Dynamics Days Europe 2022

Abstract Book

22nd – 26th August 2022
University of Aberdeen

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ABERDEEN

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MATHEMATICAL
SOCIETY

Chaos

Σ *mathematics*
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Chaos,
Solitons
& Fractals
An Interdisciplinary
Journal of Nonlinear
Science

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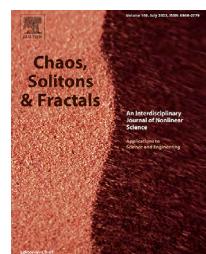
Table of Contents
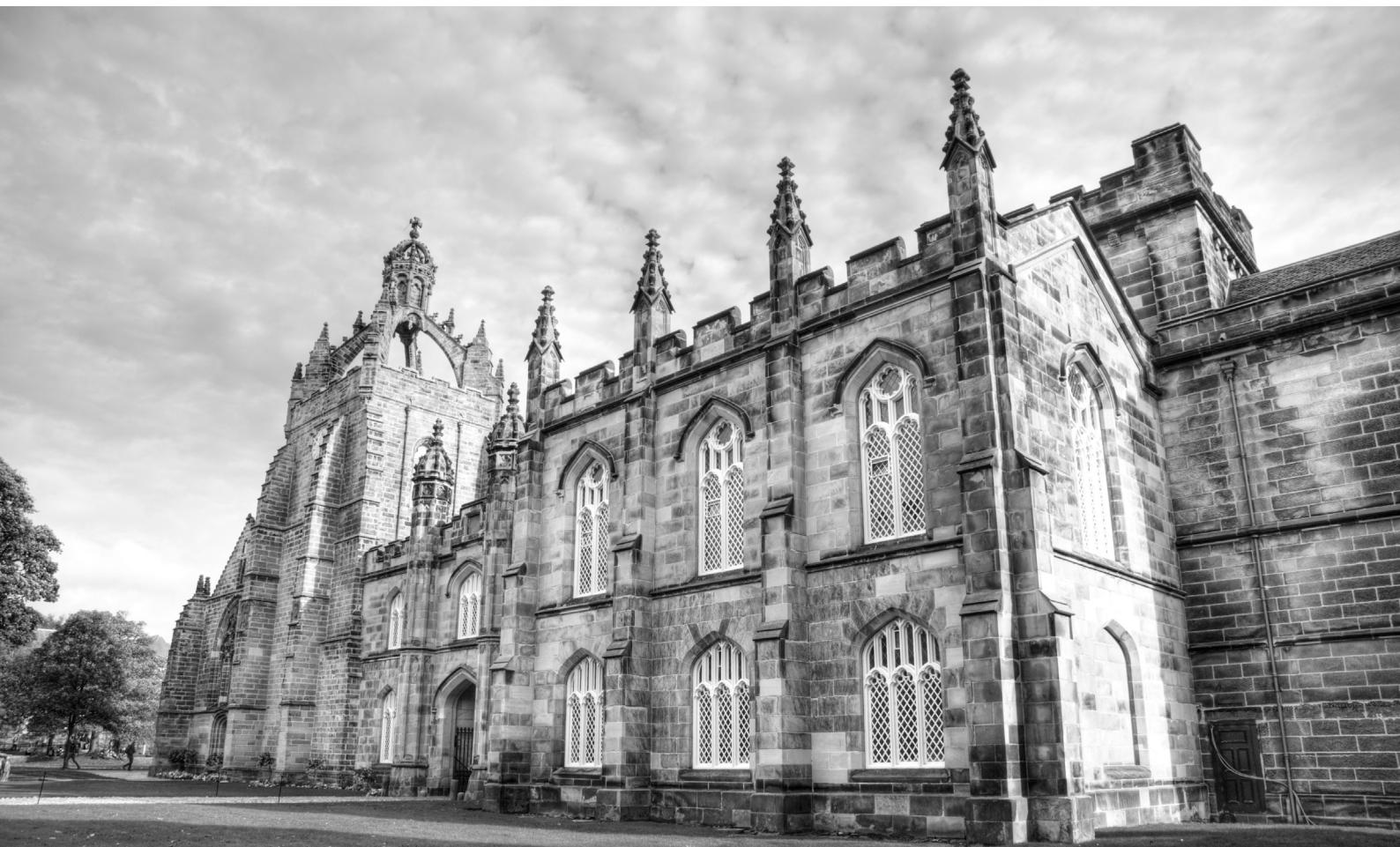
Welcome from Local Organising Committee Chair

On behalf of the University of Aberdeen and the Local Organising Committee, I warmly welcome you to the Dynamics Days Europe conference 2022 and to Aberdeen. We are delighted to be holding the first fully in-person Dynamics Days Europe conference since the start of the pandemic, and I hope that this will contribute to global efforts to reignite the spark of the social aspects in academic conferences.

The University of Aberdeen's links to the study of dynamics are well-known. James Clerk Maxwell, a Scottish scientist, regarded by many modern physicists as the scientist of the 19th century who had the greatest influence on 20th-century physics, was professor at Aberdeen in 1855-1860 when he clarified the use of the concept of angular momentum and the complex rotational motion of rigid bodies in the most general circumstances from his dynamical top, developed the dynamical theory of gases from the basic principle of independence of velocity components along perpendicular directions, and understood that the stability of Saturn's ring relies on "an indefinite number of unconnected particles, revolving around the planet with different velocities according to their respective distances. In the 21st century the university has a strong research group with a focus on the dynamics of complex systems and mathematical biology, and its applications to science, engineer, and medicine.

As well as our interesting conference programme, which includes presentations from researchers based across the globe, we also have a social programme which will make the most of the famous Scottish hospitality. I look forward to welcoming you all and having the opportunity to talk with many of you at the welcome reception on Sunday 21st August at the inspiring halls of the Aberdeen Art Gallery. At our conference dinner at the Chester Hotel on Wednesday 24th August you will have another tasting of the Scottish food, a revealing talk by Prof James Yorke, and the chance to see, learn and enjoy a traditional Scottish ceilidh dance. You will also be able to visit Haddo House and Country Park, one of the most popular attractions in the north east of Scotland. For over 500 years Haddo House was home to one family, the Gordons, who changed Haddo from a boggy valley into a stunning designed landscape of water, trees, fields and gardens.

Aberdeen is Scotland's third largest city, full of historical charm. It is rich in history from its maritime past of boat building and fishing, to more recently North Sea oil and gas and to leading the energy transition. I encourage you to take the opportunity to explore the city and the university's ancient campus while visiting. Within minutes of the conference venue you can visit King's College Chapel, St Machar Cathedral and the Seaton Park, the university's botanic gardens. In the city itself, you can visit the Maritime Museum, the Provost Skene's house, and see the second largest granite building in the world, the Marischal College. You can also visit our beautiful parks such as Duthie Park with its Winter Garden and watch Dolphins at Greyhope Bay Centre. Aberdeen is located minutes driving distant to the Cairngorms National Park and several whisky distilleries.

Enjoy, have fun and leave inspired for your next academic discoveries ☺

Murilo da Silva Baptista

Chair of Local Organising Committee

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[1] Following based on an extract from John S. Reid, 'Maxwell at Aberdeen', pp 17 – 42, 304 - 310 in Raymond Flood, Mark McCartney and Andrew Whitaker (eds), James Clerk Maxwell: Perspectives on his Life and Work (Oxford University Press, 2014).

Local Organising Committee

Dr Murilo S. Baptista

Prof Celso Grebogi

Dr Alessandro Moura

Dr Francisco Perez-Reche

Prof Antonio Politi

Prof Mamen Carmen Romano

Prof Bjoern Schelter

Prof Marco Thiel

Dr Ekkehard Ullner

Dr Francesco Ginelli (Università degli Studi dell'Insubria, Italy)

Organisational support provided by CPD Services, University of Aberdeen

Important Information

Venue

University of Aberdeen, King's College, Aberdeen AB24 3FX

Registration will be in Elphinstone Hall and a helpdesk will be in place throughout the conference.

The plenary talks will be held in the Arts Lecture Theatre

Minisymposiums and Contributed Talks will take place in in KCG7, KCF7, KCF22, KCG5 & KCG11. Please check the programme to confirm the rooms for each talk.

Posters, coffee breaks and lunch will be held in Elphinstone Hall

Staff will be on hand to direct you to the correct rooms during the conference.

Internet Access

Internet is available for delegates for use free of charge on the University of Aberdeen campus by accessing the *Aberdeen City Connect* network.

Conference Welcome Reception

Sunday 21st August 6.00pm – 7.30pm

Aberdeen Art Gallery, Schoolhill, Aberdeen AB10 1FQ

Conference Dinner

Wednesday 24th August 6.45pm - 00.00

The conference dinner will be held at the luxury 4* Chester Hotel, which is close to the city centre. Following the dinner, you have the opportunity to try out a real Scottish Ceilidh.

Chester Hotel, 59-63 Queen's Road, Aberdeen AB15 4YP

To travel to the Chester Hotel by bus, use Service 11.

Please note that registrations made after 29 July 2022 do not have the conference dinner included. Please refer to your booking to check if you have a place at the conference dinner.

Conference Excursion

Wednesday 24th August 13.30 - 17.00

Visit Haddo House and Country Park. Now owned and managed by Aberdeenshire Council and the National Trust for Scotland, Haddo House & Country Park is one of the most popular attractions in the north east.

Bus times: (please ensure you arrive 10 minutes prior to departure)

Leaving University of Aberdeen from Elphinstone Hall - 13.30
Arrival back at University of Aberdeen - 17.00

Transport

Travelling by Car or Motorcycle

Entering the city from the south or west, follow signs for the A90 (Fraserburgh and Peterhead). This leads round the ring road (Anderson Drive). Exiting from a roundabout (signed Old Aberdeen) onto Cairncry Road, continue to follow the A90 signs through two further roundabouts onto St. Machar Drive. After a third roundabout, the road bisects Old Aberdeen and local signs will direct you to University sites. From the north, Old Aberdeen is signposted on the A96 (from Dyce and Inverness) and on the A90 (from Peterhead).

Please note that there is no public car parking available on campus.

Travelling by Rail

Aberdeen is served by a number of services which stop at Aberdeen Train Station. Upon departing the train station, a taxi rank is available or walk to Union Street to access more taxis and buses.

Travelling by Bus

The University of Aberdeen is served by a number of buses from Aberdeen city centre. The following routes serve the Old Aberdeen campus, stopping in the following locations.

• Old Aberdeen (bus no. 20)

• Bedford Road, Sir Duncan Rice Library (bus no. 19)

• King Street (bus no. 1 and 2)

You can pay via cash or card.

Travelling by Taxi

The following taxi companies are available:

• Rainbow City Taxis – 01224 878787

• ComCabs – 01224 353535

• Aberdeen Taxi – 01224 200200

Should you require a taxi whilst on campus the event organisers would be happy to call and arrange one for you. Some of the operators also have Apps which you can download and use to book a taxi.

All taxi fares are metered, and most vehicles are fitted with card payment terminals.
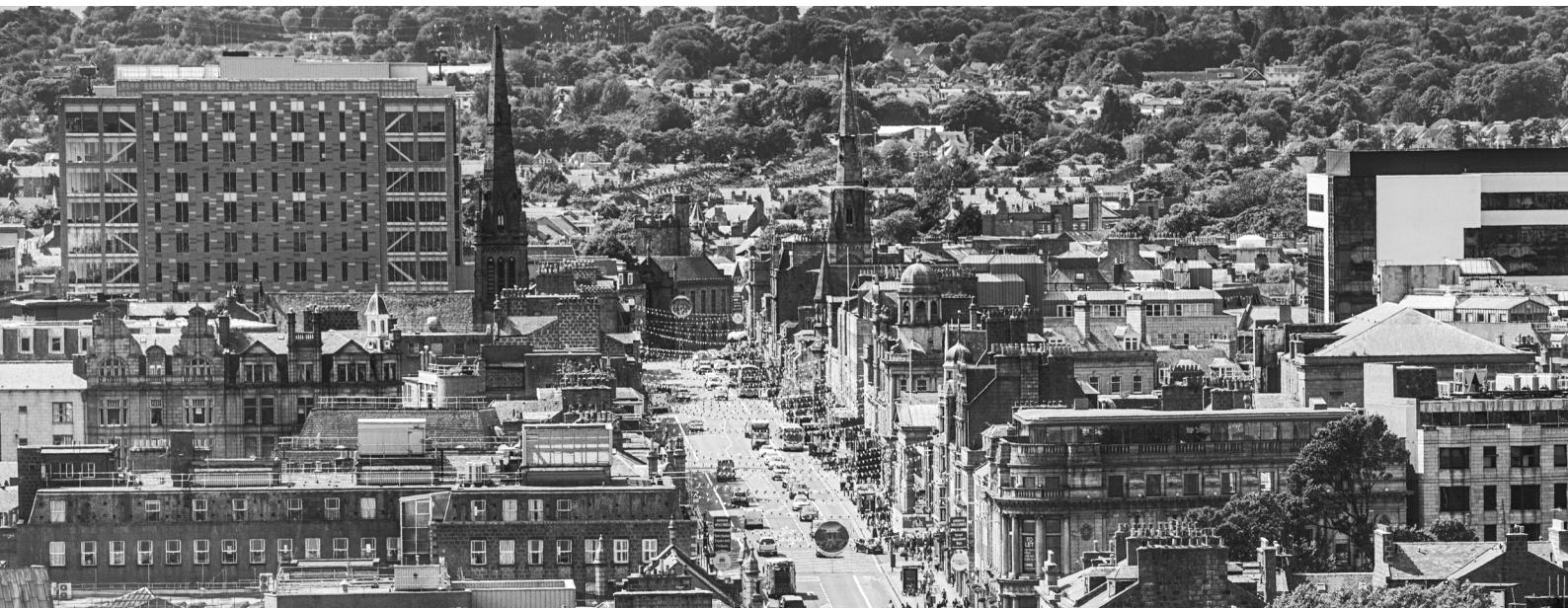
Programme

Sunday 21st August 2022

18.00 - 19.30	Welcome Reception	Aberdeen Art Gallery, Schoolhill, Aberdeen, AB10 1FQ

Monday 22nd August 2022

08.00 - 08.45	Registration & Tea & Coffee	Elphinstone Hall
08.45 - 09.00	Welcome from the organising committee	Arts Lecture Theatre
09.00 - 09.35	**Plenary** P 01 Ying-Cheng Lai *Finding the equations and structures of complex systems from data*	Arts Lecture Theatre
09.35 - 09.40	Comfort Break	
09.40 - 10.15	**Plenary** P 02 Steven Schiff *Thermal Effects on Neurons During Stimulation of the Brain*	Arts Lecture Theatre
10.15 - 10.40	Coffee Break	Elphinstone Hall

	Minisymposium	
10.40 - 12.20	**Room KCG7**	**MS 01.01** **Early Warning Signatures of Dynamical Transitions** Organisers: Prof. Cristina Masoller & Giulio Tirabassi, PhD
	Room KCF22	**MS 01.02** **Data Driven Modelling & Analysis in Weather & Climate Science** Organiser: Dr Frank Kwasniok
	Room KCG5	**MS 01.03** **Adaptive Dynamical Networks (Part i)** Organisers: Rico Berner, Thilo Gross, Christian Kuehn, Jürgen Kurths, Serhiy Yanchuk
	Room KCG11	**MS 01.04** **Dynamics & Life Sciences (Part i)** Organisers: Celso Grebogi & Mamen Romano

12.20 - 12.25	Comfort Break	
12.25 - 13.00	**Plenary** P 03 Cristina Masoller *Time crystal oscillations in a periodically forced stochastic time delayed system*	Arts Lecture Theatre
13.00 - 14.10	Lunch & Viewing of Posters	Elphinstone Hall
14.10 - 14.45	**Plenary** P 04 Tamas Tel *Climate changes of dynamical systems*	Arts Lecture Theatre
14.45 - 14.50	Comfort Break	

14.50 - 16.20	**Contributed Talks**		
	Room KCG7	**CT 01** **Machine Based-learning Modelling & Prediction (Part i)**	
	Room KCF7	**CT 02** **Networks**	
	Room KCF22	**CT 03** **Modelling**	
	Room KCG11	**CT 04** **Life Sciences (Part i)**	
	Room KCG5	**CT 05** **Stochastic Dynamics**	
16.20 - 16.45	Coffee Break		Elphinstone Hall
16.45 - 17.20	**Plenary** P 05 Fordyce Davidson *The Architecture of Bacterial Biofilms*		Arts Lecture Theatre
17.20 - 17.25	Comfort Break		
17.25 - 18.00	**Plenary** P 06 Alexey Zaikin *Intelligence and consciousness in genetic-neuron astrocyte networks*		Arts Lecture Theatre

Tuesday 23rd August

08.00 - 09.00	Tea & Coffee	Elphinstone Hall
09.00 - 09.35	**Plenary** P 07 James Gleeson *Data-driven modelling of cascades on networks*	Arts Lecture Theatre
09.35 - 09.40	Comfort Break	
09.40 - 10.15	**Plenary** P 08 Ruedi Stoop *How good is your dynamical system model?*	Arts Lecture Theatre
10.15 - 10.40	Coffee Break	Elphinstone Hall

	Minisymposium	
	Room KCF7	**MS 02.01** **Transient Chaos (Part i)** Organisers: Dr. Oleh Omel'chenko and Prof. Tamas Tel
	Room KCF22	**MS 02.02** **Recurrence-based Data Analysis** Organisers: Tobias Braun, Norbert Marwan & Deniz Eroglu
10.40 - 12.20	**Room KCG5**	**MS 02.03** **Adaptive Dynamical Networks (Part ii)** Organisers: Rico Berner, Thilo Gross, Christian Kuehn, Jürgen Kurths & Serhiy Yanchuk
	Room KCG11	**MS 02.04** **Dynamics & Life Sciences (Part ii)** Organisers: Celso Grebogi & Mamen Romano

12.20 - 12.25	Comfort Break	
12.25 - 13.00	**Plenary** P 09 Juergen Kurths *The Importance Complex Systems in Understanding Our Climate: Predictability of Extreme Climate Events*	Arts Lecture Theatre
13.00 - 14.10	Lunch & Viewing of Posters	Elphinstone Hall
14.10 - 14.45	**Plenary** P 10 Ulrich Parlitz *Challenges in cardiac dynamics*	Arts Lecture Theatre
14.45 - 14.50	Comfort Break	
14.50 - 16.20	**Contributed Talks**	
	Room KCG7	**CT 06** **Machine Learning-based Modelling & Prediction (Part ii)**
	Room KCF7	**CT 07** **Characterisation of Nonlinear Dynamics (Part i)**
	Room KCF22	**CT 08** **Inference & Modelling**
	Room KCG5	**CT 09** **Life Sciences (Part ii)**
	Room KCG11	**CT 10** **Syncronisation (Part i)**
16.20 - 16.45	Coffee Break	Elphinstone Hall

16.45 - 17.20	**Plenary** P 11 Aneta Koseska *Real-time biochemical computations at criticality*	Arts Lecture Theatre
17.20 - 17.25	Comfort Break	
17.25 - 18.00	**Plenary** P 12 Sarika Jalan *Multiple routes to abrupt first-order transition to synchronization in multilayer simplicial complexes*	Arts Lecture Theatre

Wednesday 24th August 2022

08.00 - 08.45	Tea & Coffee	Elphinstone Hall
09.00 - 09.35	**Plenary** P 13 Mario Chavez *The intrinsic geometry of complex brain networks as biomarkers in epilepsy*	Arts Lecture Theatre
09.35 - 09.40	Comfort Break	
09.40 - 10.15	**Plenary** P 14 Jesús Gómez-Gardeñes *Hunting mosquitoes with networks*	Arts Lecture Theatre
10.15 - 10.40	Coffee Break	Elphinstone Hall

	Minisymposium	
10.40 - 12.20	**Room KCG7**	**MS 03.01** **Mean-field Dynamics in Oscillatory & Neural Systems** Organisers: Gloria Cecchini, PhD & Pau Clusella
	Room KCF7	**MS 03.02** **Transient Chaos (Part ii)** Organisers: Dr. Oleh Omel'chenko and Prof. Tamas Tel
	Room KCG22	**MS 03.03** **Enhancing Gender Balance in Non-linear Dynamics** Organisers: Dr. Simona Olmi and Prof. Anna Zakharova
	Room KCG5	**MS 03.04** **Adaptive Dynamical Networks (Part iii)** Organisers: Rico Berner, Thilo Gross, Christian Kuehn, Jürgen Kurths & Serhiy Yanchuk
	Room KCG11	**MS 03.05** **Dynamics & Life Sciences (Part iii)** Organisers: Celso Grebogi & Mamen Romano
12.20 - 12.25	Comfort Break	
12.25 - 13.00	**Plenary** P 15 Theo Geisel *Musicians' Synchronization and the Enigma of Swing*	Arts Lecture Theatre
13.00 - 13.30	Pick Up Packed Lunch	Elphinstone Hall

13.30 - 16.00	Conference Excursion - Haddo House, Aberdeenshire.
	Depart: Outside Elphinstone Hall 13.30
	Visit to Haddo House & Country Park
	Return: Elphinstone Hall approximately 17.00
18.45 - 00.00	Conference Dinner & Ceilidh
	Chester Hotel, 59-63 Queen's Road, Aberdeen AB15 4YP
	Dinner Talk – James Yorke

Thursday 25th August

08.00 - 08.45	Tea & Coffee	Elphinstone Hall
09.00 - 09.35	**Plenary** P 16 Benjamin Lindner *Fluctuation-dissipation theorems for systems far from equilibrium*	Arts Lecture Theatre
09.35 - 09.40	Comfort Break	
09.40 - 10.15	**Plenary** P 17 Arkady Pikovsky *Deterministic dynamics of active particles: chaos and synchronization*	Arts Lecture Theatre
10.15 - 10.40	Coffee Break	Elphinstone Hall

10.40 - 12.20	**Minisymposium**	
	Room KCG7	**MS 04.01** **Global Features of Coupled Dynamical Systems** Organiser: Dr. Jose Mujica
	Room KCF7	**MS 04.02** **Estimating Stability Indicators from Data** Organiser: Dr. Nahal Sharafi
	Room KCF22	**MS 04.03** **Metastability in Neuron Networks** Organiser: Prof. Dr. Klaus Lehnertz
	Room KCG5	**MS 04.04** **Adaptive Dynamical Networks (Part iv)** Organisers: Rico Berner, Thilo Gross, Christian Kuehn, Jürgen Kurths & Serhiy Yanchuk
12.20 - 12.25	Comfort Break	
12.25 - 13.00	**Plenary** P 18 Jordi Garcia-Ojalvo *Oscillations as organizers in cellular populations*	Arts Lecture Theatre
13.00 - 14.10	Lunch & Viewing of Posters	Elphinstone Hall
14.10 - 14.45	**Plenary** P 19 Aneta Stefanovska *Multiscale oscillatory dynamics: What happens when the frequencies are not constant?*	Arts Lecture Theatre
14.45 - 14.50	Comfort Break	

14.50 - 16.20	Contributed Talks		
	Room KCG7	**CT 11** **Fluid Dynamics**	
	Room KCF7	**CT 12** **Characterisation of Nonlinear Dynamics (Part ii)**	
	Room KCG22	**CT 13** **Classical & Quantum Dynamics**	
	Room KCG5	**CT 14** **Spacio-temporal Dynamics**	
	Room KCG11	**CT 15** **Syncronisation (Part ii)**	
16.20 - 16.45	Coffee Break		Elphinstone Hall
16.45 - 17.20	**Plenary** P 20 Ulrike Feudel *Tipping phenomena and resilience of complex systems: Theory and applications*		Arts Lecture Theatre
17.20 - 17.25	Comfort Break		
17.25 - 18.00	**Plenary** P 21 Erik Bollt *On Explaining the Surprising Success of Reservoir Computing Forecaster of Chaos? The Universal Machine Learning Dynamical System with Contrasts to VAR and DMD.*		Arts Lecture Theatre

Friday 26th August

08.00 - 08.45	Tea & Coffee		Elphinstone
09.00 - 09.35	**Plenary** P 22 James Yorke		Arts Lecture Theatre
09.35 - 09.40	Comfort Break		
09.40 - 10.15	**Plenary** P 23 Alessandro Torcini *Next Generation Neural Mass Models*		Arts Lecture Theatre
10.15 - 10.40	Coffee Break		Elphinstone Hall
10.40 - 12.20	**Minisymposium**		
	Room KCG7	**MS 05.01** **Data Driven Modelling & Analysis of Complex Dynamical Systems** Organisers: Prof. Constantinos Siettos, Dr. Lucia Russo & Prof. Yannick de Decker	
	Room KCF7	**MS 05.02** **Extreme Events** Organiser: Dibakar Ghosh	
	Room KCF22	**MS 05.03** **Critical Transitions in Nonlinear Dynamical Systems: Theory and Applications** Organisers: Ulrike Feudel & Lea Oljaca	
	Room KCG5	**MS 05.04** **Dynamics of Urban Complexity: Infrastructural Entanglements** Organisers: Ulysses Sengupta & Deljana Iossifova	
12.20 - 12.25	Comfort Break		

12.25 - 13.00	**Plenary**	Arts Lecture Theatre
	P 24	
	Jen Creaser	
	A quasipotential approach for networks of bistable nodes	
13.00 - 13.30	Closing & Vote of Thanks from Organising Committee	Arts Lecture Theatre
13.30 - 14.30	Lunch	Elphinstone Hall
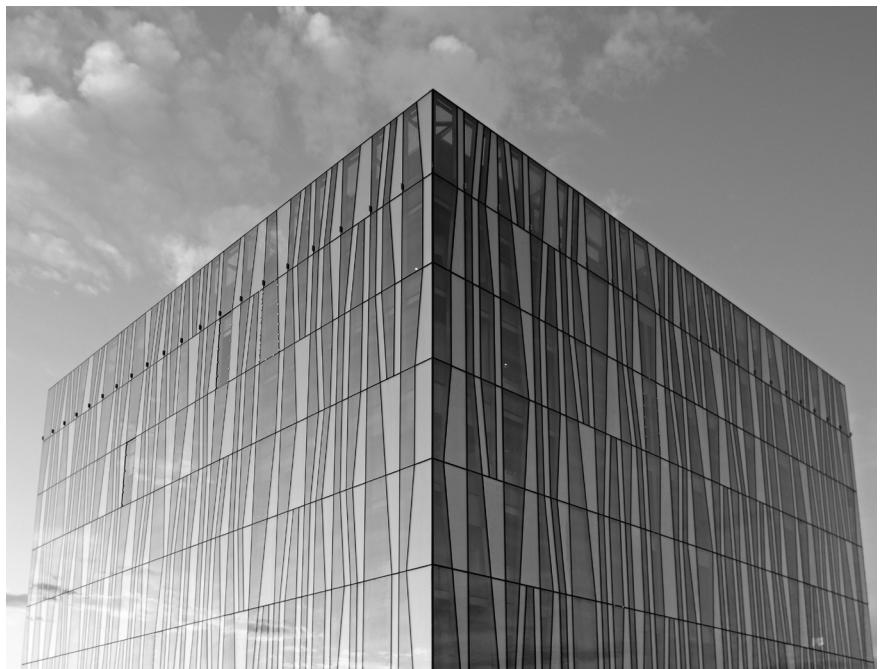
Plenary Speakers Abstracts

Monday 22nd August

09.00 – 09.35   **P 01 Finding the equations and structures of complex systems from data**

Ying-Cheng Lai, Regents Professor

Arizona State University

Abstract: In applications of nonlinear and complex dynamical systems, a common situation is that the system can be measured, but its structure and the detailed rules of the dynamical evolution are unknown. The inverse problem is to determine the system equations and structures from time series data. Sparse optimization was articulated in 2011 to find the equations of dynamical systems from data. The basic idea is to expand the system equations into a power series or a Fourier series of a finite number of terms and then to determine the vector of the expansion coefficients based solely on data through sparse optimization. In this talk, the history of this area of research will be reviewed and recent progress will be presented. Issues discussed include discovering the equations of stationary or nonstationary chaotic systems to enable the prediction of critical transition and system collapse, inferring the full topology of complex oscillator networks and social networks hosting evolutionary game dynamics, and identifying partial differential equations for spatiotemporal dynamical systems. Situations where sparse optimization works or fails will be pointed out. The relation with the traditional delay-coordinate embedding method will be discussed, and the recent development of a model-free, data-driven prediction framework based on machine learning will be mentioned.

09.40 – 10.15   **P 02 Thermal Effects on Neurons During Stimulation of the Brain**

Professor Steven J. Schiff

Yale University

Abstract: All artificial stimulation of the brain deposits thermal energy in the brain. This occurs through either Joule heating of the conductors carrying current through electrodes and magnetic coils, or through dissipation of energy in the conductive brain. Although electrical interaction with brain tissue is inseparable from thermal effects when electrodes are used, magnetic induction enables us to separate Joule heating from induction effects by contrasting AC and DC magnetic coil driving using the same energy deposition. Since mammalian cortical neurons have no known sensitivity to static magnetic fields, and if there is no evidence of effect on spike timing to oscillating magnetic fields, we can presume that the induced electrical currents within the brain are below the molecular shot noise where any interaction with tissue is purely thermal. In this study, we examined a range of frequencies produced from micromagnetic coils operating below the molecular shot noise threshold for electrical interaction with single neurons. We found that small temperature increases and decreases of $1oC$ caused consistent transient suppression and excitation of neurons during temperature change. Numerical modeling of the biophysics demonstrated that the Na-K pump, and to a lesser extent the Nernst potential, could account for these transient effects. Such effects are dependent upon compartmental ion fluxes and the rate of temperature change. A new bifurcation is described in the model dynamics that accounts for the transient suppression and excitation; in addition, we note the remarkable similarity of this bifurcation's rate dependency with other thermal rate-dependent tipping points in planetary warming dynamics. These experimental and theoretical findings demonstrate that stimulation of the brain must consider small thermal effects that are ubiquitously present in electrical and magnetic stimulation. More sophisticated models of electrical current interaction with neurons combined with thermal effects will lead to more accurate modulation of neuronal activity.

12.25 – 13.00　　　**P 03 Time crystal oscillations in a periodically forced stochastic time delayed system**

Prof. Cristina Masoller

Departament de Física, Universitat Politècnica de Catalunya

Abstract:　　　Time crystal oscillations in periodically forced many-particle systems are highly regular oscillations that persist for long periods of time, are robust to perturbations, and whose frequency differs from the frequency of the forcing signal [1].

Making use of the underlying similarities between spatially extended systems (SES) and delayed time systems (TDS) [2], we present an experimental demonstration of time-crystal-like behavior in a weakly modulated stochastic TDS: a laser with time-delayed feedback near threshold, whose output intensity (without modulation) shows abrupt noise-induced spikes at irregular times. When the laser current is modulated with a small-amplitude periodic signal, we find that the modulation generates long-range correlations in the timing of the spikes [3]. Particular modulation frequencies lead to long-range regularity in the spike timing. Despite the strong effect of noise near the threshold, the spikes lock to the modulation and remain in phase for thousands of cycles. With pulsed modulation waveform, we find both, harmonic and subharmonic lockings, while with sinusoidal waveform, we find only subharmonic locking, which is a key characteristic of time crystal behavior.

Harmonic locking is expected in classical dynamical systems under sinusoidal forcing. The lack of harmonic locking in the laser system under sinusoidal modulation is explained by simulations of a well-known model, and it is interpreted as due to the non-linear response of the laser near the threshold.

[1] Yao, N. Y. & Nayak, C. Time crystals in periodically driven systems. Physics Today 71(9), 40 (2018).

[2] Quintero-Quiroz, C., Torrent, M. C. & Masoller, C. Chaos 28, 075504 (2018).

[3] Tiana-Alsina J. & Masoller, C. Scientific Reports 12, 4914 (2022).

14.10 – 14.45   **P 04 Climate changes of dynamical systems**

Dr Tamas Tel

Department for Theoretical Physics, Eötvös University, Budapest, Hungary

Abstract: After presenting a chaotic dynamical system as a toy model of climate change, we argue that any dynamical system subjected to monotonous parameter drift can be considered to undergo its own climate change, if the rate of the parameter change is not adiabatically slow. Such a situation calls for ensemble simulations, proposed in chaos theory with the appearance of snapshot attractors, as early as 1990. In systems exhibiting trends, basic methods of standard chaos do not apply: the efficient tool of periodic orbit expansion cannot be used since periodic orbits do not exist. Furthermore, long-time limits are ill-defined since the system might become qualitatively different from the original one even after short times. The talk deals with the question of how to identify chaos in such systems. From the point of view of phase space structures, we argue that stable and unstable foliations are easy to generate numerically, without relying on the existence of hyperbolic periodic orbits. Chaos originates from a Smale horseshoe-like pattern of the foliations, the transverse intersections of which indicate a chaotic set changing in time. Furthermore, the unstable foliation is found to be part of the snapshot attractor, while the stable one turns out to be related to the basin of attraction of the time-dependent chaos. Concerning a quantitative characterization, the so-called ensemble-averaged pairwise distance is shown to provide a generalization of the concept of Lyapunov exponents, since the slope of this function can be interpreted as an instantaneous Lyapunov exponent. This is a tool by means of which a strengthening, weaking, or even disappearance of chaos can be investigated.

Bódai, Tél: Chaos 22, 023110 (2012)

Romeiras, Grebogi, Ott: Phys. Rev. A41, 784 (1990)

Jánosi, Károlyi, Tél: Nonlin. Dynamics 106, 2781 (2021)

Jánosi, Tél: Characterizing chaos in systems subjected to parameter drift, Phys. Rev.E (Letters), accepted

16.45 – 17.20   P 05 The Architecture of Bacterial Biofilms

Professor Fordyce A. Davidson

University of Dundee

Abstract: Biofilms are social communities of microbial cells that underpin diverse processes including sewage bioremediation, plant growth promotion and plant protection, chronic infections and industrial biofouling. They are hallmarked by the production of an extracellular polymeric matrix. One of the phenotypic consequences of biofilm formation is that resident microbes are highly resistant to physical stresses and antimicrobial agents. We will discuss how we have combined theory and experiment to better understand certain fundamental, yet open questions regarding the dynamic organisation of these complex bacterial communities. Much of the talk will comprise movies and pictures, with more questions posed than answers given.

Related papers

Growth arrest

https://www.pnas.org/doi/10.1073/pnas.1903982116

Wrinkle formation

https://journals.aps.org/prresearch/abstract/10.1103/PhysRevResearch.2.013165

Founder cells and competition

https://www.nature.com/articles/s41396-022-01198-8#citeas

https://doi.org/10.1111/oik.09077

17.25 – 18.00   **P 06 Intelligence and consciousness in genetic-neuron astrocyte networks**

Professor Alexey Zaikin

University College London

Abstract: Human brain has a very specific design as a result of a long evolution: a network of neurons linked in a very complex way is overlapped with a network of coupled astrocytes which are also linked to neurons. Additionally, inside each cell we have a very complicated network with ability to demonstrate intelligence properties. Naturally the research question arises how this design is related to the main feature of human brain, namely, ability to maintain a certain level of consciousness and awareness. To answer the question how quantify level of consciousness, recently the Integrated Information Theory of Consciousness has been developed, controversially claimed not only as a way to measure the complexity of brain but also its level of consciousness. I will report our results on a simple model of neuro-glial network and show that presence of astrocyte could contribute to the generation of positive Integrated Information and, hence, its evolutionary appearance was important to develop consciousness. Hence, astrocytes and genetic networks may contribute not only to the appearance of intelligence [1, 2, 3], but also consciousness [4, 5, 6].

1. Y. Tsybina, et al. Astrocyte mediate analogous memory in a multi-layer neuron- astrocytic network, Neural Computing and Applications 34, 9147-9160 (2022).

2. Susan Gordleeva, et al, Modelling working memory in spiking neuron network accompanied by astrocytes, Frontiers in Cellular Neuroscience 15, 631485 (2021).

3. L. Abrego, et al, Integrated Information as a Measure of Cognitive Processes in Coupled Genetic Repressilators, Entropy 21(4), 382 (2019).

4. Luis Abrego, et al. Estimating integrated information in bidirectional neuron-astrocyte communication. Physical Review E 103, 022410 (2021).

5. O. Kanakov, et al, Integrated Information in the Spiking- Bursting Stochastic Model, Entropy 22 (12), 1334 (2020).

6. O. Kanakov, et al., Astrocyte-induced positive integrated information in neuron-astrocyte ensembles, Physical Review E 99, 012418 (2019).

Tuesday 23rd August

09.00 – 09.35   **P 07 Data-driven modelling of cascades on networks**

Professor James Gleeson

University of Limerick

Abstract: Network models may be applied to describe many complex systems, and in the era of online social networks the study of dynamics on networks is an important branch of computational social science. Cascade dynamics can occur when the state of a node is affected by the states of its neighbours in the network, for example when a Twitter user is inspired to retweet a message that she received from a user she follows, with one event (the retweet) potentially causing further events (retweets by followers of followers) in a chain reaction. In this talk I will review some mathematical models that can help us understand how social contagion (the spread of cultural fads and the viral diffusion of information) depends upon the structure of the social network and on the dynamics of human behaviour. Although the models are simple enough to allow for mathematical analysis, I will show examples where they can also provide good matches to empirical observations of cascades on social networks.

09.40 – 10.15   **P 08 How good is your dynamical system model?**

Prof. Dr. Ruedi Stoop

University and ETH of Zurich, Switzerland

Abstract: How good a model of the dynamics of a system is, depends, obviously, on the purpose of the model. Neural networks illustrate this: If the learning is 'too precise', a network no longer generalizes, i.e., it loses a fundamental feature of what we embrace by the term 'model'. For dynamical systems, fundamental model categories are distinguished by average quantities such as Lyapunov exponents, entropies and fractal dimensions, which can reveal universal features of processes [1]. Sometimes, however, the essence of a process is at a more detailed level, requiring to take the actual dynamical steps into account. This is the case if we want to reveal what type of compiler model [2] a particular process implements, a question that is of foremost importance for assessing the potential and role of biological neural networks [3]. To access this level of insight, we have developed the new approach by excess entropies. The approach reveals differences between models and real-world data at the most refined temporal level, and, similarly, reveals hierarchies of models that attempt to reproduce the real-world data. From the approach, also the more global characteristics can be recovered. In the talk, we present this approach, apply it to maps and to neuronal data. The latter application reveals stunning properties of neural networks cultured on MEA chips.

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12.25 – 1300   **P 09 The Importance Complex Systems in Understanding Our Climate: Predictability of Extreme Climate Events**

Prof. Juergen Kurths

Potsdam Institute for Climate Impact Research and Humboldt University Berlin

Abstract: The Earth system is a very complex and dynamical one basing on various feedbacks; it covers a broad range of scales in space and time. Hence, it cannot be appropriately described and understood by using the reductionist approach, but requires advanced techniques from complex systems science. Predictions and risk analysis even of very strong (sometime extreme) events are a challenging task.

After introducing physical models for weather forecast already in 1922 by L.F. Richardson, a fundamental open problem has been the understanding of basic physical mechanisms and exploring anthropogenic influences on climate. In 2021 Hasselmann and Manabe got the Physics Nobel Price for their pioneering works on this.

After a short review of their most important contributions, I will present a recently developed innovative approach via complex networks mainly to analyze strong climate events. This leads to an inverse problem: Is there a backbone-like structure underlying the climate system? To treat this problem, we have proposed a method to reconstruct and analyze a complex network from spatio-temporal data. This approach enables us to uncover relations to global and regional circulation patterns in oceans and atmosphere, which leads to construct substantially improved predictions of high-impact events, in particular for the onset of the Indian Summer Monsoon, extreme rainfall in South America, the Indian Ocean Dipole and tropical cyclones but also to understand phase transition in the past climate.

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14.10 – 14.45   **P 10 Challenges in cardiac dynamics**

apl. Prof. Dr. Ulrich Parlitz

Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany

Abstract: The myocardium is an electrically excitable medium that supports various types of excitation waves, including stable or chaotic spiral waves that cause life-threatening arrhythmias such as ventricular fibrillation. Developing less invasive low-energy methods to terminate these arrhythmias requires a deeper understanding of the underlying chaotic spatiotemporal dynamics and novel control methods. Another challenge is the limited experimental and clinical observability of cardiac electromechanical motion due to measurement limitations that require powerful data analysis tools. In this talk, we will discuss these aspects of cardiac dynamics and demonstrate how concepts of nonlinear dynamics can provide new insights and advances in the diagnosis and treatment of cardiac arrhythmias.

16.45 – 17.20   **P 11 Real-time biochemical computations at criticality**

Dr. Aneta Koseska

Max Planck Institute for Neurobiology of Behavior – caesar

Abstract: Living systems on all scales of organization operate in changing environments. This implies that the biochemical networks, even in single cells, perform computations in real-time in order to navigate or stabilize a phenotypic output based on the dynamic external signals. In contrast to the current frameworks which rely on stable-states computations, we hypothesized that efficient real-time computations can be uniquely realized with metastable states, which are an emergent property of systems organized at criticality. We develop theoretical frameworks to study real-time computations in particular for biochemical networks in single cells, and demonstrate how single cells utilize these features for efficient navigation in environments where signals are noisy, disrupted or conflicting.

17.25 – 18.00   **P 12 Multiple routes to abrupt first-order transition to synchronization in multilayer simplicial complexes**

Prof. Dr. Sarika Jalan

Indian Institute of Technology Indore

Abstract: The presence of higher-order interactions (simplicial complexes) in networks has shown to lead to the abrupt first-order transition to synchronization. We will present our recent discovery of existence of multiple basins of attraction leading to multiple routes to the abrupt first-order transition to synchronization in multilayer simplicial comlexes. Using the Ott-Antonsen approach, we develop an analytical framework for simplicial complexes on multilayer networks, which thoroughly explains the origin and stability of all possible dynamical states, including multiple synchronization transitions, of the associated coupled dynamics. The study illustrating rich dynamical behaviours could be pivotal to comprehending the impacts of higher-order interactions on dynamics of complex real-world networks, such as brain, social and technological, which have inherent multilayer networks architecture.

Wednesday 24th August

09.00 – 09.35   **P 13 The intrinsic geometry of complex brain networks as biomarkers in epilepsy**

Dr Mario Chavez

CNRS - Paris Brain Institute

Abstract:

Epilepsy is a condition of recurrent unprovoked seizures resulting from different causes.

This neurological disorder is nowadays conceptualized as a network disease with functionally and/or structurally aberrant connections on virtually all spatial scales. In epilepsy, brain networks generate and sustain normal, physiological brain dynamics during the seizure-free interval and are involved in the generation, maintenance, spread, and termination of pathophysiological activities such as seizures. Connectivity (network) analysis in epilepsy has provided valuable information on seizure onset, propagation and termination, as well on the functional organization of the brain after a resection surgery.

Nevertheless, traditional (Euclidean) network embeddings are unable to fully capture the rich structural organization of brain connectivity, which motivates the quest for a latent geometry of the brain connectivity. In the stalk I will show how non-Euclidean geometries can be used to represent brain networks of epileptic patients, and how hyperbolic embedding can be provide an appropriate representation to unveil properties that could potentially result in robust biomarkers for surgery outcome. Namely, representation of brain networks in hyperbolic space can also identify regions of interest responsible or implicated in the surgery failure that could help understanding the origin of the unfavorable surgery outcomes for some patients.

09.40 – 10.15   **P 14 Hunting mosquitoes with networks**

Prof. Jesús Gómez-Gardeñes

University of Zaragoza

Abstract: In 2009, it was discovered that when Aedes aegypti mosquitoes are infected with a bacterium called Wolbachia transmission of the dengue virus from mosquitoes to humans is drastically reduced. Unfortunately, Aedes mosquitoes do not acquire Wolbachia in their natural environment, this bacterium has to be introduced in a laboratory and, then, the mosquitoes are released in areas affected by dengue transmission. Mosquitoes infected with Wolbachia naturally take over the local mosquito population, as the bacterium is passed on from one generation to the next. A difficult question to answer is how to make the best use of these valuable and limited resources to stop dengue transmission as much as possible. In this presentation we address this question by focusing on how to spatially distribute Wolbachia-carrying mosquitoes so that their immunizing effect reaches and protects as many people as possible. To do this, we begin by developing a data-driven metapopulation model that can be analysed through the lens of network science and non-linear dynamics. This model incorporates those aspects that drive the spatial spread of dengue, such as human mobility and the spatial distribution of humans and vectors. We will show how this model recreates and predicts the spatial spread of dengue in a given region. Once the basic ingredients of the spread of dengue disease are understood, the most important geographical areas for the emergence of an epidemic are analysed, allowing the generation of an immunisation ranking that prioritises those patches in which the release of Wolbachia-carrying mosquitoes can have the strongest (and most beneficial) impact on the spread of dengue.

12.25 – 13.00   **P 15 Musicians' Synchronization and the Enigma of Swing**

Prof. Dr. Theo Geisel

Max Planck Institute for Dynamics and Self-Organization & Bernstein Center for Computational Neuroscience Göttingen, Germany

Abstract: It is a widespread opinion that musicians who are interacting together in a performance should perfectly synchronize their timing. This view was challenged for the swing feel, a salient feature of jazz, which has eluded scientific clarification for a century. For much of this period it was considered arcane, arguing that swing can be felt but not explained, until the theory of 'participatory discrepancies' raised the controversial claim that swing is caused by microtiming deviations between different participating musicians [1].

In several projects we have clarified the controversy on the central role of microtiming deviations for the swing feel using time series analysis [2] and experiments with temporally manipulated MIDI-recordings [3,4], whose swing feel was measured through ratings of professional jazz musicians. We thereby showed that involuntary random microtiming deviations are irrelevant for swing [3], whereas we found that a particular systematic microtiming deviation between musicians enhances the swing feel and is a key component of swing in jazz [4]. It consists in slightly delaying downbeats but not offbeats of soloists with respect to a rhythm section. This effect was unknown to professional jazz musicians, who are using it unconsciously but were unable to determine its nature.

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Thursday 25th August

09.00 – 09.35   **P 16 Fluctuation-dissipation theorems for systems far from equilibrium**

Prof. Benjamin Lindner

Bernstein Center for Computational Neuroscience Berlin and Institute of Physics, Humboldt University Berlin

Abstract: Fluctuation-dissipation theorems are well established theoretical tools in statistical physics; they relate the spontaneous fluctuations of a system to its linear response to a weak external perturbation. Originally developed for systems in thermodynamic equilibrium, researchers have explored non-equilibrium versions of such relations since the 1970s; however, for many systems as for instance spiking nerve cells we still lack a thorough understanding how their pronounced spontaneous variability might be related to the response and transmission properties with respect to external stimuli. In my talk I will discuss a few new variants that apply to certain non-equilibrium systems and might be useful in several respects.

In the first part I briefly discuss a nonlinear version of a fluctuation-dissipation theorem for non-equilibrium systems with Markovian dynamics; for a number of examples, I show that for this type of theorem significantly fewer experimental trials are required than for the standard theorem that involves the linear response function.

In the second part of the talk I turn to spiking neurons and derive a simple set of fluctuation-response relations for different variants of integrate-and-fire models. I show how these relations can be used to (i) extract the response properties from observations of the spontaneous spiking, (ii) calculate analytically certain statistics of interest, (iii) extract properties of the underlying dynamics such as the spectra of the intrinsic noise that are otherwise inaccessible.

09.40 – 10.15　　**P 17 Deterministic dynamics of active particles: chaos and synchronization**

Prof. Arkady Pikovsky

University of Potsdam

Abstract:　　In most cases, active particles with a self-propulsion are considered as intrinsically noisy objects. Here, I report on the purely deterministic aspects of active particle dynamics. The first part is based on a paper [I. Aranson and A. Pikovsky, Phys. Rev. Lett. v. 128, 108001 (2022)]. Here an overactive limit is considered, where particles have constant velocities but are deflected by external potential forces and interactions. Remarkably, for potential forces the dynamics is purely Hamiltonian one. It is mainly chaotic, but can be synchronized by non-conservative alignment interactions. The second part is based on a paper [A. Pikovsky, J. Phys. Complex., v. 2, 025009 (2021)]. Here I report on self-propelled chiral particles with a finite activity, subject to conservative collisions. This system demonstrates a supertransient transition to a synchronous state where collisions disappear.

12.25 – 13.00　　**P 18 Oscillations as organizers in cellular populations**

Prof. Jordi Garcia-Ojalvo

Universitat Pompeu Fabra, Barcelona

Abstract:　　Multicellular organisms rely on a careful spatiotemporal orchestration of form and function, covering multiple biological scales that range from molecules to populations. Much current research is being devoted to understanding how space and time are integrated as organisms develop. In this talk I will discuss how this is accomplished in bacterial biofilms, which are large communities of bacterial cells that form under stress. Specifically, I will describe experimental and theoretical evidence showing that nitrogen stress in B. subtilis biofilms leads to concentric ring patterns that organize the community spatially. This behavior results from temporal oscillations in the metabolic state of cells at the growing periphery of the biofilm. The temporal periodicity of these oscillations is eventually transformed into spatial periodicity, similarly to the segmentation clock that underlies the formation of somites in vertebrates.

14.10 – 14.45   **P 19 Multiscale oscillatory dynamics: What happens when the frequencies are not constant?**

Professor Aneta Stefanovska

Lancaster University

Abstract: There are many cyclic dynamical systems in nature whose frequencies are not constant. This is most notably the case in living systems, but there are many other examples ranging from collective modes in condensed matter, to ionospheric magnetic fields, to tidally driven water levels. They result in complex behaviour whose dynamics is difficult to decipher and which is often in practice treated as stochastic. When time is taken as a physical quantity and an additional dimension in the analysis, their seemingly noisy dynamics can be revealed as being predominantly deterministic.

In this talk, non-autonomous oscillatory dynamics will be considered with a focus on phenomena resulting from frequency modulation. This is often a result of energy exchange between different systems to adjust the relevant velocity. In fact such systems are neither chaotic nor stochastic, but distinct class of dynamical systems in their own right. We will show that, counterintuitively, they are more robust in terms of stability. We will demonstrate that despite being low-dimensional they can appear as highly complex, or stochastic, when time is not explicitly taken into account. Numerical approaches suitable for analysis of such systems will be presented and applied to examples including cell energy metabolism, circadian rhythms, cardiovascular and brain dynamics, tidal oscillations and electrons on the surface of superfluid helium. The approach taken is designed for the description of finite-time, rather than asymptotic (infinite-time), dynamics.

16.45 – 17.20   **P 20 Tipping phenomena and resilience of complex systems: Theory and applications**

Prof. Dr. Ulrike Feudel

Institute for Chemistry and Biology of the Marine Environment, Carl von Ossietzky University Oldenburg, Germany

Abstract: Many systems in nature are characterized by 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 critical transitions from one stable state to another. Such critical transitions are called tipping phenomena in climate science, regime shifts in ecology. They 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 characteristic time scales 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 climate science and ecosystem dynamics. 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.

17.25 – 18.00   **P 21 On Explaining the Surprising Success of Reservoir Computing Forecaster of Chaos? The Universal Machine Learning Dynamical System with Contrasts to VAR and DMD.**

Erik Bollt, W. Jon Harrington Professor of Mathematics and Professor of Electrical and Computer Engineering, Director of C3S2 the Clarkson Center for Complex Systems Science

Clarkson University, Potsdam, NY

Abstract: Machine learning has become a widely popular and successful paradigm, including for data-driven science. A major application problem is forecasting complex dynamical systems. Artificial neural networks (ANN) have evolved as a clear leading approach, and recurrent neural networks (RNN) are considered to be especially well suited for. In this setting, the echo state networks (ESN) or reservoir computer (RC) have emerged for simplicity and computational advantages. Instead of a fully trained network, an RC trains only read-out weights. However, why and how an RC works at all, despite randomly selected weights is perhaps a surprise. To this end, we analyzes a simplified RC, where the internal activation function is an identity function. We explicitly connect the RC with linear activation and linear read-out to well developed time-series literature on vector autoregressive averages (VAR) that includes theorems on representability through the WOLD theorem, which already perform reasonably for short term forecasts. In the case of a linear activation and now popular quadratic read-out RC, we explicitly connect to a nonlinear VAR (NVAR), which performs quite well. Further, we associate this paradigm to the now widely popular dynamic mode decomposition (DMD), and thus these three are in a sense different faces of the same concept. We illustrate our observations in terms of popular benchmark examples including Mackey-Glass differential delay equations and the Lorenz63 system.

Friday 26th August

09.00 – 09.35   **P 22 Large and Small Chaos Models**

James A Yorke, Research Professor

University of Maryland College Park

Abstract: To set the scene, I will discuss a large whole-Earth model for predicting the weather, and our method for initializing such a model, and what aspects of chaos are essential.

Then I will discuss a couple related "very simple" maps that tell us a great deal about very complex models. The results on simple models are new, either recently published or even newer than that.

I will discuss the logistic map mx(1-x). Its dynamics can make us rethink climate models.

Also, we have created a piecewise linear map on a 3D cube that is unstable in 2 dimensions in some places and unstable in 1 in others. It has a dense set of periodic points that are 1 D unstable and another dense set of periodic points that are all 2 D unstable.

The talk is based on the following recent projects on simple models. See also my recent arXiv papers with Roberto De Leo, Yoshi Saiki, and Hiroki Takahasi including:
Can the flap of butterfly's wings shift a tornado out of Texas -- without chaos? (in preparation)

09.40 – 10.15   P 23 Next Generation Neural Mass Models

Prof. Alessandro Torcini

CY Cergy Paris Université

Abstract: I will first give a brief overview of the next generation neural mass models, which represent a complete new perspective for the development of exact mean field models of heterogenous spiking neural networks [1]. Then I will report recent results on the application of this formalism to reproduce relevant phenomena in neuroscience ranging from cross-frequency coupling [2] to theta-nested gamma oscillations [3], from slow and fast gamma oscillations [4] to synaptic-based working memory [5]. I will finally show how these neural masses can be extended to capture fluctuations driven phenomena induced by dynamical sources of disorder, naturally present in brain circuits such as background noise and current fluctuations due to the sparsness in the connections [6-8]

References

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12.25 – 13.00   **P 24 A quasipotential approach for networks of bistable nodes**

Dr Jen Creaser

University of Exeter

Abstract: It is well known that the addition of noise in a multistable system can induce random transitions between states. In a network, the presence of coupling introduces dependence between nodes leading to sequences of noise-induced transitions in a so-called "domino effect". The timing and order of the resulting domino cascades are emergent properties of the network. Analysis of the transient dynamics responsible for these cascades is crucial to understanding the drivers of a range of applications from neurological disorders to climate tipping cascades. We have previously shown how symmetrically coupled elements can be thought of as a gradient or potential system. In this case, we classify the timing and order of tipping cascades using geometric analysis via the computation of their potential landscape. For non-symmetrically coupled, i.e. more realistic coupling structures, the coupled elements do not form a potential system and there is no closed-form for the potential landscape. In these cases, an approximation of the potential called the quasipotential (QP) can be used.

Theoretically introduced by Friedlin and Wentzel in the 80s, the QP has remained elusive as it is hard to compute for a given system. The recent development of a range of numerical algorithms has facilitated the computation of the QP in low-dimensional systems. Here we use the QP to investigate a chain of coupled bistable nodes and identify a range of behaviours that are not present in the symmetric case.

Minisymposiums

Monday 22nd August

MS 01.01 – Early warning signatures of dynamical transitions

Organisers: Prof. Cristina Masoller & Giulio Tirabassi, PhD

Universitat Politécnica de Catalunya

MS 01.01.01

Forecasting Events in the Complex Dynamics of a Semiconductor Laser with Optical Feedback

Andrés Aragoneses, Eastern Washington University, USA

Abstract

Complex systems performing spiking dynamics are widespread in Nature. They cover from earthquakes, to neurons, variable stars, social networks, or stock markets. Understanding and characterizing their dynamics is relevant in order to detect transitions, or to predict unwanted extreme events. Here we study, under an ordinal patterns analysis, the output intensity of a semiconductor laser with feedback in a regime where it develops a complex spiking behavior. We unveil that, in the transitions towards and from the spiking regime, the complex dynamics presents two competing behaviors that can be distinguished with a thresholding method. Then we use time and intensity correlations to forecast different types of events, and transitions in the dynamics of the system.

MS 01.01.02

Percolation framework to anticipate sudden shifts in irregular climate oscillations

Noémie Ehstand, IFISC: Institute for Cross-Disciplinary Physics and Complex Systems, Spain

Abstract

Functional networks are powerful tools to study statistical interdependencies in extended systems. They have been used to get insights into the structure and dynamics of complex systems in various areas of science. The current study builds upon the work of Rodríguez-Méndez et al. (2016) who proposed early-warning measures for critical transitions in model systems and in observations of climate phenomena such as El Niño, based on percolation theory in correlation networks. Our aim is to better understand the potential of such percolation measures for anticipating transitions in spatially extended complex systems beyond the case of critical transitions. In particular, we consider several models exhibiting irregular oscillatory behavior, and explore how percolation-based methods can anticipate the (sharp) transitions between different stages of the oscillation.

MS 01.01.03

Testing Critical Slowing Down as a Bifurcation Indicator in a Low-Dissipation Dynamical System

Mathias Marconi, Université Côte d'Azur - Institut de Physique de Nice, France

Abstract

We study a two-dimensional low-dissipation nonautonomous dynamical system, with a control parameter that is swept linearly in time across a transcritical bifurcation. We investigate the relaxation time of a perturbation applied to a variable of the system and we show that critical slowing down may occur at a parameter value well above the bifurcation point. We test experimentally the occurrence of critical slowing down by applying a perturbation to the accessible control parameter and we find that this perturbation leaves the system behavior unaltered, thus providing no useful information on the occurrence of critical slowing down. The theoretical analysis reveals the reasons why these tests fail in predicting an incoming bifurcation.

Co-author - Massimo Giudici

MS 01.01.04

Correlation lag times provide a reliable early-warning indication of approaching bifurcations in spatially extended dynamical systems

Giulio Tirabassi, Universitat Politécnica de Catalunya, Spain

Abstract

Identifying approaching bifurcations and regime transitions from observations is an important challenge in time series analysis with practical applications in many fields of science. Well-known indicators are the increase in spatial and temporal correlations. However, the performance of these indicators depends on the system under study and on the type of approaching bifurcation, and no indicator provides a reliable warning for any system and bifurcation. Here we propose an indicator that simultaneously takes into account information about spatial and temporal correlations. By performing a bivariate correlation analysis of signals recorded in pairs of adjacent spatial points, and analyzing the distribution of lag times that maximize the cross-correlation, we find that the variance of the lag distribution displays an extreme value that is a consistent early warning indicator of the approaching bifurcation. We demonstrate the reliability of this indicator using different types of models that present different types of bifurcations, including local bifurcations (transcritical, saddle-node, supercritical, and subcritical Hopf), and global bifurcations.

MS 01.02 - Data-driven modelling & analysis in weather and climate science

Organiser: Frank Kwasniok - University of Exeter, UK

MS 01.02.01

Data-driven deterministic and stochastic subgrid-scale parameterisation in atmosphere and ocean models

Frank Kwasniok, Department of Mathematics, University of Exeter, UK

Abstract

Atmospheric, oceanic and climate dynamics encompass a huge range of spatial and temporal scales without any clear scale separation. Due to limited computational resources there are inevitably unresolved scales and processes in atmosphere and ocean models which need to be accounted for by so called parameterisation schemes. We here discuss data-driven hybrid modelling, that is, a given underresolved physics-based model is augmented with data-based, machine-learning-style elements in order to capture the effect of the unresolved scales and processes on the resolved variables. A pattern-based approach is introduced: Pairs of patterns in the space of possible predictors and the space of the subgrid forcing are identified in a predictive manner to form a deterministic subgrid modelling scheme which may then be extended with stochastic terms. The methodology is exemplified and explored on the Lorenz 1996 multiscale system and an intermediate-complexity atmospheric model with realistic mean state and variability.

MS. 01.02.02

Uncertain turbulent fluxes in the atmospheric boundary layer: a stochastic data-model fusion approach

Nikki Vercauteren, Department of Geosciences, University of Oslo, Norway

Abstract

Limited computer resources lead to a simplified representation of unresolved small-scale processes in weather and climate models, through parameterisation schemes. Among the parameterised processes, turbulent fluxes exert a critical impact on the exchange of heat, water and carbon between the land and the atmosphere. Turbulence theory was, however, developed for homogeneous and flat terrain, with stationary conditions. The theory fails in unsteady flow contexts or with heterogeneous landscapes, but no alternative, viable theory is available. This is not only a source of error in forecasts or climate scenarios, but also a source of model uncertainty which should be characterised and considered when using weather and climate models.

I will present a data-driven approach to develop a stochastic parameterisation of turbulent fluxes, thereby representing the model uncertainty arising from the incomplete representation of our unsteady atmosphere. This is particularly relevant in cold environments or at nighttime, where the atmospheric boundary layer is stably stratified. Turbulence then coexists with non-turbulent motions from the grey zone between the largest turbulent eddies and smallest mesoscale motions, traditionally specified to be 2km horizontal scale. These non-turbulent motions can include density currents, wave-like motions or two-dimensional modes and represent a non-stationary forcing of turbulence. The stochastic parameterisation extends conventional models and enables the representation of the resulting unsteady, intermittent fluxes. It could help overcome some of the limitations of weather and climate models to represent mixing in the stable boundary layer.

This is joint work with Vyacheslav Boyko and Sebastian Krumscheid.

MS 01.02.03

On the typicality of persistent atmospheric extreme events

Vera Melinda Galfi, Department of Earth Sciences, Uppsala University, Sweden

Abstract

In order to deal with the climate crisis, the challenge is to understand how global warming will affect extreme events. We frequently experience cases when not mainly the intensity but rather the duration of the event is the key factor in terms of impact. We call these long-lasting extreme events persistent extremes. Extreme events however do not have to be surprising or unpredictable. Moreover, the stronger and the longer the event is, the more energy is needed to generate and maintain it, and the less possibilities the climate system has to realise it. This means that persistent extremes occur usually in a specific way. I will discuss the concept of typicality of persistent extremes based on large deviation theory. I will show what aspects of typicality we observe in case of persistent extremes, such as heatwaves and persistent anomalies of the North Atlantic jet stream.

MS 01.02.04

Towards mining weather and climate extremes via Riemannian optimization

Abdel Hannachi, Department of Meteorology, University of Stockholm, Sweden

Abstract

Weather and climate data are witnessing an explosion in size, begging for new and efficient approaches to explore and analyze these large-scale data, and acquires wisdom and knowledge pertaining to different aspects of the climate system, such as extremes.

In this regard, dimension reduction methods become an integral part in weather and climate. These methods represent different versions of matrix factorization. The different methods yield different representations along with own advantages and disadvantages. For instance conventional methods of EOF analysis exhibit a number of drawbacks such as scaling and mixing. These methods focus mostly on the bulk of the probability distribution of the system in state space and overlook its tail.

This talk explores a different method, the archetypal analysis (AA), which focuses precisely on the extremes. AA seeks to approximate the convex hull of the data in state space by finding "corners" that represent "pure" types or archetypes through computing mixture weight matrices.

Unlike the conventional multistep algorithm of AA, based on the alternating constrained least squares, here a new manifold-based optimization algorithm is presented that optimizes for the weights simultaneously. The algorithm proves quite efficient compared to the alternating algorithm. The method will be presented and application to sea surface temperature discussed.

MS 01.03 - Adaptive dynamical networks (part i)

Organisers - Rico Berner [1], Thilo Gross [2-4], Christian Kuehn [5], Jürgen Kurths [6], Serhiy Yanchuk [6-7]

[1] Department of Physics, Humboldt Universität zu Berlin, Newtonstraße 15, 12489, Berlin, Germany

[2] Helmholtz Institute for Functional Marine Biodiversity at the University of Oldenburg (HIFMB), Oldenburg, Germany

[3] Alfred-Wegener-Institute, Helmholtz Centre for Marine and Polar Research, Bremerhaven, Germany

[4] Carl-von-Ossietzky University, Institute for Chemistry and Biology of the Marine Environment (ICBM), Oldenburg, Germany

[5] Faculty of Mathematics, Technical University of Munich, Boltzmannstr. 3, D-85748, Garching bei Munich, Germany

[6] Potsdam Institute for Climate Impact Research, 14473 Potsdam, Germany

[7] Institute of Mathematics, Humboldt University Berlin, 12489 Berlin, Germany

MS 01.03.01

Complex dynamics in adaptive networks of phase oscillators

Erik A. Martens, Centre for Mathematical Sciences, Lund University, Sweden

Abstract

Networks of coupled dynamical units give rise to fascinating collective dynamics, such as the synchronization of oscillators/neurons, and are fundamental to the proper functioning of neural networks in the brain. Adaptive network dynamics describes the interplay between dynamics on and of the network and arises naturally in a variety of contexts, including neural plasticity in the brain. Such plasticity adds an additional layer of complexity: the collective node dynamics influence the dynamics of the network and vice versa. We study a model of Kuramoto phase oscillators with a general adaptive learning rule with three parameters that includes as special cases both (anti-)Hebbian learning and spike time dependent plasticity. An important feature is a parameter that allows us to perturb off the non-adaptive manifold with stationary coupling to study the impact of adaptation on the collective dynamics. We carry out a detailed bifurcation analysis for N=2 oscillators bidirectionally asymmetric coupling and provide stability diagrams. We find that adaptation dynamics (in terms of nontrivial bifurcations) arises only when the learning strength exceeds a critical threshold. While aforementioned special cases for the learning rule yield non-trivial multi-stability and bifurcation scenarios, our analysis reveals that mixed-type learning rules yield far more complicated and rich dynamics such as a transition to chaotic dynamics. Second, we numerically investigate large systems with N=50 oscillators and investigate which of our findings carry over from the case of N=2 oscillators.

MS 01.03.02

Chimera States in a Coevolutive Multilayer Network framework via Geometric Singular Perturbation Theory

Luis Venegas-Pineda, University of Groningen, Netherlands

Abstract

Over the last decades chimera states have attracted considerable attention as unexpected symmetry-broken spatio-temporal patterns exhibiting simultaneous synchronous and incoherent behaviour under particular conditions. Although 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 presentation, I will address the case of coevolutive coupling occurring in a multilayer network composed by two populations of different kinds of heterogeneous phase oscillators via a mean-field approach. Moreover, a time-scale separation between the dynamics of the elements and the adaptive coupling strength connecting them allows the employment of Geometric Singular Perturbation Theory (GSPT) results in order to obtain a better insight on the dynamics of the system from a fast-slow perspective. First, I will propose a mechanism for the emergence of chimera states through coevolutive intra-coupling over one of the populations. Thereafter, I will discuss the effects of an adaptive inter-coupling strength and compare both results. Finally, the possibility of producing breathing chimera states by specific coevolutionary coupling dynamics will be discussed

MS 01.03.03

Adaptive cluster synchronization in complex dynamical networks

Francesco Sorrentino, University of New Mexico Albuquerque, USA

Abstract

We consider how cluster synchronization may emerge in networks of coupled oscillators via adaptation. We propose a stability analysis, based on the formulation of a master stability function, to study cluster synchronization in a large class of networks with different adaptive rules. This approach decouples the role of the network topology from that of the dynamics and allows a reduction of the stability problem in a low-dimensional form.

MS 01.04 – Dynamics and life sciences

Organisers – Celso Grebogi, Mamen Romano

University of Aberdeen

MS 01.04.01

Computational Modelling of Wnt Signalling-Controlled Gene Regulatory Networks in Early Embryonic Development and Heart Muscle Differentiation.

Stefan Hoppler, University of Aberdeen

Abstract

The biological cell is central for life on planet Earth. Larger lifeforms consist of many cells, which differentiate from each other during embryonic development to carry out specialised functions in specific locations. The gene is the key unit for carrying information controlling differentiation of specific cells within the overall context of embryonic development. Cells differentiate via differential expression of gene products from an essentially identical collection of genes (genome).

WNT SIGNALLING is an important biochemical pathway that animal cells use to coordinate differential gene expression and thereby cell differentiation. The Wnt signalling pathway consists of

- WNT Signal, but also WNT-binding Inhibitor molecules, which are both secreted by cells and can move between cells;

- WNT Receptors located on the cell surface of individual cells; and

- components of a signal transduction cascade, activated in individual cells by WNT Signals binding to Receptors.

- beta-catenin is a crucial such signal transduction component, which regulates expression of Wnt target genes.

IN THE EARLY EMBRYO, Wnt signalling regulates at two different stages remarkably different biological outcomes, by regulating the expression, of not as expected two, but of at least five classes of Wnt target genes. Computational modelling helps us test our logic in interpreting these results to build a comprehensive gene regulatory network.

IN HEART DEVELOPMENT, Wnt signalling regulates gene expression of Wnt-binding inhibitors and cell-surface receptors in a feedback loop, which our computational modelling suggests shapes the Wnt signal distribution and sharpens the resulting boundary between heart muscle and non-muscle tissue.

MS 01.04.02

Tipping point and noise-induced transients in ecological networks

Celso Grebogi, University of Aberdeen

Abstract

A challenging and outstanding problem in interdisciplinary research is to understand the interplay between transients and stochasticity in high-dimensional dynamical systems. Focusing on the tipping-point dynamics in complex mutualistic networks in ecology constructed from empirical data, I will address the phenomena of noise-induced collapse and noise-induced recovery. Two types of noise are studied: environmental (Gaussian white) noise and state-dependent demographic noise. The dynamical mechanism responsible for both phenomena is a transition from one stable steady state to another driven by stochastic forcing, mediated by an unstable steady state. Exploiting a generic and effective two-dimensional reduced model for real-world mutualistic networks, I will show that the average transient lifetime scales algebraically with the noise amplitude, for both environmental and demographic noise. I will present a physical understanding of the scaling laws through an analysis of the mean first passage time from one steady state to another. The phenomena of noise-induced collapse and recovery and the associated scaling laws have implications to managing high-dimensional ecological systems.

MS 01.04.03

Using dynamic simulations of movement in the design of assistive devices for people with tetraplegia

Dimitra Blana, University of Aberdeen

Abstract

Following a spinal cord injury, signals from the brain are unable to reach the muscles, so voluntary muscle contraction is no longer possible. Functional Electrical Stimulation (FES) can induce muscle contraction and hence restore movement. One of the main challenges is to determine the most favourable setup for the stimulation for each individual, namely, where to place the electrodes and what muscle activation patterns to use to achieve desired movements. Here we describe the use of a personalised dynamic model of the musculoskeletal system that simulates viable movements based on end-point goals, and identifies the muscle activation patterns required to achieve them. We use an implicit formulation for the musculoskeletal dynamics, and we solve the optimal control problem with Direct Collocation. We demonstrate the method on one participant with an incomplete C5 level spinal cord injury, and we present simulations of reaching movements with and without FES. Results show physiologically plausible muscle activations, and smooth movements approximating the end-point goal.

MS 01.04.04

Finding the resistance distance and eigenvector centrality from the network's eigenvalues

Nicolas Rubido, University of Aberdeen

Abstract

There are different measures to classify a network's data set, which have different success rates depending on the problem. For example, the resistance distance and eigenvector centrality measures have been successful in revealing ecological pathways and differentiating between biomedical images of patients with Alzheimer's disease, respectively. The resistance distance measures an effective distance between two nodes of a network considering all possible shortest paths between them, and the eigenvector centrality, measures the relative importance of each node in the network. However, both measures require knowing the network's eigenvalues and eigenvectors. Here, we show that we can closely approximate [find exactly] the resistance distance [eigenvector centrality] of a network only using its eigenvalue spectra, where we illustrate this by experimenting on resistor circuits, real neural networks (weighted and unweighted), and paradigmatic network models — scale-free, random, and small-world networks. Our results are supported by analytical derivations, which are based on the eigenvector-eigenvalue identity. Since the identity is unrestricted to the resistance distance or eigenvector centrality measures, it can be applied to most problems requiring the calculation of eigenvectors.

Tuesday 23rd August 2022

MS 02.01 – Transient Chaos

Organisers Dr. Oleh Omel'chenko [1] and Prof. Tamas Tel [2]

[1] Institute of Physics and Astronomy, University of Potsdam, Germany
[2] Institute for Theoretical Physics, Eötvös Lorand University, Budapest, Hungary

MS 02.01.01

Non-monotonic Transients to Synchrony in Kuramoto Networks and Electrochemical Oscillators

Oleh Omel'chenko, Institute of Physics and Astronomy, University of Potsdam, Germany

Abstract

We report on the unusual dynamical features of the transients from random initial conditions to a fully synchronized (one-cluster) state, which are observed in numerical simulations with the Kuramoto model and experiments with oscillatory nickel electrodissolution. In particular, the numerical simulations revealed that certain networks (e.g., globally coupled or dense Erdös-Rényi random networks) showed relatively simple behavior with monotonic increase of the Kuramoto order parameter from the random initial condition to the fully synchronized state and that the transient times exhibited a unimodal distribution. However, some modular networks with bridge elements were identified which exhibited non-monotonic variation of the order parameter with local maximum and/or minimum. In these networks, the histogram of the transients times became bimodal and the mean transient time scaled well with inverse of the magnitude of the second largest eigenvalue of the network Laplacian matrix. The non-monotonic transients increase the relative standard deviations from about 0.3 to 0.5, i.e., the transient times became more diverse. The non-monotonic transients are related to generation of phase patterns where the modules are synchronized but approximately anti-phase to each other. The predictions of the numerical simulations were demonstrated in a population of coupled oscillatory electrochemical reactions in global, modular, and irregular tree networks. The findings clarify the role of network structure in generation of complex transients that can, for example, play a role in intermittent desynchronization of the circadian clock due to external cues or in deep brain stimulations where long transients are required after a desynchronization stimulus.

MS 02.01.02

Predicting Transient Chaos Using Machine Learning

Ying-Cheng Lai, Arizona State University, USA

Abstract

In nonlinear dynamical systems, transient chaos can occur after the system undergoes a critical transition. To predict transient chaos based solely on time series data collected before the transition is challenging. We develop a model-free, machine-learning based solution by exploiting reservoir computing to incorporate a parameter input channel into the neural network. We demonstrate that, when the machine is trained in the normal functioning regime with a chaotic attractor (i.e., before the critical transition), the transition point can be predicted accurately. Remarkably, for a parameter drift through the critical point, the machine is able to not only tell us that the system will be in a transient state, but also accurately predict the probability distribution of the transient lifetime and its average.

References:

1. L.-W. Kong, H.-W. Fan, C. Grebogi, and Y.-C. Lai, "Machine learning prediction of critical transition and system collapse", Physical Review Research 3, 013090, 1-14 (2021)
2. L.-W. Kong, H.-W. Fan, C. Grebogi, and Y.-C. Lai, "Emergence of transient chaos and intermittency in machine learning", Journal of Physics Complexity 2, 035014, 1-16 (2021)

MS 02.01.03

Flow-Network Characterization of Transient Chaos in Open Systems

Emilio Hernandez-Garcia, Instituto de Fisica Interdisciplinar y Sistemas Complejos (IFISC), CSIC-UIB, Palma de Mallorca, Spain

Abstract

The Lagrangian Flow Network framework enriches set-oriented methodologies with tools from graph theory to provide coarse-grained descriptions of transport by fluid flows or dynamical systems. Here we revise the basics of this framework and describe its application to open chaotic flows. Network nodes with high values of out-degree identify the location of the chaotic saddle and its stable manifold, whereas nodes with high in-degree highlight the location of the saddle and its unstable manifold. Network entropy values in the time-forward and time-backwards directions also distinguish these dynamical objects. The cyclic clustering coefficient, associated with the presence of periodic orbits, takes non-vanishing values at the location of the saddle itself. Finally, the coarse-grained character of the description will be briefly explored to assess the validity of a local and finite-time extension of Kantz-Grassberger-type relationships.

Work in collaboration with E. Ser-Giacomi, V. Rodriguez-Mendez, C. Lopez and G. Drotos.

MS 02.01.04

State-Dependent Vulnerability of Synchronization in Ecological Networks

Everton S. Medeiros, Institute for Chemistry and Biology of the Marine Environment, Carl von Ossietzky University, Oldenburg, Germany

Abstract

In ecology, species ability of colonizing new patches in search for better conditions of resources is known to increase the structural stability of population dynamics in ecosystems. In contrast, such spatial dispersal constitutes interconnections among patches that facilitates synchrony of their population dynamics. This synchronizing aspect may elevate the risk of localized extinctions to become global, and therefore, causing the collapse of the whole ecosystem. In this context, we offer a mechanism to avoid this downside in which unstable, and transient, dynamics, at the level of patches emerge as stable, and perpetual, in the connected system. Specifically, unstable chaotic sets in the local population dynamics of the patches behave as stable in the spatially distributed system and generate alternative desynchronized states. Sets of state-dependent perturbations leading the spatial system to undesired synchronized solutions and the ones leading the system to desynchronization are analysed. Despite the generality of the reported phenomenon, we demonstrate our findings and explain the mechanism in a three level food web describing the population dynamics in the patches and a diffusive coupling to represent the connections due to dispersal.

MS 02.02 – Recurrence-based data analysis

Organisers - Tobias Braun, Norbert Marwan, Deniz Eroglu

Potsdam Institute for Climate Impact Research

MS 02.02.01

Recent trends in recurrence analysis of dynamical systems

Norbert Marwan, Potsdam Institute for Climate Impact Research, Germany

Abstract

The last decade has witnessed a number of important and exciting developments that had been achieved for improving recurrence plot based data analysis and to widen its application potential. I will give a brief overview about important and innovative developments, such as computational improvements, alternative recurrence definitions (event-like, multiscale, heterogeneous, and spatio-temporal recurrences) and ideas for parameter selection, theoretical considerations of recurrence quantification measures, new recurrence quantifiers (e.g., for transition detection and causality detection), and correction schemes. Moreover, new perspectives have recently been opened by combining recurrence plots with machine learning.

MS 02.02.02

A recurrence flow based approach to state space reconstruction

Tobias Braun, Potsdam Institute for Climate Impact Research, Germany

Abstract

In the study of nonlinear observational time series, reconstructing the system's state space via time-delay embedding represents the basis for many widely-used analyses. Recurrence plots indicate the appropriateness of the underlying embedding parameters by the presence of well-formed diagonal lines that represent the predictability of the system's evolution. However, an approach that systematically exploits this information for optimal state space reconstruction is so far missing.

In this talk, we propose a recurrence based framework for state space reconstruction. The concept is based on a novel recurrence quantification measure that captures how well a fictive fluid can permeate an RP diagonally, the recurrence flow. The recurrence flow can be regarded as a nonlinear dependence measure that quantifies the relationship between multiple time series based on the predictability of their joint evolution. We demonstrate the effectiveness of the proposed method in detecting nonlinear multiscale relations and informing on the choice of optimal embedding parameters for complex real-world time series.

MS 02.02.03

Transformation cost spectrum for irregularly sampled time series

Çelik Ozdes, Kadir Has University, Turkey

Abstract

Climate system is a real-world complex system enacting an intricate interaction structure. This interaction structure is very hard to detect in real life where a network reconstruction procedure requires dealing with sparse and noisy data coming from multi-scale spatiotemporal dynamics. Palaeoclimate data sets are also not regularly sampled, and the measurements are not precise. To model this error process, we fit a trained transformation-cost time series (TACTS) to palaeoclimate data using an optimized metric of segment similarity. TACTS can act as a regularly sampled proxy to be used in detecting the dynamical properties of data sets using recurrence quantification methods. This procedure reveals interactions that are often not detectable in the original data. We then use sliding windows analyses of these recurrence measures to obtain the temporal networks that define our data sources' interaction. We use this method to reconstruct the evolution of the climate interaction networks to reveal their transient and stable interaction patterns.

MS 02.02.04

Multiplex Recurrence Networks

Deniz Eroglu, Kadir Has University, Turkey

Abstract

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 discuss a multiplex recurrence network approach by combining recurrence networks with the multiplex network approach to investigate the dynamics of systems from short multivariate time series. The potential use of this approach will be demonstrated on coupled map lattices and climate-related research problems. In the applications, topological changes in the multiplex recurrence networks allow for detecting regime changes in their dynamics.

MS 02.02.05

Ordinal pattern analysis for physiological data with ties

Thomas Stemler, University of Western Australia, Australia

Abstract

Time series of physiological data like body temperature often has repeated data values, when sampled with high resolution. Today it is easy to automatically record several months of temperature data with such high resolution. These ties in the data are problematic when using ordinal pattern analysis, especially when these ties make up a huge proportion of the data set. Using temperature data from a herd of alpacas we explore a method to deal with such ties and try to distinguish the herd members that are geldings from other male alpacas.

MS 02.03 - Adaptive dynamical networks (part ii)

Organisers - Rico Berner [1], Thilo Gross [2-4], Christian Kuehn [5], Jürgen Kurths [6], Serhiy Yanchuk [6-7]

[1] Department of Physics, Humboldt Universität zu Berlin, Newtonstraße 15, 12489, Berlin, Germany

[2] Helmholtz Institute for Functional Marine Biodiversity at the University of Oldenburg (HIFMB), Oldenburg, Germany

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[4] Carl-von-Ossietzky University, Institute for Chemistry and Biology of the Marine Environment (ICBM), Oldenburg, Germany

[5] Faculty of Mathematics, Technical University of Munich, Boltzmannstr. 3, D-85748, Garching bei Munich, Germany

[6] Potsdam Institute for Climate Impact Research, 14473 Potsdam, Germany

[7] Institute of Mathematics, Humboldt University Berlin, 12489 Berlin, Germany

MS 02.03.01

Hebbian plasticity in simplicial complexes: Robustness to de-synchronization

Sarika Jalan, Indian Institute of Technology Indore, India

Abstract

The collective dynamics of man-made and natural complex systems represented by conventional graphs, for a long, have been modelled using pairwise networked Kuramoto oscillators. When subjected to distinct adaptation-based features, the pairwise networked Kuramoto oscillators have led to a phenomenon termed first-order or explosive synchronization.

Breaking away from the traditional approach of assuming adaptation in the pairwise coupling, we consider adaptive higher-order coupling interactions among the oscillators, and show that dynamically adaptive pure triadic and tetradic couplings give birth to first-order routes to desynchronization, whose onsets are entirely manageable through respective Hebbian learning parameters. Mean-field analyses presented for the two- and three-simplicial complexes successfully explain the dependence of the onset points of abrupt desynchronization on the respective Hebbian learning parameters.

References

Hebbian plasticity rules abrupt desynchronization in pure simplicial complexes, AD Kachhvah, S Jalan, New Journal of Physics (Fast Track) 24, 052002 (2022),

Explosive synchronization and chimera in interpinned multilayer networks, AD Kachhvah, S Jalan, Physical Review E (Letter) 104 (4), L042301 (2021),

Explosive synchronization in interlayer phase-shifted Kuramoto oscillators on multiplex networks, A Kumar, S Jalan, Chaos: An Interdisciplinary Journal of Nonlinear Science (Fast Track) 3, 041103 (2021).

MS 02.03.02

Asymmetric adaptivity induces recurrent synchronization in dynamical networks

Serhiy Yanchuk, Potsdam Institute for Climate Impact Research, Germany

Abstract

Rhythmic activities that alternate between coherent and incoherent phases are ubiquitous in chemical, ecological, climate, or neural systems. Despite their importance, general mechanisms for their emergence are little understood. We present a framework for describing the emergence of recurrent synchronization in dynamical networks with adaptive interactions. This phenomenon is manifested at the macroscopic level by temporal episodes of coherent and incoherent dynamics that alternate recurrently. At the same time, the dynamics of the individual nodes do not change qualitatively. We identify asymmetric adaptation rules and temporal separation between the adaptation and the dynamics of individual nodes as key features for the emergence of recurrent synchronization. Our results suggest that asymmetric adaptation might be a fundamental ingredient for recurrent synchronization phenomena as seen in pattern generators, e.g., in neuronal systems.

MS 02.03.03

Heterogeneous nucleation in finite size adaptive dynamical networks

Jan Fialkowski, Technical University of Berlin, Germany

Abstract

Phase transitions in equilibrium and nonequilibrium systems play a major role in the natural sciences. In dynamical networks, phase transitions organize qualitative changes in the collective behavior of coupled dynamical units. Adaptive dynamical networks feature a connectivity structure that changes over time, co-evolving with the nodes' dynamical state. We show the emergence of two distinct first-order nonequilibrium phase transitions in a finite size adaptive network of heterogeneous phase oscillators. Depending on the nature of defects in the internal frequency distribution, we observe either an abrupt single-step transition to full synchronization or a more gradual multi-step transition. This observation has a striking resemblance to heterogeneous nucleation. We develop a mean-field approach to study the interplay between adaptivity and nodal heterogeneity and describe the dynamics of multicluster states and their role in determining the character of the phase transition. Our work provides a theoretical framework for studying the interplay between adaptivity and nodal heterogeneity.

MS 02.04.04

Evolutionary Dynamics of Molecular Regulatory Networks

Samuel V. Scarpino, Pandemic Prevention Institute, The Rockefeller Foundation, USA

Abstract

From self-replicating molecules to human socio-technical systems, the evolutionary trajectory of living systems is characterized by network dynamics. However, the rules governing the evolution of molecular regulatory networks, and the role of these networks in structuring the complexity of living systems, remain indefinite. Here, we develop and study a novel mathematical framework for the evolutionary dynamics of molecular regulatory networks. Using this framework, we show from first principles how the frequency of molecular regulatory networks at equilibrium will be proportional to each network's eigenvector centrality in the genotype network. Next, we determine which network characteristics are favored in response to a range of selective pressures and molecular constraints. Finally, using graph theory and a coarse-graining approach, we embed our framework into a fitness landscape model that can efficiently predict a population's evolutionary trajectory through the space of possible molecular networks. Our work provides a mechanistic explanation for the topology of molecular regulatory experiencing various evolutionary forces and a path towards linking theory to empirical data.

MS 02.04 – Dynamics and life sciences

Organisers – Celso Grebogi, Mamen Romano

University of Aberdeen

MS 02.04.01

Mathematical models of tetrapod joint patterning: how does a finger get its knuckles?

Tom Hiscock, University of Aberdeen

Abstract

Embryonic development – the process by which a single cell becomes a complex animal – involves a remarkable complexity of spatiotemporal dynamics. I seek to understand the rules underpinning these dynamics by building biologically-inspired dynamical models (e.g., PDEs). In this talk, I will describe how we have used this approach to address a classic but unresolved question in developmental biology: how are joints patterned in the developing limb? By forming at regular intervals, joints allow our fingers to bend, and enable a diversity of functions across species (e.g., walking, grasping, flying). Whilst many relevant genes and cell behaviours have been identified, it remains unclear how these key players co-ordinately control the location, number, and orientation (i.e., the patterning) of joints within each digit. By formalising mathematical models of digit development – in collaboration with experimentalists – we have developed a more rigorous and mechanistic understanding of the spatiotemporal dynamics of joint patterning in vivo.

MS 02.04.02

Natural selection and the spatial distribution of DNA replication origins

Alessandro Moura, University of Aberdeen

Abstract

DNA replication in many organisms starts from replication origins with well-defined locations on the genome. The spatial distribution of the origins in the genome is particularly important in ensuring that replication is completed quickly. Cells are more vulnerable to DNA damage and other forms of stress while they are replicating their genome. This raises the possibility that the spatial distribution of origins is under selection pressure. In this work we investigate the hypothesis that natural selection favours origin distributions leading to shorter replication times. Using a simple mathematical model, we show that this hypothesis leads to two main predictions about the origin distributions: that neighbouring origins that are inefficient (less likely to fire) are more likely to be close to each other than efficient origins; and that neighbouring origins with larger differences in firing times are more likely to be close to each other than origins with similar firing times. We test these predictions using next-generation sequencing data, and show that they are both supported by the data.

MS 02.04.03

Random growth processes to model power-law and log-normal avalanche size statistics in solids and living cells

Paco Perez-Reche, University of Aberdeen

Abstract

The deformation experienced by many solid materials when subject to varying external stress is not a smooth process, but it occurs through a sequence of abrupt changes called avalanches. For example, avalanche dynamics in solids have been studied in connection to structural phase transitions, fracture and plasticity. A common feature to all these systems is that the size of avalanches is remarkably variable and obeys long-tailed distributions with a power-law decay. Interestingly, we also observed avalanche deformation dynamics for living cells. This was surprising but not fully unexpected since cells are a soft material that exhibits liquid and solid-like properties. In contrast to avalanches in solids, however, we found that avalanche sizes obey log-normal statistics. I will begin the presentation talking about experimental results on the deformation of solids and living cells. I will then present numerical and mathematical results on random growth processes we proposed that provide a unified framework for log-normal and power-law avalanche size statistics.

MS 02.04.04

Systems biology approaches to understanding human neurodevelopmental diseases: a battle against homeostasis

Ian Stansfield, University of Aberdeen

Abstract

The addition of amino acids to tRNAs by aminoacyl-tRNA synthetase enzymes is central to the process of cellular protein synthesis. Mutations in the tRNA synthetase genes cause serious neurodevelopmental defects in human, but the molecular consequence of failure to efficiently charge tRNAs is unclear. Using yeast as a model system, together with a mathematical model of translation, we show that in mutant-replicating situations, cellular homeostasis reduces protein synthesis to match the reduced supply of charged tRNA by depleted synthetase. Despite this homeostatic mechanism, the cell nevertheless initiates a so-called GCN4 uncharged tRNA stress response. We explain how these findings reveal an important stress response-dampening role for tRNA synthetases in normal healthy cells.

Wednesday 24th August

MS 03.01 – Mean-field Dynamics in oscillatory and neural systems

Organisers Gloria Cecchini, PhD & Pau Clusella

University of Barcelona

MS 03.01.01

Exact finite-dimensional reduction for a population of noisy oscillators and its link to Ott-Antonsen and Watanabe-Strogatz theories

Rok Cestnik; Potsdam University, Potsdam, Germany

Abstract

We consider ensembles of noisy phase oscillators in the thermodynamic limit of infinite number of units. The oscillators are globally coupled in the first harmonic, and are subject to independent Cauchy noise or Cauchy distributed frequencies (or both). We describe an exact, global dimensionality reduction, reducing the full system to 6 dimensions for any initial condition. We relate our approach to known dimensionality reductions for oscillatory ensembles, in particular, showing that in the case of identical oscillators with no noise the description reduces to 3 dimensions and is equivalent to the Watanabe-Strogatz approach.

MS 03.01.02

How phase resetting curves influence excitatory-inhibitory based rhythms

Pau Pomés Arnau; Department of Information and Communication Technologies, Universitat Pompeu Fabra, Barcelona, Spain

Abstract

The interplay between excitation (E) and inhibition (I) is a prominent mechanism of generation of neuronal oscillations. As a result of the E-I feedback loop, models consisting of an excitatory and an inhibitory population robustly display rhythmic dynamics. Each cycle is initiated by an excitatory boost of activity, which triggers and inhibitory increase of activity. The emergence of E-I based rhythms have been traditionally investigated using neuronal oscillators with Type 1 phase resetting curves (PRC), which display phase advances/delays in response to excitatory/inhibitory inputs, respectively. However, experimental studies reveal that very often inhibitory neurons have Type 2 PRC, and this may largely influence synchronization of E-I based rhythms. Here we systematically investigate E-I based oscillations using two-population phase models of excitatory and inhibitory neurons with Type 1 and Type 2 PRC, respectively. The model can be reduced to a two population Kuramoto model, which is analytically tractable to a large extent. We first analyze the synchronization of a pair of E and I neurons, and find that in some cases Inhibition can precede excitation in the E-I cycles. Then we analyze two populations of identical neurons. Besides the standard fully synchronized state, the model shows a novel class of partially synchronized states, which we investigate in detail using the so-called Ott-Antonsen theory. Finally we show that such partially synchronized states also emerge in E-I networks of conductance-based spiking neurons, when inhibitory neurons have Type 2 PRCs.

MS 03.01.03

Regular and sparse neuronal synchronization are described by identical mean field dynamics

Pau Clusella; Universitat Pompeu Fabra (Department of Medicine and Life Sciences), Barcelona, Spain

Abstract

Fast oscillations (30-200Hz) are a prominent component of neural activity. Recently, exact neuronal mean-field theories for heterogeneous networks of quadratic integrate and fire (QIF) neurons have been achieved, which explain that neurons frequency- lock due to feedback inhibition. This gives rise to fast collective rhythms at the frequency of the synchronized neurons. Yet, the suitability of such models to faithfully describe neuronal oscillations is seriously challenged by a remarkable dynamical feature of single neurons during episodes of fast oscillations: Neurons do not fire regularly with a fast rhythm, but sparsely at a very low rate. Theoretical studies have demonstrated that such sparse synchronization emerges in populations of spiking neurons with inhibitory feedback and noise. Here, we exploit the fact that mean field theories for QIF neurons can be extended to include noise, and show that QIF networks with inhibitory feedback and noise robustly display sparse synchronization. Moreover, we demonstrate that fast collective oscillations are largely independent of whether single cell dynamics is periodic and fast, or stochastic with low firing rates.

MS 03.01.04

Mean-field model of consequential reward-driven decision making

Gloria Cecchini; Department of Mathematics and Informatics, Universitat de Barcelona, Barcelona, Spain

Abstract

How is the knowledge of consequence incorporated into decisions between reward-driven visual options? Despite the vast literature on reward driven decision-making (Soltani et al. 2006, Wong Wang 2006, Marcos et al. 2013), the neural computations underlying option complexity and their potential consequence on our daily decision-making processes remain to be well understood and properly formalized.

Towards this end, here we introduce a theoretical formalization of decision-making that reproduces an approximation of the dynamics of two neural populations, capable of learning sequences of binary decisions adaptively to maximize cumulative reward. Our model incorporates complexity, visual stimuli discrimination and predicted consequence into its dynamics in a parsimonious fashion. Furthermore, our model also embodies internal oversight mechanisms of consequence, and of learning by reinforcement.

We have tested this model with behavioural results of an ad-hoc experimental task. Human participants were instructed to perform sequences of binary decisions aiming at maximizing cumulative reward throughout the sequence, often in the absence of explicit reward. In brief, at each trial the participants had to select between two presented visual stimuli. The magnitude of the stimuli was conditioned to the participants' previous decisions (the consequence). Remarkably, the predictions of our model reproduced both the non-trivial inhibitory patterns of decision-making, as well as the sequences of decisions of each individual pattern, regardless of their level of performance throughout the experimental session.

In conclusion, we introduce a novel model of decision-making that incorporates the notion of consequence during the decision-making process and learns optimal strategies.

MS 03.02 – Transient Chaos (Part ii)

Organisers Dr. Oleh Omel'chenko [1] and Prof. Tamas Tel [2]

[1] Institute of Physics and Astronomy, University of Potsdam, Germany

[2] Institute for Theoretical Physics, Eötvös Lorand University, Budapest, Hungary

MS 03.02.01

Macroscopic Chaos in Mean-Field Models of Identical Phase Oscillators

Antonio Politi, Institute for Complex Systems and Mathematical Biology, SUPA, University of Aberdeen, UK

Abstract

The spontaneous emergence of irregular collective dynamics in ensemble of nonlinear oscillators is a rather ubiquitous phenomenon. However, the minimal requirements for the onset of such a regime are still unclear. In particular, the role played by the complexity of the single dynamical units is not fully understood. Here I show that a Kuramoto-Daido model equipped with a three-harmonics coupling function, can give rise to very long irregular transients, characterized by a fluctuating synchrony. The relationship between this regime and the transversal Lyapunov exponents is also illustrated with the help of the multifractal formalism.

MS 03.02.02

Chaotic Transients in Excitable Media

Ulrich Parlitz, Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany

Abstract

The spatiotemporal dynamics of excitable media may be governed by chaotic transients. We present examples of this kind of transient chaos in the 2D Fenton-Karma model describing the propagation of electrical excitation waves in cardiac tissue. Using numerical simulations it is shown how the average duration of chaotic transients depends on model parameter values and other characteristics like the dominant frequency, the size of the excitable gap, pseudo ECGs, the number of phase singularities and parameters characterizing the action potential duration restitution curve. These quantities are used to predict the average transient time of chaotic wave dynamics using polynomial regression. Work in collaboration with M. Aron, T. Lilienkamp, and S. Luther

MS 03.02.03

The Transient Charm of Decay

György Károlyi, Institute of Nuclear Techniques, Budapest University of Technology and Economics, Budapest, Hungary

Abstract

In undriven dissipative systems all motion decays since dissipation continually decreases the available mechanical energy. Chaotic motion can only show up transiently. Traditional transient chaos is, however, caused by the presence of an infinity of unstable orbits. In the lack of these, chaos in undriven dissipative systems is of another type: it is termed doubly transient chaos as the strength of transient chaos is diminishing in time, and ceases asymptotically. A clear view of such dynamics is provided by identifying KAM tori or chaotic regions of the dissipation-free case, and following their time evolution in the dissipative dynamics. The tori often smoothly deform first, but later they become disintegrated and dissolve in a kind of shrinking chaos. Various dynamical measures can be utilized for the characterization of this process and they illustrate that the strength of chaos is first diminishing, and after a while disappears, the motion enters the phase of ultimate stopping. Meanwhile, with the decrease of the energy, the boundary between basins of attraction become gradually simpler, from fractal to smooth.

Work in collaboration with Tamás Tél.

MS 03.02.04

Transient Chaos in Systems Subjected to Parameter Drift

Julia Cantisan, Departamento de Fisica, Universidad Rey Juan Carlos, Madrid, Spain

Abstract

In nature, there is a vast variety of systems that cannot be modeled by the same set of parameters as time passes. This may be caused either by the contact with its environment or due to internal factors. In this talk, we present the implications of a parameter drift in the evolution of a system. For that purpose, we show the analysis of two multi-stable systems with chaotic attractors: the Lorenz system and the time-delayed Duffing oscillator. In the first case, the drift is contained in the Rayleigh number. In the case of the Duffing oscillator, it is the time delay itself which suffers the drift. For small but non-negligible parameter change rates, we show that when a parameter crosses a bifurcation point at pbif, the non-autonomous system suffers a regime shift which appears for pcr > pbif. We have uncovered the scaling laws relating the transient lifetime with the parameter change rate. Surprisingly, we find a gamma distribution of lifetimes in the case of the time-delayed oscillator, instead of a normal distribution as previously reported for non-delayed systems. Finally, for the Lorenz system we also explore the possibility of recovering the transient state by reversing the parameter to its original value.

Work in collaboration with Jesús M. Seoane and Miguel A.F. Sanjuán.

MS 03.03 – Enhancing gender balance in nonlinear dynamics

Organisers: Dr. Simona Olmi [1] and Prof. Anna Zakharova [2]

[1] Consiglio Nazionale delle Ricerche- Istituto dei Sistemi Complessi
[2] Technische Universität Berlin-Institut für Theoretische Physik

MS 03.03.01

Hebbian learning governed Robust desynchronization in pure simplicial complexes

Prof. Sarika Jalan, IIT Indore, India

Abstract

For decades, consideration of the pairwise interaction between different networked dynamical units has been at the forefront to capture the underlying dynamics affecting distinct dynamical processes on various physical and biological complex systems. However, complex systems such as brains and social interaction networks have the underlying topology of higher-order connections. The higher-order interactions are often framed using simplicial complexes that are topological structures.

Breaking away from the traditional approach of assuming adaptation in the pairwise coupling [2,3], we consider adaptive higher-order coupling interactions among the oscillators and investigate the repercussions of the Hebbian learning-inspired adaptation in higher-order couplings on synchronization dynamics of oscillator ensembles [1]. We show that the coupling weights in pure simplicial complexes experiencing such adaptation give rise to first-order routes to desynchronization, whose onsets are entirely characterized by respective Hebbian learning parameters. Mean-field analyses presented for the order parameters for the adaptive 2- and 3- simplicial complexes strongly corroborate with the respective numerical assessments.

References

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2. Explosive synchronization in interlayer phase-shifted Kuramoto oscillators on multiplex networks A Kumar, S Jalan Chaos: An Interdisciplinary Journal of Nonlinear Science (Fast Track) 3, 04110 (2021)
3. Interlayer Hebbian plasticity induces first-order transition in multiplex networks AD Kachhvah, X Dai, S Boccaletti, S Jalan New Journal of Physics 22 (12), 122001 (2020)

MS 03.03.02

Dynamical properties of neuromorphic Josephson junctions

Dr. Johanne Hizanidis, University of Crete, Greece

Abstract

Neuromorphic computing exploits the dynamical analogy between many physical systems and neuron biophysics. Superconductor systems, in particular, are excellent candidates for neuromorphic devices due to their capacity to operate in great speeds and with low energy dissipation compared to their silicon counterparts. In this study we revisit a prior work on Josephson Junction-based "neurons" in order to identify the exact dynamical mechanisms underlying the system's neuron-like properties and reveal new complex behaviors which are relevant for neurocomputation and the design of superconducting neuromorphic devices. Our work lies at the intersection of superconducting physics and theoretical neuroscience, both viewed under a common framework, that of nonlinear dynamics theory.

MS 03.03.03

Destructive interaction of extreme wind events with electrical networks

Dr. Mehrnaz Anvari, PIK Potsdam, Germany

Abstract

Societal infrastructures like power grids in the Gulf Coast of the United States are frequently hit by annual Tropical Cyclones (TC) and, therefore, suffers a lot of damages which cost hundreds of millions of dollars. Recent recorded data in the Atlantic Ocean shows an increase in coastal temperature, which promote more frequent and intense TCs in this region. Therefore, considering the vulnerability of the electrical network against extreme wind loads and, consequently, increasing its robustness to withstand these events is of great importance. In our recent work, we model the wind-induced failure of transmission lines in the Texan electrical network in the context of seven tropical cyclones that passed over Texas in the last 18 years. Using a probabilistic line fragility model, we study the statistics of triggered cascading failures and caused power outages. The results allow us to identify vulnerable regions and provide important insights into the structural stability of the power grid. Most importantly, we propose a way to efficiently increase the resilience of the power grid such that worst-case scenarios become significantly less likely.

MS 03.03.04

Epidemic dynamics in different scales

Dr. Fakhteh Ghanbarnejad, Sharif University of Technology (SUT), Tehran, Iran

Abstract

Here I will review my recent works [1-14] on modeling interacting contagious dynamics in different temporal and spatial scales, for example coupled SIR or SIS dynamics, in mean field approximations and also on different random generated or empirical complex networks. I show and discuss how our recent results have been improving our understanding and prediction of epidemic dynamics and disease ecology while raising new questions and challenges in physics of critical phenomena.

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MS 03.03.05

Partial synchronization in complex networks: chimeras and beyond

Prof. Anna Zakharova, TU Berlin, Germany

Abstract

Dynamical transitions from synchronized to desynchronized regimes and vice versa involve the formation of partial synchronization patterns with applications to both biological and man-made systems. The most prominent example is given by chimera states [1]. In the present talk, we discuss the occurrence of chimera states in complex networks of coupled neural systems. Moreover, we investigate another peculiar pattern called solitary states [2] that has recently received a lot of attention. We show how chimera states and solitary states are formed in dynamical networks of different kinds including single- and multilayer networks.

References

1. A. Zakharova, Chimera Patterns in Networks: Interplay between Dynamics, Structure, Noise, and Delay, Understanding Complex Systems (Springer, Cham, 2020) doi: 10.1007/978-3-030-21714-3
2. A. Zakharova, Investigating partial synchronisation in complex dynamical networks, Research Features 2022 doi: 10.26904/RF-141-2648415675

MS 03.04 - Adaptive dynamical networks (part iii)

Organisers - Rico Berner [1], Thilo Gross [2-4], Christian Kuehn [5], Jürgen Kurths [6], Serhiy Yanchuk [6-7]

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MS 03.04.01

Adaptive self-organized criticality in cortical and artificial intelligence networks

Christian Meisel, Charité Berlin & Berlin Institute for Health, Germany

Abstract

A recurrent idea in the study of dynamical networks is that there is a fundamental connection between critical phase transitions and optimal information processing. In this talk I will review conceptual and empirical evidence for the relevance of critical dynamics in cortical networks and how this state is controlled by adaptive synaptic plasticity mechanisms, vigilance state and antiepileptic drug action.

I will then discuss how the criticality framework may also serve to improve an understanding of information processing in artificial intelligence deep neural networks, and how these insights may potentially be used to refine their computational properties.

MS 03.04.02

Modelling the emergence of different frequency-coupled rhythms in rats' brainstem via mean-field models of spiking neural networks with adaptation

Simona Olmi, Istituto dei Sistemi Complessi, Consiglio Nazionale delle Ricerche, Florence, Italy

Abstract

Whisking is the rhythmic cyclic vibrissae sweeping action, consisting of repetitive forward (protraction) and backward (retraction) movements at an average frequency of about 8 Hz. At the basis of whisking generation is the vIRt nucleus in the medulla, composed of inhibitory neurons which innervate motoneurons of the vibrissa muscles. Starting from the microscopic dynamics of quadratic integrate-and-fire (QIF) neurons, we construct and analyze an exact neural mass model of the vIRt circuit composed of two inhibitory coupled neuronal populations with adaptation and exponentially decaying synapses, with the purpose of finding a model able to explain the generation of a rhythm driving the whisking activity in rodents. In particular we show here the role played by the adaptation in guiding the emergent dynamics. Various dynamical regimes can be observed: periodic collective oscillations (in phase and in antiphase), asymmetric collective oscillations, asymmetric fixed points and various bistability regions in the parameter space. In addition to that, it is found that adaptation is a mechanism by which Cross-Frequency Coupling between theta and gamma frequencies can occur. We also introduce the effects of the pre-Bötzinger complex through an external inhibitory oscillating forcing and we study the phase locking between the two populations, in order to evaluate the forcing influence on both populations. It turns out that phase locked states are possible and there are cases in which the forced populations are not fully entrained with the external input.

MS 03.04.03

Resonant velocity tuning of solitary states in networks of coupled phase oscillators

Jakob Niehues, Potsdam Institute for Climate Impact Research, Potsdam, Germany

Abstract

Electrical power grid dynamics can be modeled as coupled oscillators on sparse complex networks. In addition to the desired operating state, in which all nodes are synchronized at network frequency, there exists a variety of partially synchronized states. Solitary states consist of a large, synchronized cluster and a single oscillator that rotates with a different velocity. They pose a threat to power grid stability, as they would cause overload damages and can be easily reached through single-node perturbations. Especially vulnerable to such perturbations are dense sprouts, which are degree-1 nodes with distinct topological properties and a well-connected neighbor. Novel solitary states in which the velocity of the dense sprout differs from its natural velocity have recently been discovered in numerical simulations. In this work, we propose a two-node model with which we can theoretically explain the novel solitary states. In this model, the rest of the synchronized complex network is reduced to its key factor, i.e. the degree of the neighbor $n+1$. Applying a linearization approach, we obtain an analytical solution approximating the full complex dynamics. We then derive a self-consistency equation for the velocity of the solitary node, that we find close to $\sqrt{K n}$, where K denotes the universal coupling strength of the oscillators' phase differences. We demonstrate that our model resembles highly localized network modes in the linear stability regime around the operating state. The velocity of the dense sprout arises from resonance with this network mode under the constraint of matching the network's power flow.

MS 03.04.04

Neuroscience needs Bifurcation Theory: Neural criticality and critical drift in adaptive neuro-inspired networks

Silja Sormunen, Aalto University

Abstract

The critical brain hypothesis states that the brain operates near a critical state, marked by a bifurcation point. While originally a fringe idea, this hypothesis is now supported by a substantial amount of experimental evidence. Nevertheless, many theoretical questions remain open. What is the nature of the dynamical states between which the brain operates? And how can the brain remain at a critical state while constantly adapting to changing task requirements? In this talk I argue that basic results from bifurcation theory suggest answers to these questions. The adaptive self-organization of the brain happens in a very high dimensional parameter space, and hence the critical states can be expected to form a high-dimensional manifold inside this space. Consequently, self-organization to a codimension-1 bifurcation hardly constrains the values of the most important parameters. The system can thus continue to drift through parameter space while remaining at criticality. In the course of this drift, further bifurcations may be encountered leading to high-codimension criticality.

Co-authors - Thilo Gross, Jari Saramäki

MS 03.05 – Dynamics and life sciences

Organisers – Celso Grebogi, Mamen Romano

University of Aberdeen

MS 03.05.01

Field cycling imaging: measuring water dynamics in vivo

Lionel Broche, University of Aberdeen

Abstract

NMR is an ubiquitous technique providing a wealth of information over a wide variety of disciplines, using nuclear spin resonance in a magnetic field. While NMR experiments mostly happen in a fixed field, it is possible to explore the behaviour of materials in a variable field as well. This is the principle behind Fast Field Cycling (FFC) and, while simple, this approach provides valuable information about molecular dynamics similar to the Optical Kerr Effect (OKE) but non-invasively.

Our research group has developed FFC methods for whole-body imaging, which opens new and exciting avenues for the discovery of new biomarkers based on molecular dynamics linked with biological activity, but also brings new and complex problems of modelling. This presentation will provide an overview of this topic and of the problems currently faced in this field.

MS 03.05.02

Real-world applications of the science devoted to understand from data the cause and effect relationship

Murilo Baptista, University of Aberdeen

Abstract

The study of the cause-and-effect relationship - so called causality - lies at the heart of the scientific method. In this talk, I will briefly introduce the ideas and fundamentals behind methods to study causality in complex systems, and approaches we have developed to study causality from data obtained from real world systems with different spatial and temporal characteristics. I will then present several real-world applications to infer the connectivity of neural networks from time-series, to characterize how socio-economic cause-and-effect variables modify after a natural disaster in the Brazilian municipalities, to determine how long one must collect information about the positive cases of Covid19 to be able to predict with a given accuracy the number of posterior deaths in a region of the world, and to understand how standard stock market assets influence the cryptocurrencies.

MS 03.05.03

Collective irregular dynamics in spiking neuronal networks

Ekkehard Ullner, University of Aberdeen

Abstract

Irregular firing activity is a frequently observed phenomenon in certain areas of the mammalian brain, such as hippocampus or cortical neurons, playing a key role in the brain's function. This irregular dynamic emerges from the interaction of many units. We focus on a regime called *collective irregular dynamics* (CID) as a form of partial synchronisation. It is characterised by a complex dynamical structure and differs from other synchronized states. CID is a ubiquitous phenomenon and emerges amongst others spontaneously in recurrent networks of spiking neurons. We focus here on balanced random networks of identical leaky-integrate-and-fire models and networks of phase oscillators with a suitable phase response curve. We study also more realistic finite-width pulses in terms of exponential spikes and contrast the results with the usual approach of artificial delta spikes.

We use analytical and numerical techniques, e.g., linear stability analysis of the synchronous and asynchronous regime, various types of Lyapunov exponents and a detailed finite-size scaling analysis, to conclude that CID is a bona fide thermodynamic phase, clearly different from the standard asynchronous dynamic. CID is robust also in our more natural setup with finite-width pulses.

MS 03.05.04

Translation dynamics

Mamen Romano, University of Aberdeen

Abstract

Translation is the process by which proteins are made in cells from their template mRNAs. We have developed a series of translation dynamics models based on a paradigmatic transport process from non-equilibrium statistical physics. In this talk I will present some recent developments, including a model that describes how translation is distorted upon a viral infection and genetic mutations affecting the translational apparatus.

Thursday 25th August

MS 04.01 – Global features of coupled dynamics systems

Organiser - Dr. Jose Mujica

Vrije Universiteit Amsterdam

MS 04.01.01

Stability of heteroclinic cycles in rings of coupled oscillators

Rob Sturman, University of Leeds, UK

Abstract

Networks of interacting nodes connected by edges arise in almost every branch of scientific enquiry. The connectivity structure of the network can force the existence of invariant subspaces, which would not arise in generic dynamical systems. These invariant subspaces can result in the appearance of robust heteroclinic cycles, which would otherwise be structurally unstable. Typically, the dynamics near a stable heteroclinic cycle is non-ergodic: mean residence times near the fixed points in the cycle are undefined, and there is a persistent slowing down. In this paper, we examine ring networks with nearest-neighbour or nearest-m-neighbour coupling, and show that there exist classes of heteroclinic cycles in the phase space of the dynamics. We show that there is always at least one heteroclinic cycle which can be asymptotically stable, and thus the attracting dynamics of the network are expected to be non-ergodic. We conjecture that much of this behaviour persists in less structured networks and as such, non-ergodic behaviour is somehow typical.

MS 04.01.02

Hierarchy of Exact Low-Dimensional Reductions for Populations of Coupled Oscillators

Rok Cestnik, Postdam University, Germany

Abstract

We consider an ensemble of phase oscillators in the thermodynamic limit, where it is described by a kinetic equation for the phase distribution density. We propose an ansatz for the circular moments of the distribution (Kuramoto-Daido order parameters) that allows for an exact truncation at an arbitrary number of modes. In the simplest case of one mode, the ansatz coincides with that of Ott and Antonsen [Chaos 18, 037113 (2008)]. Dynamics on the extended manifolds facilitate higher dimensional behavior such as chaos, which we demonstrate with a simulation of a Josephson junction array. The findings are generalized for oscillators with a Cauchy-Lorentzian distribution of natural frequencies.

MS 04.01.03

Coupling of heterogeneous slow-fast systems with MMOs. New patterns and ROM simulations

Alejandro Barrera Moreno, University of Seville, Spain

Abstract

In Fernández-García and Vidal [Physica D 401 (2020)], the authors have analyzed the features between two identical 3D slow-fast oscillators, symmetrically coupled, and built as an extension of the FitzHugh–Nagumo dynamics generating Mixed-Mode Oscillations (MMOs). In this model, the third variable of each oscillator aims at representing the time-varying intracellular calcium concentration in neurons. The global model is therefore six-dimensional with two fast variables and four slow variables with strong symmetry properties.

In the present work, we have considered two extensions for this model. First, we consider heterogeneity among cells via one parameter which tunes the intrinsic frequency of the output. Also, we analyze the coupling of the two oscillators for different values of the parameter and identify new patterns of antiphasic synchronization, with non-trivial signatures and that exhibit a Devil's Staircase phenomenon when varying the heterogeneity parameter for a fixed coupled parameter. Second, we introduce a network of N cells divided into two clusters: the coupling between neurons in each cluster is excitatory, while the coupling between the two clusters is inhibitory. Such system aims at modelling the interactions between neurons tending to synchronization in each of two subpopulations that inhibit each other, like ipsi- and contra-lateral motoneurons assemblies. To perform the numerical simulations in this case when N is large, as an initial step towards the network analysis, we consider Reduced Order Models (ROMs) to save computational costs.

MS 04.01.04

Heteroclinic cycles under forced symmetry breaking: coupled oscillators, reduced dynamics, normal forms and invariant manifolds

Jose Mujica, Vrije Universiteit Amsterdam, The Netherlands

Abstract

Networks of oscillatory units are an active area of research due to their connections with brain functions and the complex collective dynamic arising on these models. We consider a network of coupled oscillators which, in the fully symmetric case, supports a robust dissipative heteroclinic cycle between dynamically invariant sets with localised frequency synchrony. The heterocilinic connections involved in the cycle lie on invariant subspaces yield by the symmetries of the system and are caused by the presence of higher order interactions.

In this talk, we focus on what happens in this heteroclinic structure when the symmetries of the system are broken. In particular, we will discuss some partial results on how such a perturbation affects the asymptotic dynamic near saddle sets involved in the cycle. To this end, we study normal forms for the reduced dynamics obtained via a parametrisation method. This will set up the stage for further numerical investigation of these global connections.

MS 04.02 – Estimating stability indicators from data

Organiser - Dr. Nahal Sharafi

Hamburg University of Applied Sciences

MS 04.02.01

Estimating covariant Lyapunov vectors from data

Sarah Hallerberg

Abstract

Covariant Lyapunov vectors characterize the directions along which perturbations in dynamical systems grow. They have also been studied as predictors of critical transitions and extreme events. For many applications like, for example, prediction, it is necessary to estimate the vectors from data since model equations are unknown for many interesting phenomena. We propose a novel method for estimating covariant Lyapunov vectors based on data records without knowing the underlying equations of the system. In contrast to previous approaches, our approach can be applied to high-dimensional data-sets. We demonstrate that this purely data-driven approach can accurately estimate covariant Lyapunpov vectors from data records generated by low and high-dimensional dynamical systems. The highest dimension of a time-series from which covariant Lyapunov vectors were estimated in this contribution is 128. Being able to infer covariant Lyapunov vectors from data records could encourage numerous future applications in data-analysis and data-based predictions.

MS 04.02.02

Guidelines for data-driven approaches to study transitions in multiscale systems: the case of Lyapunov vectors

Nikki Vercauteren, University of Oslo, Norway

Abstract

In climate science, systems with multiple metastable states are ubiquitous. Knowing their stability properties and the probability of transitioning from one state to another is of great help to understand and predict the dynamics of such systems. Many tools have been developed to address this challenge, among which covariant Lyapunov vectors have proven to be very useful. The numerical calculation of these vectors generally requires an a priori knowledge of the set of equations governing the dynamics, and therefore cannot be applied directly to experimental data. However, data-driven methods have been developed to estimate the covariant Lyapunov vectors based on observed time-series. Our study aims to identify the crucial conditions under which a data-driven approach can successfully estimate the alignment of covariant Lyapunov vectors to predict critical transitions. To this end, we discuss in detail the FEM-BV-VAR model-based clustering tool to construct models for multi-scale systems and test the subsequent covariant Lyapunov vectors estimations on three systems of increasing dynamic complexity, including two explicit classical models and experimental data for turbulent flow. As the tested method is expected to be relevant in a wide range of climate science applications, our key contribution is to show under which circumstances reliable results can be expected.

MS 04.02.03

Inferring the instability of a dynamical system from the skill of data assimilation exercises

Yumeng Chen, University of Reading, Britain

Abstract

Data assimilation (DA) aims at optimally merging observational data and model outputs to create a coherent statistical and dynamical picture of the system under investigation. Indeed, DA aims at minimizing the effect of observational and model error and at distilling the correct ingredients of its dynamics. DA is of critical importance for the analysis of systems featuring sensitive dependence on the initial conditions, as chaos wins over any finitely accurate knowledge of the state of the system, even in absence of model error. Clearly, the skill of DA is guided by the properties of dynamical system under investigation, as merging optimally observational data and model outputs is harder when strong instabilities are present. In this paper we reverse the usual angle on the problem and show that it is indeed possible to use the skill of DA to infer some basic properties of the tangent space of the system, which may be hard to compute in very high-dimensional systems. Here, we focus our attention on the first Lyapunov exponent and the Kolmogorov–Sinai entropy and perform numerical experiments on the Vissio–Lucarini 2020 model, a recently proposed generalization of the Lorenz 1996 model that is able to describe in a simple yet meaningful way the interplay between dynamical and thermodynamical variables. Based on these numerical experiments, we illustrate a possible way to infer instability properties from the skill of data assimilation.

MS 04.02.04

Stability indicators in DynamicalSystems.jl

George Datseris, Max Planck Institute for Meteorology, Hamburg, Germany

Abstract

DynamicalSystems.jl is a general purpose software library for nonlinear dynamics and nonlinear timeseries analysis with implementations of hundreds of algorithms of the field. The library also has several implementations of stability indicators, from the most basic Lyapunov exponents to some relatively newer methods based on e.g., expansion entropy or cross-correlation decays. In this presentation we will briefly overview these methods, and illustrate how they can be computed on the fly, for any dynamical system, using DynamicalSystems.jl. Within this minisymposium I hope to motivate the community to request, or even better contribute, more stability indicators in DynamicalSystems.jl, but also discuss how to generically implement newer, machine-learning-based methods.

MS 04.03 – Metastability in neuron networks

Organiser - Klaus Lehnertz, Prof. Dr.

University of Bonn

MS 04.03.01

Towards a unifying view of metastability in neuroscience

Kalel Luiz Rossi, Carl von Ossietzky Universität Oldenburg, Germany

Abstract

Several works in the Neuroscience literature discuss the idea of metastable brain dynamics. They present evidence from a wide variety of experiments and suggest important cognitive and sensory functional roles of metastability. A careful comparison between works reveals, however, that the meaning ascribed to metastability can vary widely and even be incompatible - for instance, some consider noise to be essential for metastability, while others rule noise out of metastability. We attempt to resolve these inconsistencies by reviewing and discussing the different definitions of metastability, and using insights from Physics and Dynamical Systems theory to suggest a refined general definition of metastability. This involves the succession of distinct activity patterns and includes several other definitions in the literature as specific types of metastability. The properties, functional roles, and possible dynamical mechanisms of those types of metastability are then discussed. We illustrate each type with concrete examples in experiments and modelling, and also study a model displaying several types of metastability over its parameter range. We believe that this work can aid in the unification of our current knowledge about metastability, an important stepping stone for the understanding of brain dynamics.

MS 04.03.02

Mesoscopic description of metastability in networks of spiking neurons with short-term plasticity

Bastian Pietras, Universitat Pompeu Fabra Barcelona, Spain

Abstract

Bastian Pietras, Universitat Pompeu Fabra, Spain; Valentin Schmutz, École Polytechnique Fédérale de Lausanne, Switzerland; Tilo Schwalger, Technische Universität Berlin, Germany The neuronal mechanisms of various cognitive functions have been linked to metastable dynamics of recurrent neural networks. Metastability, such as population spikes or spontaneous transitions between Up- and Down-states, may result from slow fatigue processes (e.g., short-term depression of presynaptic synapses), from noisy fluctuations, or from an interplay of both. Previous modeling studies that consider either detailed spiking neuron networks, or heuristic firing rate models, have not provided satisfactory mechanistic insights how single neuron dynamics and finite-size fluctuations contribute to metastable population activity. In this talk, we will propose a mesoscopic description for networks of spiking neurons with short-term depression that is based on a rigorous reduction from microscopic neuron dynamics. With this novel mesoscopic model, we investigate typical examples of metastable network dynamics and also shed new light on hippocampal replay.

MS 04.03.03

Connecting individual network structures to collective behavior in oscillator systems

Roberto C. Budzinski, The University of Western Ontario, Canada

Abstract

The study of nonlinear oscillator networks has applications throughout physics, biology, and neuroscience. In this context, the Kuramoto Model (KM) plays an important role in modeling and analysis of networked systems. However, the relationship between the structure of specific, individual networks and the resulting dynamics in these systems remains unclear. Here, we present a new mathematical approach that allows us to relate the connectivity of an individual network, either taken from real-world data or from one realization of a random graph, with the spatiotemporal pattern of oscillations and transient behavior of the system. This approach utilizes a complex-valued matrix formulation for the KM, which has a specific correspondence with the original model. This allows an analytical approach to the study of phase synchronization, chimera states, and traveling waves in oscillator networks for transient time and in individual networks. With this approach, we can make a clear connection between the spectrum of the matrix describing the network with the resulting dynamics. This gives us a new perspective of synchronization phenomena in terms of complex eigenmodes, which in turn offers a unified geometry for synchronization phenomena in nonlinear oscillator networks.

MS 04.03.04

Utilizing metastability to design a testbed for a data-driven estimation of resilience in networked dynamical systems

Tobias Fischer, University of Bonn, Germany

Tobias Fischer [1,2], Thorsten Rings [1,2], M. Reza Rahimi Tabar [3,4], Klaus Lehnertz [1,2,5]

[1] Department of Epileptology, University of Bonn Medical Centre, Bonn, Germany
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[3] Department of Physics, Sharif University of Technology, Tehran, Iran
[4] Institute of Physics, Carl von Ossietzky University of Oldenburg, Oldenburg, Germany
[5] Interdisciplinary Center for Complex Systems, University of Bonn, Bonn, Germany

Abstract

Complex networks composed of FitzHugh-Nagumo oscillators are known to exhibit a rich variety of dynamical behaviors, including recurrent extreme events. We utilize such networks to develop a toy model of a multistable system that is capable of self-generating transitions between various states (dynamical regimes). Various control parameters allow us to modify resilience of the multistable networked dynamical system in a controlled manner. We analyze multivariate time series of the system's observables to evaluate the suitability of a recently proposed data-driven estimator of resilience that specifically probes temporal changes of the network's coupling structure. In this talk, we report first findings for the resilience estimator.

MS 04.04 - Adaptive dynamical networks (part iv)

Organisers - Rico Berner [1], Thilo Gross [2-4], Christian Kuehn [5], Jürgen Kurths [6], Serhiy Yanchuk [6-7]

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MS 04.04.01

Inferring untrained dynamics of complex systems using adapted recurrent neural networks

Miguel C. Soriano, University of the Balearic Islands, Mallorca, Spain

Abstract

Due to their many degrees of freedom and potentially multiple time scales, the prediction and analysis of complex system dynamics represents challenging tasks. Learning the dynamics from data of real-world complex systems, artificial intelligence methods are becoming ubiquitous in the cases where analytical models are unavailable. Nonetheless, the predictions of such data-driven models often demand large amounts of data and are mainly restricted to the dynamical regimes that are already present in the training data. In this contribution, we focus on the far-reaching question of whether it is possible to infer untrained (size-dependent) dynamical regimes of complex dynamical systems, training a neural network to learn the dynamics for one system size only. We demonstrate that it is possible, given certain symmetry properties, to infer the dynamics for system sizes far away from the trained size for two well-known dynamical systems, namely a Mackey-Glass delay system and a spatially extended Kuramoto-Sivashinsky model. The proposed method involves training a recurrent neural network on a time series for a single parametrization example and, subsequently, adapting the topology of the neural network for the inference of unseen dynamical regimes. We link this inference ability of the presented neural networks to their particular design, considering the translational symmetries of delay and spatially extended systems. Altogether, we pave the way to exploit symmetries in complex systems for far-reaching generalizations that allow to infer untrained dynamics. The minimal requirements on training data and the low computational costs make our method well applicable to various real-world systems.

MS 04.04.02

Emergent Diversity and Persistent Turnover in Evolving Microbial Cross-Feeding Networks

Leonhard Lücken, The University of Oldenburg, Germany

Abstract

A distinguishing feature of many ecological networks in the microbial realm is the diversity of substrates that could potentially serve as energy sources for microbial consumers. The microorganisms are themselves the agents of compound diversification, e.g., via metabolite excretion or overflow metabolism. It has been suggested that the richness of different substrates is an important condition for the immense biological diversity in microbial ecosystems. I explain how continuously changing complex cross-feeding networks (CFN) of microbial species may develop from a simple initial community given some elemental evolutionary mechanisms of resource-dependent speciation and extinctions using a network flow model. Our model demonstrates that high microbial and molecular diversity can be an emergent property of the evolution in cross-feeding networks, which may affect transformation and accumulation of organic matter in natural systems, such as soils and oceans.

MS 04.04.03

What adaptive neuronal networks teach us about power grids

Rico Berner, Humboldt Universität zu Berlin, Germany

Abstract

This contribution provides a new perspective on power grids by demonstrating that they 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 pseudocoupling weights. In this work, the relation between these two types of networks, in particular the model of phase oscillators with inertia (swing equation for power grids) and the model of neuronal phase oscillators with adaptivity, is used to gain insights into the dynamical properties of multifrequency clusters [2], which may destabilize the desirable completely synchronized operating state of the power grid. This relation holds even for more general classes of power grid models that include voltage dynamics. Building on this relation between phase oscillators with inertia and adaptive networks, a new perspective on solitary states in power grid networks [3] and their influence on network stability is provided and illustrated by the ultrahigh-voltage power grid of Germany.

References

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2. R. Berner, S. Vock, E. Schöll, and S. Yanchuk: Phys. Rev. Lett. 126, 028301 (2021).
3. H. Taher, S. Olmi, and E. Schöll: Phys. Rev. E 100, 062306 (2019).

MS 04.04.04

Coupled oscillators, dead zones, and networks with effective adaptivity

Christian Bick, Vrije Universiteit Amsterdam, Netherlands

Abstract

To describe networks of coupled oscillators one traditionally considers "physical" connections between units. However, depending on the functional form of the coupling and the geometry of the oscillation, network nodes may actually be effectively decoupled on open sets of phase space: We show how this induces a "dead zone" in the (effective) coupling function. This can lead to dynamics that depend on the successive recoupling and decoupling of oscillators – a network with effective adaptivity where the network adapts quickly compared to the oscillator dynamics.

Friday 26th August

MS 05.01 – Data-driven Modelling and analysis of complex dynamical systems

Organizers- Prof. Constantinos Siettos [1], Dr. Lucia Russo [2], Prof. Yannick de Decker [3]

[1] University of Naples Federico II,
[2] Dr. Lucia Russo: Consiglio Nazionale delle Ricerche, STEMS
[3] Prof. Yannick de Decker: Université Libre de Bruxelles,

MS 05.01.01

Data-driven detection of unstable states, stability information and bifurcations in laboratory experiments

Jens Starke, Dept. of Mathematics, University of Rostock, Germany.

Abstract

Information about the bifurcation structure of laboratory experiments is very useful. First, for mathematical modelling and model verification, a comparison of the bifurcations results is a much more critical test than just comparing data from time-series for selected parameter values. Second, for cases where closed mathematical equations are not yet known, experimentally obtained bifurcation diagrams help in engineering applications to find parameter regions for a reliable operation mode. A control based continuation method to perform a bifurcation analysis directly for lab experiments allows to observe and investigate also unstable solution branches which were otherwise not observable in laboratory experiments. As the stationary points are stabilized with these control methods, the stability information of the original system gets lost. We introduce a method to construct the whole bifurcation diagram including information about stability and bifurcation points of the underlying uncontrolled equilibria. The methods are illustrated for the Zeeman catastrophe machine, a bistable mechanical experiment and the uncovering of unstable states in a pedestrian flow experiment.

MS 05.01.02

Quantum Process Tomography from Time-Delayed Measurements

Felix Dietrich, Department of Informatics, Technical University of Munich, Germany

Abstract

The goal of quantum process tomography is to determine the type and layout of a quantum system, given measurements of the system behavior. Conventionally, the approach uses many initial states together with the process output to determine the tomography. In this talk, we describe an alternative approach which requires only a single (or few) known initial states together with time-delayed measurements. With this information, we can reconstruct the underlying unitary map and corresponding Hamiltonian of the system. The Takens embedding theorem provides an overarching mathematical framework and feasibility guarantee of our method. We explain how the reconstruction of a single qubit Hamiltonian works in this setting and discuss numerical methods and experiments for general few-qubit and two-dimensional lattice systems with local interactions. As an illustrative example, our approach allows to extract the Hamiltonian of a two-qubit system from observations of only one of the qubits.

MS 05.01.03

Finding nonlinear emergent behaviour in a spatial tropical forest model

Speaker 3 Information

Jan Sieber, Dept. of Mathematics, University of Exeter, UK

Abstract

We demonstrate how one can use controlled simulations to determine closed equations for a slow-fast cellular automaton modelling fire feedback in tropical forest-grass landscapes. In particular, we find that the two most important percolation quantities in the model, the forest perimeter length and the "grass-weighted" forest perimeter length are determined by forest area. Thus, one can use simple bifurcation analysis arguments to study the vulnerability of a landscape to tipping (self-accelerating forest die-back).

MS 05.02 – Extreme events in dynamical systems – Mechanisms and predictability

Organiser - Dibakar Ghosh

Indian Statistical Institute, Kolkata, India

MS 05.02.01

Extreme events in dynamical systems: Mechanisms and predictability

Syamal Kumar Dana, National Institute of Technology, Durgapur, India; Lodz University of Technology, Lodz, Poland

Abstract

Extreme events such as cyclones, floods and tsunamis, rogue waves have devastating impact on life and infrastructure. Due to lack of appropriate model of high dimensional natural systems, a trend of research has started in the last few decades to explore the mechanisms of the origin of extreme events in dynamical systems. Experiments have also been done to reproduce the phenomena in the laboratory. I will explain some of the fundamental sources of instabilities (namely, interior crisis, intermittencies) that may lead to recurrent and occasional large events larger than the average events that have been defined as extreme events in dynamical systems and share our personal experience on such studies in a variety of systems. The main purpose of studying extreme events is to address the question of prediction that is most important for humanity for mitigating a disaster caused by extreme events. I will discuss the question of predictability how it is being investigated in dynamical systems and using model-free data-driven machine learning methods.

MS 05.02.02

Climate network analysis of extreme events: Tropical Cyclones

Neelima Gupte, Department of Physics, Indian Institute of Technology Madras, Chennai, 600036, India

Abstract

We construct climate networks based on surface air temperature data to identify distinct signatures of such as cyclones, El Nino and La Nina events which trigger many climatic disruptions around the globe with serious economic and ecological consequences. The climate network shows a discontinuous phase transition in the size of the normalised largest cluster and the susceptibility during cyclonic events. We analyze these quantities for a year (2016) which had three successive cyclones, viz Cyclone Kyant, cyclone Nada and cyclone Vardah, and compare these with a year (2017) where a single cyclone, cyclone Ockhi was seen. The microtransitions in these two cases show distinct patterns. The signatures of the cyclones can be seen in other quantities like the degree distributions, betweenness centrality measures and other network characterizers. We discuss the implications of these results for further analysis.

MS 05.02.03

Characterizing predictive edges in complex networks that can generate extreme events

Timo Broehl, Department of Epileptology, University Hospital Bonn, Venusberg Campus 1, 53127 Bonn, Germany; Helmholtz-Institute for Radiation and Nuclear Physics, University of Bonn, Nussallee 14-16, 53115 Bonn, Germany

Abstract

Extreme events can be observed in the dynamics of many networked dynamical systems. Such events are usually considered to be rare and recurrent events of high amplitude. Previous research on the generation of extreme events, mostly considered either the collective dynamics or dynamics of single vertices (subsystems). Addressing the question whether precursors of extreme events can be identified from interaction dynamics between subsystems. Using our recently proposed edge centrality concepts, we identified precursory structures in evolving interaction networks derived from time series of system observables. We highlight our findings at the example of complex networks of FitzHugh–Nagumo oscillators as well as on evolving functional brain networks derived from multi-day, multi-channel electroencephalographic recordings from subjects recurrently transiting into and out of epileptic seizures.

MS 05.02.04

Extreme events in complex networks and statistical analysis

Dibakar Ghosh, Physics and Applied Mathematics Unit, Indian Statistical Institute, Kolkata 700108, India

Abstract

Heterogeneity is always a source of instability in interacting dynamical systems. It is a pressing question how heterogeneity of any form, system parameter or network topology, affects the overall dynamics of a network. The role of topological heterogeneity in a network is, particularly, important here where the nodes are associated with identical dynamical systems and interacting via repulsive coupling. In fact, interplay of network heterogeneity and repulsive interaction between the oscillators triggers extreme events (rare, but recurring and significantly large deviation from the original dynamics) in the nodes, which succumb to a range of repulsive coupling. In other way, we will discuss a network of heterogeneous dynamical systems under global coupling and explored the role of repulsive interactions. An interplay of heterogeneity of a system parameter and the repulsive interaction between the nodes leads to triggering of extreme events in a fraction of dynamical units in the network. The probability density function of these highly deviated values fits well with the generalized extreme value distribution. Meanwhile, the distribution of recurrence time intervals between extreme events resembles the Weibull distribution.

MS 05.03 – Critical systems in nonlinear dynamical systems: theory and applications

Organisers - Ulrike Feudel [1], Lea Oljaca [2]

[1] University Oldenburg, Germany

[2] University of Exeter, UK

MS 05.03.01

Are transitions in the climate predictable? Learning from the paleoclimatic records.

Peter Ditlevsen

Abstract

It is taken for granted that the limited predictability in the initial value problem, the weather prediction, and the predictability of the statistics are two distinct problems. Predictability of the first kind in a chaotic dynamical system is limited due to critical dependence on initial conditions. Predictability of the second kind is possible in an ergodic system, where either the dynamics is known and the phase space attractor can be characterized by simulation or the system can be observed for such long times that the statistics can be obtained from temporal averaging, assuming that the attractor does not change in time.

For the climate system the distinction between predictability of the first and the second kind is fuzzy due to the lack of scale separation between fast and slow components of the climate system.

The non-linear nature of the problem furthermore opens the possibility of multiple attractors, or multiple quasi-steady states. As the paleoclimatic record shows, the climate has been jumping between different quasi-stationary climates. The question is: Can such tipping points be predicted? This is a new kind of predictability (the third kind).
The Dansgaard-Oeschger climate events observed in ice core records are analyzed in order to answer some of these questions. The result of the analysis points to a fundamental limitation in predictability of the third kind.

MS 05.03.02

Noise Induced Transitions in a Bistable Toy Model of Climate

Calvin Nesbitt

Abstract

A multistable system in the presence of (weak) stochastic forcing will exhibit transitions between its different attractors on long timescales. We study these noise induced transitions in a bistable toy model of climate. The model couples the Lorenz 96 model, a set of dissipative, chaotic differential equations mimicking atmospheric dynamics, to a zero dimensional energy balance model and has a nontrivial two way feedback between the different components .

We will study the case where there are two chaotic attractors within the phase space and examine noise induced transitions between the states. In particular we estimate both the transition rates, via a Kramers type law, and the most likely transition paths (instantons) from stochastic simulation. Moreover, we compute the instantons in a second way using the Minimum Action Method and compare it with our empirical estimates.

MS 05.03.03

Rate-Induced Tipping of the Compost Bomb: Sizzling Summers, Heteroclinic Canards and Metastable Zombie Fires

Eoin Geoffrey O'Sullivan

Abstract

The Arctic is the fastest warming region on Earth. Understanding how a rapidly changing climate change impacts Arctic systems is therefore an important challenge. This is the basis of the `Compost-Bomb' instability, a theorized runaway heating of northern latitude peat soils when atmospheric temperature rises faster than some critical rate, first proposed in [Luke & Cox, European Journal of Soil Science (2011), 62.1] and analysed in [Wieczorek et al, Proceedings of the Royal Society A (2011), 467.2129]. The Compost Bomb instability was one of the first examples of what is known as Rate-induced tipping or R-tipping.

The key trigger for the compost bomb instability is heat produced by microbial respiration. Here, the original soil carbon and temperature model of Luke & Cox is augmented with a non-monotone microbial respiration function, for a more realistic representation of the process. This gives rise to a meta-stable state, reproducing the results of [Khvorostyanov et al, Tellus (2008), 60B] where a complex PDE model is used. Two non-autonomous climate forcings are examined: (i) a rise in mean air temperature over decades (ii) a short-lived extreme weather event, with the rate-induced compost bomb observed in each. Using techniques of compactification, singular perturbation theory and desingularisation, we reduce the R-tipping problem to one of heteroclinic orbits, uncovering the tipping mechanism for each climate change scenario.

MS 05.03.04

Natural measures of asymptotically autonomous systems

Julian Newman

Abstract

Although chaotic attractors for autonomous dynamical systems show sensitive dependence on initial conditions, they also typically support a "physical" or "natural" measure that characterises the statistical behaviour of almost all initial conditions near the attractor with respect to a background measure such as Lebesgue. I will discuss notions of "natural measures" for nonautonomous systems that limit to an autonomous system as time tends to negative infinity. (This can then be used to define "tipping probabilities" for deterministic systems with multiple attractors subject to a real-time parameter-shift.) Heuristically, the idea is to start with a natural measure of the past-limiting autonomous system and then "evolve it forward in time, starting at time negative infinity, under the nonautonomous system"; we consider when it is possible to make this concept rigorous.

MS 05.04 – Dynamics of urban complexity: infrastructural entanglements

Organizers – Ulysses Sengupta, Deljana Iossifova

MS 05.04.01

Infrastructuring as Caring: Transforming Infrastructural Entanglements

Yahya Gamal

Abstract

The notion of infrastructural entanglements describes the relationships and correlations that practices of infrastructuring engender between components of infrastructural configurations and other social, ecological, political, or otherwise defined systems. Infrastructuring is at the heart of socio-spatio-eco-technical transformations that often have negative outcomes over time. The absence, presence and transformation of infrastructure is prone to (re-)producing socioecological injustices in the short- and long term. In view of the climate emergency and lurking socio-economic crises, I argue that systemic and transdisciplinary approaches are fundamental to the design of research and interventions in current infrastructural dynamics. Whether and how interventions transform infrastructural entanglements towards greater sustainability is essentially an ethical question. To become sustainable, infrastructuring (as a transformative process) must be aligned with the ethico-political position of caring.

MS 05.04.02

Exploring the linkages between formal and informal solid waste management in developing countries through a system dynamics approach

Denise P. Lozano Lazo, Alexandros Gasparatos

Abstract

Most cities in the developing world continue to experience difficulties related to solid waste management (SWM). In these developing contexts formal SWM systems are still struggling with performance issues and an inability to serve urban residents properly. Moreover, pressures such as accelerated urbanization, unplanned growth and social inequalities are posing additional challenges, contributing to higher sustainability impacts from the underperformance of formal SWM system. Amid this situation, informal waste management initiatives are a common response to fill the gaps in formal service provision in poorly served areas of developing cities, or as an income generation opportunity, particularly for the poorer segments of society.

The present study aims to map the main linkages of the formal and informal subsystems in the SWM system in a developing city experiencing accelerated urbanization. The focus is Santa Cruz de la Sierra, the largest city of Bolivia, which has experienced large but also unplanned growth over the past decades. Data gathered through interviews, participatory modelling sessions with local stakeholders, and participatory observation, was used to map causal relationships throughout SWM formal and informal activities in the city, and consolidated through causal loop diagrams. Subsequently, the possible effects of different policy scenarios in the formal and informal SWM systems were evaluated through a system dynamics model, in order to understand the outcomes and trade-offs for both subsystems in each scenario.

MS 05.04.03

Where is the Complexity? Exploring the Theoretical Frameworks in Simulative Urban Modelling

Anis Alsharif, Manchester Metropolitan University

Abstract

Complexity theories have been incorporated into urban planning research to describe dynamic and temporal urban processes demonstrating adaptive, anticipatory and emergent phenomena for some time. Related computational urban models have moved on from the initial experiments testing hypotheses based on existing theories of cities. By moving away from aggregation-based models, and due to the growing popularity of data-driven simulative approaches, 'Simulative Urban Models' (SUMs) have increasingly embraced bottom-up approaches and decentralised urban dynamics. Despite the shift away from tests on generalised theories of cities, the configuration of SUMs still implicitly or explicitly operationalises theories at various stages/points. The assumptions incorporated from these theories can bias or limit model-based approaches in terms of their ability to engage with complexity in urban systems. This paper presents a new analytical framework to understand the range and point of incorporation of theories within SUMs. Previous attempts have discussed methods - under different disciplinary and multi-disciplinary contexts - ranging from quantitative urban modelling and system dynamics to mathematical spatial models. The focus of this new analytical framework is specifically on the theories in SUM methodologies within urban spatial planning, excluding transport modelling. Through the development of this framework, we trace the use of theories within SUM methodological development over time to understand their role. While there are several current operational 'computer-based geographical simulative urban modelling frameworks' being used to support urban spatial research - reflecting the range of theories utilised - specific engagement with complexity theories remains unclear. Our attempt to explore genuine engagement with complexity is based on a comprehensive understanding of the historic development and current theories utilised within existing SUMs.

MS 05.04.04

Land Market Preferences in Formal-informal Contexts: Urban Segregation Emergent Patterns

Yahya Gamal

Abstract

The evolution of cities in terms of land use entails complex land market procedures between buying and selling actors. The actors have (1) different underlying motivations to participate in land markets and (2) different preferences towards the land plots' physical attributes. Motivations and preferences are based on each individual's experience and expectations which are subject to social, economic and cultural aspects.

In this study, I explore such motivations towards participating in formal-informal land markets in Cairo, Egypt. I abstract these motivations into four observable categories. Further, I propose a quantitative aggregation for such motivations to describe land market preferences. I incorporate such approach in a land use Agent Based Model (ABM) for Cairo, and I run a set of exploratory simulations to understand the complex effect of formal-informal land markets on land use change. The results indicate a set of emerging patterns of socio-economic segregation due to market preferences.

MS 05.04.05

Uncovering the hidden social dynamics behind disaster decreeing in Brazil

Norma Valencio

Abstract

Disaster decrees are legal dispositifs adopted by public administration to deal with the multidimensional losses and damages triggered by an extreme or rare event. These dispositifs are designed to restore the communitarian social-spatial features to the state preceding the crisis and to increase the local resilience towards similar threats in future. However, in Brazil, the disaster decreeing presents an abnormal dynamic. In this country, the frequency of disaster decreeing is consistently high (over 25% of the municipalities declaring disasters per year, on average, since 2003), and shows spatial clusters of recurrence. This anomaly, due to its constancy, should not be explained by the characteristics of the associated event, but instead by the systemic failure in the institutional and communitarian capacity to deal with it. Hence, in this work, we evaluate the dynamics of disasters decrees in Brazil in the period 2003-2022, per event type, comparing with parameters of social, economic and infrastructure natures. For this, we use the Causal Mutual Information toolbox to assess both the shared information and the flow of causal information between variables. The national panorama is defined and them we zoom in to a case of particular interest, which is the intersection of Belo Horizonte metropolitan region with the Rio das Velhas watershed.

Contributed Talks

Monday 22nd August

CT 01 - Machine-learning based modelling & prediction (Part i)

CT 01.01

Evaluation of a data-driven model using reservoir computing from dynamical system point of view

Kengo Nakai[1], Miki U. Kobayashi[2], Yoshitaka Saiki[3], Natsuki Tsutsumi[3,4]

[1]Tokyo University of Marine Science and Technology, Japan. [2]Rissho University, Japan. [3]Hitotsubashi University, Japan. [4]ALBERT, Japan

Abstract

It has been reported that reservoir computing is effective in the inference of time-series and some characteristics [1]. A reservoir is a recurrent neural network whose internal parameters are not adjusted to fit the data in the training process. What is done is to train the reservoir by feeding it an input time-series and fitting a linear function of the reservoir state variables to a desired output time-series.

We have succeeded in modeling a macroscopic behavior of a three-dimensional chaotic fluid flow, which requires only past time-series data as training data [2,3]. A single model can infer short time behaviors from various initial conditions. The model also generates statistical properties which mimic the original ones. However, it is not clear to what extent a model constructed by reservoir computing can capture dynamical structures. In this talk we construct a model from training time-series of dynamical system with tangencies between stable and unstable manifolds or hetero-chaos, coexisting of invariant sets of different number of unstable dimensions. We confirm that these dynamical properties as well as fixed points and periodic orbits can be reconstructed by reservoir computing. This talk is based on [4,5].

1. Z.Lu, J.Pathak, B.Hunt, M.Girvan, R.Brockett, and E.Ott, Reservoir observers: Model-free inference of unmeasured variables in chaotic systems, Chaos 27, 041102 (2017)
2. K.Nakai and Y.Saiki, Machine-learning inference of fluid variables from data using reservoir computing, Phys.Rev.E, 98, 023111 (2018)
3. K.Nakai and Y.Saiki, Machine-learning construction of a model for a macroscopic fluid variable using the delay-coordinate of a scalar observable, Discrete Contin.Dyn.Syst S14, 1079 (2021)
4. M.Kobayashi, K.Nakai, Y.Saiki, and N.Tsutsumi, Dynamical system analysis of a data-driven model constructed by reservoir computing, Phys.Rev.E 104, 044215:1-7 (2021)
5. M.Kobayashi, K.Nakai, and Y.Saiki, Reconstruction of hetero-chaos by a data-driven model using reservoir computing (in preparation)

CT 01.02

Predicting high-dimensional heterogeneous time series employing generalized local states

Sebastian Baur[1], Christoph Räth[1,2]

[1]Deutsches Zentrum für Luft und Raumfahrt, Germany.
[2]Ludwig-Maximilians-Universität München, Germany

Abstract

Tremendous advances in predicting the behavior of complex systems have been made in recent years by applying machine learning.

For high-dimensional systems, these machine learning methods often suffer from the "curse of dimensionality" meaning that the number of nodes of the network has to be considerably larger than the dimensionality of the input data rendering the training unfeasible with a naive approach.

With a parallel prediction scheme based on local states (LS), however, the forecasting of high-dimensional chaotic spatiotemporal systems of arbitrarily large extent becomes possible [1]. The definition of LS relies on defining spatial local neighborhoods, thus the knowledge of the position of the time series in space is a necessary prerequisite for defining LS.

Yet, the similarity of time series can also be defined in a much more general way by deducing a distance measure and thus a local neighborhood from the correlations among the time series. We employ this approach to define generalized local states (GLS) for the prediction of high-dimensional systems with which some of the shortcomings of the LS approach can be overcome [2].

First, GLS can make excellent predictions in the case of mixed systems, where LS are doomed to fail. In our examples GLS is even able to infer the different origins of a set of heterogeneous time series, for which the generating processes are unknown.
Second, prediction of high-dimensional systems remains feasible when no spatial information is available. This is more and more the typical case in real world applications, when analyzing such heterogeneous data sets like remote sensing data, financial data, social media data, etc.

[1]   Pathak, Jaideep, et al. "Model-free prediction of large spatiotemporally chaotic systems from data: A reservoir computing approach." PRL (2018)

[2]   Baur, Räth. "Predicting high-dimensional heterogeneous time series employing generalized local states." PRR (2021)

Numerical Integration of stiff ODEs and DAEs with Physics-Informed Shallow Random Projection Machine Learning

Gianluca Fabiani[1], Evangelos Galaris[2], Lucia Russo[3], <u>Constantinos Siettos</u>[4]

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[2]Dept. of Mathematics and Applications, University of Naples Federico II, Italy.
[3]Institute of Science and Technology for Energy and Sustainable Mobility, Consiglio Nazionale delle Ricerche, Italy.
[4]Dept. of Mathematics and Applications & Scuola Superiore Meridionale, University of Naples Federico II, Italy

Abstract

Machine learning has been used for the numerical solution of time-dependent differential equations (ODEs and PDEs) as an alternative to classical numerical analysis methods. Over the last few years the interest in developing new machine-learning and deep-learning methods to solve stiff, high-dimensional and complex problems has been renewed. In particular, physics informed machine learning has been recently addressed to overcome the curse of dimensionality in the training of deep learning networks, thus incorporating knowledge on the physics. Here, we show how how shallow random projections within the framework of physics-informed framework can be used to efficiently solve difficult time-dependent differential systems including stiff ODEs, DAEs and systems of PDEs resulting from the discretization in space with e.g. Finite Differences. Importantly, we show that the proposed numerical method outperforms in several cases well established numerical integrators for stiff systems both in terms of numerical accuracy and computational cost.

CT 02 - Networks

CT 02.01

Evolutionary optimization of networks towards complexity: graph connectivity evolution driven by complexity measures as fitness functions

Archan Mukhopadhyay, Jens Christian Claussen

University of Birmingham, United Kingdom

Abstract

Do we understand what comprises complexity? The apparent complexity of biological and social interaction networks is commonly highlighted as emerged from evolutionary processes, on subsequent levels [1]. But how can complexity of a graph, discarding both regularity and randomness, be defined? Is a complex topology beneficial (from logistics to neural synchronization)?

Here we approach graph complexity from a novel and unique framework [2]: using one of the proposed complexity measures as fitness function for an evolutionary optimization process: what network structures will result? In this framework, we use one complexity measure (as Offdiagonal Complexity [3], Medium Articulation, Cr or Ce, among others [4]) as fitness function and evaluate the emerged graph topologies by the other complexity measures. While some complexity measures evolve towards common goals, we also observe counterintuitive cases resulting in regular graphs. Finally, we investigate the dynamics of synchronization processes as a function of network complexity.

References

[1] J Maynard Smith and E Szathmary (1997), The major transitions in evolution

[2] Archan Mukhopadhyay and Jens Christian Claussen (2022, in preparation)

[3] Jens Christian Claussen 2007, Offdiagonal Coplexity, Physica A 375,365

[4] Kim and Wilhelm 2008, What is a complex graph, Physica A 387, 2637

CT 02.02

Controlling collective behavior of network dynamics against link modifications

Sajjad Bakrani[1], Narcicegi Kiran[1], Tiago Pereira[2,3], Deniz Eroglu[1]

[1]Kadir Has University, Turkey
[2]University of Sao Paulo, Brazil
[3]Imperial College London, United Kingdom

Abstract

The precise control of network dynamics can only be achieved by understanding the effect of systems' components, such as intrinsic dynamics and network topology. Our particular interest in this direction is understanding the response of collective dynamics (e.g., synchronization) of chaotic oscillators on complex networks to link modifications, especially when enhancing the connectivity of a network not only does not improve the collective dynamics but also results in hindering it. This counter-intuitive phenomenon (also known as Braess's paradox) becomes important in applications when extra connections are added in favor of observing a more robust collective behavior. We study this problem for two common network motifs: cycles and stars. We consider a weakly connected digraph containing these two motifs and investigate the scenarios in which adding extra links, which makes the graph strongly connected, hinders the collective behavior. To do this, we study the spectral properties of the graph Laplacians, particularly the spectral gap, and analyze how adding links affects the spectral gap of the Laplacian matrix.

CT 03 - Modelling

CT 03.01

The cavity method for minority games on financial markets

Tim Ritmeester, Hildegard Meyer-Ortmanns

School of Science, Jacobs University Bremen, Germany

Abstract

We use the cavity method from statistical physics for analyzing the transient and stationary dynamics of a minority game that is played by agents performing market arbitrage. On the level of linear response the method allows to include the reaction of the market to individual actions of the agents as well as the reaction of the agents to individual information items of the market, from which we derive a self-consistent solution to the minority game. In particular we analyze the impact of general nonlinear price functions on the amount of arbitrage if noise from external fluctuations is present. We identify the conditions under which arbitrage gets reduced due to the presence of noise. When the cavity method is extended to time dependent response of the market price to previous actions of the agents, the individual contributions of noise from external fluctuations in price and information and from noise due to the choice of strategies can be pursued in the transient dynamics until a stationary state is reached and in a zoom into the stationary dynamics. In contrast to a Curie-Weiss level of a mean-field approach, the market response included by the cavity method captures the realistic feature that the agents may have a preference for a certain choice of strategies without getting stuck to a single choice. The failure of the method in the critical regime reveals a possible mechanism that induces a transition to a phase with strong outliers in the volatility.

References

T. Ritmeester and H. Meyer-Ortmanns, J. Stat. Mech. 043403~1-38 (2022).

T. Ritmeester and H. Meyer-Ortmanns, Physica A 573, 125927~1-19 (2021).

CT 03.02

Analysis of the Football Transfer Market Network

Tobias Wand

WWU Münster, Germany. CeNoS Münster, Germany

Abstract

Football clubs buy and sell players for millions of Euros and until Covid, their combined transfer values were growing steadily at an impressive rate. Instead of analysing their aggregated transfer activities, one can take a look at the topology of the network of player transfers: complex networks have already been used in various sciences and provide a novel approach to investigate the football transfer market network and in particular the impact of Covid on the football transfer market [1].

References

[1]   T. Wand, "Analysis of the Football Transfer Market Network". J Stat Phys 187, 27 (2022).

CT 03.03

Efficacy and neighbourhoods, or how the community's actions affect crime rates.

Laura Jones, David Lloyd, Ian Brunton-Smith

University of Surrey, United Kingdom

Abstract

What if residents of a neighbourhood could influence crime rates through their behaviour? This is what postulates the theory of collective efficacy. Collective efficacy is the conviction shared by a group of people that they can work together to successfully complete a specific task. The idea is that the difference in neighbourhoods' inner structure leads to spatial variation in crime rates. Many models exist that show the negative link between collective efficacy and crime but the literature in studying the formation of patterns is still limited. We present a novel convolution model of collective efficacy that allows for a mathematical investigation of neighbourhood and resource effects on the formation of collective efficacy and transitions between different regions of collective efficacy.

CT 03.04

Dynamics of particle aggregation in de-wetting films of complex liquids

Junzhe Zhang, David Sibley, Dmitri Tseluiko, Andrew Archer

Loughborough University, United Kingdom

Abstract

We consider the dynamic wetting and de-wetting processes of films and droplets of complex liquids, focusing on the case of colloidal suspensions, where the particle interactions cause agglomeration. This leads to complex dynamics within the liquid and of the liquid-air surface. Incorporating concepts from thermodynamics, we construct a model consisting of a pair of coupled partial differential equations that represent the evolution of the liquid film and the effective colloidal height profiles using the thin-film approximation. The model extends to also include mass transfer effects due to solvent to evaporation and condensation. We determine the relevant phase behaviour of the uniform system, including finding associated binodal and spinodal curves, helping to uncover how the emerging behaviour depends on the particle interactions. Performing a linear stability analysis of our system enables us to identify parameter regimes where agglomerates form, which we independently confirm through numerical simulations. We obtain various dynamics such as uniform colloidal profiles in an unstable situation evolving into agglomerates and thus elucidate the interplay between evaporation, de-wetting and particle aggregation in complex liquids on surfaces.

CT 04 - Life Sciences (Part i)

CT 04.01

Ramp Function Approximations of Michaelis-Menten Functions in a Model of Plant Metabolism

Skye Dore-Hall, Roderick Edwards

University of Victoria, Canada

Abstract

Adams, Ehlting, and Edwards showed that in a model of plant phenylalanine metabolism following Michaelis-Menten kinetics, there are two mechanisms by which primary metabolism can be prioritized over secondary metabolism when input is low: the *Precursor Shutoff Valve* (PSV) and threshold separation. Analysis of the model was made difficult due to the presence of the Michaelis-Menten terms; hence, it is worth considering whether linear approximations of these terms can be used to both simplify the model and keep its qualitative behaviour intact. In this talk, we will introduce piecewise approximations of Michaelis-Menten functions called *ramp functions*. We will show that when the Michaelis-Menten terms are replaced by ramp functions in the model, the PSV is completely effective when it comes to the prioritization of primary metabolism under low input conditions, while threshold separation is effective when the PSV is absent, but only if the threshold constant of the secondary metabolic pathway is sufficiently larger than that of the primary pathway.

CT 04.02

Regulation of stem cell dynamics through volume exclusion

Rodrigo García-Tejera, Linus Schumacher, Ramon Grima

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Abstract

Maintenance and regeneration of adult tissues rely on the self-renewal of stem cells. Enabling regeneration without over-proliferation requires precise regulation of the stem cell proliferation and differentiation rates. The nature of such regulatory mechanisms in different tissues, and how to incorporate them in models of stem cell population dynamics, is incompletely understood. The critical birth-death (CBD) process is widely used to model stem cell populations, capturing key phenomena, such as population asymmetry and scaling laws in clone size distributions. However, the CBD process neglects regulatory mechanisms. Here, we propose the birth-death process with volume exclusion (vBD), a variation of the birth-death process that takes into account crowding effects, such as may arise due to limited space in a stem cell niche. While the deterministic rate equations predict a single non-trivial attracting steady state, the vBD master equation predicts extinction and a transient distribution of stem cell numbers that can be bimodal. We investigate the accuracy of the system-size expansion (including finite size corrections to the linear-noise approximation), the quasi-steady state approximation, and the WKB method to approximate the probability distribution solution of the vBD master equation, as well as the mean extinction time. Our study suggests that the size distribution of a stem cell population and its extinction dynamics bear signatures that may be useful to detect negative feedback mediated via volume exclusion.

The fundamental benefits of multiplexity in ecological networks

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Abstract

From a dynamical point of view, 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 parameter drifts can drive various ecological systems towards a tipping point. Discovering natural and engineering mechanisms to mitigate or delay a tipping point is of considerable interest. We investigate the dynamics of tipping point in multilayer ecological networks supported by mutualism and uncover a natural mechanism that can postpone the occurrence of a tipping point: multiplexity. In particular, for a double-layer mutualistic system of pollinators and plants, coupling between the network layers naturally occurs when there is migration of certain pollinator species from one layer to another. Multiplexity emerges as the migrating species establish their presence in the target layer and therefore have a simultaneous presence in both layers. We demonstrate that the new mutualistic links induced by the migrating species with the residence species have some fundamental benefits to the well being of the ecosystem such as delaying the tipping point and facilitating species recovery. The implication is that articulating and implementing control mechanisms to induce multiplexity can be of significant value to sustaining certain types of ecosystems that are or will be in danger of extinction as the result of environmental changes.

CT 04.04

How can contemporary climate research help understand epidemic dynamics? -- Ensemble approach and snapshot attractors

Tamás Kovács

Institute of Physics, Eötvös University, Budapest, Hungary

Abstract

Standard epidemic models based on compartmental differential equations are investigated under continuous parameter change as external forcing. We show that seasonal modulation of the contact parameter superimposed upon a monotonic decay needs a different description from that of the standard chaotic dynamics. The concept of snapshot attractors and their natural distribution has been adopted from the field of the latest climate change research. This shows the importance of the finite-time chaotic effect and ensemble interpretation while investigating the spread of a disease. By defining statistical measures over the ensemble, we can interpret the internal variability of the epidemic as the onset of complex dynamics—even for those values of contact parameters where originally regular behaviour is expected. We argue that anomalous outbreaks of the infectious class cannot die out until transient chaos is presented in the system. Nevertheless, this fact becomes apparent by using an ensemble approach rather than a single trajectory representation. These findings are applicable generally in explicitly time-dependent epidemic systems regardless of parameter values and time scales.

CT 05 - Stochastic Dynamics

CT 05.01

Extended Poisson-Kac theory: A unifying framework for stochastic processes with finite propagation velocity

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[2]The Francis Crick Institute, London, United Kingdom.
[3]Queen Mary University of London, School of Mathematical Sciences, United Kingdom

Abstract

We present a theoretical framework for stochastic processes possessing physically realistic finite propagation velocity [1]. Our approach is motivated by the theory of Levy walks, which we embed into an extension of conventional Poisson-Kac processes. The resulting extended theory employs generalised transition rates to model subtle microscopic dynamics, which reproduces non-trivial spatio-temporal correlations on macroscopic scales. It thus enables the modelling of many different kinds of dynamical features, as is illustrated by three examples.

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CT 05.02

Minimal invariant sets of Random Dynamical systems with bounded noise

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Imperial College London, United Kingdom

Abstract

The theory of dynamical systems is pivotal in real-world applications ranging from computer algorithms to weather prediction. Realistically, there exists uncertainties or random noises, which translated to the study of random dynamical systems. Consider a discrete-time dynamical system with bounded noise where it can be represented by a set-valued mapping. We are interested in changes in the minimal invariant sets under these set-valued mappings. In this talk, we investigate their boundary dynamics which would help in detecting discontinuous changes of the sets. We then look at simple examples of linear maps with bounded noise where the minimal invariant sets are generally non-trivial.

CT 05.03

Construction and application of phase reduction in coherent excitable systems

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Abstract

Noise-induced coherent oscillation in excitable systems is a counterintuitive yet universal phenomenon. Due to the absence of a deterministic limit cycle, the classical phase reduction cannot be applied for reducing the dimensionality, which has hindered deeper theoretical analysis and clearer phenomenological revelation. Here, we established, for the first time, a phase reduction framework for noise-induced oscillations in coherent excitable systems. By applying it to the cases of periodic forcing, mutual coupling and global coupling, it is shown that phase dynamics via our reduced phase equation are in consistent with the results of Monte Carlo simulations.

Tuesday 23rd August

CT 06 - Machine learning-based modelling & prediction (Part ii)

CT 06.01

Data driven reconstruction of spatiotemporal chaos in three-dimensional excitable media

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Abstract

The cardiac muscle is an excitable medium that can exhibit complex dynamics, including spatiotemporal chaos associated with (fatal) cardiac arrhythmias. On a small scale, cardiac tissue consists of interacting cardiac muscle cells embedded in an extracellular matrix. These cells interact electrically and mechanically, and their coherent motion is triggered by the propagation of electrical excitation waves, including spiral or scroll waves. While mechanical motion within the myocardium can be observed with ultrasound, there are no noninvasive techniques (to date) to measure the electrical state within the tissue. Electrical excitation (membrane potential) and intracellular calcium can be measured optically using fluorescent dyes, but only at the surface of Langendorff-perfused isolated hearts. To overcome this limitation of observable quantities, we address the task of predicting the electrical state inside the heart from surface data using data-driven reconstruction by means of artificial neural networks. We study the feasibility of this approach in a homogenous and isotropic excitable medium with spatiotemporal dynamics in three spatial dimensions, applying and comparing different machine learning methods (i.e. LSTM, Convolutional Autoencoder, ...). In the talk, the methods used will be presented and the possibilities and limitations of cross-prediction of spatiotemporal chaos will be discussed.

CT 07 – Characterisation of nonlinear Dynamics (Part i)

CT 07.01

Suppression of quasiperiodicity in circle maps with quenched disorder

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Abstract

We show that introducing quenched disorder into a circle map leads to the suppression of quasiperiodic behavior in the limit of large system sizes. Specifically, for most parameters the fraction of disorder realizations showing quasiperiodicity decreases with the system size and eventually vanishes in the limit of infinite size, where almost all realizations show mode-locking. Consequently, in this limit, and in strong contrast to standard circle maps, almost the whole parameter space corresponding to invertible dynamics consists of Arnold tongues.

CT 07.02

Fisher-Shannon complexity plane using ordinal patterns

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[2]Carleton College, USA

Abstract

Being able to distinguish the different types of dynamics present in a given nonlinear system is of great importance in complex dynamics. It allows to characterize the system, find similarities and differences with other nonlinear systems, and classify those dynamical regimes to understand them better. For systems that develop chaos it is not always easy to distinguish determinism from stochasticity. In analyzing non-invertible maps by projecting them on the two-dimensional Fisher–Shannon plane using ordinal patterns, we find that this technique unveils inner details of the structure underlying the complex and chaotic dynamics of a system, not easily exposed by other methods. It also reveals signatures common to most of the non-invertible maps, and demonstrates its capability to distinguish determinism from stochasticity. We extract some underlying symmetries that allow us to simulate the behavior on the complexity plane for a wide range of the control parameters in the chaotic regimes. The method also unveils the self-similar behavior in chaotic systems.

CT 07.03

Methods and software for estimating basins of attraction of arbitrary dynamical systems

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[2]Nonlinear Dynamics, Chaos and Complex Systems Group, Departamento de Física, Universidad Rey Juan Carlos, Spain

Abstract

Estimating basins of attraction of dynamical systems is useful in the context of multistable systems and tipping points. However, doing so numerically and efficiently is a difficult task. We present a new method for finding attractors and basins of attraction of arbitrary dynamical systems by utilizing recurrences in the state space. This method outperforms naive implementations with ensemble evolution until convergence to attractors. It is also superior to other known alternatives because it requires no knowledge of the attractors, besides an arbitrarily large state space box that may contain the attractors. Our method, among with others, is implemented in DynamicalSystems.jl, a general purpose software for nonlinear dynamics. With it, one can calculate basins of attraction of any dynamical system in less than 10 lines of code using a generic and extendable API. This will be showcased during the talk by running real code for the Julia language.

CT 08 - Inference & modelling

CT 08.01

Nonlinear Dynamics in Vibrational Energy Harvesting Devices

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Abstract

Microscopic Energy Harvesting Devices are designed to convert mechanical energy from ambient vibrations into electrical energy, which is then used to power small electronic devices, for example wireless sensor nodes. In many natural environments, the frequency content and amplitudes of the ambient vibration will either change over time or will be difficult to characterize beforehand. Simple linear devices with a fixed resonance frequency will therefore often not be suitable. Nonlinear vibrational energy harvesting devices promise a high efficiency over a broad range of non-stationary external vibration. However, the nonlinearity also gives rise to complex dynamical features which makes the resulting device difficult to understand and control. For example a number of different energy branches might co-exist, with the most efficient one being "hidden", i.e. not accessible by simple frequency sweeps. Typically branches appear as fixed-points in a suitable Poincare map of the external drive and their stability and existence is governed by bifurcations in the drive parameters.

In this presentation we show how the use of methods from nonlinear dynamics allows us to discover, characterize and access previously hidden high-energy branches. In particular the use of suitable force-displacement diagrams lets us visualize the transacted energy per cycle for a given energy branch both theoretically and experimentally. This allows us to exploit non-linear dynamics to design highly efficient nonlinear energy harvesting devices.

CT 08.02

Robust Causal Inference for Irregularly Sampled Time Series from Dynamical Systems

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Abstract

While equation-based approaches allow us to describe and model different dynamical systems, their limited domain of applicability and validity, especially in nonlinear and non-equilibrium circumstances, has led numerous data-driven approaches to come into play. Among these, causal inference from time series has proved itself as a useful tool for studying the interactions between coupled systems and giving insights into their underlying mechanisms. Although a lot of causality estimation techniques have been proposed for non-linear systems, they usually give spurious results when applied to time series with short length, missing samples and unevenly sampled data. Compression-Complexity Causality (CCC) [1] is a recently proposed causality measure inspired from complexity estimators based on lossless 'data-compression' algorithms and has been found to be robust to the above-mentioned limitations. However, this measure is still limited to scalar time series. To extend CCC applicability to complex real-world systems, which are most-often multi-dimensional, we propose a method that first symbolizes the time-series from an observable of a multidimensional dynamical system based on Taken's method of time-delayed embedding. Time-delayed vectors are transformed into a one-dimensional sequence using permutation or ordinal patterns coding [2]. The combination of permutation coding and CCC enables us to propose and apply the novel 'Permutation CCC (PCCC)' on simulated data. Simulation analyses reveal that PCCC retains the original strengths of CCC and performs much better than some existing state-of-the-art approaches. We apply PCCC to some real-world data from climatology and paleoclimatology with missing samples, irregular sampling and/or short length to make useful inferences about the major drivers of climate on different temporal-scales.

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[2] Bandt, C., & Pompe, B. (2002). Permutation entropy: a natural complexity measure for time series. Physical review letters, 88(17), 174102.

CT 08.03

Non-linear dynamics of an accidental underwater compressed air release

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Abstract

The modeling of the gas release due to an accidental damage in a pressurized gas storage tank is a key element in the risk analysis process. Mathematical models have been used to predict the time-varying discharge rate until the complete draining of the gas volume [1]. These unsteady models take into account the decrease of gas density during the isentropic expansion as well as the transition between sonic and subsonic flow regime when only a small quantity of gas is remaining.

Here we present a new mathematical model for the discharge rate. This model addresses the specific case of a subsonic leakage from a ten-meter high underwater immersed storage tank which contains compressed air. The open-bottom tank in in direct contact with the submarine environment so that tank pressure is governed by the hydrostatic pressure. The unsteadiness of the regime relies on the variation of the volume occupied by the gas in the tank induced by the rising of the liquid interface and the resulting variation of tank pressure in time.

The dynamics of the release is given in terms of the gas height into the tank by solving a non-linear Ordinary Differential Equation.

References

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CT 08.04

Soft hydrogel structures: from surface instabilities to collective behavior

Pawan Kumar, Dezső Horváth, <u>Ágota Tóth</u>

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Abstract

Tubular hydrogel structures are grown in a flow-driven system by injecting acidic polysaccharide solution into an alkaline solution. When the sol-gel transition occurs in the vicinity of the wall, the interplay of adhesive and buoyant forces yields various forms of surface instabilities. The selection of wrinkling, creasing and folding patterns can be governed by solution composition, orientation, and injection rate. In a different scenario, a single drop of fueled polysaccharide solution can lead to the formation of hydrogel beads that can self-propel on the liquid. Collective behavior of these beads results in synchronized patterns.

CT 09 – Life Sciences (Part ii)

CT 09.01

DNA Transport in Micropillar Arrays – Elastic Turbulence Resulting in Macroscopic Ordered Waves

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Abstract

We have studied the formation of ordered waves in microflows of highly concentrated DNA solutions using epifluorescence and polarization microscopy. The DNA solution flows through microfluidic channels with micropillar arrays. Here we observe the dynamics of DNA as a function of flow rate, buffer composition, concentration and molecular length, at low Reynolds numbers and high Elasticity numbers. The waves appear above thresholds in terms of DNA concentration and flow velocity and consist of DNA at higher concentration and extension compared to the bulk solution at zero flow. The waves have two specific orientations and flow directions arranged around the symmetry axis along the microfluidic channel.

We identify elastic effects as central to the origin of the waves. Pairs of vortices occur at the scale of the individual pillars in the array that are not seen in purely viscous flows. These vortex pairs are unstable and it is their shedding in synchronous groups stretching across tens to hundreds of rows of pillars, travelling through the array, that we observe as waves.

The geometry and symmetry of the pillars and the array strongly influence the formation of the waves. Specifically, we see macroscopic waves in quadratic arrays, whereas for arrays with hexagonal geometry we only observe short-range fluctuations. Also the symmetry of the pillars affect the wave formation. While an array with circular pillars exhibit similar wave patterns for two opposite flow directions, an array with triangular pillars results in two different wave patterns consistent with the symmetry of the pillars.
Our work contributes to the understanding of rheology of highly concentrated polymer solutions in microfluidics and opens up for high-throughput handling of complex fluids, something that has long been identified as an important limitation in the field of microfluidics.

Dual-tipping: investigating abrupt state transitions induced by a coupling of rate- and noise-induced effects in a marine ecological system

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Abstract

The interaction between phytoplankton (prey) and zooplankton (predator) in a marine ecosystem can be described by the Truscott-Brindley model, which exhibits two different behaviours depending on the growth rate of the prey. It can be: (1) bistable, having two different stable states with low and high phytoplankton biomass, respectively; (2) in an excitable regime, in which one stable state describing equilibrium between predator and prey exists, with possibility for the formation of phytoplankton blooms as a result of perturbations. In case (1) the influence of noise leads to critical transitions between the steady states as in any other bistable system. In case (2), different critical transitions are possible: a) the application of noise will lead to occasional plankton blooms (occasional excitations of the system); b) without noise a slow change in the growth rate of the prey leads to a rate-induced transition resulting also in the formation of plankton blooms. In our study we combine the two different behaviours by considering fluctuations on the growth rate that cause the system to continually switch between bistability and excitable behaviour. We begin by exploring – in the purely bistable regime - how residence times within the competing attracting states differ according to whether Gaussian white noise or correlated noise is assumed for the stochastic growth rate parameter r, and in parallel look at how these two noise types influence the blooming behaviour for the purely excitable case. We investigate how residence times depend on the mean distance of r to the saddle-node bifurcation (that induces the transition between excitability and bistability) and the size of its typical deviations from this position. Finally, we present results on the combination of rate- and noise-induced critical transitions, performing in addition time-dependent changes to the mean distance from the bifurcation point and the size of typical deviations.

A Simple Mathematical Model for the COVID-19 Outbreak and Its Applications

Roman Cherniha, Vasyl' Davydovych,

Institute of Mathematics of NAS of Ukraine, Ukraine.

Abstract

A mathematical model based on a dynamical system in the form of nonlinear ordinary differential equations is proposed for quantitative description of the outbreak of the novel coronavirus pandemic. The model possesses remarkable properties, such as as full integrability and exact solutions in an explicit form. The comparison with the public data shows that exact solutions of the model (with the correctly specified parameters) lead to the results, which are in good agreement with the measured data in China during the first wave. Prediction of the total number of the COVID-19 cases is discussed and examples are presented using the measured data in Austria, Poland and Ukraine. A generalization of the model in order to take into account the space distribution of the COVID-19 cases is suggested as well. The talk is based on the recent papers published by the authors in Symmetry 2020, 12, 990. **https://doi.org/10.3390/sym12060990**

CT 09.04

Nonlinearity, chaos and bubbles in DNA molecules

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Abstract

We numerically simulate the dynamics of DNA through the coarse-grained nonlinear Peyrard-Bishop-Dauxois (PBD) model [1], and investigate the phenomenon of "bubbles", thermal openings in the DNA double strand. Certain of these bubbles are posited to play an important role as a dynamical factor in DNA transcription, with a propensity to form near some transcription binding sites [2]. We study various aspects of these bubbles and the nonlinearity of the strand, using a rationally-determined definition for determining the open/closed state of a base pair [3]. These aspects include the inherent lifetimes and occurrence probabilities of bubbles in random sequences as well as viral and bacterial promoters [4], and further timescale studies of out-of-equilibrium fluctuations in the double strand. These results are additionally discussed in the context of the chaotic dynamics inherent to the nonlinear model.

References

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CT 10 – Syncronisation (Part i)

CT 10.01

Normalized multivariate phase locking in electroencephalographic recordings from epilepsy patient

Anaïs Espinoso, Ralph G. Andrzejak

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Abstract

Multivariate quantitative analysis allows one to characterise the dynamics underlying signals from multi-channel electroencephalographic (EEG) recordings. We here use a quantity often referred to as Kuramoto order parameter to assess the degree of locking of a set of L phases. The expected value of this measure for a set of independent phases is non-zero and depends on L. This is important to keep in mind in the application to EEG recordings, where L is given by the number of channels. This number varies not only across patients, but also when only subsets of channels are analysed. Therefore, we use the value expected for L independent phases to define a normalized multivariate phase locking (μ). First, we study the measure under controlled conditions with a network composed of non-identical Rössler oscillators coupled mutually with a certain link probability. The technique's sensitivity for the coupling is measured by analysing multiple realizations for different link probabilities. The results show that the technique's performance depend on several parameters: number of nodes, frequencies of the nodes, noise, among others. In the second part, we analyse one hundred multi-channel intracranial EEG seizure recordings from sixteen epilepsy patients. We use the Hilbert transform to extract the instantaneous phase and determine μ for each time sample to see the temporal evolution of this measure along the seizure. We find a variety of spatiotemporal patterns of μ across the seizures. In general, there is an increase of synchronization of all channels when the seizure starts. Furthermore, in some cases, a low level of synchronization is obtained during the seizure. In many cases, after the end of the seizure, there is a pronounced hypersynchronous activity. In conclusion, conceptually simple and easy to compute signal analysis techniques can help to study the evolution of seizures.

Phase and amplitude response inference from observations

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Abstract

We propose a method for inferring phase-amplitude dynamics from observations of perturbed limit cycle oscillators, as a natural extension to the phase inference method [Cestnik-Rosenblum, Sci. Rep. 8, 13606 (2018)]. We compare it to several methods used in recent literature, in particular the commonly used Hilbert embedding approach. By testing on example oscillators where the ground truth is known we can clearly highlight the advantages and limitations of each technique. For uses on experimental data, we additionally describe how to asses inference quality by evaluating how well the model can reproduce observations. As a realistic example we also test all the methods on observations of a chaotic oscillatory ensemble.

CT 10.03

Critical parameters of the synchronisation's stability for coupled maps in regular graphs

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Abstract

Coupled Map Lattice (CML) models are particularly suitable to study spatially extended behaviours, such as wave-like patterns, spatio-temporal chaos, and synchronisation. Complete synchronisation in CMLs emerges when all maps have their state variables with equal magnitude, forming a spatially-uniform pattern that evolves in time. Here, we derive critical values for the parameters – coupling strength, maximum Lyapunov exponent, and link density – that control the synchronisation-manifolds linear stability of diffusively-coupled, identical, chaotic maps in generic regular graphs (i.e., graphs with uniform node degrees) and class-specific cyclic graphs (i.e., periodic lattices with cyclical node permutation symmetries). Our derivations are based on the Laplacian matrix eigenvalues, where we give closed-form expressions for the smallest non-zero eigenvalue and largest eigenvalue of regular graphs and show that these graphs can be classified into two sets according to a topological condition (derived from the stability analysis). We also make derivations for two classes of cyclic graph: k-cycles (i.e., regular lattices of even degree k, which can be embedded in Tk tori) and k-Möbius ladders, which we introduce here to generalise the Möbius ladder of degree k=3. Our results highlight differences in the synchronisation manifold's stability of these graphs – even for identical node degrees – in the finite size and infinite size limit.

Thursday 25th August

CT 11 – Fluid Dynamics

CT 11.01

A minimal phase-coupling model for intermittency in turbulent systems

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Abstract

Turbulent systems exhibit a remarkable multi-scale complexity, in which coherent, intense, and rare events in the velocity gradients induce scale-dependent statistics with strong departures from Gaussianity – a phenomenon known as intermittency. Correspondingly, in Fourier space, phase correlations can give rise to complex scale-dependent properties, as the one developed in the presence of coherent shocks. A quantitative relation between real-space structure, statistics, and phase synchronization is currently missing. Here, we address this problem in the framework of a minimal phase-coupling model which enables a detailed investigation by means of dynamical systems theory and multi-scale high-resolution simulations. The model is formulated in terms of Fourier phases whose dynamical coupling resembles the one in Navier-Stokes turbulence. Specifically, it is Burgers turbulence with the important distinction that the amplitudes are kept at fixed values such that only the Fourier phases evolve. By changing the spectrum slope α we can tune the coupling strength of the phases and study how the intermittency of the underlying velocity field changes. We find that both very steep and very shallow spectra exhibit close-to-Gaussian statistics, while strong departures from Gaussianity are observed for intermediate slopes comparable to the ones in hydrodynamic and Burgers turbulence. We show that the non-Gaussian regime of the model coincides with a collapse of the dynamical system to a lower-dimensional attractor and the emergence of phase synchronization, thereby establishing a dynamical-systems perspective on turbulent intermittency.

CT 11.02

Linear versus nonlinear transport during chaotic advection in fluid flows

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Abstract

Presented is a study on the explicit demarcation of the region of validity of a linear canonical representation for chaotic advection of Lagrangian fluid parcels in "chaotic seas" in two-dimensional (2D) and three-dimensional (3D) time-periodic fluid flows governed by Hamiltonian mechanics. The concept of lobe dynamics admits exact geometric demarcation of this region of validity and, inherently, distinction of the portions of chaotic seas with essentially linear versus nonlinear Lagrangian transport. This furthermore admits explicit establishment of a topological equivalence between the (embedded) Hamiltonian structure of the Lagrangian dynamics in 2D (3D) flows and their canonical form. The linear transport region in physical space encompasses four adjacent subregions that each correspond with one of the four quadrants in canonical space and may exchange material with their environment in two essentially nonlinear ways. First, exchange between quadrants within the linear transport region and, second, exchange with the exterior of this region. Both forms of exchange can be linked to specific subsets of material elements defined by interacting lobes and combined give rise to a circulation through the quadrants of the linear transport region that systematically exchanges material with the exterior.

CT 11.03

2D invariant manifolds in 3D flows: perturbed locations under general perturbations and instantaneous flux

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Abstract

This talk introduces a geometric Melnikov method to analyze two-dimensional stable or unstable manifolds associated with a saddle point in three-dimensional non-volume preserving autonomous systems. The time-varying perturbed locations of such a manifold is obtained under very general, non-volume preserving and with arbitrary time-dependence, perturbations. The explicit computability of the leading-order spatio-temporal location of the manifold is demonstrated. In unperturbed situations with a two-dimensional heteroclinic manifold, the theory is adapted to quantify the splitting into a stable and unstable manifold, and thereby obtain an instantaneous flux quantification in terms of a Melnikov function. The time-varying instantaneous flux theory does not require any intersections between perturbed manifolds, nor rely on descriptions of lobe dynamics. The theory has specific application to transport in fluid mechanics, where the flow is in three dimensions and flow separators in forward/backward time are two-dimensional stable/ unstable manifolds. Separators and transport are computed for both the classical and the swirling versions of Hill's spherical vortex. This work is in collaboration with Sula Priyankara and Erik Bollt.

CT 11.04

Dynamics-based Machine Learning Of Transitions In Couette Flow

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Abstract

We present a low-dimensional reduced-order model for one of the canonical shear flows, plane Couette flow. Above a certain Reynolds number, this flow admits nontrivial equilibrium solutions, which can be viewed as fixed points in the phase space of velocity fields. These solutions, called exact coherent states (or ECSs), are the building blocks that organize general, more complicated flows. Several reduced-order models have been proposed to capture the ECSs and the connecting orbits between them. Examples include truncated modal projections of the governing Navier Stokes equations or, more recently, methods motivated by machine learning. However, while projection-based approaches can capture relevant ECSs, it is a priori unclear how many modes need to be considered.

On the other hand, popular data-driven methods, such as Dynamic Mode Decomposition (DMD), cannot describe coexisting ECSs. Spectral submanifolds (SSMs) theory offers an alternative for reduced-order modeling. Recently, these invariant manifolds were extracted purely from measurement data. Here we apply these results to construct SSMs of simple ECSs of shear flows. We show that certain scalar functions of the flow can successfully parametrize the most important SSMs. These scalar functions are the energy input and output rate and, hence, have direct physical relevance. The low-dimensional SSMs we extract from data serve as connections between the coexisting fixed point ECSs. By restricting the dynamics to these SSMs, we obtain accurate reduced-order models, capturing all asymptotic states of the full Navier Stokes equations.

We emphasize, however, that many of these features are universal among all canonical shear flow configurations. In particular, a similar approach might apply to pipe flow, where efficient reduced-order models could help explain some aspects of the subcritical transition to turbulence.

CT 11.05

Experimental study of the beads-on-string structure during viscoelastic filament stretching with digital holography

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Abstract

Viscoelastic fluids are currently used for a wide variety of applications in food, chemical, cosmetics and pharmaceutical industries. They are dilute or semi-dilute solutions of high-molecular-weight polymers. For some concentrations, the controlled stretching of the fluid leads to the formation of beads-on-string structures which are characterized by drops connected by a filament. In our case, the controlled extension of the viscoelastic fluid is achieved thanks to an in-house filament stretching device. In order to analyse the 3D dynamic of the beads-on-string structure, i.e. to measure the displacement and the velocity of the bead-like drops during and after the stretching process, we use double exposure Holographic imaging. Holography allows us to choose a 3D volume of space to capture the entire phenomenon. Thanks to Holography, we can focus on one or several planes along the optical axis in order to estimate the 2D coordinates of beads in each plane. The computation of these planes leads to a reconstructed volume where the 3D displacements of beads along the x, y and z axes can be extracted. The dynamic of beads-on-string structures may depend on several factors which are linked to the fluid properties but also to the initial state and elongation parameters. The aim of this work is to experimentally identify the factors which are appropriate to observe a repeatable beads-on-string structure before studying the influence of an orthogonal air current.

CT 12 – Characterisation of nonlinear dynamics (Part ii)

CT 12.01

An inflated dynamic Laplacian to discover the formation and dissipation of coherent sets

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Abstract

Finite-time coherent sets (FTCSs) are distinguished regions of phase space that resist mixing with the surrounding space for some finite period of time; physical manifestations include eddies and vortices in the ocean and atmosphere. The boundaries of finite-time coherent sets are examples of Lagrangian coherent structures (LCSs). The selection of the time duration over which FTCS and LCS computations are made in practice is crucial to their success. If this time is longer than the lifetime of coherence of individual objects then existing methods will fail to detect the shorter-lived coherence. It is of clear practical interest to determine the full lifetime of coherent objects, but in complicated practical situations, for example a field of ocean eddies with varying lifetimes, this is impossible with existing approaches. Moreover, determining the timing of emergence and destruction of coherent sets is of significant scientific interest. In this talk I will introduce new constructions to address these issues. The key components are an inflated dynamic Laplace operator and the concept of semi-material FTCSs. We make strong mathematical connections between the inflated dynamic Laplacian and the standard dynamic Laplacian [Froyland, 2015], showing that the latter arises as a limit of the former. The spectrum and eigenfunctions of the inflated dynamic Laplacian directly provide information on the number, lifetimes, and evolution of coherent sets. The new computational methods will be illustrated with examples from fluid flow and geophysical data sets.

CT 12.02

Characterizing chaos in Hamiltonian systems subjected to parameter drift

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Abstract

In low-dimensional Hamiltonian systems subjected to parameter drifts we show, based on papers [1, 2, 3], that the dynamics can best be understood by following ensembles of initial conditions corresponding to KAM tori of the initial (drift-free) system. When such ensembles are followed, torus-like objects called snapshot tori are obtained, which change their location and shape. Sub-ensembles corresponding to chaotic seas of the drift-free problem can also be followed in any scenario. We call these sub-ensembles snapshot chaotic seas, while the joint ensemble of them and of the tori is called the snapshot phase portrait. After some time, most of the tori break up and become entrained into the snapshot chaotic seas. Such chaotic seas are shown to be foliated by time-dependent unstable and stable foliations, supporting time-dependent Smale horseshoes. The average pairwise distance initiated on an original torus hardly changes in time at first, but crosses over into an exponential growth when the snapshot torus breaks up. The crossover time can be predicted based on the time-dependent stable foliation.

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CT 12.03

Zeta functions and complex dimensions of orbits of dynamical systems

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Abstract

The standard zeta function can be generalized to a zeta function of the so-called fractal string. Various (almost equivalent) definitions of zeta functions of a general bounded set that generalize this definition have been introduced by Lapidus. It was shown that the poles and their principal parts of the meromorphic extension, if it exists, of a zeta function of a set reveal the intrinsic geometry of the set. In particular, the set is considered fractal if there are non-real complex dimensions. We prove the existence of the meromorphic extensions of fractal zeta functions of orbits of dynamical systems generated by parabolic germs of analytic diffeomorphisms on the real line and describe their complex dimensions. We relate them to some intrinsic properties of the generating function and to the geometry of its orbits. This is a joint work with Goran Radunovic, University of Zagreb, and Pavao Mardesic, University of Burgundy. For more information, see *[2010.05955v1] Fractal zeta functions of orbits of parabolic diffeomorphisms (arxiv.org)*.

CT 12.04

Chaotic Diffusion in Delay Systems: Giant Enhancement by Time Lag Modulation

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Abstract

We consider a typical class of systems with delayed nonlinearity, which we show to exhibit chaotic diffusion. It is demonstrated that a periodic modulation of the time-lag can lead to an enhancement of the diffusion constant by several orders of magnitude. This effect is the largest if the circle map defined by the modulation shows mode locking and more specifically, fulfills the conditions for laminar chaos. Thus we establish for the first time a connection between Arnold tongue structures in parameter space and diffusive properties of a delay system. Counterintuitively, the enhancement of diffusion is accompanied by a strong reduction of the effective dimensionality of the system.

CT 12.05

Emerging of complex multistability and attractor with broken symmetry in quorum sensing coupled identical ring oscillators.

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Abstract

Variety of dynamic regimes in populations of identical oscillators depends on the properties of isolated elements and the design of their interactions. The main pathways to variability may already manifest themselves in a pair of identical 3-dimensional ring oscillators (based on synthetic 3-gene Repressilator) coupled using the 'quorum sensing (QS)' process natural for interbacterial communications. In this work, QS is implemented as an additional network incorporating elements of the ring as both the source and the activation target of the fast diffusion QS signal. This version of indirect nonlinear coupling exhibits the formation of a very rich array of attractors. Using a parameter-space defined by the individual oscillator amplitude and the coupling strength, we found the extended area of parameter-space where the identical oscillators demonstrate quasiperiodicity, which evolves to chaos via the period doubling of either resonant limit cycles or complex antiphase symmetric limit cycles with five winding numbers. The symmetric chaos extends over large parameter areas up to its loss of stability, followed by a system transition to an unexpected mode: an asymmetric limit cycle with a winding number of 1:2 emerging from pitchfork bifurcation of the unstable in-phase cycle. After long evolution across parameter-space, the 1:2 cycle demonstrates a period doubling cascade which restores the symmetry of dynamics by formation of symmetric chaos, which nevertheless preserves the memory of the asymmetric limit cycles in the form of stochastic alternating "polarization" of the time series. All stable attractors coexist with some others, forming remarkable and complex multistability including the coexistence of torus and limit cycles, chaos and regular attractors, symmetric and asymmetric regimes. We traced the paths and bifurcations leading to all areas of chaos, and presented a detailed map of all transformations of the dynamics.

CT 13.01 - Classical & quantum dynamics

Curl force dynamics: classical and quantum

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Abstract

Newtonian forces depending only on position but which are non-conservative, i.e.whose curl is not zero, are termed as 'curl forces'. As a consequence, there is no associated scalar potential and therefore no obvious Hamiltonian or Lagrangean formulation for the dynamics (of the familiar isotropic kinetic energy + scalar potential type) and, except in special cases, no obvious conserved quantities. Nevertheless, the motion is non-dissipative (volume-preserving in position and velocity space). The conspiracy of these two features manifests itself in unusual form of theclassical dynamics e.g. restrictions on the geometry of periodic orbits and unbounded chaos. An important physical example is the effective forces exerted on small polarizable particles by light. The curl force dynamics generated by optical vortices could be studied experimentally.

The clear manifestation of curl forces as effective forces in electrodynamics make it relevant to seek their quantum effects too. This remains, in general, an open problem, due to largely Hamiltonian based formulation of quantum mechanics. All is not lost however and there is relief yet for the quantum seekers!! A large class of such non-conservative forces (though not all) can be generated from a special type of Hamiltonian, in which kinetic energy is an anisotropic quadratic function of momentum (e.g. forces exerted on electrons in semiconductors).

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CT 13.02

Controlling dissipative quantum nonlinear dynamics using weak measurement back-action

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Abstract

Quantum backaction from weak measurement affects the behavior of quantum systems. We consider a nonlinear driven Duffing oscillator system implementation in a nonlinear optical cavity, and we show that the choice of phase setting φ for a laser used in measurement can change the dissipation for the spread variables of the quantum state. This can considerably increase the energy absorbed via the energy channel of the spread variables and enhance quantum effects. This suggests novel applications to quantum control, as we demonstrate, including inducing and reducing chaos in quantum trajectories, as well as a striking example in which the energy in the spread variables allows for a dynamical tunneling between energetically separated dynamical steady-states, from chaos to regularity. We discuss projects on experimental verification, including quantifying the regularity through ordinal pattern analysis of experimental signals.

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CT 13.03

A new spectral invariant for quantum graphs

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Abstract

The Euler characteristic i.e., the difference between the number of vertices |V| and edges |E| is the most important topological characteristic of a graph. However, to describe spectral properties of graphs with mixed Dirichlet and Neumann vertex conditions it is necessary to introduce a new spectral invariant, the generalized Euler characteristic $\chi G := |V| - |V_D| - |E|$, with $|V_D|$ denoting the number of Dirichlet vertices [1-3]. We demonstrate theoretically and experimentally that the generalized Euler characteristic χ_G of quantum graphs can be determined from small sets of lowest eigenfrequencies. If the number of the graph edges and vertices is known, the generalized Euler characteristic χ_G can be used to determine the number of Dirichlet vertices. The χ_G has been tested experimentally applying microwave networks including the isoscattering ones.

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CT 14 – Spacio-temporal dynamics

CT 14.01

Prediction of specific spatiotemporal patterns in nonlinear oscillator networks with distance-dependent time delays

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Abstract

The Kuramoto model plays a central role in the modeling and analysis of networked systems. The relationship between the individual connection scheme, time delays, and the resulting dynamics in these systems, otherwise, remains not well understood. Here, we study Kuramoto systems with distance-dependent delays to explain the mechanism behind traveling waves recently observed in neural data. Our analytical approach shows that the specific spatiotemporal patterns in Kuramoto systems can be captured in a mathematical description. Here, using this analytical approach, we demonstrate that time delays shape the spectrum of a matrix associated with the system, leading to the emergence of waves with a preferred direction. We then create analytical predictions for the specific spatiotemporal patterns that are observed in the original time-delay Kuramoto model. This approach is general to systems with heterogeneous time delays at finite scales, permitting the study of spatiotemporal dynamics in a broad range of applications.

CT 14.02

Nonlinear fourier analysis: solving nonlinear wave equations and analyzing wave data

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Abstract

An infinite class of nonlinear wave equations with well-defined dispersion can be solved by the methods of **Nonlinear Fourier Analysis** (NFA) [Osborne, 2010]. I give an overview of this method and apply the results to the physical understanding of **rogue and freak waves** in the ocean. This method derives from a fundamental Theorem of Algebraic Geometry due to Baker [1907] and Mumford [1982]: The most general, single valued, multiply periodic, meromorphic functions can be derived from Riemann theta functions. It has also been shown that the **Periodic Inverse Scattering Transform** (IST) [Belokolos, et al, 1994] (for solving integrable, nonlinear wave equations) is related to this theorem: Explicit exact spectral solutions can be written in terms of **quasiperiodic Fourier series** [Osborne, 2018] [Osborne, 2020], which shockingly gives solutions to nonlinear equations as a **linear superposition of sine waves**. Thus, in modern terms, the "soliton equations" can all be solved by a linear superposition law in terms of **quasiperiodic Fourier series**. **Hamiltonian perturbations** of these equations, even though stochastic, can be solved to a good approximation by a theorem of Kuksin [1999]. All of these methods are tools of a **new field of KAM theory for nonlinear partial differential equations** [Kappeler and Juergen Poeschel] and thus a plethora of important data analysis tools are being developed and applied to the study of ocean wave data. Amazingly, a large body of **coherent structures** have been discovered in wave data using these methods, including **solitons, Stokes waves, vortices, breather trains, etc**. A major source of rogue waves in the ocean are found in breathers whose central wave in a packet are among the largest waves ever found. I discuss the application of these methods to laboratory and ocean wave data.

CT 14.03

Correlation Entropy: Quantifying non-equilibrium ensemble dynamics

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Abstract

Understanding how a system evolves from a far-from-equilibrium state to equilibrium, i.e. from a low-entropy to a high-entropy state is a problem where limited progress has been made, restricted to a few specific systems and conditions. One useful direction is the attempt to connect the microscopic behavior of the trajectories of the ensemble to the thermodynamics of the system, and the evolution of the information in it. We introduce Correlation Entropy $\Pi(\rho)$ as a measure that allows us to track the generation of entropy in an ensemble ρ evolving in a complex dynamical system, predicated on understanding the average loss of local correlations between neighboring elements of the ensemble. This quantity is computationally tractable and adapts well across systems, including possible experimental applications. We find that $\Pi(\rho)$ reproduces all intuitions and results from previous works about how such an entropy should behave, as well allowing novel insights into regimes and systems previously not explored because of computational difficulties.

We see that this measure distinguishes the different temporal scales of the dynamics of the system, as well as captures the global loss of information as the ensemble relaxes to equilibrium. Among other features, we see the expected S-shaped relaxation to equilibrium for generally chaotic systems. We study several 1D and 2D iterative maps, and we find a universality in the evolution of the systems characterized by a de-correlation exponent that behaves similarly to Lyapunov exponent. We expect Correlation Entropy to be an excellent framework to support experimental work, and to be a valuable tool in quantifying the dynamics of ensembles evolving from a low entropy to a high entropy state.

CT 15 – Syncronisation (Part ii)

CT 15.01

Causal Properties of Synchronizing Systems

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Abstract

The idea of 'causal stability' and the 'causal stability synchronization theorem' have recently been proposed and proved by us [1]. This work theoretically establishes the 'causal' or 'spatial' conditions for chaotic synchronization. Synchronization of coupled chaotic systems is a ubiquitous phenomenon in nature, of much interest to the dynamical systems community. However, from the time it was discovered, synchronization has always been considered as a temporal phenomenon with the 'temporal conditions' required for systems to synchronize thoroughly studied and well established. On the other hand, 'causality estimators' based on time-series are widely used to study coupled dynamical systems. Though the fate of many coupled systems is synchronization, no rigorous mathematical relationship has been established between 'causal properties' of systems and their ability to synchronize. By proving the causal stability synchronization theorem for identical chaotic systems coupled unidirectionally, our work opens up the possibility to study chaotic synchronization with the lens of causality. Alongside, we provide causality based empirical conditions to predict 'synchronizing variables' based on the time series of the master system alone. Synchronizing variables are the variables which when coupled lead the systems to synchronization. In this work, we test for the robustness of the proposed empirical conditions on different dynamical systems started with different initial conditions. This is important for future real word applications where prediction of synchronizing variables is essential, e.g., in the control of chaos and the control of synchronization (such as in epilepsy, communication or electrical circuits). We also compare our empirical criterion with the criterion of 'negative conditional Lyapunov exponents', an existing necessary temporal criterion for synchronization.

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CT 15.02

Adaptation of higher-order interactions facilitates anti-phase explosive synchronization

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Abstract

For decades, consideration of the pairwise interaction between different networked dynamical units have been at the forefront to capture the underlying dynamics of various physical and biological complex systems. However, it has been sufficiently emphasized that complex systems such as brains and social interaction networks have the underlying topology of higher-order connections, which can be framed using simplicial complexes. Furthermore, adaptation is at the backbone of the construction and functioning of many physical and biological complex systems.

We investigate the transition to synchronization of oscillator ensembles encoded by simplicial complexes in which pairwise and higher-order coupling weights adapt with time through the Hebbian learning mechanism. These concurrently evolving disparate adaptive coupling weights lead to a novel phenomenon in that the in-phase synchronization is completely obliterated; instead, the anti-phase synchronization is originated. Besides this, the onsets of anti-phase synchronization and desynchronization are manageable through both dyadic and triadic Hebbian learning rates. The theoretical validation of these numerical assessments is delineated thoroughly by employing Ott-Antonsen dimensionality reduction. The framework and results would help to understand the underlying synchronization behavior of a range of real-world systems, such as the brain functions and social systems where interactions evolve with time.

CT 15.03

Feedback control of globally coupled oscillators based on the analysis of a phase oscillator model

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Abstract

Synchronization of coupled oscillators is observed in a wide range of systems. It is essential for some systems, such as cardiac pacemaker cells, to function appropriately. However, pathological synchronization also exists. For example, excessive synchronization arises in the brains of Parkinsonian patients. These desirable and undesirable synchronization phenomena have motivated the studies on the feedback control of oscillatory assemblies. Specifically, it has been demonstrated that global feedback can induce synchronization, desynchronization, and oscillation quenching. However, analyzing all of these typical transitions within a single framework is difficult, and thus the effect of global feedback has been only partially understood in each framework. In this study, we consider Sakaguchi-Kuramoto model with a global feedback loop and perform bifurcation analysis with the help of Ott-Antonsen theory to obtain the phase diagrams in that all of the three transitions are identified (Ozawa and Kori, 2021). The bistable regions in the phase diagram explain how one fails to realize a desirable collective state when only the linear stability of that state is taken into account. Based on the phase diagram, we propose strategies to control the collective state of the oscillators with minimal feedback strength. Furthermore, we apply our theory to control limit-cycle oscillators, utilizing the fact that the feedback in our phase model can be implemented as a linear combination of two macroscopic signals obtained from the limit-cycle oscillators.

Posters

PS 01

Phase-Isostable Reduction of Coupled Oscillator Networks

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Abstract

Networks of coupled oscillators appear in many areas of applied mathematics, from the classic example of fireflies flashing in sync to power grids and models of neural activity. The most common method for analysing these networks is to track the difference in the phase of oscillators and how this causes them to interact. However, this method breaks down beyond the weak coupling limit. By tracking a measure of the amplitude of oscillations as well as phase, we can make analysis more accurate and extend the analysis to stronger coupling regimes.

PS 02

Analysis of temporal correlations in the dynamics of nonlinear systems

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Abstract

One of the great challenges in complex and chaotic dynamics is to reveal its deterministic structures. These dynamical structures are sometimes a consequence of hidden symmetries, which are consequence of the deterministic underlying laws. Detecting and understanding them can allow the study of complex systems even without knowing the full description of the equations that drive the system. Here we introduce a new set of parameters, called Dynamical Visibilities, that quantify temporal correlations in the dynamics of nonlinear systems. The visibilities measure the departure of the dynamics of a given system from internal symmetries. These symmetries could be related with reversibility, or related to internal frequencies. We have applied this technique to well-known chaotic systems, such as the logistic map and a modified sine-circle map, as well as to experimental data from diode laser with optical feedback and external modulation. For the latter case, we describe the dynamics of the photonics system with the modified sine-circle map and find how the visibilities of the iterative model present equivalent results as those of the laser. Our results shows the method to be robust in characterizing dynamics and highlighting transitions in behavior.

PS 03

Emergent noise-aided logic through synchronization

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Abstract

Noise-aided logic gates that harness the interplay of noise and nonlinearity has garnered continued research interest [1,2]. In this talk we present a novel dynamical scheme to obtain a reconfigurable noise-aided logic gate that can yield all six fundamental 2-input logic operations, including the elusive XOR operation [3]. The setup consists of two coupled bistable subsystems that are each driven by one subthreshold logic input signal, in the presence of a noise floor. The synchronization state of their outputs, robustly maps to 2-input logic operations of the driving signals, in an optimal window of noise and coupling strengths. Thus *the interplay of noise, nonlinearity and coupling, leads to the emergence of logic operations embedded within the collective state of the coupled system*. We elucidate this idea through numerical simulations, proof-of-principle circuit experiments and detailed characterization of the parameter space where robust operations are obtained.

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PS 04

Reduced order network of incompressible magnetohydrodynamic turbulence

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Abstract

Magnetohydrodynamic turbulence is characterized by its nonlinear, chaotic dynamics which exhibit the additional Elsässer symmetry, in contrast to hydrodynamic Navier-Stokes systems. Using this property as a starting point, a (port-) Hamiltonian structure of the equations is introduced, resembling the conservative transport of energy generally depicted as a cascade.

Simplifications of the energy transport mechanism yield a complex network of Fourier nodes, enabling a vast reduction of complexity comparable to shell models which allows for reaching Reynolds numbers of 106 and above. However, the energy-based formulation of the model requires a precise treatment of other relevant quadratic ideal invariants, e.g. cross-helicity and magnetic-helicity, which imposes constraints on the energy dynamics. Hence, setting detailed rules on the conservative flux of energy while respecting further intrinsic constraints yields a cascading network which exhibits dynamics observed in plasma turbulence and direct numerical simulations.

The simple model acts as a surrogate of the complex turbulent dynamics that correctly captures the energetic scale-by-scale transport in consistent combination with the simultaneous transfer of cross helicity. Due to its modular network structure the model can straightforwardly be embedded into other numerical approximations of turbulent magnetohydrodynamics, e.g. in direct numerical simulations of star formation or other complex plasma-physical processes. This model ansatz aims at linking the dynamics of commonly considered closed systems to its environment while maintaining computational feasibility by reduction to the dominating dynamical features - the employed port-Hamiltonian network concept renders this type of model more robust, flexible and closer to the physical foundations than the standard shell-model approach.

PS 05

Non-stationarity in correlation matrices for wind turbine data

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Abstract

Modern utility-scale wind turbines are equipped with a Supervisory Control And Data Acquisition (SCADA) system gathering vast amounts of operational data that can be used for analysis to improve operation and maintenance of turbines. We analyze high frequency SCADA-data from the Thanet offshore wind farm in the UK and evaluate Pearson correlation matrices for a variety of observables with a moving time window. This renders possible an assessment of the internal dynamics and the non-stationarity in mutual dependencies of different types of data. Drawing from our experience in other complex, dynamic systems, such as financial markets and traffic, we show this by employing a hierarchical k-means clustering algorithm on the correlation matrices. The different clusters exhibit distinct typical correlation structures to which we refer as states. Looking first at only one and later at multiple turbines, the main dependence of these states is shown to be on wind speed. In accordance, we identify them as operational states arising from different settings in the turbine control system based on the available wind speed. We model the boundary wind speeds separating the states based on the clustering solution. This allows the usage of our methodology as a pre-processing for analysis, e.g. failure detection or prediction, by sorting new data based on wind speed and comparing it to the respective operational state, thereby taking the non-stationarity into account.

PS 06

A quasi-potential landscape view on critical transitions of the Atlantic ocean circulation

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Abstract

The Atlantic Meridional Overturning Circulation (AMOC) belongs to potential tipping elements in the Earth system, exhibiting multistability in paleoclimatic observations and climate models. While recent studies have shown a weakening of the circulation over the past decades, it remains unclear whether the system is close to a tipping point leading to an AMOC collapse, and how a critical transition between the competing metastable states would occur. It is thus crucial to better understand the global stability properties of climate models describing the AMOC. From a dynamical systems perspective, the phase space of a multistable non-gradient system can be characterised by a non-equilibrium potential landscape, with valleys corresponding to the different basins of attraction. The quasi-potential, defined by the Freidlin-Wentzell theory of large deviations, offers insight into the statistics of critical transitions under stochastic dynamics. Here we adopt this view to explore the bistable behavior of simple box models of the AMOC under stochastic freshwater forcing. We identify the edge state – or "mountain pass" – separating the two basins of attraction, and analyse its role for noise-induced transitions. Particularly, we compare residence times and transition paths for forcing with Gaussian and non-Gaussian (Lévy) noise, and relate simulated with theoretical results. We discuss the conditions when trajectories follow the minimum action path. Demonstrating how concepts of large deviation theory can be applied to simple stochastic box models, we hope to build a basis for investigating the global stability of more complex models of the AMOC.

PS 07

Flow in an hourglass: particle friction and stiffness matter

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Abstract

For usual granular materials, the discharge rate from a silo is known to be time independent (constant flow rate). This is in contrast to liquids, for which the decreasing height leads to decreasing pressure, resulting in gradually decreasing flow rate during a discharge process. We performed laboratory experiments and numerical simulations of silo discharge with traditional (frictional hard) granular materials and grains with reduced surface friction and hardness [1]. We show, that particle stiffness has a strong effect on the qualitative features of flow rate. For deformable grains, lowering the friction coefficient leads to a gradual change in the discharge curve: the flow rate becomes filling height dependent, it decreases during the discharge process. For hard grains, the flow rate is much less sensitive to the value of the friction coefficient.

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PS 08

The influence of the local dynamics in the phase synchronization of a network of a Hindmarsh-Rose neurons.

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Abstract

In this work we study the phenomenon of phase synchronization of a network composed of Hindmarsh-Rose neuron. We show how the individual dynamics of the neurons (periodic or chaotic) affects the phase synchronization process of the network, when the coupling parameter is varied. We show that the synchronization process is a function of the individual neuron dynamics, regardless the network topology. To do so, we construct a bi-dimensional parameter space where the individual dynamics of the neurons may be periodic or chaotic. We notice three regions of interest: the first one, where the individual action potential of the neurons is chaotic and depicts burst regime; the second one, where the dynamics is periodic and depicts burst regime; and a third one, where the neuron dynamics is periodic but depicting spiky regime. For chaotic neurons, the synchronization rote as the coupling parameter grows, shows a monotonic transition, characterized as the large the coupling, the large the synchronization level. When the action potentials of neurons are periodic, the dynamics depicts phase locking for small coupling, leading to a phase synchronized network. As the coupling increases a desyncronization process first occurs, followed by the traditional synchronization rote as the coupling increases. That characterizes a non-monotonic transition to phase synchronization of the network, where two very distinct thresholds of synchronization occur. Finally, a case in which the action potential of neurons is periodic in a spike regime. For this case, a small coupling promotes chaotic dynamics before any phase locking process take place. In this case, again, an almost monotonic transition to synchronization takes place as the coupling parameter is increased.

PS 09

Modelling Seizure Dynamics: A new neural mass approach

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Abstract

Epilepsy has long been recognised as a dynamic complex disease involving a paroxysmal change in the activity of millions of neurons, often resulting in seizures. The use of phenomenological neural mass models for average population activity has helped shed light on the mechanisms for generating transitions like those observed in EEG recordings during the evolution of a seizure. However, such models have little to say about potential mechanisms for exaggerating hyper- and hypo-synchrony of neurons within a population. We describe a new class of neural mass model that can be derived from a network of spiking neurons with both chemical and electrical (gap junction mediated) synapses (typically not represented in neural mass models). These models reduce the description of potentially billions of neurons to a small number of physically meaningful macroscopic variables (for population firing rate, mean membrane potential, and synchrony). One major advantage of these models is the interpretability of parameters in terms of features at the single neuron level. To emphasise the usefulness of this new neural mass model we apply it to study how brain network properties lead to variations in seizure dynamics and if they can be used to determine if seizures will appear focal or generalised.

PS 10

Symbolic partition in chaotic maps

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Abstract

In this work, we only use data on the unstable manifold to locate the partition boundaries by checking folding points at different levels, which practically coincide with homoclinic tangencies(HTs). The method is then applied to the classic two-dimensional Henon map and a complex three-dimensional map. Lyapunov exponents are computed through the metric entropy based on the partition, to show the validity of the current scheme.

Furthermore, we also extend the method into hyperchaotic maps, such as folded-towel maps. Metric entropy is computed again to verify the partitions.

The fractalization of torus and relevant bifurcations in the quasi-periodically forced logistic map

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Abstract

The bifurcation phenomena relevant to the fractalization of torus observed in the quasi-periodically forced logistic map are investigated. We obtained a phase diagram with an improved resolution by numerically detecting the creation of a repelling invariant set that should occur with the transition from a stable and smooth torus to an SNA on the fractalization route. Two types of bifurcation routes from a stable torus to a chaotic attractor, namely the routes via SNA and the routes with apparently direct transition, are uncovered. The results of numerical observation of the fine structures of the attractors also support the co-existing two types of bifurcation routes. The fractalization of the attractor with negative transverse lyapunov exponent (torus or SNA) is observed in both bifurcation routes. Thus the fractalization phenomenon should not be considered as a phenomenon that induces nor is induced by the loss of smoothness of a torus, although these two phenomena are intimately related.

PS 12

Identification of multistable coherent regimes in spiking neural networks

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Abstract

Analysis of spiking neural networks assumes an understanding of regimes that are possible for a given network under a variety of internal and external parameters. Often networks of spiking neurons exhibit multistability - the coexistence of different dynamic regimes with the same set of parameters depending on the initial conditions. Identifying the characteristics of such multistable regimes is instrumental to control network dynamics.

To identify the dynamical regimes, we developed a novel analysis methodology that allows to efficiently and automatically construct maps of the network coherent states that can show multistability. Our approach is based on the adaptive coherence measure (ACM). ACM provides automatic disambiguation of synchronized clusters, traveling waves, chimera states, and asynchronous regimes. In addition, ACM can determine the number of clusters in the case of cluster synchronization.

To plot a multistability map, the pipeline includes two steps. The first step is to scan the space of initial conditions for the fixed parameter values to search for coherent states. To do that, one can randomly choose initial conditions, run the dynamics, and calculate ACM to determine the relevant regime. For each parameter value, the constructed map will consist of the regime label and the set of initial conditions. In the second step, recursively using the natural continuation algorithm and calculation of the ACM parameter, one can determine the boundary of the existing area of the regime in the parameter space. For optimization of boundary search, it is possible to use an exploration algorithm that is similar to the BFS (Breadth-First Search) algorithm.

We describe a new approach and demonstrate it for two spiking neural networks: a Morris-Lecar type-II inhibitory neural network and a Morris-Lecar type-I excitatory neural network with a ring topology. We show multistability maps for variative values of the synaptic coupling strength and connectivity parameter.

PS 13

How well is a Kantz–Grassberger-type relationship satisfied for local finite-time characteristics of transient chaos?

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Abstract

We have recently introduced an escape rate and fractal dimensions suitable for characterising local finite-time properties associated with transient chaos in open dynamical systems in a coarse-grained description. We have numerically found 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 this contribution, we quantify this claim as a function of the integration time and the box size, and also show that some other attempts to define the quantifiers in question perform worse in this respect. As an outlook, we sketch an application to the escape of particles from the atmosphere across the globe.

PS 14

Numerical Solution of Quasi-Linear Parabolic Partial Differential Equations with Physics Informed Random Projection Neural Networks

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Abstract

We address a shallow physics informed machine learning scheme based on the concept of random projections with Gaussian Kernels to numerically solve time-dependent nonlinear Partial Differential Equations (PDEs) and in particular Quasi-linear PDEs. We also address an adaptation scheme based on error control to adjust the time interval of integration. We prove the approximation properties of the scheme and demonstrate its efficiency considering two benchmark problems, namely the one-dimensional viscous Burgers' equation and the one-dimensional Allen-Cahn phase-field PDE. The performance of the scheme is also compared with Deep-learning and Gaussian Processes but also with a spectral Fourier discretization as implemented in the Chebfun package.

PS 15

Adaptive Running Models for Shoe Design

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Abstract

Additive manufacturing has become a viable and trendy production method for the midsoles of running shoes. While traditional midsoles are made from uniform foam materials, shoes made with 3D printing technology can be designed to have spatially varying material properties, potentially allowing for the creation of higher performing running shoes than exist on the market today. Exploring this expanded design space, however, is difficult because the process of fabricating and testing new designs is slow and expensive. Therefore, to identify shoe designs that may be high-performing and thus worthy of pursuing further through fabrication and testing, a new method for predicting the performance of midsole designs was created. This method is based on both a dynamical model of running and on the existing biomechanical running data available in the field. This new model treats muscle activation as an optimization problem that a runner's body is trying to solve. The optimization problem has an initially unknown objective function which is learned from data. The resulting model successfully recreates the relationship between shoe properties and running performance for well-established shoe designs, and it allows the flexibility for evaluation of shoes which have yet to be made. Specific 3D-printed midsole geometries were then evaluated using this method, and the predicted highest performing shoe design was fabricated for further evaluation.

PS 16

Synchronization patterns in globally coupled Stuart-Landau oscillators

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Abstract

We study clusterized states in globally coupled Stuart-Landau oscillators, a paradigmatic model for patterning processes.

To investigate 2-Cluster states, we set up a reduced model using collective variables, in which the cluster size ratio is an additional bifurcation parameter.

We analyse longitudinal instabilities leading to complex 2-Cluster behaviour in the reduced system.

By including test oscillators, we study instabilities transversal to the 2-Cluster manifold, i.e. changes of the cluster type.

Using numerical bifurcation analysis we find stability regions of cluster solutions of different types.

In these, solitary states serve as primary patterns for clustering processes and allow an analytical treatment. The identified instabilities can be seen as building blocks of pathways to complex behaviour such as chimeras and extensive chaos as well as splay states occuring for varying parameters.

With the analytical and numerical approach presented here we identify different transition scenarios from synchrony to complex behaviour by reducing the coupling strength. We locate each of these scenarios in regions in the plane of shear parameters.

PS 18

Cardiomyocytes' signal propagation on thin domains in the Karma model

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Abstract

The questions if and how electrical signals propagate along heart tissue are key to decide if the organ is able to sustain a healthy beat or not. To understand better what factors could either help or disrupt this propagation we study a polynomial version of the Karma model, specifically developed to fit cardiomyocyte's behaviour well while maintaining the advantages of a low-dimensional model similar to FitzHugh-Nagumo. On the real line we analytically derive a stable travelling pulse using phase plane analysis and geometric singular perturbation theory. Furthermore, in order to compare the mathematical results to experimental data we extend the problem to a more realistic 2-dimensional domain. With our work now we aim to prove when and how we can approximate the problem of signal propagation on a thin tissue by a 1-dimensional pulse. For that we use the method of matched asymptotics to approximate the solution. However, the system has now 2 small parameters corresponding to the time scale separation and the aspect ratio of the domain. Depending on how they interact with the problem as well as each other, the asymptotic approximation differs. Therefore, we do not find one unique expansion but instead a family of separate asymptotic regimes, each with a corresponding approximation. Finally, using direct numerical simulations we compare and connect different initial conditions to the asymptotic regimes found in the analysis in the hope to understand how this family of approximations comes together to represent the full system.

PS 19

Numerical study of the convection in three-layer liquid-metal-batteries

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Abstract

Due to their potential cheapness and long-life time, liquid metal batteries (LMBs) form a promising way for storing electrical energy [1]. LMBs are made of three liquid layers: the top light metal is the negative electrode, the middle layer (electrolyte) is made of molten salts, and the bottom dense layer is the positive electrode. The electrodes have to be in liquid state to work best. This liquid state shall ideally be maintained by the current density, as it generates Joule heating into the electrolyte.

To achieve that, the work consisted in finding different material combinations from [1–4], different aspect ratios and physical values (fixed current density, maximum temperature etc.), which are characterized by a set of dimensionless numbers (Grashof, Reynolds, Prandtl, etc.) taken from [3,4].

The problem was then investigated by solving numerically the convection equations within the Boussinesq-Oberbeck approximation, coupled to heat diffusion in the electrodes, with help of Comsol Multiphysics software. A mixed boundary condition (heat exchange h) was considered, at the top and bottom boundaries to describe LMB temperature control.

The obtained results are compared with [3,4], where h coefficient was not taken into account (infinite value). The relevance of the quiescent state, with zero flow velocity, can then be discussed.

It is solved analytically with the Joule heating taken in account only in the electrolyte. For all considered cells and aspect ratios, the negative electrode does not sustain its molten state without a hot external temperature, unless the heat exchange coefficient h is added. With such model of LMB temperature control, there's a range of parameters where the maximum temperature in the liquid metals is maintained above their melting points, and below their boiling point.

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PS 20

Slater's criterion for the localization of invariant spanning curves in a family of area preserving maps

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Abstract

We investigate the localization of invariant curves for a family of two dimensional Hamiltonian mappings, described by the dynamical variables I and θ, according to Slater's criterion. Slater theorem says there are three different return times for an irrational translation over a circle in a given interval. The returning time, which measures the number of iterations a map needs to return to a given periodic or quasi periodic region, has three responses along an invariant spanning curve and they are related to the continued fraction expansion used to the translation and obey the Fibonacci sequence. We also analyse the rotation number of these curves and they are all related to a noble number, leading to a devil's staircase structure. The behaviour of the rotation number as a function of invariant spanning curves located by Slater's criterion resulted in an expression of the power law in which the exponent is equal to the absolute value of the control parameter γ, which controls the speed of the divergence of θ in the limit the action I is sufficiently small.

PS 21

Causal structure of time-reversed networks

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Abstract

The inference of causal relations between observable phenomena is paramount across scientific disciplines, however the means for such enterprise without experimental manipulation are limited. A commonly applied principle is that of the cause preceding and predicting the effect, taking into account other circumstances. Intuitively, when the temporal order of events is reverted, one expects the cause and effect to switch roles. This has been demonstrated in bivariate linear systems and utilized in design of improved causal inference scores, while such behavior in linear systems has been put in contrast with nonlinear chaotic systems where the inferred causal direction appears unchanged under time reversal.

We follow the observations in linear processes in more depth [1], extending the analysis to networks, deriving the necessary and sufficient condition of causal structure reversal under time reversal for vector autoregressive processes of order 1; showing that the key property is the normality of the causal interaction matrix. We provide an analytic proof that causal structure reversal happens perfectly in the bivariate case only in two particular trivial symmetric cases, and the minimal unidirectionally coupled network showing causal structure reversal has 3 subsystems.

We finally turn to real-world data, studying the extent to which the causal structure reversal appears in brain and climate network under time reversal, showing that already the linear approximations of both brain and climate systems show imperfect causal structure reversal under time reversal, while the extent to which this property is broken is closely predicted by deviation of the coupling matrix from normality. Finally, we discuss the relevance of these findings in a wider context, including how it problematizes use of comparison with time-reversed version of a given process for inference of causal structures.

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PS 22

Directed Persistent Homology as a tool for brain connectivity characterization

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Abstract

Topological Data Analysis (TDA) has already been applied to study network connectivity structure across fields. We suggest to use persistent homology (PH) not only for dependence - functional connectivity (FC) networks, but also to directed, causal, networks – the effective connectivity (EC). We test the PH discriminatory power in two examples of disease-related brain connectivity alterations: epilepsy seizures captured by electrophysiology – EEG, and schizophrenia (using functional magnetic resonance imaging - fMRI). We use multiple PH-based features and quantify discrimination of healthy from diseased brain states by a support vector machine (SVM). We compare this approach to standard undirected PH and raw EC/FC [1]. The fMRI data included signal from 90 brain regions capturing 10 minute brain activity in 90 schizophrenia patients and 90 healthy controls; the data were obtained using standard processing [1]. The scalp EEG data used 23 electrodes, fs=256Hz from 18 subjects with intractable seizures, providing 102 epileptic events of 20 to 120 seconds and non-epileptic segments of the same length. The intracranial EEG data from 16 epilepsy patients, included the first 30 seconds of a seizure and 30 seconds starting 1 min before the first seizure. Pearson correlation and Granger Causality (GC) provided estimates of FC and EC.

We observe that directed PH can detect altered brain connectivity, however comparison against standard PH and the use of the raw FC/EC matrices reveals challenges to be overcome to fully utilize the theoretical promise of TDA and establish it as a common tool in neuroimaging. In particular, in the schizophrenia task TDA performed close to random, while raw connectivity reached 80% accuracy; likely due to topographical (rather than topological) specificity of the effects.

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PS 23

Oscillations and bistability in the autocatalytic reaction network of imine hydrolysis

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Abstract

In biochemistry, hydrogen bonding is an essential structure forming factor, therefore function and activity of enzymes strongly depend on the pH of the medium. Acid-base equilibria are needed to maintain physiological pH to attenuate fluctuations in hydrogen ion concentration. Redox reactions generally change the pH and because their rate depends on it, they often autocatalytic with respect to hydrogen ion. The positive feedback can provide the fundamental nonlinearity necessary in controling far-from-equilibrium systems. However, an autocatalytic reaction under the mild conditions of organic molecules must interact with the acid-base equilibria present. Imines, for example, hydrolyze with their rate depending on the pH of the solution. For those, where hydrolysis rate is negligible in acidic medium, we show that their clock reaction, both substrate-depleting and autocatalysis driven, is a result of the delicate interplay between the autocatalytic hydroxide ion production and the acid-base equilibria of the components. We show that with the addition of a reaction removing hydroxide ion we can obtain bistability and even oscillations in an open system.

PS 24

Spatial early warning signals for Arctic summer sea ice loss

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Abstract

Every year, the area of the Arctic sea ice decreases in the boreal spring and summer and reaches its yearly minimum in the early autumn. Due to global warming, Arctic summer sea ice will most probably disappear.

The spatial structure of sea ice varies over time and we expect it to show significant changes before summer sea ice disappears. Thus, spatial behaviour might yield an early warning signal for summer sea ice loss.

Here, we track the summer sea ice border from time series obtained from models of various complexity and observations and study its spatial behaviour, notably its deformation, as Arctic summer sea ice approaches disappearance.

PS 25

Which method is more suitable for causality detection in my data?

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Abstract

Most causality detection techniques are based on one of two principles. Granger-like approaches reveal causality by decreasing the prediction error after adding information from the driving system. Cross-mapping approaches reveal causality if the driving system can be expressed from the driven system. These two different approaches work on different kinds of data, the first one appreciates noise in the system, and the second one (especially if it comes out from the nearest neighbour models) benefits from clean, noiseless data. The first one is more suitable for autoregressive models and the second one shines more on data from noiseless dynamic systems.

But which approach to choose for data with unknown origin? We will focus on this problem in our contribution and we compare our method with existing methods (False Nearest Neighbours, ...).

PS 26

Optimization of weak periodic input waveforms for global entrainment of limit-cycle oscillators

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Abstract

We propose a general method for optimizing weak periodic input waveforms for global entrainment of limit-cycle oscillators, which is based on phase reduction and nonlinear programming. Using averaged phase equation, we optimize the Fourier coefficients of the input waveform to maximize prescribed objective functions, which can be applied to a wider class of optimization problems, including global entrainment objectives. As demonstrations, we consider two optimization problems for achieving fast global convergence of the oscillator and realizing global phase distribution control for the population of oscillators. We show that the proposed method can successfully yield optimal input waveforms to realize the desired states in both cases.

PS 27

Transition to hyperchaos and rare large-intensity pulses in Zeeman laser

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Abstract

In this presentation, we explore a few distinct types of intermittent large-intensity pulses,namely, Pomeau-Manneville intermittency, quasiperiodic intermittency, and quasiperiodic breakdown to chaos, that originate from periodic, quasiperiodic, and chaotic states, respectively, in Zeeman laser. During the transitions to large-intensity pulses, we observe the origin of hyperchaos. We classify the transitions to hyperchaos as discontinuous against a parameter change, in all the cases, however, from periodic to hyperchaos, it shows hysteresis, but during quasiperiodic and chaotic to hyperchaos transition, no hysteresis is recorded. These features are revealed by plotting the two largest Lyapunov exponents of the laser model against the parameter. The turbulent phases of intermittency always consist of large intensity pulses. The large intensity pulses show characteristic features of extremes, in the sense, that they are larger than a significant height and have a probability of rare occurrence.

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PS 28

Ordinal Patterns as Robust Biomarkers in Multichannel EEG Time Series

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Abstract

Neurobiological changes in healthy and pathological ageing and their electrophysiological correlates (EEG) are still an important topic in the neuroscience community. We extract ordinal pattern based features from multichannel EEG time series to differentiate between two age groups and also between individuals. We consider functional connectivity in the form of ordinal pattern-based mutual information and single channel features in the form of the pattern distributions in each individual EEG channel. Both functional connectivity and single-channel features are subjected to nonlinear dimensionality reduction using t-distributed stochastic neighbour embedding.

We analyse the separation of EEGs from different age groups and individuals and demonstrate that ordinal pattern-based measures yield results comparable to frequency-based measures applied to preprocessed data, and outperform them if applied to raw data. Our analysis yields no significant differences in performance between single-channel features and functional connectivity features regarding the question of age group separation.

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Delay Dynamics in an Economic Model

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Abstract

This poster is about the qualitative behavior of an economic model proposed by D. Meyer (cf. [1]). It is shown that under certain conditions on the parameters the system has uniformly bounded and no non-trivial periodic solutions. Subsequently, a possible equilibrium on the boundary of the positive phase space not discussed in [1] was founded and showed that if there is no interior equilibrium, then the equilibrium at the boundary will become unstable, whereas the equilibrium at the boundary will be stable. In order to have more realism, two types of delay will be introduced: an infinite distributed delay and a discrete delay. It is shown that contrary to the result in [1] the distributed delay does not change the stability of the equilibrium points. Finally, by introducing a discrete delay, it was showed that at a certain parameter value Hopf bifurcation takes place: periodic solutions arise.

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PS 30

Optimal tuning of natural frequency to mitigate multipath propagation interference in multiuser chaotic communication

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Abstract

In this work, we study a wireless communication system designed to handle multi users, each communicating with their own frequency bands. We analyse the performance of the system - its information capacity – while considering different number of users, and different configurations for the multipath propagation scenarios for each user and their base frequency. Our interest is to discover worst- (blind spots) and best-case scenarios (maximal information transmission). Our results show that a prior effective choice of parameters, such as the natural frequency of the chaotic signal, lead to significant throughput improvement and, in some cases, even enable an error-free communication. It is often to be expected that physical constrains in the channel may block higher-frequency signals used in standard non-chaotic communication systems. For our chaos-based communication system, we show that a significant wireless channel constraint, the multipath propagation, becomes less disruptive, the higher the frequency of the user. That is a win-win result. Not only does the higher frequency allow more information to be transmitted, but it also prevents multipath interference. Moreover, there is an ideal relationship between the time of propagation for the signals with the user natural frequency that results in a communication with no interference due to multipath, thus effectively creating a wireless communication system with similar gains as that obtained for wired communication where multipath propagation is not a significant issue.

PS 31

Data-driven prediction of critical transitions in dynamical systems

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Abstract

Critical transitions or tipping points are large, possibly irreversible qualitative changes in the behaviour of a dynamical system in response to small changes in the input. Examples in the climate system are a collapse of the Atlantic Meridional Overturning circulation or the retreat of Arctic summer sea ice. Many other examples can be found in the areas of ecology, biology, medicine or economics. There has been a lot of research activity in extracting generic early-warning signs of critical transitions from time series data, for example, increasing autocorrelation and variance. However, their robustness, specificity and selectivity is still under debate and there is little research so far on their actual predictive power (Zhang et al., 2015).

Here, we develop further the explicit dynamical modelling of critical transitions from time series data using non-stationary, that is, non-autonomous dynamical systems (Kwasniok, 2015, 2018). 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. Modern techniques of stochastic system identification including spatio-temporal approaches are used. 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. We produce so called risk profiles, that is, estimates of the likelihood of tipping at particular time points in the future under different scenarios and parameter assumptions.

References

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PS 32

Intermittent chimera-like and bi-stable synchronization states in network of distinct Izhikevich neurons

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Abstract

Phase synchronization phenomena of neuronal networks is one of many features depicted by real networks that can be studied using computational models. Here, we proceed numerical simulations of a globally connected network composed of non-identical (distinct) Izhikevich neuron model to study clustered phase synchronization. We investigate the case which, once coupled, there exist two main neuron clusters in the network: one of them is bi-stable, depicting phase-synchronized or unsynchronized states, depending on the initial conditions; and the second one showing just unsynchronized state. For the set of initial conditions that lead the first cluster to the synchronized regime, we observe a chimera-like pattern of the network. For small network, the dynamics can also present intermittent chimera-like scenario. For the last case, we propose a mechanism for intermittent chimera states based on two features: the coexistence of a synchronized cluster with an unsynchronized one; and the capability of one cluster to display bi-stability depending on the signal trait by which it is forced. We conclude with an understanding of intermittent chimera-like dynamics as the limit case where bi-stability is not maintained, that occurs due to the loss of uniformity in the neuron input synaptic currents.

PS 33

Drift instabilities in localised Faraday patterns

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Abstract

Nature is intrinsically heterogeneous, and remarkable phenomena can only be observed in the presence of intrinsically nonlinear heterogeneities. Spontaneous pattern formation in nature has fascinated humankind for centuries, and understanding underlying symmetry-breaking instabilities has been of longstanding scientific interest. In this talk, I will summarize theoretical and experimental evidence that heterogeneities can generate convection (drift instabilities) in the amplitude of localized patterns. We derive a minimal theoretical model describing the growth of localized Faraday patterns under heterogeneous parametric drive, unveiling the presence of symmetry-breaking nonlinear gradients. Furthermore, the model reveals new dynamics in the phase of the underlying patterns, exhibiting convective instabilities when the system crosses a secondary bifurcation point. Finally, we discuss the impact of our results in understanding convective instabilities induced by heterogeneities in generic nonlinear extended systems far from equilibrium.

PS 34

Numerical Analysis of Global Bifurcations in Liquid Crystals under Shear Flow

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Abstract

We analyze the nonlinear dynamics of a macroscopic model describing the dynamics of liquid crystals, when subjected to shear flow. The model consists of system of ODEs obtained from the Smoluchowski equation through the DOI closure approximation. Varying the intensity of the shear rate, the nonlinear dynamics is characterized from the emergence of many different periodic regimes, local bifurcations and a period doubling cascade route to chaos. Moreover, we observed many global global bifurcations like crisis, intermittencies and bifurcations of chaotic attractors. The analysis of these global phenomena is conducted by numerical computation of the stable and unstable manifolds, of both periodic and stationary solutions and their interactions inside parameter space. Several global bifurcations have been thus detected and characterized. The impact of the closure approximation on the global dynamics is also discussed.

PS 35

Chaotic diffusion in a dissipative standard mapping: an analytical investigation

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Abstract

We investigate the chaotic diffusion for the Dissipative Standard Mapping by the analytical solution of the Diffusion Equation. The mapping is described by two dynamical variables, θ and I, and two control parameters, γ and ε. The first one controls the intensity of the dissipation and the second, the nonlinearity of the system. From the equations of the mapping, we obtain analytically the solution of the Diffusion Equation and, then, we compare to the numerical simulations and we obtain a well agreement between them.

PS 36

Chaos and coexisting attractors in replicator-mutator maps

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Abstract

Evolutionary game theory has been successfully used to model Darwinian selection. A systematic study of Darwinian selection, for a non-overlapping population in the absence of mutation, has shown that chaotic outcomes can emerge for the simplest case of two-player-two-strategy games depending on the dynamical game-theoretic model and the game under study [V. Pandit et. al., Chaos, **28**, 033104 (2018)]. However, the phenomenon of mutation is frequently present in both biological and social systems undergoing evolution through replication-selection processes. Here we have shown that mutation, in a generation-wise nonoverlapping population with a two-player-two-strategy symmetric game, gives rise to coexisting stable population states, one of which can even be chaotic [Archan Mukhopadhyay et al 2021 J. Phys. Complex. **2** 035005 (2021)]. The presence of the chaotic state renders a way to prevent the cooperators in the population from going extinct. Specifically, we have used replicator maps with two types of mutation (additive and multiplicative mutations), and have rigorously found all possible two-dimensional payoff matrices for which physically allowed solutions can be achieved in the dynamics of those equations. Subsequently, we have also discovered the various possibilities of bistable outcomes—e.g., coexistences of fixed point and periodic orbit, periodic orbit and chaos, and chaos and fixed point—in the resulting replicator-mutator maps.

Note

When this paper [Archan Mukhopadhyay et al 2021 J. Phys. Complex. 2 035005 (2021)]– on which this abstract is based– was written and published, I (Archan Mukhopadhyay), was a Ph.D. student at IIT Kanpur, India.

PS 37

Resonant velocity tuning of solitary states in networks of coupled phase oscillators

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Abstract

Electrical power grid dynamics can be modeled as coupled oscillators on sparse complex networks. In addition to the desired operating state, in which all nodes are synchronized at network frequency, there exists a variety of partially synchronized attractor states. Solitary states consist of a large, synchronized cluster and a single oscillator that rotates with a different velocity. They pose a threat to power grid stability, as they would cause overload damages and can be easily reached through single-node perturbations. Especially vulnerable to such perturbations are dense sprouts, which are degree-1 nodes with distinct topological properties and a well-connected neighbor.

Novel solitary states in which the velocity of the dense sprout differs from its natural velocity have recently been discovered in numerical simulations. In this work, we propose a two-node toy model with which we can theoretically explain the presence of the novel solitary states. In this model, the rest of the synchronized complex network is reduced to its key factor, i.e. the degree of the neighbor n+1. Applying a linearization approach, we obtain an approximate analytical solution close to the full complex dynamics.

We then derive a self-consistency equation for the velocity of the solitary node, that we find close to $\sqrt{(K\,n)}$, where K denotes the universal coupling strength of the oscillators' phase differences. We demonstrate that the toy model resembles highly localized network modes in the linear stability regime around the operating state. The velocity of the dense sprout arises from resonance with this network mode under the constraint of matching the network's power flow.

PS 38

Emergence of major and minor peaks in population dynamics of malaria

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Abstract

Malaria is a parasitic vector-borne disease endemic in many parts of the world. Many vector-borne diseases are known to show seasonality, where most of the cases arise only during a certain season. For mosquito-borne diseases, this increase in prevalence is often attributed the temperature and rainfall which affects the vector population size by modulating the rate of reproduction and development of vectors. However recent studies have shown biannual peaks in the prevalence of mosquito-borne diseases in certain parts, which cannot be attributed to seasonality alone. In this poster, we investigate the reason behind such patterns using a minimal differential equation model for malaria involving seasonally varying mosquito population. As a result, we found that the intermediate immune loss induces the biannual peaks. The period-doubling bifurcation to chaos by changing the immune loss rate and its universality are also discussed as well.

PS 39

Theoretical approach to the links between the performance of photonic reservoir computing and the dynamic regimes of a semiconductor laser with delayed feedback

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Abstract

Recently introduced, the concept of photonic delayed reservoir computing is a supervised machine learning technique inspired by the ability of biological neurons to process information streams.

These systems have rich regimes, as they are photonic components subject to optical injection and optical feedback. For instance, semiconductor lasers are good candidates for reservoir and they are consistent systems depending on parametric ranges. Consistency is known as the ability of a dynamic system to produce an identical response to slightly different inputs (e.g. spontaneous emission noise).

Several metrics are used to characterise the ability of such a network to perform complex tasks and to estimate the best parametric ranges of operation.

We have studied metrics, such as memory capacity, which characterises the ability of the system to retain some of the previous information during a certain time. Another metric used is the computational capacity, which characterises the ability of the reservoir to best perform dynamically, independently of the task.

We have analysed the consistency of a laser subjected to optical injection and feedback in a delayed reservoir computing architecture. A consistent response to an input is necessary for the reservoir to function properly. It also appears that to achieve the best performance, the system parameters must be brought to a trade-off between memory capacity, consistency and dynamical regime. The response of a chaotic reservoir will be significantly different from a stable reservoir.

We link the performances of neuromorphic photonic systems to the dynamical regimes encountered. We provide arguments to justify physically the performance of photonic reservoir neural networks through the study of dynamic regimes and the influence of the nature of the bifurcations encountered.

This theoretical work was carried out by extensive numerical simulations of a Lang-Kobayashi model of an all-optical information injection system into a semiconductor laser with feedback.

PS 41

Dynamical basis of cellular sensing and responsiveness to spatial-temporal signals

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Abstract

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.

PS 42

Recurrence analysis of chaotic transient orbits: Application in tokamaks

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Abstract

In this work, we show that recurrence analysis of transient 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 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 characterize particular regions of the space that indicate very distinct dynamical behaviours.

PS 43

Using local bandwidths for the estimation of Kramers-Moyal coefficients

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Abstract

A variety of systems can be modeled with stochastic differential systems (SDEs). A well known approach is the reconstruction of the drift and diffusion terms of a Langevin equation with data-driven methods. One of the most used estimation methods for this kind of reconstruction is the Nadaraya-Watson estimator which is a nonparametric, data-driven approach. To improve the estimation of the drift coefficients of a stochastic process we suggest a method to obtain local optimized bandwidths which are minimizing the error of the approximation of the first conditional moments of a univariable system which will eventually reduce the error of the drift estimation. Furthermore, we compare this new approach to a global bandwidth estimation and an estimation which is based on a fixed number of next neighbors.

PS 44

Characterizing Short-Range Correlations and Von Neumann Entropy for the Collatz Map

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Abstract

The Collatz map $C(n)$ is a simple rule for iterating natural numbers: given $n \in \mathbb{N}$, if n is even, then $C(n) = n/2$, if n is odd, then $C(n) = 3 n + 1$. The Collatz map is related to one of the hardest open problems in mathematics, the Collatz Conjecture. It states that the map $C(n)$ eventually has only one periodic orbit with infinite basin of attraction. In this study we address the behaviour of transient orbits of the Collatz map. Our goal is try to characterize the potential existence of complexity, scale-free behaviour and self-organizing criticality (SOC) in the Collatz series as hypothesized in the literature. Several time series in the usual base-10 representation are used to construct stationary orbits, so to compute the power-spectra and the detrended-fluctuadtion-analysis (DFA) exponents β and α, as well as to investigate short-range correlations. A distinct representation of natural numbers as a sum of powers of two is used to calculate the von Neumann entropy for the orbits. For $n \in \mahtbb{N}$, one can write $n = 2^{m_1}+2^{m_1+m_2}+\cdots+2^{m_1+m_2+\cdots+m_r} \equiv (m_1, m_2, \dots, m_r)$ as an unique --- if some restrictions on the m_i's are imposed --- r-dimensional vector, called m-vector. The evolution of the m-vector with the Collatz map generates time-series $m_i(t)$ for each $i=1,2,\ldots,r$. Generating N time-series of the $m_i(t)$'s, a $N \times N$ Pearson correlation matrix $\mathbf{R}$ is constructed. Using a recently proposed method to calculate the von Neumann entropy for $\mathbf{R}$, we discuss how to associate an entropy measure to the Collatz transient orbits.

PS 45

Inferring network connectivity using modified Reservoir Computing

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Abstract

Inference of directed links in networks of interacting systems is a problem spanning many disciplines. In systems out of equilibrium this problem is a special case, where samples are not independent but structured as time series. In this context, Recurrent Neural Networks (RNN) have attracted recent attention, due to their ability to learn from sequences.
We introduce a method to infer connectivity from the time series of a network, using Reservoir Computing (RC). We show how modifications of the standard RC architecture enable a reliable computation of links between nodes. While the method does not require information about the underlying mathematical model, its performance is even improved if the selection of hyper-parameters is roughly informed by knowledge about the system. The method is illustrated with examples from different complex systems, ranging from networks of chaotic Lorenz systems to biological neurons. Using simulations of these systems, we demonstrate its power and limitations under a variety of conditions, such as noise levels, delayed interactions, size of the network and hidden variables.

PS 46

Biological oscillators: time delays, synchronization and cellular mechanics

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Abstract

Biological oscillators underlie many of the processes crucial to an organism's development and survival. Examples include the cell division cycle, the 24h circadian rhythms or the segmentation clock, which is responsible for laying down the segmented body plan of vertebrates. These oscillations are typically generated by biochemical reactions in the cell. Multistep mechanisms and transport of molecules, among other factors, can introduce time delays into these interactions. To account for delays and their often unknown origin, biological oscillators can be modeled by delay differential equations.

Single oscillating cells may signal to other cells and couple their oscillations. This can lead to synchronization and the formation of traveling waves. The way in which the signaling occurs is important: it may be through diffusion of a signaling molecule, or mediated by cell-to-cell contact. In the latter case, a cell's shape and position relative to its neighbors impacts the coupling. To capture this, models need to take into account the interplay between cell mechanics and biochemistry.

Here, I will present how delay equations can be used to model biological oscillators and how the interplay between mechanics and biochemistry affects coupling and synchronization. I will illustrate the modeling results with examples from the early embryonic cell cycle and the vertebrate segmentation clock.

PS 47

Dynamics of large sample-to-sample fluctuations in networks of phase oscillators

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Abstract

Complex networks with heterogeneous parameters across the units (quenched disorder) differ in their long-term dynamics depending on the specific realization (sample) of their parameters. These fluctuations between realizations are known to increase during phase transitions, but their dynamics is still poorly understood. To remedy this, we investigate finite networks of Kuramoto (phase) oscillators, where transitions to phase synchronization are known to correspond to non-equilibrium phase transitions. We study two network topologies: one proposed by Watts and Strogatz that randomly rewires connections from a k-nearest-neighbor lattice up to a random network; and another in which the strength of connections decays according to the units' distances. The dynamics on both topologies is similar: systems have transitions to phase synchronization, due to either increasing the coupling strength or switching connections from short-range to long-range. During these transitions, there is a very large increase in sample-to-sample fluctuations, induced by either shuffling the natural frequencies, changing the frequency of a single unit, or even resampling the topology. In particular, changing a single unit's frequency can radically alter the whole network's behavior. Furthermore, the Watts-Strogatz networks are multistable, with the number of attractors increasing during the transitions similarly to the sample-to-sample fluctuations, a mechanism that further enhances the fluctuations. Finally, we argue that the increase in sample-to-sample fluctuations, and the corresponding large sensitivity, can occur in a wide variety of other systems, and lead to an enhanced flexibility of the system.

PS 48

Dynamics of targeted ransomware negotiation

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Abstract

Cryptographic ransomware is a form of malware that enables a cybercriminal to extort money from their victims by encrypting their data, rendering it inaccessible. The particularly lucrative nature of ransomware drives cybercriminals to improve their technology and strategy in the pursuit of greater profit. Recently, the development of *targeted ransomware* has enabled cybercriminals to target large organisations for ransoms far greater than possible with traditional methods, dramatically increasing the impact of ransomware. These developments have significantly changed the dynamics of ransomware, with the introduction of sunk costs and ransom negotiation affecting the strategies adopted by cybercriminals and their targets. Here, we consider how the development of targeted ransomware has affected the dynamics of ransomware negotiations. We construct a model of ransomware negotiations as an asymmetric non-cooperative two-player game. In particular, our model considers the investments that a malicious actor must make in order to conduct a successful targeted ransomware attack. We demonstrate how imperfect information is a crucial feature for replicating observed real-world behaviour. Furthermore, we present optimal strategies for both the malicious actor and the target, and demonstrate how imperfect information results in a non-trivial optimal strategy for the malicious actor.

Noise-induced degeneration in online learning

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Abstract

In order to elucidate the plateau phenomena caused by vanishing gradient, we herein analyse stability of stochastic gradient descent near degenerated subspaces in a multi-layer perceptron. In stochastic gradient descent for Fukumizu-Amari model, which is the minimal multi-layer perceptron showing non-trivial plateau phenomena, we show that (1) attracting regions exist in multiply degenerated subspaces, (2) a strong plateau phenomenon emerges as a noise-induced synchronisation, which is not observed in deterministic gradient descent, (3) an optimal fluctuation exists to minimise the escape time from the degenerated subspace. The noise-induced degeneration observed herein is expected to be found in a broad class of machine learning via neural networks.

PS 50

Is medium range order the backbone of low temperature universalities in amorphous materials?

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Abstract

Despite observation of the low temperature universalities of physical properties, e.g. thermal, spectral and acoustic, in amorphous materials many decades ago and many attempts by defects based models, a unanimous agreement of their explanation is still considered elusive. Our theoretical approach in studies [1-4], based on a representation of the amorphous solid as a collection of generic fixed size molecular clusters, indicates that the explanation requires another universality, hitherto unknown, i.e a ratio of two length scales related to short and medium range order molecular structures. This talk would discuss the theoretically origin of the ''length-ratio'' universality and describe its appearance in other universalities along with comparison with experimental results.

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PS 51

Entanglement growth in bipartite systems: a multi-parametric Wishart ensemble approach

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Abstract

A maximally entangled state of a many body quantum system is expected, by definition, to be ergodic. Based on Berry's Gaussian random wave hypothesis in context of quantum chaotic systems, a typical ergodic many body eigenstate constitutes a random fock-space vector with independently distributed Gaussian entries. This in turn leads to a standard Wishart random matrix ensemble representation of the reduced density matrix for a bipartite system. The entanglement measures for the latter can then be derived from a knowledge of the eigenvalue statistics of the former.

A typical many body state however need not be ergodic and can exhibit different degree of localization e.g. localized, partially localized or extended, based on system parameters. As a consequence, the reduced density matrix for a bipartite system requires consideration of a general class of Wishart random matrix ensembles where system-dependence appears through distribution parameters of the matrix elements. This in turn affects the distribution of the Schmidt eigenvalues and thereby entanglement measures e.g Von-Neumann and Renyi entropies.

It is natural to query therefore e.g. (i) how the entropy of entanglement of the state is affected by system conditions, (ii) starting from a state with arbitrary entanglement, can a controlled variation of system parameters lead to maximum entropy of entanglement? We derive here the evolution equation for the entanglement entropy with changing system conditions and attempt to answer some of these queries.

PS 52

Complex network measures reveal optimal targets for deep brain stimulation and identify clusters of collective brain dynamics

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Abstract

An important question in computational neuroscience is how to improve the efficacy of deep brain stimulation by extracting information from the underlying connectivity structure. Recent studies also highlight the relation of structural and functional connectivity in disorders such as Parkinson's disease. Exploiting the structural properties of the network, we identify nodes of strong influence, which are potential targets for Deep Brain Stimulation (DBS). Simulating the volume of the tissue activated, we confirm that the proposed targets are reported as optimal targets (sweetspots) to be beneficial for the improvement of motor symptoms.

Furthermore, based on a modularity algorithm, network communities are detected as set of nodes with high-interconnectivity. This allows to localise the neural activity, directly from the underlying structural topology. For this purpose, we build a large scale computational model that consists of the following elements of the basal ganglia network: subthalamic nucleus (STN), globus pallidus (external and internal parts) (GPe-GPi), extended with the striatum, thalamus and motor cortex (MC) areas, integrating connectivity from multimodal imaging data. We analyse the network dynamics under Healthy, Parkinsonian and DBS conditions with the aim to improve DBS treatment. The dynamics of the communities define a new functional partition (or segregation) of the brain, characterising Healthy, Parkinsonian and DBS treatment conditions.

PS 53

Nonlinear dynamics of the tape peeling trace

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Abstract

When the adhesive tape is peeled, two-type structures appear at the peeling front depending on how fast the tape is peeled. In particular, at a critical peeling speed, the two structures switch chaotic, and the peeled trace shows Sierpinski-gasket like fractal pattern [1].

There are attempts to construct a mathematical model to reproduce these dynamics, and a phase-field with asymmetric interactions using a ramp function model was proposed in [2-4]. While the model proposed in [2-4] can reproduce the quantitative dynamics, it doesn't show Sierpinski-gasket like patterns.

In this work, we developed a new noiseless partial differential equation model based on a reaction-diffusion system which can describe this pattern formation.

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PS 54

Heteroclinic units acting as pacemakers for entrained dynamics of cognitive processes

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Abstract

Heteroclinic dynamics is a suitable framework for describing transient and reproducible dynamics such as cognitive processes in the brain. We demonstrate how heteroclinic units can act as pacemakers to entrain larger sets of units from a resting state to hierarchical heteroclinic motion such 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 the pacemaker and the driven units. Noise as well as a small back-coupling to the pacemaker considerably facilitate synchronization. Units can be synchronously entrained to different temporal patterns, depending on the selected path in the hierarchical heteroclinic network. 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. In view of brain dynamics, our results indicate a possibly ample repertoire for coding information in temporal patterns, produced by sets of synchronized units entrained by pacemakers, without finetuning of the parameters, and distributed in space.

PS 55

Noise induced swarming

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Abstract

We report on the effect of correlated noise on the velocities of self propelled particles. Correlations in the random forces acting on self propelled particles can induce directed collective motion, i.e. swarming. Even with repulsive coupling in the velocity directions, which favors a disordered state, strong correlations in the fluctuations can align the velocities locally leading to a macroscopic, turbulent flow field. On the other hand, while spatially correlated noise is aligning the velocities locally, the swarming transition to globally directed motion is inhibited when the correlation length of the noise is nonzero, but smaller than the system size. We analyze the velocity alignment in d dimensional space in the mean field model of globally coupled velocity vectors.

PS 56

Dynamics of Healthy Human Gut BFGs under antibiotics perturbation

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Abstract

Our model investigated the dynamics of a healthy gut BFGs (Bacterial functional groups) under different antibiotics perturbation.

We observed that the introduced antibiotics do not only affect the targeted BFGs (Lactate Producers and Butyrate Producers 3), but also indirectly affected the concentration of these interacting BFGs and all associated metabolites. Increasing or decreasing the decay/ death rate of BFGs due to antibiotics will always produce corresponding impart in both BFG's concentration until the elastic limit is reached. We also observed that there is a time interval when various antibiotics produced a greater effect on each BFGs' concentration.

PS 57

A graphical tool for measuring information between EEG channels

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Abstract

Electroencephalography (EEG) are electric measurements of the human scalp at many locations (channels), with recorded fluctuations of the order of μV and 1-50Hz due to synchronization of neuron activity. Single channels typically exhibit behaviour compatible with deterministic chaos. This suggests that information theory methods are best suited for determining the association or causality between EEG channel pairs. However, tools for EEG pre-processing and analysis and information theory analysis and either highly computationally demanding or require a steep learning curve, which is unfeasible in clinical settings. In this work, we present a Python-based software with lower computational requirements and a friendly graphical user interface, allowing for the EEG pre-processing, analysis and comparison of up to two systematic conditions and several experiment events. This is intended to support both research activity and future daily professional practice. As an illustration, we consider the case of an experiment where a volunteer with deep brain stimulation (DBS) repeats a series of tasks (i.e., events) with the DBS switched on or off (i.e., conditions). Among the results that the software allows for computation, it is included the maximum Lyapunov exponent of each channel and the correlation (Pearson or Spearman), spectral association (coherence or phase lag index) and shared and transferred information (mutual information and transfer entropy) of each channel pair for every condition/event in the experiment. The program also includes the option for building dynamic functional connectomes using correlation or information theory measurements and present the results as videos. A future update will include the option to analyse data of volunteer groups instead of only individuals.

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Chebyshev Dynamical Systems and their Generalisations

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Abstract

We show that, among all smooth one-dimensional maps conjugated to an *N*-ary shift (a Bernoulli shift of *N* symbols), Chebyshev maps are distinguished in the sense that they have least higher-order correlations. We generalise our consideration to a family of shifted Chebyshev maps, presenting analytic results for two-point and higher-order correlation functions. We also discuss the eigenvalues and eigenfunctions of the Perron-Frobenius operator of *N*th-order Chebyshev maps and their shifted generalisations. The spectrum is degenerate for odd N. Finally, we consider coupled map lattices of shifted Chebyshev maps and numerically investigate zeros of the temporal and spatial nearest-neighbour correlations, which are of interest in chaotically quantised field theories.
Reference

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PS 59

Geometric analysis of fast-slow PDEs with fold type singularity

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[6]No affiliation, Germany

Abstract

We study a fast-slow, reaction-diffusion PDE system, consisting of two equations on a bounded domain, with a fold singularity in the reaction term of the fast variable, while the slow variable assumes the role of a dynamic bifurcation parameter. This extends the classical fast-slow dynamic fold bifurcation problem to an infinite-dimensional setting. Our approach is to use a spectral Galerkin discretisation and the techniques of Geometric Singular Perturbation Theory (GSPT) on the resulting high-dimensional ordinary differential equation systems. In particular, away from the fold singularity we obtain the existence of invariant manifolds, while in a neighbourhood of the singularity we using geometric desingularisation via a blow-up method.

Finally, we connect the invariant manifolds obtained through this discretisation process with invariant manifolds that exist in the original phase space of the PDE system.

PS 60

Fractal analysis of planar nilpotent singularities and numerical applications

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Abstract

The goal of our work is to give a complete fractal classification of planar analytic nilpotent singularities. For the classification, we use the notion of box dimension of (two-dimensional) orbits on separatrices generated by the unit time map. We also show how the box dimension of the one-dimensional orbit generated by the Poincar\' e map, defined on the characteristic curve near the nilpotent center/focus, reveals an upper bound for the number of limit cycles near the singularity. We introduce simple formulas for numerical calculation of the box dimension of one- and two-dimensional orbits and apply them to nilpotent singularities.

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1 Zoology Building
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3 23 St Machar Drive
4 King's Museum (Old Town House)
5 Students' Union Building
6 St Mary's
7 Fraser Noble Building
8 Elphinstone Road Halls
9 The Sir Duncan Rice Library
10 Meston Building
11 Chaplaincy Centre
12 Confucius Institute
13 Security Office/Mailroom
14 Counselling Service
15 Edward Wright Building
16 Edward Wright Annexe

17 MacRobert Building
18 William Guild Building
19 Arts Lecture Theatre
20 Taylor Building
21 Old Brewery
22 New King's
23 Regent Building
24 University Office
25 Elphinstone Hall
26 Linklater Rooms
27 King's College Chapel
28 King's College Centre
29 King's College
30 King's Pavilion
31 50-52 College Bounds
32 Butchart Centre

33 Crombie Annexe
34 Crombie Halls
35 Rocking Horse Nursery
36 King's Hall
37 Powis Gate/Muslim Prayer Room
38 Johnston Hall
39 Humanity Annexe
40 Humanity Manse
41 Bedford Road Workshops/CHP
42 Johnston Centra
43 International Centre
44 Science Teaching Hub

(P) Regulated Parking

* Aberdeen Sports Village

Map

TO HILLHEAD HALLS

CRUICKSHANK BOTANIC GARDEN

CRUICKSHANK BOTANIC GARDEN

TILLYDRONE AVENUE

THE CHANONRY

DON STREET

DUNBAR STREET

ST MACHAR DRIVE

ST MACHAR DRIVE

KING STREET

ELPHINSTONE ROAD

HIGH STREET

DUNBAR STREET

BEDFORD ROAD

MESTON WALK

COLLEGE BOUNDS

REGENT WALK

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ASV* →

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