformation is needed to avoid catastrophic tipping points in increasingly interconnected human-environment systems. However, the question of how collective, cooperative behavior – in which intelligent actors seek ways to jointly improve their welfare in dynamic environments – is unresolved. To make progress in this area, mathematical models are essential. To date, however, no modeling framework can address the elements of collective behavior from intelligent actors in complex biophysical environments in a consistent and understandable manner. In this talk, I'll present an overview of ideas and recent works on moving forward with this challenge and reshaping human-environment modeling.

Toward strict investigation of sustainable development of society: Formalization and models

Alexander Makarenko

Institute for Applied System Analysis at National Technical University of Ukraine (KPI)
makalex51@gmail.com

Concepts and models for sustainable development and transformation of large socials systems are considered. Some ways for formalization of scenarios of transformations are proposed. It is proposed the description of a new approach to mentality accounting in operational research (OR), which is based on internal representation of mental images. There are considered: 1) Sustainable development as a mathematical problem, including a formal definition of sustainable development with ethic accounting. 2) New models of large social systems, 3) The influence of the ethical aspects of the transformation of social systems. 4) Risk assessment in scenarios for large socio- economic systems. 5) Transformation of society. 6) Anticipatory aspects of sustainable development.

In the case of crisis conditions (for example, in a war situation), the variables change very quickly. Therefore, it is necessary to make a special adaptation of the problem of sustainable development to such conditions. Here we note several areas of setting such problems for crisis conditions. They may look differently depending on the scale and aspects under consideration.

References

[1] Makarenko, A.: Sustainable development and principles of social systems modeling. Generis Publisher, 2020. 173 p.

[2] Makarenkoo, A.: Collective Properties of Large Social Systems. New Approaches. Taras Shevchenko 6th Int. Conf. on Social Sciences. Kyiv 04-05 April 2021. Vol. 3, p. 911–916. ISBN 978-605-70554-1-5

Concerted efforts of politics, society and science can effectively turn down tipping risks

Nico Wunderling (1,2,3), Saverio Perri (3), Wolfram Barfuss (1,4), Amilcare Porporato (3,5), Michael Oppenheimer (6), Jonathan F. Donges (1,2,3), Simon A. Levin (3,7), Johan Rockström (1,2)

(1) Earth System Analysis, Potsdam Institute for Climate Impact Research (PIK), Member of the Leibniz Association, 14473 Potsdam, Germany; (2) Stockholm Resilience Centre, Stockholm University, Stockholm, SE-10691, Sweden; (3) High Meadows Environmental Institute, Princeton University, Princeton, 08544 New Jersey, USA; (4) Institute for Theoretical Physics, University of Tübingen, 72076 Tübingen, Germany; (5) Department of Civil and Environmental Engineering, Princeton University, Princeton, 08540 New Jersey, USA; (6) Department of Geosciences and the School of Public and International Affairs, Princeton University, Princeton, 08540 New Jersey, USA; (7) Ecology & Evolutionary Biology, Princeton University, Princeton, 08544 New Jersey, USA
`nico.wunderling@pik-potsdam.de`

Several climate tipping elements such as the Amazon rainforest or the large ice sheets on Greenland and Antarctica are showing increasing signs of dramatic change in response to human-made global warming. While dangerous tipping risks can be reduced by keeping strict temperature guardrails set by international agreements, so far, such agreements have prompted only moderate emission cuts due to socio-political challenges. Here, we couple a conceptual model of interacting climate tipping elements to a simplified social model outlining an energy-production transition toward clean energy. Using this coupled model, we find that three ingredients are required for a fast sustainability transition, avoiding the largest tipping risks: (i) Strong political incentives to invest in clean energies, (ii) high societal pressure to avoid crossing climate tipping thresholds, and (iii) scientific guidance leading to sufficiently small uncertainties in tipping points. If these conditions are met, we reveal that tipping risks can be reduced by a factor of up to 20, in particular when uncertainties in tipping element thresholds are reduced significantly.

Uncovering complex dynamics in the Earth system using Earth system data cubes

Miguel D. Mahecha, Chaonan Ji, Guido Kraemer, Francesco Martinuzzi, David Montero, Karin Mora, Martin Reinhardt, Maximilian Söchting

Remote Sensing Centre for Earth System Research, Leipzig University, Germany
`miguel.mahecha@uni-leipzig.de`

Analysing Earth system dynamics based on high-dimensional data streams remains a major scientific challenge. However, we need to understand the coupled dynamics of land-atmosphere interactions in order to manage the ecosystems of the future taking into account changes due to increasing intensities of climate extremes, ongoing land cover change, and legacies of past anomalies. In this contribution, we will first present advances in the Earth System Data Cube concept for analysing high-dimensional dynamics in the Earth system. Advances range from interactive visualisations that make terabytes of data accessible to everyone to the latest deep learning applications. Second, we will highlight some scientific advances in understanding the coupled land-atmosphere system in response to climate extremes. Finally, we give an outlook towards considering “biodiversity” as a control of land-surface dynamics.

Theoretical ecology meets marine geochemistry: Approaching the enigmatic persistence of dissolved organic matter in the oceans

Bernd Blasius

ICBM, University of Oldenburg
`blasius@icbm.de`

Marine dissolved organic matter (DOM) is a highly diverse mixture of compounds, accounting for one of the Earth's largest active carbon pools with a similar amount of reduced carbon as all living biomass on land and in the oceans combined. Aquatic organisms continuously release a myriad of organic molecules that become food for microbes, but a residual fraction of DOM resists microbial degradation and accumulates in the ocean for millennia, resulting in the huge standing stock of refractory DOM. The reasons behind this DOM persistence, where starving microbes fail to utilize the energy source of their surrounding organic matter, remain unknown. Here, I present a recently developed model framework that captures the interaction between a complex mixture of DOM compounds and a diverse community of microbial consumers as bipartite networks of DOM release and microbial turnover. Extending classic consumer-resource systems, the model yields surprising rich dynamic structure, including parameter regimes with chaotic dynamics, suggesting that microbial communities in the deep sea are characterized by self-organized temporal fluctuations. Including evolutionary processes, the model predicts a strong diversification of externally supplied DOM that creates niches for invasion of new microbial consumers, yielding cascades of subsequent extinctions of others. This leads to complex co-evolutionary dynamics subject to persisting turnover, even in stable environments. Thereby, microbial communities self-organize into different modules, akin to trophic layers in food-webs, and the system evolves to a state of highly diluted and diverse DOM in which micro-heterotrophs are living at the edge of their fitness range. These model results provide a mechanistic understanding of how the huge recalcitrance and diversity of DOM might emerge from the complex interactions between microbial communities and organic molecules. Finally, I show how implementing the DOM-microbe interactions into a global ocean model allows to capture large-scale DOM patterns in the ocean and to model expected changes of the DOM inventory in future climate scenarios.

Posters W
World-Earth system analysis

W1 – Scaling of tectonics, biogeographical structures, and macroevolution

Andrej Spiridonov (1), Shaun Lovejoy (2), Lauras Balakauskas (1)

(1) Department of Geology and Mineralogy, Vilnius University, Lithuania; (2) 2 Physics Department, McGill University, Canada
s.andrej@gmail.com

The fundamental questions of macroevolution are: what drives origination and extinction of taxa, and what is the long-term expected pattern of global biodiversity change? Here we use the perspective of time scaling and multiplicative multifractal processes in suggesting unified framework connecting multiscale Earth system dynamics, and scale free and time scale dependant features of evolutionary dynamics. Here we tackle a classical problem in evolutionary paleobiology – the causes of demise of the major marine animal phylum Brachiopoda through the Phanerozoic eon. We analyzed the evolution of longitudinal and latitudinal geographic ranges of brachiopod genera and compared their dynamics to the continental fragmentation index dynamics, which reflects the degree of fragmentation or conversely amalgamation of continents and terrains. The Haar fluctuation analyses of geographic ranges and continental indices revealed that there is a direct functional connection between the fragmentation and the shapes and sizes (in longitudinal direction) of brachiopod ranges. Positively scaling tectonics controls the positive scaling of geographical distributions of brachiopods. Since geographic ranges in times other than mass extinctions are the major determinants of survival, this indicates that the stability, and conversely the turnover of marine biota is directly related to the multiscale random dynamics of continental amalgamation. The low of brachiopod geographic ranges and the occurrence of the most isometric shapes of their ranges are coincident to the maximal amalgamation of the supercontinent Pangaea. Therefore, the multiscale perspective in combination with the advanced tools of nonlinear dynamics show significant potential in solving decades-long problems, and building unified theory of coupled Earth-Life dynamics. The study was supported by the project S-MIP-21-9 “The role of spatial structuring in major transitions in macroevolution”.

W2 – Modelling the evolution of the volcanic plume height as a function of the eruption time and the seasonal climate

Françoise Martine Enyegue à Nyam, Collins Djouda Paguem

Department of Physics Faculty of Science, University of Yaoundé I, Cameroon
francem2019@yahoo.com

The forecasting of the volcanic plume height is the topic of many studies in physical volcanology. Therefore, several physical and mathematical models have been used. One of the leading physical models derived from observations is the Woods model since 1988 which includes a gas thrust, buoyancy driven and tracking zones. In the same way, a second physical study was published, showing that the atmospheric boundary is made up of three layers: the surface, the mixing or convective and the free atmosphere layer whose thicknesses vary with the daytime and seasonal climate. By comparing these two models, we find a similarity and we wonder if one can justify the other or if these two models are complementary. In this project we use the Reynolds Averaged Navier Stokes equations separating the turbulent fluctuations from the stationary evolution of the different variables to model and simulate the evolution of the lower atmosphere in terms of the daytime. The results show that the height of the atmospheric boundary layer increases from midnight and reaches its maximum at twelve noon, and decreases thereafter till its minimum at midnight. From the data analysis method, we were able to determine a first pattern in winter. In particular, we find that the volcanic plume height is weakly affected by the wind speed which is known to be a major factor in the forecast of volcanic plume height. We plan to redefine the seasonal climate in order to find other patterns, to identify the seasonal factors that control the dynamics of the volcanic plume height. Our mathematical model based on the Navier Stokes equations has also allowed us to simulate the evolution of plume velocity as a function of height, hence to predict the duration of an eruption, thanks to the known results.

W3 – Spatiotemporal dynamics of the ITCZ using complex network analysis of outgoing longwave radiation

Gaurav Chopra (1), V. R. Unni (2), R. I. Sujith (1)

(1) Indian Institute of Technology Madras; (2) Indian Institute of Technology Hyderabad
gauravforward18@gmail.com

We study the Spatiotemporal dynamics of the Inter-Tropical Convergence Zone (ITCZ) using the complex network analysis of Outgoing Longwave Radiation (OLR). We use the Pearson's correlation to construct the network. The OLR data for thirty years (1992–2021) with a resolution of three hours is considered. The OLR network brings out the regions in the tropics affected by the ITCZ. The network also captures the significant variation in the characteristics of the ITCZ with geographical location. We use community detection to subdivide the tropics into regions of similar ITCZ characteristics. Communities in the OLR network reveal the seasonal position and structure of the ITCZ. The densely connected communities explicitly represent the mean structure of the ITCZ in the Northern and Southern hemispheres during the respective spring and summer seasons. Across these communities, the ITCZ shows coherent annual migration patterns. These communities also have a significant amount of long-range intra-community connections which is representative of the large-scale structure of the ITCZ. Meanwhile, communities encompassing the equatorial Pacific, Atlantic and Indian oceans have relatively sparse connections due to incoherence in the annual migration pattern and strength of the ITCZ in these regions. Furthermore, most connections within these communities are short-range or local connections, while long-range connections are scarce.

W4 – Towards modelling the Anthropocene: Conception and analysis of potential planetary-scale socio-ecological feedbacks the nexus of climate change, loss of biosphere integrity and human mitigation behaviour

Hannah Prawitz

(1) Potsdam Institute for Climate Impact Research; (2) IRI THESys at Humboldt-University Berlin
prawitz@pik-potsdam.de

Ever since we entered the Anthropocene, (some) humans are not only affected by earth system changes but are the most important determinant of environmental alterations like climate change and the sixth mass extinction. This leads to non-linear interactions and complex systems that challenge current predominant modelling approaches. Thus, a new generation of models is needed that integrate coupled human and environmental dynamics endogenously and go well beyond established Integrated Assessment Models.

Recently, some studies were published that propose such an integrated understanding and include dynamical social factors like norms and values regarding human emissions behaviour in their analyses and found possible social tipping elements. However, those models almost only regard the planetary boundary dimension of climate change, and there are currently no models that address social actions and social tipping points, which are also critical to effectively mitigate biodiversity loss.

This study aims to address aforementioned issues, as it seeks to understand how a combined socio-climate-biodiversity model – that concentrates on human values and behavior – might provide insights into the trajectories of global temperatures and biodiversity loss by focusing on two main feedback loops:

1. Climate-Biosphere Feedback: Climate change and Biosphere Integrity are the two core Planetary Boundaries and there are crucial climate-biosphere interactions that could significantly alter the resilience of the Earth system. However, ecosystem level feedbacks are not routinely included in models and projections.

2. Risk perception – Mitigation Feedback: The human perception of the environmental state and a corresponding risk can trigger pro-environmental behaviors. Extreme events but also gradual change can motivate people to intensify their mitigation efforts.

Based on a systematic review, a model that depicts those interactions between the climate system and the biosphere is coupled with a simple model that conceptualises human mitigation behaviour. The coupling is done by using the copan:CORE framework for World-Earth modelling, which allows for capturing all human and natural processes adequately. The resulting nonlinear dynamics and interactions, the sensitivity of all included formulas and parameters, as well as possible tipping points are explored using a Monte Carlo Analysis. This allows a wide variation of terms and parameters and an analysis of the importance of interactions and feedbacks in the resulting complex system.

W5 – Inferring dynamical information of the Earth system by dimensionality-reduction

Leonard Schulz, Karin Mora, Jürgen Vollmer, Miguel Mahecha

University of Leipzig Institute for Theoretical Physics, Remote Sensing Centre for Earth System Research
leonard.schulz@posteo.net

Understanding dynamics of the Earth system such as the climate is challenging for many reasons. Relevant systematic information can be obtained from observation time series. For variables such as carbon uptake by vegetation, there are only short observation time series and we do not have accurate models. Dimensionality-reduction methods decompose the delay-embedded observations into additive data-adaptive modes. These modes offer an understanding of information about underlying dynamics, such as dominant timescales. The analysis of climate models has been shown to require nonlinear dimensionality-reductions in order to extract such systematic information. The extraction quality of such information is highly impeded by the interactions between modes such as variance compression and degeneracy. Here we show the difference in timescale extraction by Singular Spectral Analysis and Nonlinear Laplacian Spectral Analysis for carbon uptake measurements. The influence of nonlinear inter-annular variability, the role of the seasonal trend, and the role of the delay-embedding are investigated. We showed that dimensionality-reduction methods need to be applied correctly to extract timescale related information, such as the unharmonic seasonal trend. Utilizing the additional feasibility to differentiate quasiperiodic variability accurately from such trends, nonlinear methods offer the reliable extraction of relevant information in observation-data. Besides timescales, the individual modes also enable the investigation systematic information about the the Earth system, such as spatiotemporal coupling dynamics from phase synchronization.

W6 – Phase transitions in machine learning

Markus Abel (1,2), Thomas Seidler (1,2), Markus Quade (1), Fabian Emmerich (2,3)

(1) Ambrosys GmbH; (2) Potsdam University; (3) 4Cast GmbH & Co KG
markus.abel@ambrosys.de

The methods of statistical mechanics are used in a wide range of applications exceeding the physics domain, such as problems from biology, chemistry, socio-ecology, graph theory, and last, but not least statistical learning theory. The latter is key to many studies in climatetology, e.g., in the context of tipping points.

The prediction of critical points motivates us to apply the methods to study phase transitions to statistical learning or methods of artificial intelligence (AI). To this end, we draw the anology between learning in AI and physical systems, like the well-understood Ising model: the development of AI applications has a two-fold nature in that the data used and the AI algorithm belong tightly together via the problem and objective defined. Here, we understand data and algorithm textit-together as a statistical system. An extremely relevant question concerns the nature of the cognition transition, i.e., the phase transition that characterises the ability of an AI algorithm to recognize objects or fulfill a task successfully. This transition may be classified according to its universaltiy class and consequently this may be a way to obtain fundamental understanding of AI algortihms. In this contribution, we illustrate the concepts by a study of large-scale weather events over europe: we investigate 3 years of ERA data from ECMWF over Europe with clustering algorithms in order to determine structure of large-scale weather over Europe. The results are important, both for the unsupervised classification of weather and for the understanding of the cognition transition in AI.

W7 – Local resource dynamics and normative spreading of behaviour in a world-earth model

Max Bechthold

Potsdam Institute for Climate Impact Research, Germany
max.bechthold@stud.uni-heidelberg.de

Analysis of Earth system dynamics in the Anthropocene requires explicitly taking into account the increasing magnitude of processes operating in human societies, their cultures and economies and their growing feedback entanglement with those in the physical, chemical and biological systems of the planet. One major process in the domain of the anthroposphere that is entangled with environmental processes, is the spreading of behaviour in a social norms and groups context. This talk introduces a World-Earth model that tries to model such norms and groups, their influence on human behaviour and the resulting effects on the dynamics of a renewable resource, which illustrates either a sustainable or unsustainable macro outcome. The models implementation in the copan:CORE framework is explained, which is designed to explicitly model with a focus on feedback interactions between the environmental and the socio-cultural realm. Finally, analyses of the model with tools from statistical physics are laid out and implications of these results on the importance of social norms in the transition to a more sustainable future are discussed.

W8 – Artificial trees and sustainable development – Towards coupling decision making on carbon dioxide removal with a comprehensive Earth system modeling framework

Moritz Adam (1,2), Kira Rehfeld (1)

(1) University of Tübingen, Geo- and Environmental Centre (GUZ); (2) Institute of Environmental Physics Heidelberg
moritz.adam@uni-tuebingen.de

At the current rate of decarbonization, limiting global warming to 2 degree Celsius by 2100 requires large-scale artificial carbon dioxide removal (CDR). CDR approaches involve extensive interventions in the Earth system. As a result, they are likely to conflict with the United Nations' Sustainable Development Goals (SDGs). This raises the dilemma of trade-offs between mitigating global warming and achieving other SDGs, while reduced CO_2 concentrations would also positively impact some SDGs. Simulation-based decision support on CDR has so far been limited to quantifying globally driven effects of individual CDR processes in the Earth system. Coupled spatial simulations of land use decisions on CDR and their impacts on sustainable development and ecosystem services do not exist. However, for proactive management, the question of how agents could interact with the Earth system through CDR in space and time and how they could, themselves, respond to CDR side effects is vital.

Here, we outline our concept towards interactively simulating CDR land use decisions in a comprehensive Earth system model (ESM). Our setup consists of two main building blocks: an extensively expanded and validated version of the Max Planck Institute-ESM and an agent-based model of coupled CDR decisions that is to be developed. The ESM representation resolves some challenges to represent idealized CDR land cover explicitly in space within coupled Earth system simulations. It parametrizes irradiation-driven CO_2 withdrawal and responds interactively to transient negative emission targets derived from socioeconomic scenarios. Incorporating potential trade-offs between CDR technologies and sustainable development, the land use component could simulate idealized decision-making under different configurations of simulated agents, climate, biosphere, and CDR impacts. It will be coupled to the Earth system's state and CDR side effects, driving the CDR land cover within the ESM in turn. Our coupled setup will enable studying idealized interactions between CDR side effects and land use decisions to enrich the debate on the impacts and trade-offs of CDR. It could also open a new way toward comprehensive World-Earth modeling.

W9 – Assortativity and consensus: A stylized model of frontrunner cities and global sustainability action

Niklas Kitzmann, Jonathan Donges

Potsdam Institute for Climate Impact Research (PIK)
kitzmann@pik-potsdam.de

Among the global community of cities, some display higher readiness than others to take action for decarbonization and sustainability. Often, these "Frontrunner Cities" are far ahead of their local peers and national legislative context. This phenomenon creates the potential to blaze a trail and pull other actors along, but also for increased polarization and division.

The formation of Frontrunner Cities is one example of humans tendency for assortative mixing: associating themselves with groups and individuals that they share some characteristics (such as political positions) with. We investigate the effects that such assortative behavior has on a political action consensus under growing pressure. Using several stylized models of social contagion and peer influencing, we show that assortative behavior can lead to faster consensus-forming when influence is drawn from both the local (peer) and global (aggregate) contexts. In the Frontrunner City example, this translates to a faster global response to rising global anthropogenic environmental pressures.

W10 – Synchronization theory for Quaternary ice age cycles

Takahito Mitsui (1,2), Metteo Willeit (2), Niklas Boers (1,2,3)

(1) Technical University of Munich; (2) Potsdam Institute for Climate Impact Research; (3) University of Exeter
mitsui@pik-potsdam.de

The dominant periodicity of glacial-interglacial cycles changed from 41 thousand years (kyr) to roughly 100 kyr across the Mid-Pleistocene Transition (MPT) around one million years ago. The mechanisms leading to these dominant periodicities and their changes during the MPT remain debated. Here we propose a synchronization theory explaining these features of glacial cycles and confirm it using an Earth system model that reproduces the MPT under gradual changes in volcanic CO2 outgassing rate and regolith cover. We show that the model exhibits self-sustained oscillations without astronomical forcing. Before the MPT, glacial cycles synchronize to the 41-kyr obliquity cycles because the self-sustained oscillations have periodicity relatively close to 41 kyr. After the MPT the time scale of internal oscillations becomes too long to follow every 41-kyr obliquity cycle, and the Earth's climate system synchronizes to the 100-kyr eccentricity cycles that modulate the amplitude of climatic precession. The latter synchronization is only possible with the help of the 41-kyr obliquity forcing through a nonlinear mechanism that we term vibration-enhanced synchronization.

W11 – Learning biosphere response to climate drivers using echo state observers

Francesco Martinuzzi (1,2), Miguel D. Mahecha (1,2,3), Karin Mora (2,3)

(1) Center for Scalable Data Analytics and Artificial Intelligence, Leipzig University, Germany; (2) Remote Sensing Centre for Earth System Research, Leipzig University, Germany; (3) German Centre for Integrative Biodiversity Research (iDiv), Leipzig, Germany
martinuzzi@informatik.uni-leipzig.de

Modeling the vegetation dynamics response to climate drivers represents a crucial component in the understanding of land-atmosphere interactions. Driven by nonlinear behavior, the biosphere state presents long term trends, a strong seasonal component as well as an immediate nonlinear response to weather stimuli. Vegetation memory effects also play a role, affecting its response to external inputs. In addition, while some atmospheric variables are known to have a stronger impact on vegetation dynamics compared to others, their influence is hard to quantify and the full extent of the relationship remains unknown. All of these factors compound, making the vegetation state and its drivers a challenging system to model. We frame the problem of modeling vegetation dynamics from atmospheric drivers as creating a function, called observer, that can infer unmeasured state variables from known components. In this study we show that echo state networks (ESNs), used as observers, can learn the normalized difference vegetation index (NDVI) from climate variables such as temperature and precipitation. This approach is tested for a range of conditions, such as different vegetation covers and locations in various climate zones in the European continent. The quality of the results is examined with multiple measures including those quantifying temporal approximation changes. Challenges and limitations are also discussed. Our results show that ESNs are a powerful AI paradigm for modeling land-atmosphere interactions, able not only to replicate the trend and seasonal components of the vegetation dynamics but also sub-seasonal dynamics.

MS5
Cardiovascular dynamics and sleep disorders

Sleep research using non-linear analysis supports the understanding of physiological brain functions

Thomas Penzel

Sleep Medicine Center, Charite Universitätsmedizin Berlin, Berlin, Germany
thomas.penzel@charite.de

Human sleep has been studied using behavioral observation first. Sleep is a state of unconsciousness. Based on behavior and on recording of brain activity, it is possible to distinguish wakefulness, rapid-eye-movement sleep (REM sleep), and non-REM sleep. Non-REM sleep can be further differentiated in light sleep and deep sleep according to the difficulty to wake up a person.

Because sleep is a function not only of the brain, but of the entire body, sleep recording includes the recording of respiration, cardiovascular functions, limb movements, audio and visual channels. All these signals, their recording and their evaluation are specified and described in an international manual for recording and analysis of sleep. These additional signals are of major importance when diagnosing sleep disorders.

Today much is known about the recording of sleep and many efforts take place to automate the analysis of sleep. This analysis has targeted not only the brain signals, but also the other signals and success differs according to the different sources of physiological signals. Taking all signals and analysis results together helps to improve the understanding of normal and disturbed sleep. Linear analysis had long been used for the analysis of these signals. Today non-linear analysis of signals helps to extract characteristic features for the description of sleep and sleep disorders. Now, not only feature extraction, but signals themselves are used for a new analysis of sleep stages and sleep disorders. With increasing computational power new methods for big data analysis can be used to obtain better understanding of physiological functions during sleep.

Measuring synchronization of physiological systems in sleep – Chances and challenges

Dagmar Krefting

University Medical Center Göttingen
dagmar.krefting@med.uni-goettingen.de

Synchronization between different physiological systems is examined to investigate their interaction depending on the physiological state, including various disorders. For example, cardio-respiratory synchronization is frequently assessed; and heart and brain interaction is increasingly acknowledged as an important research topic. Synchronization is typically determined by methods of (linear and nonlinear) time-series analysis applied to multidimensional biosignals. However, the complex dynamics of the human physiology as well as the heterogeneity of biosignal measurements and timescales pose challenges to the applicability of methods of nonlinear data analysis. Robustness and reproducibility of synchronization effects are therefore critical for the interpretation of analysis results. In sleep, different synchronization pattern – that can also be interpreted as different topologies of the human physiological network – have been observed, with deviations in different sleep disorders. Results from these studies are presented and discussed.

Assessment of cardiorespiratory variability from a clinician's perspective

Beata Graff (1), Grzegorz Graff (2), Krzysztof Narkiewicz (1)

(1) Medical University of Gdansk; (2) Gdansk University of Technology
bgraff@gumed.edu.pl

Cardiovascular variability has been proven to be a marker of autonomic modulation and some of the measures can serve as indicators of cardiovascular risk. Heart rate variability might be analyzed using various, linear and non-linear methods [1]. There are fewer techniques for blood pressure variability analysis but the clear-cut recommendations how to perform analysis of both short- and long term recordings exist [2].

Surprisingly, less is known about the analysis of respiration [3]. Although present guidelines underlie the impact of breathing on the derived heart rate and blood pressure variability parameters, no detailed instructions are given. So called Cheyne-Stokes respiration (CSR), presenting as repeating rises and falls in ventilation separated with periods of apnea, is a well-known finding in patients with heart failure and several approaches were made to capture and quantify the dynamics of CSR [4,5]. Similar pattern of respiration with apnea or without (periodic breathing) is also frequent in various pathologies during the night- and day-time.

However, the clinical use of measures of heart rate, blood pressure and respiratory variability is still limited. On the other hand, we are witnessing the rapid development of data collection and analysis methods. Therefore, there is an unique chance for gaining a better insight into cardiorespiratory physiology and, as a consequence, wider application of measures of cardiovascular variability in clinical practice.

The talk will outline the possibilities and challenges of cardiorespiratory regulation assessment. In particular, the specificity of the respiration analysis will be discussed – the variety of patterns and the related difficulties in the qualitative and quantitative assessment of their alterations.

References

[1] Heart rate variability. Standards of measurement, physiological interpretation, and clinical use. Eur Heart J. 1996;17:354-81

[2] Parati G, Ochoa JE, Salvi P, et al. Prognostic Value of Blood Pressure Variability and Average Blood Pressure Levels in Patients With Hypertension and Diabetes. Diabetes Care 2013; S 312-24

[3] van den Bosch OFC, Alvarez-Jimenez R, de Grooth HJ, Girbes ARJ, Loer SA. Breathing variability-implications for anaesthesiology and intensive care. Crit Care. 2021;25: 280

[4] Ponikowski P, Anker SD, Chua TP, et al. Oscillatory breathing patterns during wakefulness in patients with chronic heart failure: clinical implications and role of augmented peripheral chemosensitivity. Circulation. 1999;100:2418-24

[5] Granitza P, Kraemer JF, Schoebel C, Penzel T, Kurths J, Wessel N. Is dynamic desaturation better than a static index to quantify the mortality risk in heart failure patients with Cheyne–Stokes respiration? Chaos. 2018;28:106312

Asymmetries of heart period dynamics assessed by its cumulative accelerations and decelerations

Dirk Cysarz, Friedrich Edelhäuser

Integrated Curriculum for Anthroposophic Medicine, Witten/Herdecke University, Herdecke, Germany
d.cysarz@rhythmen.de

Heart period dynamics can be analyzed by methods derived from symbolic dynamics. A binary series representing the succession of acceleration and deceleration of heart periods still contains relevant information. However, assessing asymmetries in the heart period series needs more information. Here, we aim to complement measures of binary symbolic dynamics by properties closely related to the binary representation, i.e., cumulative accelerations and decelerations of heart period as basic characteristics underlying heart rate variability. The distributions of the accelerations and decelerations were quantified by the shape parameter of the Weibull function. This approach was applied to 1087 RR tachograms from healthy subjects covering the entire adulthood (age range: 18 to 84 years). Each parameter was analyzed per age decade. The average RR interval increased at old age compared to the youngest age group (median RR interval 839 ms vs. 970 ms). SDNN was constant up to 39 years and declined for older subjects (56 ms vs. 36 ms). The median acceleration was not different from the median deceleration in any age group. The shape parameter of the Weibull function differed for accelerations and decelerations in three age groups (20 to 29, 30 to 39 and 40 to 49 years). The median cumulative acceleration was different from the median cumulative deceleration for the age groups 20–29 and 50 to 59 years. The shape parameters for cumulative accelerations and decelerations were different in all age groups except in older subjects (age groups 70 to 79 and > 80 year). The analysis of cumulative accelerations and decelerations complement information derived from the analysis of binary symbolic dynamics. The results provide clear evidence for asymmetries in heart period dynamics.

Adapting pulse sequences for an efficient termination of spiral wave chaos

Thomas Lilienkamp (1), Ulrich Parlitz (2), Stefan Luther (2)

(1) Nuremberg Institute of Technology Georg Simon Ohm; (2) Max-Planck Institute for Dynamics and Self-Organization
thomas.lilienkamp@th-nuernberg.de

Life threatening cardiac arrhythmia such as ventricular fibrillation are governed by a chaotic electrical excitation wave dynamics, governed by spiral or scroll waves. Several new defibrillation concepts aiming at terminating arrhythmia with reduced side effects in comparison to the conventional method, by using pulse sequences of lower energy. In most of these studies, the temporal distance between consecutive pulses is kept constant. We demonstrate in a numerical study, how adapting the temporal distances between pulses may significantly alter the success rate of pulse sequences.

Nonlinear dynamics in live explanted human hearts – From spiral waves to unstable periodic orbits including period three and chaos

Flavio H. Fenton, Uzelac Ilija, Neal Bhatia, Shahriar Iravanian, and Elizabeth M. Cherry

(1) School of Physics, Georgia Tech; (2) Emory University; (3) School of Computational Science and Engineering, Georgia Tech
ffenton@gatech.edu

In this talk we will present experimental data from simultaneous voltage and calcium optical mapping obtained from seven live explanted human hearts (from patients receiving a new heart). We present the first quantitative detailed dynamics of stable functional voltage and calcium spiral waves in the ventricles with both chirality. We also show several examples of period doubling bifurcations, and complex long periodic orbits obtained during fast pacing, including several examples of period three and chaos quantified with a Lyapunov exponent. We then demonstrate how period doubling in space can lead to a complex substrate for the propagation of electrical waves in the human heart that initiate continuous multiple short lived spiral waves resulting in complex spatiotemporal dynamics (fibrillation). Finally, we present a theory of spiral wave "teleportation" that can be used to terminate these multiple spiral waves within one perturbative shock.

Posters S
Cardiovascular dynamics and sleep disorders

S1 – Dimorphism sexual and frequency cardiac: Non-linear method analyses

Alondra Albarado-Ibañez, Martha Ita-Amador, Julian Torres-Jacome

(1) Aplicaciones biotecnológicas Instituto de Ciencias Benemérita Universidad Autónoma de Puebla; (2) Fisiopatología Cardiovascular Complejo Nororiental Benemérita Universidad Autónoma de Puebla; (3) Fisiopatología Cardiovascular Instituto de Ciencias Benemérita Universidad Autónoma de Puebla
alondra.albarado@correo.buap.mx

The heart rate variability time series is a novel approach for prognostic and diagnostic development of disease that produces lethal arrhythmias. Until, the data shown were on the male sex, due to the data of female sex have influence hormonal period and other rhythms. However, in this study, the time series shows the existence of a delicate difference between them independently of the hormonal period. We obtained the RR intervals of ECG of college students, 134 females and 68 males. Disclosed the heart rate in female 74 bpm is minor than 77 bpm in male, the principal characteristic in analysis of FFT were that highest wave on the lower frequencies in male while in female highest frequencies. The analyses suggest an ability to differentiate the rhythm cardiac according to gender.

S2 – Estimating the decomposition of the mutual information rate in short-term cardiovascular variability time series: Comparison between different discretization strategies

Chiara Barà, Yuri Antonacci, **Luca Faes**

Department of Engineering, University of Palermo, Italy
luca.faes@unipa.it

In the study of interacting physiological systems, model-free tools for the analysis of bivariate time series are fundamental to provide a proper description of how the coupling among systems arises from the underlying possibly non-linear regulatory mechanisms. Among the tools devised to perform this analysis, information-theoretic measures are largely explored to infer cardiovascular (CV), cardiorespiratory (CR) and cerebrovascular (CB) interactions from pairs of physiological time series. In this context, the so-called mutual information rate (MIR) is a long-known measure of the dynamic interaction between two random processes, which can be reliably computed from bivariate linear models fitting the observed time series but is much harder to quantify if the model assumptions are relaxed.

In this work, we present a framework for the model-free estimation of the MIR between two random processes X and Y, expressed equivalently as the sum of the individual entropy rates of X and Y minus their joint entropy rate, or as the sum of the transfer entropies from X to Y and from Y to X plus the instantaneous information shared by the processes at zero lag. Each information dynamic measure is estimated through discretization of the random variables forming the processes, performed either via uniform quantization (binning approach) or rank ordering (permutation approach), followed by computation of the entropy terms composing the measure.

The two estimation approaches are compared on three datasets collected from young healthy subjects and including short time series (250–300 points) of (i) heart period and respiratory flow measured during spontaneous and paced breathing, (ii) heart period and systolic arterial pressure measured at rest and during head-up tilt, and (iii) mean arterial pressure and cerebral blood flow velocity measured at rest and during head-up tilt. The statistical significance of the MIR and each of its constituent terms was assessed by means of surrogate data analysis.

Our results show that, with careful selection of the estimation parameters, statistically significant and physiologically meaningful patterns of the MIR and of its components can be achieved in the analyzed datasets. We found that paced breathing at slow breathing rates induces less complex and more coupled CR dynamics, while postural stress leads to an unbalancing of CV and to less complex pressure dynamics with preserved CB interactions. These results are better highlighted by the permutation approach, thanks to its more parsimonious representation of the discretized dynamic patterns which allows to limit the curse of dimensionality.

S3 – From 2D to 3D: Comparing the performance of different GPU based algorithms to simulate cardiac excitation wave dynamics

Daniel Suth, Thomas Lilienkamp

Nuremberg Institute of Technology – Computational Physics
daniel.suth@th-nuernberg.de

In the field of cardiac dynamics, numerical simulations play an important role in understanding fundamental mechanisms and features of the dynamics within the myocardium. Of special interest are chaotic processes of cardiac dynamics, such as ventricular fibrillation, and methods for their treatment.

Electrical activity in the myocardium can be modelled as a set of coupled partial differential equations (PDE). These equations can, for instance, be solved using Runge-Kutta methods.

The use of the rapidly developing capabilities of graphics processing units (GPU) allows a significant acceleration of computation times, compared to CPU-based computations, for the numerical solution of the given PDEs. However, writing the necessary source code to exploit the full potential of GPUs is often a major challenge. Nowadays, there are various possibilities and software packages to realize this. We present a comparison of different possibilities to perform GPU calculations in order to investigate their performance in different situations and to highlight the advantages and disadvantages over CPU-based calculations.

The objective of this study is to investigate the possibilities of current programming languages and their respective libraries that enable the usage of GPUs (and thus a significant acceleration of computing time). Of particular interest are comparisons in terms of performance (in computing time) and code complexity.

We therefore implemented four different cardiac cell models for the simulation of electrical activity in the myocardium in both CPU- and in GPU-capable code.

All models were simulated on two-dimensional and on three-dimensional spatial domains. Furthermore, all models were simulated on a realistic three-dimensional geometry of a cardiac muscle in order to introduce a benchmark for further studies. Time measurements were performed to investigate the speedup in computational time due to the utilization of GPUs.

S4 – Information dynamics of heart rhythm, repolarization and amplitudes time series in Long QT Syndrome

Mateusz Ozimek, Karolina Rams, Jan Zebrowski, Teodor Buchner

Faculty of Physics, Warsaw University of Technology
mateusz.ozimek.dokt@pw.edu.pl

The human organism is considered complex and consists of many interacting subsystems. These interactions are nonlinear, and such systems are characterized by a high degree of complexity, which is closely related to health condition and age. Interactions between subsystems can be considered in terms of physiological networks. In our work, we examined a fragment of such a network that governs the cardiac cycle. We focus on the relations between heart rhythm and repolarization. For this, the framework of information dynamics was used. Our goal is to find metrics, which can be useful for risk stratification of LQTS based on noninvasive 24-hour Holter ECG. We have estimated entropy measures for as well univariate as multivariate time series. The conditional entropies were calculated for simultaneous RR, QT and diastolic intervals (DI). Moreover, we also consider time series of amplitude values of QRS and T wave. We study the asymmetry of information flow. The data were extracted from the ECG recordings in two of the THEW databases: E-HOL-03-0202-003 (202 ECG of healthy individuals) and E-HOL-03-0480-013 (480 ECGs for patients with the LQTS). We study a subset of this data, for which automatic detection of QT intervals and T wave amplitude could be applied. The results show differences between healthy and LQTS patients in case of directionality of information flow. The asymmetry is present for information flow between heart rate and the time series of QT intervals and T-wave amplitudes. Estimated values of information dynamics show promising result in differentiating the complex dynamics of repolarization and hearth rhythm between healthy and LQTS patients. Machine learning tools can be used to build a model with high accuracy, specificity and sensitivity, however, bigger datasets are required.

S5 – Mechanistic neural masses for modeling seizures and spreading depolarization

Richa Tripathi (1,2), Rammah Abohtyra (1,3), **Bruce J. Gluckman** (1)

(1) Center for Neural Engineering, Penn State Universtiy, University Park, PA USA (2) Center for Advanced Systems Understanding (CASUS), HZDR, Görlitz, Germany (3) Electrical Engineering, UT Permian Basin, TX, USA
brucegluckman@psu.edu

Seizures and spreading depolarization events occur apparently spontaneously in epileptic brains. Why epileptic brains aren't seizing all the time is a fundamentally unanswered question. Brain rhythms emerge from the activity of networks of neurons. There have been many efforts to build mathematical and computational embodiments in the form of discrete cell-group activities – termed neural masses – to understand in particular the origins of evoked potentials, intrinsic patterns of brain activity, and mimic seizure dynamics. As originally utilized, standard neural masses convert input through a sigmoidal function to a firing rate, and firing rate through a synaptic alpha function to other masses. Such elements activities cannot be linked directly back to the activities of single neurons, the details of their function, genetics mutations, or linked to tissue level parameters such as extracellular potassium that are known to contribute to seizures and spreading depolarization. We defined a process to build mechanistic neural masses (mNMs) as mean-field models of microscopic membrane-type (Hodgkin Huxley type models) models of different neuron types that duplicate the stability, firing rate, and associated bifurcations as function of relevant slow variables – such as extracellular potassium and related volume-conducted features – and synaptic current; and whose output is both firing rate and impact on the slow variables – such as transmembrane potassium flux. Small networks composed of just excitatory and inhibitory mNMs demonstrate expected dynamical states including firing, runaway excitation and depolarization block, and these transitions change in biologically observed ways with changes in extracellular potassium and excitatory-inhibitory balance. Analysis of such models already provide experimentally predictable insights into why the basin of stability against seizures for epileptic brain may be smaller. Additionally, by introducing the change in function in sodium channels associated with genetic mutations associated with specific epilepsies, we similarly obtain networks that are more seizure-susceptible.

S6 – Efficient termination of cardiac arrhythmias using optogenetic resonant feedback pacing

Sayedeh Hussaini, Johannes Schroeder-Schetelig, Aidai M. Kyzy, Sarah L. Lädke, Laura Diaz, Raul Q. Uribe, Vishalini Venkatesan, Claudia Richter, Annette Witt, Vadim Biktashev, Rupamanjari Majumder, Valentin Krinski, Stefan Luther

(1) Research Group Biomedical Physics, Max Planck Institute for Dynamics and Self-Organisaion, Göttingen, Germany (2) Mathematics and Statistics, University of Exeter, United Kingdom
sayedeh.hussaini@ds.mpg.de

Over the past decade, optogenetics has been explored from basic to translational research, particularly in the area of control of cardiac arrhythmia, i.e., abnormal electrical activity of the heart. Caridac optogenetics is a technique which allows normal light-insensitive cardiac tissue to become senstitive to light stimuli by genetic modification. A better mechanistic understanding of the onset, progression, and control of cardiac arrhythmias benefits the development of alternative methods to conventional treatments, which are often associated with significant side effects for patients. To this end, optogenetics is a promising tool for these fundamental research.

We study the control of arrhythmias in N=5 intact Langendorff-perfused alphaMHC-ChR2 mouse hearts using two protocols: (i) a single global light pulse (duration10 and 100 ms, wavelength 470 nm) and (ii) resonant feedback stimulation with a sequence of global light pulses (duration 20 ms, wavelength 470 nm). The termination success rate is determined as a function of light intensity for both protocols. ECG recording and potentiometric optical mapping (dye Di-4-ANBDQPQ) are used to measure cardiac activation before, during, and after optical control. Corresponding numerical simulations of cardiac tissue are performed using the Bondarenko model in conjunction with a channelrhodopsin-2 model in a 2D domain 25×25 mm^2.

Resonant feedback pacing supersedes single pulse in termination efficacy in Langendorff-perfused alphaMHC-ChR2 mouse hearts [reduced by two orders of magnitude with respect to I_{50} = intensity for 50% termination success]. We observe efficient termination of arrhythmias using resonant feedback pacing even at subthreshold light intensities, i.e., below the minimum light intensity required to evoke an action potential. Numerical simulations show a dose-response consistent with the experimental findings. At subthreshold light intensities, simulations suggest that resonant feedback pacing results in resonant drift of the spiral wave core and subsequent arrhythmia termination.

S7 – Spatial-temporal organisation of cardiac fibrillation: From principles to patients

Stefan Luther

Max Planck Institute for Dynamics and Self-Organization, Am Fassberg 17, D-37077 Goettingen, Germany
`stefan.luther@ds.mpg.de`

Cardiac fibrillation is an electro-mechanic dysfunction of the heart that is driven by complex three-dimensional electrical excitation waves, resulting in incoherent mechanical contraction, loss of pumping function, and risk of sudden cardiac death. The nonlinear dynamics of vortex-like rotating waves play an essential role in the spatial-temporal organisation of fibrillation. However, the visualisation of these rotors, their interaction with each other and with the three-dimensional heterogeneous and anisotropic anatomical substrate remains a significant scientific challenge. In our talk, we will discuss the nonlinear dynamics of electrical and mechanical rotors during ventricular fibrillation. We will also address the application of rotor mapping using high-resolution 4D ultrasound for novel diagnostic and therapeutic approaches.

MS6
Dynamics of complex biological systems

Arnold tongues in mouse embryonic development

Alexander Aulehla

European Molecular Biology Laboratory (EMBL)
`aulehla@embl.de`

We study the origin and function of collective signaling oscillations in embryonic development. Oscillatory signaling is linked to the sequential segmentation of the vertebrate embryo body axis and the formation of pre-vertebrae, somites. Most strikingly, signaling oscillations are coordinated between neighboring cells and result in spatio-temporal wave patterns that traverse the embryo periodically. I will discuss how we employ general synchronisation principles and entrainment to reveal the fundamental dynamical properties of this embryonic coupled oscillator network.

Fluctuation-dissipation relations for spiking neurons

Benjamin Lindner

Humboldt Universität zu Berlin, Germany
`benjamin.lindner@physik.hu-berlin.de`

Spontaneous fluctuations and stimulus response are essential features of neural functioning but how they are connected is poorly understood. I derive fluctuation-dissipation relations (FDR) between the spontaneous spike and voltage correlations and the firing rate susceptibility for i) the leaky integrate-and-fire (IF) model with white noise; ii) an IF model with arbitrary voltage dependence, an adaptation current, and correlated noise. The FDRs can be used to derive thus far unknown statistics analytically [model (i)] or the otherwise inaccessible intrinsic noise statistics [model (ii)].

Oscillations, Arnold tongues and chaos in cell dynamics

Mogens H. Jensen

Niels Bohr Institute, University of Copenhagen
mhjensen@nbi.dk

When some human cells are damaged or stressed they respond by oscillating protein densities as have been observed for two famous transcription factors p53 and NF-kB (1). The oscillations have a period of 3–5 hours and appear in both healthy and sick cells. p53 is a cancer gene while NF-kB plays a role in diabetes. For p53 we show that that droplets of repair proteins form around damage sites in an oscillating fashion thus preventing Oswald ripening. The period of oscillations provides an optimal time scale for the repair mechanism (2). By apply an external periodic protein signal, the internal oscillation can lock to the external signal and thus controls the genes. The locking occurs when the ratio between the two frequencies is a rational number leading to Arnold tongues. If tongues overlap, chaotic dynamics appear which strongly influence gene production. The oscillations can be used as a diagnostic tool to distinguish different cancers. Our findings are in good agreement with experimental data from our collaborative groups at Harvard Medical, Beijing and Taiwan.

References

[1] M.L. Heltberg, S. Krishna, L.P. Kadanoff and M.H. Jensen, A tale of two rhythms: Locked clocks and chaos in biology (Review), Cell Systems, 12, 291-303 (2021).

[2] M.S. Heltberg, A. Lucchetti1, F.-S. Hsieh, D.P.M. Nguyen, S.-h.Chen and Mogens H. Jensen, Enhanced DNA repair through droplet formation and p53 oscillations, Cell 185, 4394-4408 (2022).

Statistical theory of asymmetric damage segregation in clonal cell populations

Arkady Pikovsky (1), Lev Tsimring (2)

(1) Department of Physics and Astronomy, University of Potsdam; (2) BioCircuits Institute, University of California San Diego
pikovsky@uni-potsdam.de

Asymmetric damage segregation (ADS) is ubiquitous among unicellular organisms: After a mother cell divides, its two daughter cells receive sometimes slightly, sometimes strongly different fractions of damaged proteins accumulated in the mother cell. Previous studies demonstrated that ADS provides a selective advantage over symmetrically dividing cells by rejuvenating and perpetuating the population as a whole. In this work we focus on the statistical properties of damage in individual lineages and the overall damage distributions in growing populations for a variety of ADS models with different rules governing damage accumulation, segregation, and the lifetime dependence on damage. We show that for a large class of deterministic ADS rules the trajectories of damage along the lineages are chaotic, and the distributions of damage in cells born at a given time asymptotically becomes fractal. By exploiting the analogy of linear ADS models with the Iterated Function Systems known in chaos theory, we derive the Frobenius-Perron equation for the stationary damage density distribution and analytically compute the damage distribution moments and fractal dimensions.

Heteroclinic dynamics as framework for cognitive processes

Bhumika Thakur, **Hildegard Meyer-Ortmanns**

School of Science, Jacobs University Bremen
h.ortmanns@jacobs-university.de

Heteroclinic dynamics is a suitable framework for describing transient but reproducible dynamics such as cognitive processes in the brain. It allows an implementation of winnerless competition so that different hierarchical processes in time possibly proceed in parallel at different places in space. We demonstrate how heteroclinic dynamical units, assigned to the sites of a grid, can act as pacemakers to entrain larger sets of units from a resting state to hierarchical heteroclinic motion, manifest as fast oscillations modulated by slow oscillations. The entrainment range depends on the type of coupling, the spatial location of the pacemaker and the individual bifurcation parameters of both the pacemaker and the driven units. We demonstrate why noise can considerably facilitate synchronization. Depending on the selected path in the heteroclinic network, units can be synchronously entrained to different temporal patterns. Such patterns are believed to code information in brain dynamics. Depending on the number and the location of pacemakers on a two-dimensional grid, synchronization can be maintained in the presence of a large number of resting state units and mediated via target waves when the pacemakers are concentrated to a small area of such a grid. Under a quench in the bifurcation parameter, hierarchical heteroclinic motion appears to be rather inert. In view of brain dynamics, our results indicate a possibly ample repertoire for coding information in temporal patterns. While these temporal patterns are produced by sets of synchronized units entrained by pacemakers and propagated in space, no finetuning of the parameters is needed for the entrained units.

Network-based approaches to prediction and control of epileptic seizures

Klaus Lehnertz

(1) Department of Epileptology; (2) Helmholtz Institute for Radiation and Nuclear Physics; (3) Interdisciplinary Center for Complex Systems, University of Bonn; Bonn; Germany
klaus.lehnertz@ukbonn.de

Epilepsy is nowadays conceptualized as a large-scale brain network disease with functionally and/or structurally aberrant connections It is one of the most common serious neurological disorders, affecting approximately 65 million people worldwide. Epileptic seizures are the cardinal symptom of this multi-facetted disease and are usually characterized by an overly synchronized firing of neurons. Seizures cannot be controlled by any available therapy in about 25% of individuals. Over the last decades, an improved characterization of the spatial-temporal dynamics of the epileptic process could be achieved with concepts and methods from nonlinear dynamics, statistical physics, synchronization and network theory. I will provide an overview of the progress that has been made using network-based approaches to prediction and control of epileptic seizures and will discuss necessary extensions to further advance the field.

Additive noise-induced stability tuning in neuronal systems

Axel Hutt (1), Jérémie Lefebvre (2)

(1) Team MIMESIS, Université de Strasbourg, CNRS, INRIA, ICube, F-67000 Strasbourg, France; (2) Department of Biology, University of Ottawa, ON, Canada
axel.hutt@inria.fr

For a long time, multiplicative noise has been known to control the stability and evolution of nonlinear systems, whereas additive noise does not. Today additive noise-induced stability modifications attract more and more attention in theoretical research, e.g., work on stochastic bifurcations [1], random dynamical systems [2] or on stochastic random networks [3]. The presented work illustrates additive noise-induced effects in spatially extended systems [4] and stochastic random networks demonstrating coherence resonance [5]. Models of frequency induction and switching [6] in the brain demonstrate the mechanisms' possible importance in understanding neural processes.

References

[1] N. Sri Namachchiava, Stochastic Bifurcations, Appl. Math. Comput. 38(2):101-159 (1990)

[2] L. Arnold, Random Dynamical Systems, Springer (1998)

[3] A. Hutt, Front. Appl. Math. Stat. 8:879866 (2022)

[4] A.Hutt et al., Phys. Rev. Lett. 98:230601 (2007)

[5] A. Hutt et al., Front. Appl. Math. Stat. 7:697904 (2021)

[6] A. Hutt et al., NeuroImage 179:414-428 (2018); A. Hutt and J. Lefebvre, Brain Top. 35:108-120 (2021)

Posters B
Dynamics of complex biological systems

B1 – Modelling, parameter and state estimation, and optimal control of COVID-19 pandemic: A study case of Cameroon

Cedric Hameni Nkwayep, **Samuel Bowong**

University of Douala
sbowong@fs-univ-douala.cm

In this paper, we formulate and analyze a compartmental model of COVID-19 in order to predict and control the outbreak in Cameroon. We first formulate a comprehensive mathematical model based on ordinary differential equations for the dynamical transmission of COVID-19 in Cameroon. We provide the theoretical analysis of the model. After, assuming continuous measurement of the weekly number of newly COVID-19 detected cases, newly deceased indivijduals and newly recovered individuals, the Ensemble of Kalman filter (EnKf) approach is used to estimate the unmeasured variables and unknown parameters which are assumed to be time-dependent using real data of COVID-19 in Cameroon. We present the forecasts of the current pandemic in Cameroon using the estimated parameter values and the estimated variables as initial conditions. Our findings suggest that at November 2022, the basic reproduction number is approximately 1.86 in Cameroon meaning that the disease will not die out without any control measures. Also, the number of undetected cases remains high, which could be the source of new vagues of COVID-19 pandemic. Further, we found that there is a necessity to increase timely the surveillance by using awareness programs, detection process and the eradication of the pandemic is highly dependent on the control measures taken by the government. Based on this continuous model, the COVID-19 control is formulated and solved as an optimal control theory problem, indicating how control terms based on the awareness programs, detection process and vaccination should be introduced to reduce the number of COVID-19 infected individuals in Cameroon. Results provide a framework for designing the cost-effective strategies for COVID-19 with these three intervention strategies.

B2 – Nonlinearity in biochemical networks resulting from protein homo-oligomerisation

Daniel Koch

Max Planck Institute for Neurobiology of Behaviour
daniel.koch@mpinb.mpg.de

Reversible protein homo-oligomerisation, i.e., the formation of larger protein complexes out of identical subunits, is observed for 30-50% of all vertebrate proteins. Despite being a ubiquitous phenomenon, the specific function of protein homo-oligomerisation remains poorly understood. Based on simple mass-action and Miachelis-Menten models, I show that homo-oligomerisation could be a versatile mechanism for a range of nonlinear phenomena including homeostasis, ultrasensitivity and bistability via pseudo-multisite modification. Applying these findings to a real biological example, I will present the first dynamical systems model of phospholamban (PLN), a crucial mediator protein of the physiological “fight-or-flight” response triggered by beta-adrenergic signaling and a key regulator of calcium cycling in heart muscle cells. Importantly, PLN forms homo-pentamers whose function remained elusive for decades. Simulations and model analyses demonstrate that pentamers enable bistable phosphorylation and further constitute substrate competition based low-pass filters for phosphorylation of monomeric PLN. Both predictions of the model were confirmed experimentally by demonstrating substrate competition in vitro and and by demonstrating hysteresis of pentamer phosphorylation in cardiomyocytes. These non-linear phenomena may ensure consistent monomer phosphorylation and calcium cycling despite noisy signaling activity in the upstream network and may be impaired by perturbations (e.g., via genetic mutations or in the context of underlying heart disease) which cause cardiac arrhythmias. These studies show that homo-oligomerisation can play unanticipated and potentially disease relevant roles in biochemical signaling networks.

Stabilizing equilibrium in an array of the neuronal oscillators by injecting electrical current proportional to inverted mean membrane potential

B3 – Elena Adomaitienė, Skaidra Bumelienė, Arūnas Tamaševičius

Center for Physical Sciences and Technology, Vilnius, Lithuania
elena.tamaseviciute@ftmc.lt

Synchronous behaviour of coupled dynamical systems is a common phenomenon observed in nature, science, and engineering [1]. In most cases synchronization is a desirable effect. However, sometimes it can have a harmful impact. For example, too strong synchrony in neuronal arrays, can cause Parkinsonian tremor. There are three main techniques developed so far to avoid undesirable synchrony. The first one employs some sophisticated feedback signal which artificially destroys the synchronous states [2]. The second way to get around the problem is to suppress the activity of the spiking cells by means of stabilizing their originally unstable equilibrium [3,4]. The mechanism of damping is related to the so-called oscillation death [5,6]. The third method to destroy synchrony is the well-known deep brain stimulation (DBS) employing high frequency periodic electrical pulses. The mechanism of the DBS is not fully understood. Some authors suppose, that high frequency forcing stabilizes the steady states of neurons [7]. In this paper, using the asymmetric FitzHugh–Nagumo model [3,4], we describe a method to stabilize the equilibrium of the neuronal oscillators by injecting electrical current I_{inj} proportional to the inverted mean membrane potential $-\bar{x}$, specifically $I_{\mathrm{inj}} \propto (v - \bar{x})$. Here $\bar{x}$ is the mean value of the individual potentials x_i averaged over the ensemble, v is a constant adjustable term used to avoid the undesirable DC component of the current. In contrast to the previous techniques, which implicate the control term either as $I_{\mathrm{inj}} \propto (z - x_i)$ [3], where the adaptive reference z is the low-pass filtered value of the mean $\bar{x}$, or as $I_{\mathrm{inj}} \propto (v - x_i)$ [4], here we employ the $\bar{x}$ instead the x_i. The motivation behind such a choice is that the individual variables x_i are not accessible in complex biological systems.

References

[1] A. Pikovsky, M. Rosenblum, J. Kurths, Synchronization: A Universal Concept in Nonlinear Sciences, Cambridge University Press, Cambridge, 2003.

[2] N. Tukhlina, M. Rosenblum, A. Pikovsky, J. Kurths, Phys. Rev. E, v.75, 011918 (2007)

[3] A. Tamaševičius, S. Bumelienė, E. Adomaitienė, Phys. Rev. E, v.99, 042217 (2019)

[4] E. Adomaitienė, S. Bumelienė, A. Tamaševičius, Nonlin. Dyn., v.99, 2129- 2137 (2020)

[5] E. Ullner, A. Zaikin, E. I. Volkov, J. Garcia-Ojalvo, Phys. Rev. Lett. v.99, 148103 (2007)

[6] A. Koseska, E. Volkov, J. Kurths, Phys. Rev. Lett. v.111, 024103 (2013)

[7] K. Pyragas, V. Novičenko, P. Tass, Biol. Cyber., v.107, 669-684 (2013)

B4 – Dynamics of collective flora behaviour from crowd-sourced data

Karin Mora (1,2), Jana Wäldchen (3), Michael Rzanny (3), Guido Kraemer (1), Ingolf Kühn (1,4,5), Patrick Mäder (6), Miguel D. Mahecha (1,2)

(1) Remote Sensing Centre for Earth System Research, Leipzig University; (2) German Centre for Integrative Biodiversity Research (iDiv), Halle-Jena-Leipzig; (3) Max Planck Institute for Biogeochemistry, Jena; (4) Martin Luther University Halle-Wittenberg; (5) Helmholtz Centre for Environmental Research – UFZ; (6) Ilmenau University of Technology
karin.mora@uni-leipzig.de

Monitoring changes in phenology, i.e., changes in flora states, is key to understanding the impact of climate change on ecosystems and biodiversity. Crowd-sourced data from smartphone applications are gaining in popularity in many ecological applications and are especially relevant for automated species recognition. However, the potential of crowd-sourced data for studying phenology at macroecological scales has not been deeply explored. We aim to quantify the collective phenological cycle of plant co-ocurrences based on citizen science data.

We analyse crowd-sourced German plant observation data collected with the smartphone application Flora Incognita, which identifies plant species native to Central Europe from images in real time using deep learning. We propose that the dynamics of collective flora behaviour is embedded in the temporal co-occurrence observations. To extract this collective phenological dynamics we propose the manifold learning method isometric feature mapping. As this approach is data driven no a priori assumptions are made about how to define collective behaviour. We propose a complexity measure to characterise the dynamics across large spatial scales.

Our results demonstrate that the phenology of macroecological patterns can be effectively detected from crowd-sourced plant observation data. The strong collective flowering in spring and summer allows us to clearly characterise phenological transitions, specifically the faster changes in spring compared to autumn. The emerging complexity measure of collective behaviour is an indicator for linear and nonlinear temporal changes in macroecological patterns in the summer and the rest of the year, respectively. Despite biases and uncertainties associated with opportunistically collected crowd-sourced data it is possible to derive meaningful indicators for monitoring plant phenology. In the near future multi-year records of such data will be available to explore phenological shifts and how they are impacted by climate change in near real time.

B5 – Control attenuation and second wave scenario in a cellular automata SEIR epidemic model

Michele Mugnaine (1), Enrique C. Gabrick (2), Paulo R. Protachevicz (1, 3), Kelly C. Iarosz (4, 5), Silvio L. T. de Souza (6), Alexandre C. L. Almeida (7), Antonio M. Batista (2, 8), Iberê L. Caldas (1), José D. Szezech Jr. (2, 8), Ricardo L. Viana (9)

(1) Institute of Physics, University of São Paulo, Brazil; (2) Graduate Program in Science – Physics, State University of Ponta Grossa, Ponta Grossa, PR, Brazil; (3) Institute for Complex Systems and Mathematical Biology, SUPA, University of Aberdeen, United Kingdom; (4) Faculdade de Telêmaco Borba, FATEB, Brazil; (5) Graduate Program in Chemical Engineering Federal Technological University of Paraná, Brazil; (6) Federal University of São João del-Rei, Campus Centro-Oeste, Brazil; (7) Statistics, Physics and Mathematics Department, Federal University of São João del-Rei, Brazil; (8) Department of Mathematics and Statistics, State University of Ponta Grossa, Brazil; (9) Department of Physics, Federal University of Paraná, Brazil
mmugnaine@gmail.com

Mathematical models are applied to study the consequences and to estimate the future of a disease spread in a population. They are an important tool to analyze impacts and plan to mitigate epidemics in communities. In order to estimate the impact of control measures and a possible second wave of infections, we analyze the SEIR epidemic model based on cellular automata. The control measure is based on the restriction of individual mobility in space. From our mathematical simulations, we observe that the implementation of control measures decreases the amplitude of the curve of infected individuals and increases the duration of the spread. For a control with more than 70% of the possible paths of contact blocked, the decrease in the total number of infected individuals is greater than 15%, throughout the epidemic. Analyzing the possibility of a second wave of infections in our CA based model, our numerical results show that the total attenuation of control measures in the system can lead to a second wave scenario, and it happens for greater values of the control parameter.

B6 – The fundamental benefits of multiplexity in ecological networks

Yu Meng (1), Ying-Cheng Lai (2), Celso Grebogi (3)

(1) Max Planck Institute for the Physics of Complex Systems, Dresden, Germany; (2) School of Electrical, Computer and Energy Engineering, Arizona State University, Tempe, USA; (3) Institute for Complex Systems and Mathematical Biology, School of Natural and Computing Sciences, King's college, University of Aberdeen, UK
meng@pks.mpg.de

a tipping point presents perhaps the single most significant threat to an ecological system as it can lead to abrupt species extinction on a massive scale. climate changes leading to the species decay parameter drifts can drive various ecological systems towards a tipping point. we investigate the tipping point dynamics in multilayer ecological networks supported by mutualism. we unveil a natural mechanism by which the occurrence of tipping points can be delayed by multiplexity that broadly describes the diversity of the species abundances, the complexity of the interspecific relationships, and the topology of linkages in ecological networks. for a double layer system of pollinators and plants, coupling between the network layers occurs when there is dispersal of pollinator species. multiplexity emerges as the dispersing species establish their presence in the destination layer and have a simultaneous presence in both. we demonstrate that the new mutualistic links induced by the dispersing species with the residence species have fundamental benefits to the wellbeing of the ecosystem in delaying the tipping point and facilitating species recovery. articulating and implementing control mechanisms to induce multiplexity can thus help sustain certain types of ecosystems that are in danger of extinction as the result of environmental changes.

B7 – Scaling relationship between nuclear density and cell cycle duration in frog egg extracts

Nikita Frolov, Liliana Piñeros, Bartosz Prokop, Lendert Gelens

Laboratory of Dynamics in Biological Systems, Department of Cellular and Molecular Medicine, KU Leuven
nikita.frolov@kuleuven.be

The cell cycle is a highly regulated spatio-temporal process controlled by a large and complex network of proteins. Precise coordination of its timing during early embryogenesis guarantees the healthy development of the organism. Conversely, abnormalities of the cell cycle duration might critically affect later development. Previous studies recognized the size of the nucleus as one of the determinants of the cell cycle period. However, the exact relationship between these quantities is not yet fully understood.

In this work, we use extensive data analysis to reveal such a relationship in cell-free extracts of the Xenopus laevis frog, a suitable biological model in which one can manipulate biochemical conditions and nuclear density. We identify that the cell cycle period scales under the variation of nuclear density. More strikingly, we reveal a mapping of nuclear density from cycle to cycle, based on which we can to predict the idealized trajectory of cell division progression during early embryogenesis.

B8 – Simulating the locomotion of C. Elegans via an extended Hindmarsh–Rose model

Philipp Hövel (1), Sebastian Jenderny (2), Karlheinz Ochs (2), Jorge Ruiz (3), Thomas Maertens (4)

(1) Christians-Albrechts-Universität zu Kiel, Germany; (2) Ruhr-Universität Bochum, Germany; (3) Bernstein Center for Computational Neuroscience Berlin, Germany; (4) Technische Universität Berlin, Germany
philipp.hoevel@gmail.com

We investigate how locomotory behavior is generated in the brain focusing on the paradigmatic connectome of nematode Caenorhabditis elegans (C. Elegans), which includes different layers describing connections via electrical gap junctions and various chemical synapses. We study neuronal and muscular activity patterns that control forward locomotion. Combining Hindmarsh–Rose equations for neuronal activity with a leaky integrator model for muscular activity, we model the dynamics within the multi-layer network and predict the forward locomotion of the worm using a harmonic wave model. Finally, we present a power-flow-based simplification of the model, which is inspired by electronic circuit synthesis and allows the emulation of neuronal behavior on larger networks by means of analog circuits.

B9 – Livestock-environment-interaction in naturally ventilated housing on the example of ammonia

Sabrina Hempel (1), Huyen Vu (1), Moustapha Doumbia (1), Qianying Yi (1), David Janke (1), Thomas Amon (1, 2)

(1) Leibniz Institute for Agricultural Engineering and Bioeconomy (ATB); (2) Free University of Berlin, Institute of Animal Hygiene and Environmental Health
shempel@atb-potsdam.de

Contemporary livestock husbandry is far from being sustainable. One the one hand, livestock is in principle capable to provide essential micronutrients from food that is not digestible by humans and thus could recycle otherwise unused nutrients. On the other hand, there are issues of animal welfare, the competition between food and feed and the pollutant emissions of gases and particles, which are negatively affecting the climate system, environment and health.

One crucial substance in this context is ammonia, where nearly half of all global emissions are associated with livestock husbandry (particularly cattle and pig farming). However, there are large differences in the emission rate between individual farms, which are not well understood so far. One of the reasons is the complex interaction between outdoor climate, indoor microclimate and the emission source strength and gas dilution. We use fluid dynamics and reaction-kinetics modelling to better understand these interactions, predict emission values, optimize monitoring systems, and identify and evaluate emission mitigation potentials.

Simulations of a naturally ventilated dairy cattle building, as it is common in many parts of Europe and the US, showed that annual average ammonia emission strongly depends on the relation between pH and temperature in urine puddles and liquid manure, while variations at the daily and subdaily time scale are dominated by changes in the local airflow patterns. The latter emerge from a complex interplay of building characteristics, inflow conditions and buoyancy effects, which renders smart ventilation control challenging. At the same time, the typical air flow patterns are associated with large differences in air quality in different locations with regards to temperature and pollutant concentration.

Without adapting the husbandry systems (e.g., using targeted cooling / heating, feed and/or manure additives, fast separation of urine and faeces and smart ventilation control) several thousand tons of ammonia will be additionally released from livestock husbandry as a consequence of climate change.

B10 – Modelling and analysis of the mean-field SIWS epidemic model with higher-oder interactions

Shaoxuan Cui, Fangzhou Liu, Hildeberto Jardón Kojakhmetov, Ming Cao

Bernoulli Institute University of Groningen, Research Institute of Intelligent Control and Systems Harbin Institute of Technology, Bernoulli Institute University of Groningen, ENTEG University of Groningen
s.cui@rug.nl

Recently, a simplicial model of social contagion has been proposed. Such a model captures not only the pairwise interactions but also the multi-body interactions, which makes the model more realistic. However, the model only takes human-to-human interaction into account and does not consider the possibility of spreading via media. By further coupling the system with a pathogen-like dynamics, we propose a new mean-field simplicial epidemic model (SIWS-type, where W stands for the media compartment). Our model captures the indirect spreading through media like Tiktok or Twitter. We provide analytical results showing that our model may present bistability. We further give a number of sufficient conditions for the stability of the healthy-state and the endemic equilibrium.

B11 – Eco-evolutionary dynamics with multi-games under mutation

Sourav Roy (1), Sayantan Nag Chowdhury (2), Prakash Chandra Mali (1), Matjaz Perc (3, 4, 5), Dibakar Ghosh (2)

(1) Department of Mathematics, Jadavpur University, Kolkata, West Bengal, India; (2) Physics and Applied Mathematics Unit, Indian Statistical Institute, Kolkata, West Bengal, India; (3) Faculty of Natural Sciences and Mathematics, University of Maribor, Maribor, Slovenia
sourav.roy738@gmail.com

Major section of practical scenarios impart significant favor to defection over cooperation due to natural selection, depicting the instinct of persistence and survivability of the strongest living creature in nature at the very tail end of each dilemma. Be that as it may, the emergence of cooperation is omnipresent in most of the biological, social, and economic systems, proving out to be sufficiently contrary to the well-cherished Darwinian theory of evolution. Many researches have been devoted to understand and establish in a better manner how and why cooperation is being preserved among self-interested individuals even in their competition for limited resources. In our work, we go further beyond one single social dilemma, since individuals usually encounter various social challenges in various complex chains of scenario day by day. In particular, we implement a mathematical model with analytical and numerical studies, which incorporates both the prisoner's dilemma and the snowdrift game, to be taking place with complementary possibilities of occurrence with each other. We further extend this model by consideration of ecological signatures like mutation and selfless one-sided contribution of altruist free space. The nonlinear evolutionary dynamics that results out from these upgrades offer a broader range of equilibrium outcomes, and it also often favors cooperation over defection with the increasing chain of iteration. With the help of analytical and numerical calculations, our theoretical model sheds light on the mechanisms that maintain biodiversity, and it helps to explain the evolution of social order in human societies.

MS7
Nonlinear dynamics in economics

Modeling state-dependent dynamics

Stefan Mittnik

Department of Statistics, Ludwig Maximilians University Munich
mittnik@gmx.de

In many empirical modeling efforts, we encounter phenomena that exhibit state-dependent behavior. The way a dynamic system responds to external influences can vary depending on the state the system is operating in. A wide range of examples can be found in natural and social sciences as well as engineering. Business cycle are a typical example in macroeconomic modeling. External shocks to an economy tend to have very different effects on variables such as employment, growth or inflation, depending on whether the economy is in a period of strong growth or in a recession. So-called state- or regime-dependent modeling strategies have been proposed to model such phenomena. In this contribution, we provide an overview of alternative approaches to state-dependent modeling of dynamic processes and discuss their relevance to specific types of applications.

(online) Stability in threshold VAR models

Pu Chen, Willi Semmler

(1) Melbourne Institute of technology (2) New School for Social Research and Bielefeld University
pchen@mit.edu.au

This paper investigates the stability of threshold autoregressive models. We review recent research on stability issues from both a theoretical and empirical standpoint. We provide a sufficient condition for the stationarity and ergodicity of threshold autoregressive models by applying the concept of joint spectral radius to the switching system. The joint spectral radius criterion offers the most generally applicable criterion to determine the stability in a threshold autoregressive model.

On risk and market sentiments driving financial share price dynamics

Marek Lampart (1,2), Alžběta Lampartová (1,3), Giuseppe Orlando (2)

(1) IT4Innovations, VSB – Technical University of Ostrava, Czech Republic; (2) Department of Applied Mathematics, VSB – Technical University of Ostrava, Czech Republic; (3) Department of Mathematics and Descriptive Geometry, Faculty of Mechanical Engineering, VSB – Technical University of Ostrava, Czech Republic
marek.lampart@vsb.cz

The goal is to investigate the dynamics of banks' share prices and related financials that lead to potential disruptions to credit and the economy. We adopt a classic macroeconomic equilibrium model with households, banks, and non-financial companies and explain both market valuations and endogenous debt constraints in terms of risk. Heterogeneous market dynamics ranging from equilibrium to cycles and chaos are illustrated. Deposits and equity are proven to be management levers for chaos control/anticontrol and the only feasible equilibrium is unstable. Finally, using real-world data, a test is conducted on the suggested model proving that our framework conforms well to reality.

On extensive dynamics of a Cournot heterogeneous model with optimal response

Marek Lampart (1,2), **Alžběta Lampartová** (1,3), Giuseppe Orlando (4,5)

(1) IT4Innovations, VSB-Technical University of Ostrava, Czech Republic; (2) Department of Applied Mathematics, VSB-Technical University of Ostrava, Czech Republic; (3) Department of Mathematics and Descriptive Geometry, Faculty of Mechanical Engineering, VSB-Technical University of Ostrava, Czech Republic; (4) Department of Economics and Finance, University of Bari, Italy; (5) Department of Mathematics, University of Bari, Italy
alzbeta.lampartova@vsb.cz

The aim of this talk is to study the dynamical properties analysis of an original specification of the classical Cournot heterogeneous model with optimal response. The analysis is performed by means of bifurcation diagrams, the 0-1 test for chaos, Power Spectral Density, histograms, and trajectory analysis. For this purpose, a new perturbation parameter of the initial condition is introduced, and together with the intensity of choice parameter, the system is researched. Extreme reach dynamics, coexisting attractors, and periodic and chaotic trajectories are investigated through massive simulations. This talk is based on the paper: On extensive dynamics of a Cournot heterogeneous model with optimal response, Chaos 32(2) (2022).

Long monthly European temperature series and the North Atlantic Oscillation

Jian Kang, Changli He, Annastiina Silvennoinen, **Timo Teräsvirta**

JK, Dongbei University of Finance and Economics, Dalian, P.R. China, CH, Tianjin University of Finance and Economics, P.R. China, AS, Queensland University of Technology, Brisbane, TT, (1) CREATES, Aarhus University (2) C.A.S.E., Humboldt-Universität zu Berlin
tterasvirta@econ.au.dk

In this presentation, the relationship between the surface air temperatures in 28 European cities and towns and the North Atlantic Oscillation (NAO) is modelled using the Vector Seasonal Shifting Mean and Covariance Autoregressive model, extended to contain exogenous variables. Central statistical and time series features of the model are discussed before moving on to discussing data and showing empirical results. The model also incorporates season-specific spatial correlations that are functions of latitudinal, longitudinal, and elevation differences of the various locations.

The empirical results, based on long monthly time series, agree with previous ones in the literature in that the NAO is found to have its strongest effect on temperatures during winter months. The transition from the boreal winter to the summer is not monotonic, however. The strength of the error correlations of the model between locations is inversely related to the distance between the locations, with a slower decay in the east-west than north-south direction. Altitude differences also matter but only during the boreal winter half of the year.

Modeling the out-of-equilibrium dynamics of bounded rationality and economic constraints

Oliver Richters

Potsdam Institute for Climate Impact Research
oliver.richters@pik-potsdam.de

The analogies between economics and classical mechanics can be extended from constrained optimization to constrained dynamics by formalizing economic (constraint) forces and economic power in analogy to physical (constraint) forces in Lagrangian mechanics. In the differential-algebraic equation framework of General Constrained Dynamics (GCD), households, firms, banks, and the government employ forces to change economic variables according to their desire and their power to assert their interest. These ex-ante forces are completed by constraint forces from unanticipated system constraints to yield the ex-post dynamics. The flexible out-of-equilibrium model can combine Keynesian concepts such as the balance sheet approach and slow adaptation of prices and quantities with bounded rationality (gradient climbing) and interacting agents discussed in behavioral economics and agent-based models. The framework integrates some elements of different schools of thought and overcomes some restrictions inherent to optimization approaches, such as the assumption of markets operating in or close to equilibrium. Depending on the parameter choice for power relations and adaptation speeds, the model nevertheless can converge to a neoclassical equilibrium, and reacts to an austerity shock in a neoclassical or post-Keynesian way.

Posters P6–8
Nonlinear dynamics in economics

P6 – Is deterministic chaos present in business cycles?

Giuseppe Orlando (1,2), **Giovanna Zimatore** (3,4)

(1) Università degli Studi di Bari "Aldo Moro", Department of Economics and Finance, Italy, (2) HSE University of Saint Petersburg, Department of Economics; (3) Department of Theoretical and Applied Sciences, eCampus University, Novedrate, Italy; (4) Institute for Microelectronics and Microsystems, IMM-CNR, Bologna, Italy
`giovanna.zimatore@uniecampus.it`

The scientific question explored is whether deterministic chaos appears in business cycles and which model between a purely deterministic one like Kaldor-Kalecki or a stochastic process like Ornstein-Uhlenbeck can best simulate reality. When statistical analyses are unable to distinguish between simulations and real-world data, the model can be assumed to be capable of reproducing reality. The methodological approach, statistical tests and a summary of the best results of recent research are briefly described with the aim of laying the foundations for a common comparison and hypothesizing and sharing new investigation strategies.

P7 – Causalities and their drivers in financial data

Haochun Ma (1), Alexander Haluszczynski (1), Davide Prosperino (1), **Christoph Räth (2)**

(1) Allianz Global Investors (AGI); (2) Institut für KI-Sicherheit, DLR
`Christoph.Raeth@dlr.de`

Identifying and describing the dynamics of complex systems is a central challenge in various areas of science, such as physics, finance, or climatology. Here, we analyze the causal structure of chaotic systems using Fourier transform surrogates that enables us to identify the different (linear and nonlinear) causality drivers. We further show that a simple rationale and calibration algorithm are sufficient to extract the governing equations directly from the causal structure of the data. We demonstrate the applicability of the framework to real-world dynamical systems using financial data (stock indices from Europe, United States, China, Emerging Markets, Japan and Pacific excluding Japan) before and after the COVID-19 outbreak. It turns out that the pandemic triggered a fundamental rupture in the world economy, which is reflected in the causal structure and the resulting equations. Specifically, nonlinear causal relations have significantly increased in the global financial market after the COVID-19 outbreak [1]. Further differential analyses revealed that that the stock indices in Germany and the U.S. exhibit a significant degree of nonlinear causality and that correlation, while a very good proxy for linear causality, underestimates causality itself [2]. The presented framework enables the measurement of nonlinear causality and motivates methods for inferring market signals, quantifying portfolio risk, and constructing less risky portfolios. Our model suggests that nonlinear causality can be used as an early warning indicator of abnormal market behavior, allowing for more accurate risk management and better portfolio construction.

References

[1] H. Ma, A. Haluszczynski, D. Prosperino & C. Räth, Identifying causality drivers and deriving governing equations of nonlinear complex systems, Chaos, 32, 103128 (2022)

[2] H. Ma, D. Prosperino, A. Haluszczynski & C. Räth, Linear and nonlinear causality in financial markets, Journal of Physics: Complexity (submitted)

P8 – Projection methods made easy

Sijmen Duineveld

Potsdam Institute for Climate Impact Research
`sijmen.duineveld@pik-potsdam.de`

We have developed a toolbox to solve Dynamic Stochastic General Equilibrium models with projection methods. Projection methods are especially useful for highly nonlinear models, such as those with inequality constraints, attracting limit cycles, or rare disasters.

The Promes toolbox (see Matlab file exchange) can greatly reduce coding time to solve such models with projection methods. The toolbox only requires the user to write a model file, define the boundaries of the grid, supply an initial guess for the policy function, and choose an algorithm. The toolbox will then solve for the policy function.

The toolbox can approximate a policy function with cubic splines, complete Chebyshev polynomials, or Smolyak-Chebyshev polynomials as basis functions. For

near-linear small scale models Chebyshev polynomials in combination with Galerkin's method perform best. For slightly more complex or less linear models splines perform better. For models with a large number of state variables a Smolyak grid is faster than the other methods, due to the sparsity of the grid.

In this paper we evaluate the performance of several algorithms in terms of speed and accuracy for three DSGE models. The first model is a standard RBC model, which can be solved in less than 0.05 seconds with all three basis functions, and a maximum error of less than 1e-6. The second model is an RBC model with habits in consumption and investment adjustment costs, which has four state variables. This model can be solved with a maximum error of 1e-5 in about 5 seconds. The third model is a highly non-linear model featuring an attracting limit cycle, which is best solved with a spline.

MS8
Causation and prediction of weather and climate extremes

A dynamical systems view of the prediction of extreme weather events in a changing climate: Insight, foresight and attribution

Leonard A. Smith

Virginia Tech (1) London School of Economics (2)
lennys@vt.edu

Quantitative insights into likely weather extremes in our future climate are in high demand. Pointed questions from both governments and various industrial sectors for clarification of the current limits to predictability and for interpretation of model output are presented in the context of simulating nonlinear dynamical systems. The probabilistic predictability of a dynamical system is not limited by chaotic dynamics inasmuch as uncertainty in the current state of the state of the system can be propagated into the future; as long as the model is perfect. Prediction via simulation with imperfect models, and the predictability of open systems in general, introduce new challenges both to the scientific community and to the communication of uncertainty and insight. Both types of challenge are illustrated through the analysis of actual probabilistic predictions of weather and of climate.

Interesting dynamical systems questions abound: Is it more useful to maintain a plethora of closely related but distinct mathematical structures of limited complicatedness or focus on a single model structure developed with significantly greater resources ("one model to rule them all")? Would there be an advantage to constructing somewhat independent models which share today's best physics and observations, but never see each other's outputs? Mathematically, what is the most effective way to present the diversity of simulations generated for the advancement of science, or in the support of decision making? In practice, how harmful is opacity (the failure to communicate known limits of today's simulations clearly) both within the sciences and to decision makers? Should we attempt probabilistic attribution of event with probability of one (as it has already happened) or search to make climate science more predictive for this type of event, by moving to shorter lead times, or by filling a basket of unprecedented events now thought vastly more likely under current conditions (and then noting they had been identified a priori) or by other means?

These questions will be examined from a dynamical systems point of view, enlightened by a good deal of experience with numerate decision makers. A Just Enough Decisive Information (JEDI) approach to applied simulation modelling of weather events in an evolving climate is suggested. The value of accepting that both the expectations from and the analysis of nonlinear models in a weather-like context differs fundamentally from those in a climate-like context is stressed.

Forecasting tropical monsoon: Advances and opportunities

Elena Surovyatkina

(1) Potsdam Institute for Climate Impact Research, Germany; (2) Space Research Institute of the Russian Academy of Sciences, Russia
elena.surovyatkina@pik-potsdam.de

Close to half of the global population relies on the monsoon to collect drinking water, grow crops, and produce electricity. The abruptness of the beginning and end of the rainy season and a month's interannual variability are key features of the phenomenon, thus making monsoon forecasts extremely challenging. The limitations of current models prevent further progress. A new strategy is urgently needed in weather and climate sciences.

Here I show that a new understanding of essential physical mechanisms of monsoon arrival and withdrawal allows more than a month in advance to predict monsoon timing. The approach is fundamentally different from the numerical weather and climate models; it is based on system analysis, statistical physics principles and newly discovered spatial-temporal regularities (or teleconnections between Tipping Elements) in a monsoon system. The forecasting relies on the re-analysis dataset: temperature, relative humidity, and outgoing longwave radiation. The approach implementation is backed up with solid evidence: 7-years-test shows a successful result forecasting 40 days in advance for the onset date and 70 days before the withdrawal date. Applicability of the methodology is not limited by specific location; it works for different parts of India – Central India, Telangana, Delhi, as well in Africa and South America.

Causality in complex systems: Multiple scales and extreme events

Milan Paluš

Institute of Computer Science of the Czech Academy of Sciences, Prague, Czech Republic
mp@cs.cas.cz

Quantification of causality in terms of improved predictability was proposed by the father of cybernetics N. Wiener [1] and formulated for time series by C. W.J. Granger [2]. The Granger causality evaluates predictability in bivariate autoregressive models. This concept has been generalized for nonlinear systems using methods rooted in Shannon information theory [3,4,5]. This approach, however, usually ignores two important properties of complex systems, such as the Earth climate: the systems evolve on multiple time scales and their variables have heavy-tailed probability distributions. While the multiscale character of complex dynamics, such as air temperature variability, can be studied within the Shannonian framework [6,7], the entropy concepts of Renyi and Tsallis have been proposed for variables with heavy-tailed probability distributions. We will discuss how to cope with multiple scales and how non-Shannonian entropy concepts can be applied in inference of causality in systems with heavy-tailed probability distributions and extreme events. Using examples from the climate system, we will focus on causal effects of the North Atlantic Oscillation, blocking events and the Siberian high on winter and spring cold waves in Europe, including the April 2021 frosts endangering French vineyards.

This study was supported by the Czech Academy of Sciences, Praemium Academiae awarded to M. Paluš.

References

[1] N. Wiener, in: E. F. Beckenbach (Editor), Modern Mathematics for Engineers (McGraw-Hill, New York, 1956)

[2] C.W.J. Granger, Econometrica 37 (1969) 424

[3] K. Hlavackova-Schindler et al., Phys. Rep. 441 (2007) 1

[4] M. Palus, M. Vejmelka, Phys. Rev. E 75 (2007) 056211

[5] J. Runge et al., Nature Communications 6 (2015) 8502

[6] M. Palus, Phys. Rev. Lett. 112 (2014) 078702

[7] N. Jajcay, J. Hlinka, S. Kravtsov, A. A. Tsonis, M. Palus, Geophys. Res. Lett. 43(2) (2016) 902-909

Recurrence plots for analysing extreme events data

Norbert Marwan (1), Tobias Braun (1), K. Hauke Kraemer (1), Abhirup Banerjee (2), Deniz Eroglu (3)

(1) Potsdam Institute for Climate Impact Research; (2) University of Hamburg; (3) Kadir Has University Istanbul
marwan@pik-potsdam.de

The analysis of time series of extreme events such as heat waves, tropical cyclones, or floods is challenging due to the heavy-tailed distribution, irregular occurrence of events and their sparsity. Traditional (linear) data analysis tools, in general, fail to tackle many research questions based on extreme events, such as synchronisation analysis or power spectrum estimation of extreme event data. We demonstrate some recent extensions of the (nonlinear) recurrence plot approach for various applications in the field of extreme events data. We demonstrate their potential for synchronisation analysis between signals of extreme events and signals with continuous and slower variations, for estimation of power spectra of spiky signals, and for analysing data with irregular sampling.

A percolation framework to anticipate fast changes in irregular climate oscillations

Noémie Ehstand (1), Reik V. Donner (2,3), Cristóbal López (1), Emilio Hernández-García (1)

(1) IFISC, Institute for Cross-Disciplinary Physics and Complex Systems (UIB-CSIC), Palma de Mallorca, Spain; (2) Department of Water, Environment, Construction and Safety, Magdeburg-Stendal University of Applied Sciences, Germany; (3) Research Department I – Earth System Science, Potsdam Institute for Climate Impact Research (PIK), Germany
n.ehstand@ifisc.uib-csic.es

Functional networks are powerful tools to investigate the structure and dynamics of complex systems. Rodriguez-Mendez et al. (2016) showed that percolation properties of correlation networks provide very early-warning indicators for bifurcation-induced tipping in several model systems. Further, they showed that the same quantities in correlation networks of observed sea surface temperatures could be used to anticipate El Nño and La Niña events. In this later case however, the question of which mechanisms generate the percolation transitions remains open.

Here, we study the percolation properties of correlation networks in spatially-extended, irregularly-oscillating systems. In particular, we consider a system of coupled stochastic FitzHugh–Nagumo oscillators and show that the percolation measures anticipate the (sharp) transitions between different stages of the oscillation. Unveiling the mechanisms which cause the percolation transitions in this system leads to a better understanding and interpretation of the outcomes of the percolation-framework when applied to the El Niño-Southern Oscillation.

This research was conducted as part of the CAFE Innovative Training Network which has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No. 813844.

Posters P1–5
Causation and prediction of weather and climate extremes

P1 – Linking anomalous high moisture transport to extreme precipitation

Akash Singh Raghuvanshi, Ankit Agarwal

Indian Institute of Technology, Roorkee, Hydrology, India
akash_sr@hy.iitr.ac.in

Integrated water vapor transport (IVT) is evaluated to assess anomalous high moisture transports (AHMT) over the Indian Subcontinent, the Arabian Sea, and the Bay of Bengal during the 2013 Uttarakhand and 2015 Tamil Nadu flood events. Using a high-resolution daily gridded rainfall data set, an attempt has been made through analysing the spatiotemporal characteristics of whether anomalous high moisture transports (AHMT) are responsible for the occurrence of heavy precipitation events during the same periods. The spatiotemporal characteristics of specific rainfall events associated with the occurrence of AHMT show the existence of a strong relationship between the presence of AHMT and extreme precipitation events for the northwestern region where AHMT penetrates inland (over Uttarakhand in 2013) and for the east coast region where AHMT make landfalls (over Tamil Nadu in 2015). Further analysis suggests that extreme precipitation events are predominantly influenced by the strong moisture convergence associated with the low-level pressure systems, wind speed, and direction developed in the vicinity of affected regions.

P2 – Characterizing extreme patterns from time series

Rubens Sautter (1), Reinaldo Rosa(1), Pablo Medina(2), Juan Valdivia(3)

(1) Lab for Computing and Applied Math, INPE, São José dos Campos, SP, Brazil, (2)Departamento de Ingenieria Industrial, Universidad de los Andes, Bogota-Colombia; (3)Departamento de Fısica, Facultad de Ciencias, Universidad de Chile, Santiago-Chile
rubens.sautter@gmail.com

The characterization of extreme events (X-events) from time series has witnessed an increase of interest due to the great observational occurrence found in several fields, such as space and environmental physics. Motivated by this challenge, we propose a new parameter space (namely, chi-space) composed of two attributes that identify different classes of extreme fluctuations in a time series. Based on reformulated measures for statistical quantiles and singularity spectra, the distance from the origin of chi-space characterizes the escape from Gaussianity and monofractality that occurs when extreme fluctuations are present in a time series. To generate time series with different patterns of extreme fluctuations, two canonical systems were carefully chosen as illustrative examples: the so-called p-model for multifractal extreme dissipation and the Lorenz chaotic model within an appropriate parameterization scheme where nonlinear noise-like dynamics is considered. The results show that the investigate attributes are able to compose a two-dimensional space in which the patterns of extreme endogenous and exogenous fluctuations can be distinguished with great precision. A third class of extreme fluctuation pattern based on multifractal diffusion is also discussed. The characterization of some observed fluctuation patterns, from space and environmental physics, are presented as a case of practical application.

P3 – A spatio-temporal analysis of global atmospheric rivers

Tobias Braun (1), Sara M. Vallejo-Bernal (1,2), Dominik Traxl (1), Norbert Marwan (1,2), Jürgen Kurths (1,2)

(1) Potsdam Institute for Climate Impact Research (PIK), 14473 Potsdam, Germany; (2) Institute of Geoscience, University of Potsdam, Germany
`tobraun@pik-potsdam.de`

Atmospheric rivers (ARs) are narrow, transient corridors of extensive water vapor transport in the lower troposphere. The role ARs play in the global water cycle can be regarded as a double-edged sword: while low-intensity ARs provide vital supply of freshwater and are rarely associated with heavy precipitation events (HPEs), high-level ARs can cause detrimental impacts when they land-fall. Detection of ARs is based on localizing anomalous atmospheric transport of moisture. Many approaches define a threshold to identify local anomalies in integrated vapor transport (IVT) in order to obtain catalogues of ARs, effectively assuming stationary atmospheric moisture levels and often excluding low-level ARs.

Here, we employ an AR-detection framework ('ARtracks') based on global ERA5 reanalysis data that utilizes image processing techniques (using the IPART algorithm). Our approach allows us to study the spatio-temporal variability of globally distributed AR tracks and potential changes due to increasing atmospheric moisture levels on a warming planet. We implement a scale that characterizes ARs based on their strength and persistence, distinguishing between ARs with potentially beneficial and detrimental impacts. A recent study has demonstrated the scope of this categorized AR catalogue for the analysis of synchronization of ARs and HPEs in North America. We analyse the robustness of our results for distinct parameter choices in the definition of AR tracks. A novel power spectral measure for the analysis of event-like time series enables us to identify significant cycles in AR occurrence. Finally, we discuss the role of land-falling ARs as a trigger of HPEs on a global scale.

P4 – Synchronized heavy rainfall events in Europe: the role of atmospheric rivers

Sara M. Vallejo-Bernal (1,2), Tobias Braun (1), Norbert Marwan (1,2), Jürgen Kurths (1,2)

(1) Potsdam Institute for Climate Impact Research (PIK), Potsdam, Germany; (2) Institute of Geoscience, University of Potsdam, Germany
`vallejo.bernal@pik-potsdam.de`

Atmospheric rivers (ARs) are channels of enhanced water vapor transport in the lower troposphere. They play a crucial role in the fresh water supply of Europe, contributing to up to 30% of the rainfall budget in some regions along the western coast. However, very intense and persistent ARs are important triggers of heavy rainfall events and have been associated with natural and economical damage. Here, we investigate the large-scale spatio-temporal synchronization patterns between heavy rainfall events and landfalling ARs over Europe, during the period from 1979 to 2019. For that, we employ ARtracks, a novel global catalog of ARs, and select the AR events whose footprint intercept Europe. Then, we use an AR-intensity scale to rank the ARs in terms of strength and persistence. Based on ERA5 daily precipitation estimates, we obtain binary time series indicating the absence or presence of heavy rainfall by thresholding the daily precipitation intensity at the 95th percentile. Subsequently, we utilize event synchronization incorporating varying delays to reveal the temporal evolution of spatial patterns of heavy rainfall events in the aftermath of land-falling ARs. Finally, using composites of integrated water vapor transport, geopotential height, upper-level meridional wind, and rainfall, we

attribute the formation of the synchronization patterns to well-known atmospheric circulation configurations, depending on the intensity level of the ARs. Our results reveal the role of ARs in the distribution of heavy rainfall events over Europe and advance the understanding of inland heavy precipitation by revealing the characteristic circulation patterns and the main climatic drivers associated to the synchronization patterns.

P5 – Spatial synchronization patterns of extreme rainfall and convection in the Asian Summer Monsoon region

Shraddha Gupta (1), Zhen Su (1), Abhirup Banerjee, Niklas Boers (1), Norbert Marwan (1), Linus Magnusson, Cristobal Lopez, Emilio Hernandez-Garcia, Florian Pappenberger and Jürgen Kurths (1, 2)

(1) Potsdam Institute for Climate Impact Research; (2) Department of Physics, Humboldt University at Berlin
`shraddha.gupta@pik-potsdam.de`

A deeper knowledge about the spatially coherent patterns of extreme rainfall events in the South and East Asian regions is of utmost importance for substantially improving the forecasts of extreme rainfall as their agro-based economies predominantly rely on the monsoon. In our work, we use a combination of a nonlinear synchronization measure and complex networks to investigate the spatial characteristics of extreme rainfall synchronicity in the Asian Summer Monsoon (ASM) region and gain a comprehensive understanding of the intricate relationship between its Indian and East Asian counterparts. We identify two modes of synchronization between the Indian Summer Monsoon (ISM) and the East Asian Summer Monsoon (EASM) – a southern mode between the Arabian Sea and south-eastern China in June which relates the onset of monsoon in the two locations, and a northern mode between the core ISM zone and northern China which occurs in July. Thereafter, we determine the specific times of high extreme rainfall synchronization, and identify the distinctively different large-scale atmospheric circulation, convection and moisture transport patterns associated with each mode. Furthermore, we discover that the intraseasonal variability of the ISM-EASM interconnection may be influenced by the different modes of the tropical intraseasonal oscillation (ISO). Our findings show that certain phases of the Madden-Julian oscillation and the boreal summer ISO favour the synchronization of extreme rainfall events in the June-July-August season between ISM and EASM. The impact of El Nino-Southern Oscillation on the convective sources of the two monsoon subsystems, and thus their interannual variability is investigated.

MS9
Tipping points

Critical transitions and perturbation growth

N. Sharafi, C. Martin, **S. Hallerberg**

HAW Hamburg
`Sarah.Hallerberg@haw-hamburg.de`

Critical transitions occur in a variety of dynamical systems. Here we employ quantifiers of chaos to identify changes in the dynamical structure of complex systems preceding critical transitions. As suitable indicator variables for critical transitions, we consider changes in growth rates and directions of covariant Lyapunov vectors. Studying critical transitions in several models of fast-slow systems, i.e., a network of coupled FitzHugh–Nagumo oscillators, models for Josephson junctions, and the Hindmarsh–Rose model, we find that tangencies between covariant Lyapunov vectors are a common and maybe generic feature during critical transitions. Additionally, we present an approach to estimate covariant Lyapunov vectors from data and another approach to calculate approximations of covariant Lyapunov vectors without using the far future of a data-record.

Glacial abrupt climate change as a multi-scale phenomenon resulting from monostable excitable dynamics

Keno Riechers (1,2), Georg Gottwald (3), Niklas Boers (1,2)

(1) Research Department Complexity Science, Potsdam Institute for Climate Impact Research; (2) Earth System Modelling, School of Engineering & Design, Technical University of Munich, Germany; (3) University of Sydney
`riechers@pik-potsdam.de`

Paleoclimate proxy records evidence repeated abrupt climatic transitions during past glacial intervals with strongest expression in the North Atlantic region. Temperature reconstructions from Greenland ice cores reveal sudden high northern latitude warming events of

up to 16°C on decadal time scales, but associated impacts extend across the globe, including disruptions of the tropical monsoon systems and temperature variations in Antarctica. Do we need this specification here? These so-called Dansgaard-Oeschger (DO) events are commonly considered as the archetype of past abrupt climate changes.

In Greenland ice core records the DO warming events are followed by phases of relatively mild temperatures termed Interstadials, which exhibit gradual cooling prior to a final phase of abrupt temperature decrease back to cold Stadials. To date, there is no consensus about the origin of this millennial-scale variability. Here, we propose an excitable model to explain the DO cycles, in which Interstadials are regarded as noise-induced state space excursions of an excitable system. Our model comprises the mutual multi-scale interactions between four dynamical variables representing Arctic atmospheric temperatures, Nordic Seas' temperatures and sea ice cover, and the Atlantic Meridional Overturning Circulation (AMOC). Crucially, the model's atmosphere-ocean heat flux is moderated by the sea ice variable which in turn is subject to large perturbations dynamically generated by a fast evolving intermittent noise process. These perturbations, which we suggest to originate from convective events in the ocean or atmospheric blocking events, may trigger Interstadial-like state space excursion seizing all four model variables. The key characteristics of DO cycles are reproduced by our model with remarkable resemblance to the proxy record; in particular, their shape, return time, as well as the dependence of the Interstadial and Stadial durations on the background temperatures are reproduced accurately. In contrast to the prevailing understanding that the DO variability showcases bistability in the underlying dynamics, we conclude that multi-scale, monostable excitable dynamics provides a promising alternative candidate to explain the millennial-scale climate variability associated with the DO events.

Bayesian on-line anticipation of critical transitions

Martin Heßler, **Oliver Kamps**

Center for Nonlinear Science, University Münster
okamp@uni-muenster.de

The design of reliable indicators to anticipate critical transitions in complex systems is an important task in order to detect imminent regime shifts and to intervene at an early stage to either prevent them or mitigate their consequences. We present a data-driven method based on the estimation of a parameterized nonlinear stochastic differential equation that allows for a robust anticipation of critical transitions even in the presence of strong noise which is a characteristic of many real world systems. Since the parameter estimation is done by a Markov chain Monte Carlo approach, we have access to credibility bands allowing for a better interpretation of the reliability of the results. We also show that the method can yield meaningful results under correlated noise. By introducing a Bayesian linear segment fit it is possible to give an estimate for the time horizon in which the transition will probably occur based on the current state of information. This approach is also able to handle nonlinear time dependencies of the parameter that controls the transition. The method can be used as a tool for on-line analysis to detect changes in the resilience of the system and to provide information on the probability of the occurrence of critical transitions in future. Additionally, it can give valuable information about the possibility of noise induced transitions. The discussed methods are made easily accessible via a flexibly adaptable open source toolkit named 'antiCPy' which is implemented in the programming language Python.

Tipping in complex systems under fast variations of parameters

Induja Pavithran, P. R. Midhun, R.I. Sujith

Department of Aerospace Engineering, IIT Madras, Chennai, India
indujap2013@gmail.com

Sudden transitions in the state of a system are often undesirable in natural and human-made systems. Such transitions under fast variation of system parameters are called rate-induced tipping. We experimentally demonstrate rate-induced tipping in a real-world complex system, namely a turbulent reactive flow system, and decipher its mechanism. The system exhibits tipping to a dangerously high amplitude oscillatory state known as thermoacoustic instability. We continuously vary a control parameter driving the system towards conditions favorable for an alternative stable state, i.e., thermoacoustic instability (stable limit cycle oscillations). We find that the wall temperature is a slow variable that varies simultaneously at a different timescale, increasing the damping of oscillations in the system variables. The competition between the effects of these different timescales determines if and when tipping occurs. There is a critical rate of change of control parameter above which the system undergoes tipping. Motivated by the experiments, we use a nonlinear oscillator model exhibiting Hopf bifurcation to generalize this tipping to complex systems where the competition between the slow and fast timescales determines the dynamics.

Data-driven anticipation and prediction of Atlantic Meridional Overturning Circulation collapse using non-autonomous spatiotemporal dynamical modelling

Frank Kwasniok

University of Exeter, UK
F.Kwasniok@exeter.ac.uk

A data-driven methodology for identifying, anticipating and predicting critical transitions in high-dimensional model or observational data sets is introduced, based on explicit non-autonomous modelling of the tipping dynamics. Unlike the more traditional early-warning signs, this allows for dynamical understanding of the underlying tipping mechanism and genuine prediction of the future system state by extrapolation. A set of spatial modes carrying the tipping dynamics are identified and a nonlinear stochastic model of appropriate complexity is estimated in the subspace spanned by these modes. Analysis of the reconstructed dynamics allows to determine the type of the impending bifurcation. Different competing tipping mechanisms can be compared and assessed using likelihood inference and information criteria. The methodology is here applied to a data set from a climate model simulation of Atlantic Meridional Overturning Circulation (AMOC) collapse, actually a freshwater hosing experiment with the FAMOUS GCM. The AMOC on-state is found to lose stability via a subcritical Hopf bifurcation; however, the transition to the off-state occurs far ahead of reaching the bifurcation point. The early collapse can be explained by a combination of rate-induced and noise-induced tipping.

Posters T
Tipping points

T1 – Frequency-dependent tipping in driven ecological system

Ayanava Basak (1), Syamal Kumar Dana (2), Nandadulal Bairagi (3)

(1) Center for Mathematical Biology and Ecology, Department of Mathematics, Jadavpur University (2) National Institute of Technology, Durgapur (3) Center for Mathematical Biology and Ecology, Department of Mathematics, Jadavpur University
ayanavafulia@gmail.com

Ecological systems with time-dependent parameters may tip, and a catastrophic shift to another state may occur due to the drifting of a parameter. The carrying capacity of an ecological system may experience a periodic fluctuation with time-dependent frequency due to anthropogenic reasons, seasonal variation, and global warming. Such a periodic fluctuation is a growing event in aquatic and terrestrial ecosystems caused by human intervention and climate change. Using three paradigmatic population models of different dimensions, we exemplify that the system may tip from its base attractor (stable fixed point, periodic, or chaotic) to another attractor with the extinction of species if the ecosystem's carrying capacity fluctuates periodically with a time-dependent frequency. For such tipping, the drifting frequency function should have the convex property. This frequency-induced tipping (what we call F-tipping) differs from conventional tipping phenomena and is a generic property of ecological systems.

T2 – Combined effects of global warming and the collapse of AMOC over South America

Da Nian (1), Sebastian Bathiany (2), Maya Ben-Yami (2), Lana Blaschke (1), Marina Hirota (3), Regina Rodrigues (4), Niklas Boers (1,2)

(1) Potsdam Institute for Climate Impact Research (PIK); (2) TUM School of Engineering and Design; (3) Federal University of Santa Catarina, Florianopolis, Brazil; (4) Federal University of Santa Catarina
danian@pik-potsdam.de

Amazon forest is at risk of dieback from the impact of future climate change on the mean annual precipitation (MAP) and mean annual temperature (MAT). This study assesses the influence on South American vegetation under two possible future climate change scenarios, global warming and global warming combined with an AMOC collapse. The most possible vegetation state can be estimated by the correspondence between the tree cover distribution and MAP through bifurcation theory. This study takes MAT as another control parameter and estimates possible schemes of vegetation state by MAP combined MAT. Comparing vegetation types in current climates to the ones in future scenarios allows the assessment of scheme shifts of vegetation states due to global warming scenario and global warming combined with an AMOC collapse scenario. The results of the scenario shift suggest that AMOC collapse does not contribute to further Amazon rainforest dieback and conversion to Savanna, it even helps to stabilize the Amazon forest and mitigate the system's loss of resilience in the global warming scenario SSP8.5.

T3 – Entropy-based early detection of critical transitions in spatial vegetation fields

Giulio Tirabassi, Cristina Masoller

Universitat Politècnica de Catalunya
giulio.tirabassi@upc.edu

In semi-arid regions, vegetated ecosystems can display abrupt and unexpected changes, i.e., transitions to different states, due to drifting or time-varying parameters, with severe consequences for the ecosystem and the communities depending on it. Despite intensive research, the early identification of an approaching critical point from observations is still an open challenge. Many data analysis techniques have been proposed, but their performance depends on the system and on the characteristics of the observed data (the resolution, the level of noise, the existence of unobserved variables, etc.). Here we propose an entropy-based approach to identify an upcoming transition in spatio-temporal data. We apply this approach to observational vegetation data and simulations from two dynamical models of vegetation dynamics to infer the arrival of an abrupt shift to an arid state. We show that the permutation entropy computed from the probabilities of two-dimensional ordinal patterns may provide an early warning indicator of an approaching tipping point, as it may display a maximum (or minimum) before decreasing (or increasing) as the transition approaches. Like other spatial early-warning indicators, the spatial permutation entropy does not need a time series of the system dynamics, and it is suited for spatially extended systems evolving on long time scales, like vegetation plots. We quantify its performance and show that, depending on the system and data, the performance can be better, similar or worse than the spatial correlation, which is a classic indicator. Hence, we propose the spatial permutation entropy as an additional indicator to try to anticipate regime shifts in vegetated ecosystems.

T4 – TransitionIndicators.jl – A high end software to accelerate research and computation of transition indicators

Jan Swierczek-Jereczek (1); **George Datseris** (2)

(1) Complutense University of Madrid, (2) University of Exeter
g.datseris@exeter.ac.uk

Tipping phenomena have become increasingly important, and are nowadays routinely studied in diverse fields, such as climate science, ecosystem dynamics and much more. Despite large interest in analyzing tipping points, software implementations have not kept up with the demand. Only a couple of published code bases exist that can help identify tipping, or transitions across states. Unfortunately, they are limited in scope, consider practically only critical slowing down as a transition identification mechanism. Additionally, in a holistic view, including documentation, testing, extend-ability, computational performance, among other factors, we believe that existing software does not reach highest quality possible. We argue that this limits the efficiency with which tipping point research is performed, but also hinters progress in methodological advancements, i.e., developing and implementing new methods that can identify transitions in data. Here we present TransitionIndicators.jl, a pure Julia package that is part of the DynamicalSystems.jl ecosystem and has been developed from scratch following highest quality standards on modern software design. It is easy to use, exceptionally well documented, outperforms existing alternatives, and provides a carefully designed extendable interface for future methodological research.

T5 – Limits of large deviation theory in predicting transition paths of tipping events

Reyk Börner (1), Ryan Deeley (2), Raphael Römer (3), Tobias Grafke (4), Ulrike Feudel (2), Valerio Lucarini (1)

(1) University of Reading, (2) Carl von Ossietzky University of Oldenburg, (3) University of Exeter, (4) University of Warwick
reyk.boerner@reading.ac.uk

Any multistable dynamical system, when driven by noise, will eventually undergo rare but important critical transitions between the competing metastable states. In the weak-noise limit, large deviation theory allows predicting the transition rate and most probable transition path of these tipping events. However, the limit of zero noise is never obtained in reality. In this work we show that, even for weak finite noise, sample transition paths may disagree with the large deviation prediction – the minimum action path, or instanton – if multiple timescales are at play. We illustrate this behavior in selected toy models from climate to neuroscience, where the dynamics exhibit a fast-slow characteristic. While the minimum action path generally crosses the basin boundary at a saddle point, we demonstrate cases in which ensembles of sample transition paths cross far away from the saddle. We discuss the conditions for saddle avoidance and relate this to the flatness of the quasipotential, a central object of large deviation theory. Further, we present an alternative approach that correctly determines the most probable transition path in these examples. Our results highlight that methods from large deviation theory must be applied cautiously in multiscale dynamical systems.

T6 – Fire prevents future Amazon forest recovery after large-scale deforestation

Markus Drüke, Boris Sakschewski, Werner von Bloh, Maik Billing, Wolfgang Lucht, Kirsten Thonicke

Potsdam Institute for Climate Impact Research, Member of the Leibniz Association, Telegraphenberg A31, 14473 Potsdam, Germany
drueke@pik-potsdam.de

The Amazon forest is regarded as a tipping element of the Earth system, because of a potential large-scale regime change from tropical forest to woodland savanna and grassland, which could be triggered by anthropogenic land use and climate change. Recent conceptual and data-driven research focused on the hysteresis of such a regime change and found that fire could enhance the irreversibility of large-scale Amazon die-back. However, large-scale feedback analyses which integrate the interplay of fire with climate and land-use change are currently lacking. Here we apply the fire-enabled Earth system model CM2Mc-LPJmL to study such feedback mechanisms in the Amazon. We specifically test the role of fire in Amazon forest recovery under different atmospheric CO_2 concentration levels (i.e., the magnitude of climate forcing) after complete deforestation. We find that fire prevents forests from regrowing on an area of 353–515 Mio ha (56–82 % of potential natural forest), depending on atmospheric CO_2 concentration. Our simulation results show that fire is a major contributor to the irreversibility of a transition from forest to grassland by locking the Amazon in a stable grassland state. These findings emphasize the urgency of keeping deforestation and atmospheric CO_2 concentrations within stable boundaries that would safeguard the Amazon forest.

T7 – Progress on data reliability and processing best practices for resilience estimation with satellite data

Taylor Smith (1), Niklas Boers (2,3,4)

(1) Universitat Potsdam; (2) Earth System Modelling, School of Engineering & Design, Technical University of Munich; (3) Potsdam Institute for Climate Impact Research; (4) Department of Mathematics and Global Systems Institute, University of Exeter, UK
tasmith@uni-potsdam.de

Satellite data is being used in a growing number of studies on ecosystem resilience, and in particular on vegetation resilience. As methods pioneered on model and deep-time studies are increasingly used in new contexts, it is important to take stock of the assumptions surrounding their use, problems particular to satellite data, and how to ensure the reliability of resilience estimation and quantify uncertainties. To address these open questions, we present ongoing work on two key topics: (1) estimating the reliability of resilience estimates from multi-sensor data sets; and (2) examining the role of de-seasoning and de-trending procedures in complex and heterogeneous time series ensembles. Satellite records – particularly at global resolutions and at multi-decade time scales – are highly heterogeneous in both space and time, and require careful consideration of how best to ensure the reliability of resilience estimates. This is particularly true for studies concerned with changing resilience through time, upon which important inferences about the changing state of global ecosystems under climate change are based.

Posters M: Methods

M1 – Stabilized universal differential equations for hybrid machine learning of conservative dynamical systems

Alistair White (1,2), Niklas Boers (1,2)

(1) Technical University of Munich; (2) Potsdam Institute for Climate Impact Research
alistair@pik-potsdam.de

Universal Differential Equations (UDEs) provide a powerful framework for combining dynamical systems with machine learning. In particular, they allow unknown parts of a differential equation model to be parameterized by a universal function approximator, such as a neural network. The result is a hybrid model, containing both process-based and data-driven components. However, the flexibility of the data-driven part of the differential equation comes at the expense of potentially violating known physical constraints, such as conservation laws. This problem is especially critical in applications requiring very long simulations, such as climate modeling, where long-term numerical stability remains one of the main barriers to adoption of hybrid models. In addition, it is hoped that enforcing physical constraints will aid generalization to out-of-sample conditions unseen during training.

We introduce Stabilized Universal Differential Equations, which augment a UDE model with compensating terms that ensure physical constraints are approximately satisfied during numerical simulations. Numerical solution of the stabilized system does not require specialized numerical methods, meaning that existing efficient solvers can be used without modification.

We apply Stabilized UDEs to the double pendulum and Henon-Heiles systems, both of which are conservative, chaotic dynamical systems with a time-independent Hamiltonian. We show that Stabilized UDE models, unlike their unstabilized counterparts, conserve energy even during very long simulations. In addition, we show that Stabilized UDE models remain numerically stable for significantly longer and reproduce the underlying dynamics of the target system with far higher accuracy than non-energy conserving models.

In addition to providing a new and lightweight method for combining physical constraints with UDEs, our results provide new evidence for the impact of physical constraints on the long-term numerical stability and dynamical fidelity of hybrid models.

M2 – Local characterization of transient chaos on finite times in open systems

Gábor Drótos (1,2,3), Emilio Hernández-García (2), Cristóbal Lopez (2)

(1) Institute for Nuclear Research, Hungary; (2) Instituto de Física Interdisciplinar y Sistemas Complejos (CSIC-UIB), Spain; (3) MTA-ELTE Theoretical Physics Research Group, Hungary
drotos@general.elte.hu

To characterize local finite-time properties associated with transient chaos in open dynamical systems, we introduce an escape rate and fractal dimensions suitable for this purpose in a coarse-grained description. We numerically illustrate that these quantifiers have a considerable spread across the domain of the dynamics, but their spatial variation, especially on long but non-asymptotic integration times, is approximately consistent with the relationship that was recognized by Kantz and Grassberger for temporally asymptotic quantifiers. In particular, deviations from this relationship are smaller than differences between various locations, which confirms the existence of such a dynamical law and the suitability of our quantifiers to represent underlying dynamical properties in the non-asymptotic regime. We also show that some other attempts to define the quantifiers in question perform worse in the mentioned respect. As an outlook, we sketch an application to the escape of particles from the atmosphere across the globe.

M3 – Network sparsification via degree- and subgraph-based edge sampling

Zhen Su (1), Jürgen Kurths (1,2), Henning Meyerhenke (3)

(1) Potsdam Institute for Climate Impact Research, Potsdam, Germany; (2) Department of Physics, Humboldt-Universität zu Berlin, Berlin, Germany; (3) Department of Computer Science, Humboldt-Universität zu Berlin, Berlin, Germany
zhen.su@pik-potsdam.de

Network (or graph) sparsification compresses a graph by removing inessential edges. By reducing the data volume, it accelerates or even facilitates many downstream analyses. Still, the accuracy of many sparsification methods, with filtering-based edge sampling being the most typical one, heavily relies on an appropriate definition of edge importance. Instead, we propose a different perspective with a generalized local-property-based sampling method, which preserves (scaled) local node characteristics. Apart from degrees, these local node characteristics we use are the expected (scaled) number of wedges and triangles a node belongs to. Through such a preservation, main complex structural properties are preserved implicitly. We adapt a game-theoretic framework from uncertain graph sampling by including a threshold for faster convergence (at least 4 times faster empirically) to approximate solutions. Extensive experimental studies on functional climate networks show the effectiveness of this method in preserving macroscopic to mesoscopic and microscopic network structural properties.

M4 – Ordinal pattern based complexity analysis of high-dimensional chaotic time series

Inga Kottlarz (1, 2), Ulrich Parlitz (1,2)

(1) Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany; (2) Institute for Dynamics of Complex Systems, Georg-August-Universität Göttingen, Göttingen, Germany
inga.kottlarz@ds.mpg.de

The ordinal pattern-based complexity-entropy plane is a popular tool in nonlinear dynamics for distinguishing stochastic signals (noise) from chaos. While successful attempts to do so have been documented for low-dimensional maps and continuous-time systems, high-dimensional systems have been somewhat neglected so far. To fill this gap, we present an analysis in the complexity-entropy plane of time series representing high-dimensional dynamics of the Lorenz-96 system, the generalized Hénon map, the Mackey-Glass equation and the Kuramoto-Sivashinsky equation. We find that time series from these systems often cannot be visually distinguished from their surrogates in the complexity-entropy plane, although a surrogate data test yields significant results in most cases. Based on these findings, we develop a guide on how to best proceed with an analysis of systems of unknown attractor dimension using the complexity-entropy approach.

M5 – Uncertainty boundaries in Hamiltonian systems

Matheus R. Sales, Michele Mugnaine, Ricardo L. Viana, Iberê L. Caldas, José D. Szezech Jr.

(1) Postgraduate Program in Physics, State University of Ponta Grossa, Brazil (2) Department of Physics, Federal University of Paraná, Brazil (3) Institute of Physics, University of São Paulo, Brazil (4) Department of Mathematics and Statistics, State University of Ponta Grossa, Brazil
jdsjunior@uepg.br

The boundaries between regular and chaotic motion in two-dimensional Hamiltonian systems are not smooth, in fact they can be very complicated with distinct levels in the hierarchy. Our main objective is to characterize the topology of these boundaries using a paradigmatic model, more specifically the standard map. We apply a recent test introduced to determine whether an orbit is regular or chaotic called the Birkhoff weighted average method. Through these results we use the uncertainty fraction method to calculate the fractal dimension. Our results point out that the initial condition in phase space plays a crucial role in uncertainty. Also, for inner levels on islands implies larger dimensions due a persistent dynamical traps.

M6 – TreeEmbedding: Optimal state space reconstruction via Monte Carlo decision tree search

Maximilian Gelbrecht (1,2), K. Hauke Krämer (2,3), Norbert Marwan (2,3)

(1) TUM School of Engineering and Design, Technical University Munich; (2) Potsdam Institute for Climate Impact Research; (3) University of Potsdam
gelbrecht@pik-potsdam.de

TreeEmbedding is a novel method for an optimal time delay state space reconstruction from uni- and multivariate time series. The embedding process is considered as a decision tree, in which each leaf corresponds to an embedding cycle and is subject to an evaluation through an objective function. By using a Monte Carlo ansatz, the proposed algorithm populates the tree with many leafs by computing different possible embedding paths and the final embedding is chosen as that particular path that minimises the objective function. The Monte Carlo approach aims to prevent getting stuck in a local minimum of the objective function and can be used in a modular way: Practitioners can choose suitable statistics for delay-preselection and the objective func-

tion themselves. The proposed method guarantees the optimization of the chosen objective function over the parameter space of the delay embedding as long as the tree is sampled sufficiently. To showcase the method, we demonstrate its improvements over the classical time delay embedding methods on various application examples. We compare recurrence plot-based statistics inferred from reconstructions of a Lorenz-96 system and highlight an improved forecast accuracy for map-like model data as well as for palaeoclimate isotope time series. The method is ready to use in the form of an accompanying Julia package TreeEmbedding.jl.

M7 – Combining multiplex networks, time series and machine learning: A methodology for reducing the dimensionality of data representation and making effective predictions

Sergio Iglesias, **Regino Criado**

Universidad Rey Juan Carlos
regino.criado@urjc.es

The processing of large amounts of information is a great challenge for which the latest big data techniques provide some solutions. In this poster we present a methodology based on time series algorithms and multiplex networks. This methodology allows to process a large amount of information and to obtain a more effective and useful way of grouping the information, allowing to solve problems with a large number of temporal variables in an efficient way. The methodology presented to combine all this information is based both on the original use of some unsupervised machine learning techniques and on the use of certain attributes of the time series and their representation as a complex multiplexed network, achieving a very significant reduction in the dimensionality of the resulting data representation. The poster includes as an application a practical example of the evolution of housing prices in New York City based on cab trips between different areas of the city.

M8 – Infinitely many conserved quantities in a weighted planar stochastic lattice and their connection to Noether's theorem

Tushar Mitra, **Md. Kamrul Hassan**

Dhaka University
khassan@du.ac.bd

In this presentation, I shall discuss a class of weighted planar stochastic lattice (WPSL1) created by random sequential nucleation of seed from which a crack is grown parallel to one of the sides of the chosen block and ceases to grow upon hitting another crack. It results in the random partitioning of the square into contiguous and non-overlapping blocks. Interestingly, we find that the dynamics of WPSL1 is governed by infinitely many conservation laws and each of the conserved quantities, except the trivial conservation of total mass or area, is a multifractal measure. On the other hand, Noether's theorem suggests that whenever there exist a continuous conserved quantity there must exist symmetry. Earlier, we have shown that area distribution exhibits dynamic scaling. In this talk we show that the distribution of every non-trivial conserved quantity too exhibits dynamic scaling. It means that the distribution of every conserved quantity at different times are similar which we show using the idea of data collapse. On the other hand, since the same system at different times are similar we call the exhibits self-similarity which is also a kind of symmetry. Besides, I will show that the dual of the lattice is a scale-free network as its degree distribution exhibits a power-law. The network is also a small-world network as we find that (i) the total clustering coefficient C is high and independent of the network size and (ii) the mean geodesic path length grows logarithmically with N.

M9 – Percolation-based Evolutionary Framework for the diffusion-source-localization problem in large networks

Yang Liu, Xiaoqi Wang, Xi Wang, Zhen Wang, Jürgen Kurths

(1) Northwestern Polytechnical University; (2) Stanford University; (3) The Chinese University of Hong Kong; (4) Potsdam Institute for Climate Impact Research
yangliuyh@gmail.com

We assume that the state of a number of nodes in a network could be investigated if necessary, and study what configuration of those nodes could facilitate a better solution for the diffusion-source-localization (DSL) problem. In particular, we formulate a candidate set which contains the diffusion source for sure, and propose the method, Percolation-based Evolutionary Framework (PrEF), to minimize such set. Hence one could further conduct more intensive investigation on only a few nodes to target the source. To achieve that, we first demonstrate that there are some similarities between the DSL problem and the network immunization problem. We find that the minimization of the candidate set is equivalent to the minimization of the order parameter if we view the observer set as the removal node set. Hence, PrEF is developed based on the network percolation and evolutionary algorithm. The effectiveness of the proposed method is validated on both model and empirical networks in regard to varied circumstances. Our results show that the developed approach could achieve a much smaller candidate set compared to the state of the art in almost all cases. Meanwhile, our approach is also more stable, i.e., it has similar performance irrespective of varied infection probabilities, diffusion models, and outbreak ranges. More importantly, our approach might provide a new framework to tackle the DSL problem in extreme large networks.

conference program online

supported by

Deutsche Forschungsgemeinschaft

P I K