XXXVI Dynamics Days Europe

Book of Abstracts

6-10 June Corfu 2016

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MS.09 Advanced Time-Series Analysis: Novel tools for Studying Dynamical Networks and Complex Systems

1.1.3 Parallel 2: 10:00-12:00

MS.10 Front Evolution in Active Fluid Flows

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OC.Session: Chaos

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Jan Sieber, Tracking unstable phenomena in experiments and complex simulations

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Jurgen Vollmer, Breaking Universality in Non-Equilibrium Statistical Physics

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MS.03 Structure and Dynamics of Future Energy Systems: Power Grids as Complex Dynamical Systems

1.2.3 Parallel 2: 10:00-12:00

MS.06 Reservoir Computing and Laser Dynamics

1.2.4 Parallel 3: 10:00-12:00

MS.12 Nonlinear Waves: Modeling. Methods and Applications

1.2.5 Parallel 4: 10:00-12:00

OC.Session: Complex Networks

1.2.6 Plenary 4: 13:30-14:30

Dimitris Kugiumtzis, Complex networks from multivariate time series: estimation and limitations

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1.3 Wednesday 8th June

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Silvana Cardoso, Dynamics of buoyancy-driven flows in the Earths subsurface and in the ocean

1.3.2 Parallel 1: 10:00-12:00

MS.01 The Kuramoto Model with Inertia in Complex Networks

1.3.3 Parallel 2: 10:00-12:00

MS.04 Emergent Dynamics of Out-of-Equilibrium Colloids

1.3.4 Parallel 3: 10:00-12:00

MS.14 Nanoscale thermal and thermoelectric transport: A dynamical systems approach

1.3.5 Parallel 4: 10:00-12:00

OC.Session: Chaos/Complex Systems

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OC.Session: Hybrid Systems/Complex Dynamics

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Yannis Kevrekidis, Mathematics for data-driven modeling - The science of crystal balls

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MS.02 New Trends in Chimera States

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MS.05 Assembly of Non-Spherical Particles

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MS.13 Time Series, Networks and Applications

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Laurette Tuckerman, Turbulent-laminar patterns

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MS.07 Noisy Dynamics in Biological Networks

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OC.Session: Chaos/Pattern Formation

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1.5 Friday 10th June

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Lorenz Thomas, The expanding world of dynamical systems: Nonsmooth shapes and robustness refuse the minus !?

1.5.2 Parallel 1: 10:00-12:30

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1.5.3 Parallel 2: 10:00-12:30

OC.Session: Nonlinear Time series Analysis

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OC.Session: Environmental/ Ecological Dynamics

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OC.Session: Chaos/Pattern Formation

2 Detailed Schedule

2.1 Monday 6th June

2.1.1 Plenary 1: 8:30-9:30

Philip Maini, Modelling cell movement dynamics in biology

2.1.2 Parallel 1: 10:00-12:00

MS.09 Advanced Time-Series Analysis: Novel tools for Studying Dynamical Networks and Complex Systems 1/1

- **MS.09.01** Macroscopic reliability of high-dimensional chaos in recurrent neural networks
- **MS.09.02** Network inference from time-series measurements
- **MS.09.03** Inferring Network Connectivity From Time Series
- **MS.09.04** Time-series similarity analysis of coupled nonlinear oscillators and application to climate data
- **MS.09.05** Using delay coordinates for specifying non-observable and redundant model parameters

2.1.3 Parallel 2: 10:00-12:00

MS.10 Front Evolution in Active Fluid Flows 1/2

- **MS.10.01** Experimental studies of reaction front barriers in laminar flows
- **MS.10.02** Calcium Carbonate Mineralization in a Confined Geometry
- **MS.10.03** Selection of Frozen Fronts in simple flow and Avalanches Dynamics in Reaction Fronts in Disordered Flow
- **MS.10.04** Effective dimensions and chemical transients in closed fluid flows
- **MS.10.05** Optimal stretching for growth in reaction-diffusion-advection systems

2.1.4 Parallel 3: 10:00-12:00

Session: Chaos

- **OC.005** Farey sequence and the largest Lyapunov exponent analysis in the ac driven Frenkel-Kontorova mode
- **OC.008** FrobeniusPerron eigenstates for asymmetric backscattering in deformed microdisk cavities
- **OC.016** Studies on integrability using higher variational equations, and applications
- **OC.044** Spiral wave chaos: Tiling, local symmetries, and asymptotic freedom
- **OC.043** Kuramoto-Sakaguchi model as an extended system : chimera, puffs and spatio-temporal intermittency

2.1.5 Parallel 4: 10:00-12:00

Session: Neurodynamics 1/2

- **OC.001** Hub dynamics in complex networks
- **OC.007** Auditory neural burst formation through spike synchronization in the cochlea
- **OC.084** Colored noise as a driver of epileptiform dynamics in a mesoscopic neuronal model
- **OC.085** Causal connectome of the human brain: how do the large-scale networks communicate?
- **OC.086** Investigating visual working memory in epileptic children with use of Spectral Granger Causality

2.1.6 Plenary 2: 13:30-14:30

Jan Sieber, Tracking unstable phenomena in experiments and complex simulations

2.1.7 Parallel 1: 15:00-17:00

MS.11 Data-based Methods for Complex Dynamical Systems 1/2

- **MS.11.01** On the Computation of Attractors for Delay Differential Equations
- **MS.11.02** A spectral clustering approach to coherent Lagrangian vortex detection
- **MS.11.03** Matching algorithms for sampling in multiscale simulations
- **MS.11.04** The design of numerical methods for statistical simulation in high-dimensional dynamical models
- **MS.11.05** Spectral analysis of flows using radial basis functions

2.1.8 Parallel 2: 15:00-17:00

MS.10 Front Evolution in Active Fluid Flows 2/2

- **MS.10.06** Burning Lagrangian Coherent Structures and pattern formation in advection-reaction-diffusion dynamics
- **MS.10.07** Chemically Induced Finger Instabilities
- **MS.10.08** Three-dimensional convection-driven fronts in autocatalytic systems
- **MS.10.09** Harmful algal blooms: combining excitability, competition and hydrodynamic flows
- **MS.10.10** Dynamics of dilute and dense bacterial suspensions under flow

2.1.9 Parallel 3: 15:00-17:00

Session: Nonlinear Dynamics/Bifurcation Theory 1/2

- **OC.059** Backbones in the parameter plane of the Hénon map
- **OC.094** Numerical methods for quasi-conservative systems
- **OC.069** Bifurcation bridges in semiconductor ring lasers subject to delayed optical feedback

- **OC.070** Extreme orbits: the key of the global organization of complex sets in the parameter space
- **OC.006** Influence of Hopf bifurcations on the external cavity modes for a laser subject to phase-conjugate feed

2.1.10 Parallel 4: 15:00-17:00

Session: Complex Networks 1/3

- **OC.014** Multistability of Phase-Locking and Topological Winding Numbers in Locally Coupled Kuramoto Models
- **OC.021** Jittering regimes in rings of pulse oscillators with delayed coupling
- **OC.041** Network Inference in the Presence of Latent Confounders: The Role of Instantaneous Causalities
- **OC.062** Vortex Currents in High Voltage AC Power Grids
- **OC.009** Chaos synchronization by resonance of multiple delay times
- **OC.047** Transition States and Invariant Manifolds

2.1.11 Parallel 1: 17:30-19:30

MS.11 Data-based Methods for Complex Dynamical Systems 2/2

- **MS.11.06** Tensor-based data-driven analysis of complex dynamical systems
- **MS.11.07** Detecting coherent sets with spacetime diffusion maps
- **MS.11.08** Transfer Operator Families and Coherent Sets
- **MS.11.09** Coherent Families: Spectral Theory for Transfer Operators in Continuous Time
- **MS.11.10** Information barriers and robustness of reduced-order models, with application to optimal control of diffusions

2.1.12 Parallel 2: 17:30-19:30

MS.08 Consistency and Chaos in Complex Photonic Systems

- **MS.08.01** Reservoir computing based on consistency of a semiconductor laser driven by a chaos mask signal
- **MS.08.02** Consistency in Chaotic Systems Driven by Time-Delayed Feedback
- **MS.08.03** Global and cluster synchronization in multi-nodal semiconductor laser network
- **MS.08.04** Quantitative relationship between phase response and chaos bandwidth enhancement in semiconductor lasers subject to optical feedback and injection
- **MS.08.05** Photonic memories using time-delayed neuromorphic optoelectronic resonators

2.1.13 Parallel 3: 17:30-19:30

Session: Biophysics 1/2

- **OC.054** The impact of the newly licensed dengue vaccine in endemic countries
- **OC.092** Stochastic Dynamics of Cancer Growth and Mutations: Modeling Lung Cancer Data
- **OC.083** Asymptotic Analysis of a Target Mediated Drug Disposition Model: Algorithmic and Traditional Approach
- **OC.099** Agent-based modeling, forecasting and control of the Ebola Epidemic in Liberia and Sierra Leone

2.1.14 Parallel 4: 17:30-19:30

Session: Nonlinear Dynamics/Bifurcation Theory 2/2

- **OC.053** Dynamics of second-order equation with large delay
- **OC.096** Self-coupling in the FitzHugh-Nagumo model in the limit of short time-delays

- **OC.097** Unstable modes in bounded slow manifolds
- **OC.042** Asymptotic stability criteria
- **OC.103** On Control-Based and Equation-Free Continuation

2.2 Thuesday 7th June

2.2.1 Plenary 3: 8:30-9:30

Jurgen Vollmer, Breaking Universality in Non-Equilibrium Statistical Physics

2.2.2 Parallel 1: 10:00-12:00

MS.03 Structure and Dynamics of Future Energy Systems: Power Grids as Complex Dynamical Systems 1/2

- **MS.03.01** Design of a simplified highly renewable European electricity system - challenges for system engineering, applied mathematics and physics of complex networks
- **MS.03.02** Synchronization stability and control in power-grid networks
- **MS.03.03** Statistical Physics for Power Grids
- **MS.03.04** Prediction, detection and spreading of failures in supply networks

2.2.3 Parallel 2: 10:00-12:00

MS.06 Reservoir Computing and Laser Dynamics

- **MS.06.01** Physical reservoir computing from a dynamical systems point of view
- **MS.06.02** Efficient signal processing in random networks that generate variability in contrast to externally generated variability
- **MS.06.03** Reservoir Computing with Photonic Delay Systems
- **MS.06.04** Brain-inspired processors based on lasers with Optical Feedback

2.2.4 Parallel 3: 10:00-12:00

MS.12 Nonlinear Waves: Modeling. Methods and Applications 1/2

- **MS.12.01** Comb solitons in micro-ring resonators
- **MS.12.02** Propagating quantum breathers in superconducting qubit lattices

- **MS.12.03** Time-asymmetric quantum physics and Gamow vectors in nonlinear waves
- **MS.12.04** Discrete breathers in granular chains
- **MS.12.05** Coherence and Decoherence in Superconducting Metamaterials

2.2.5 Parallel 4: 10:00-12:00

Session: Complex Networks 2/3

- **OC.050** Geometric Constraints and Scaling Laws in Spatial Networks
- **OC.045** Asynchronous networks & a modularization of dynamics theorem
- **OC.098** Multimodal or coupled networks: just a matter of taste?
- **OC.031** Optimal Target Control of Complex Networks
- **OC.027** Inter-layer synchronization in multiplex networks

2.2.6 Plenary 4: 13:30-14:30

Dimitris Kugiumtzis, Complex networks from multivariate time series: estimation and limitations

2.2.7 Parallel 1: 15:00-17:00

MS.03 Structure and Dynamics of Future Energy Systems: Power Grids as Complex Dynamical Systems 2/2

- **MS.03.05** Reducing Complexity in Energy System Optimizations with High Shares of Renewables
- **MS.03.06** Impact of intermittent feed-in uctuations on the dynamics of power grids
- **MS.03.07** Forecasting the electricity balancing markets volumes and sizes in presence of a high share of renewable energy sources
- **MS.03.08** Stability Measures for High-Dimensional Multi-Stable Systems
- **MS.03.09** Taming Instabilities in Power Grid Networks by Decentralized Control

2.2.8 Parallel 2: 15:00-17:00

Session: Complex Networks 3/3

- **OC.046** Identifying Dynamical Instabilities in Supply Networks Using Generalized Modelling
- **OC.082** Dynamics and Thermodynamics of Chemical Reaction Network
- **OC.023** Information Spread in Networks: Search Engines vs. Word-of-Mouth
- **OC.048** Robustness of oscillatory behavior in correlated networks
- **OC.066** Improving Network Inference of Oscillatory Systems: A Novel Framework To Reliably Identify the Correct Class Of Network

2.2.9 Parallel 3: 15:00-17:00

MS.12 Nonlinear Waves: Modeling. Methods and Applications 2/2

- **MS.12.06** Integrable nonlocal nonlinear Schrodinger equation
- **MS.12.07** Compactons in a nonlinear evolutionary PDE and its discrete analog
- **MS.12.08** Instabilities in Non-hermitian Photonic Structures
- **MS.12.09** Dynamics of wave propagation in nonlinear photonic structures with unbalanced gain and loss
- **MS.12.10** Adiabatic perturbation theory for vector nonlinear Schrodinger equation with nonvanishing boundary conditions

2.2.10 Parallel 4: 15:00-17:00

Session: Complex Systems 1/2

- **OC.039** Multistability in an erbium-doped fiber laser: photonic applications
- **OC.040** Timing of Transients: Quantifying Return Times and Transient Behavior in Complex Systems
- **OC.068** Extreme Events in Delay-Coupled FitzHugh-Nagumo Oscillators

- **OC.011** Phase dynamics of delay-coupled electronic clocks with filter induced memory effects
- **OC.091** Attractors of relaxation mappings with chaotic dynamics on a fast time scale

2.2.11 Poster Session: 17:30-19:30

2.3 Wednesday 8th June

2.3.1 Plenary 5: 8:30-9:30

Silvana Cardoso, Dynamics of buoyancy-driven flows in the Earths subsurface and in the ocean

2.3.2 Parallel 1: 10:00-12:00

MS.01 The Kuramoto Model with Inertia in Complex Networks 1/2

- **MS.01.01** Synchronization of Pendula: from Huygens to Chimeras
- **MS.01.02** Solitary states in oscillatory networks
- **MS.01.03** Nonlinear transient waves in coupled phase oscillators with inertia
- **MS.01.04** Dynamics of fully coupled rotators with unimodal and bimodal frequency distribution

2.3.3 Parallel 2: 10:00-12:00

MS.04 Emergent Dynamics of Out-of-Equilibrium Colloids 1/1

- **MS.04.01** The Collective Behaviors of Self-Propelled Particles and Drops through hydrodynamic interactions
- **MS.04.02** Emergent collective dynamics in ensembles of magnetic colloidal rollers and spinners
- **MS.04.03** Topological protection of multiparticle dissipative transport
- **MS.04.04** Hydrodynamic self-organization and mixing in suspensions of micro-rotors
- **MS.04.05** Complex Magnetic Fields Breathe Life into Fluids

2.3.4 Parallel 3: 10:00-12:00

MS.14 Nanoscale thermal and thermoelectric transport: A dynamical systems approach 1/1

- **MS.14.01** Increasing thermoelectric efficiency: Dynamical models unveil microscopic mechanisms
- **MS.14.02** Studying thermoelectricity using efficiency fluctuations
- **MS.14.03** Phononic heat transport and thermal rectification
- **MS.14.04** Towards the laws of thermodynamics for non-Markovian quantum machines

2.3.5 Parallel 4: 10:00-12:00

Session: Chaos/Complex Systems

- **OC.080** Modelling Thermostatically Controlled Loads as Coupled Oscillators for Electricity Grid Balancing
- **OC.002** Accuracy of the non-relativistic approximation to relativistic momentum diffusion at low speed
- **OC.004** Exploring the Applications of Fractional Calculus: Anomalous Diffusion of Hierarchically-Built-Polymers
- **OC.028** Stochastic Detection of an Interaction-Range in Non-Equilibrium Traffic and Granular Flows

2.3.6 Parallel 1: 13:30-15:30

MS.01 The Kuramoto Model with Inertia in Complex Networks 2/2

- **MS.01.05** Finding the role of time delays
- **MS.01.06** Nonequilibrium first-order phase transitions in the Kuramoto model in presence of inertia and noise
- **MS.01.07** Impact of network topology on synchrony of oscillatory power grids
- **MS.01.08** The 2nd order Kuramoto model in a future power grid
- **MS.01.09** Uncovering stability from sync basin in the Second-order Kuramoto model

2.3.7 Parallel 2: 13:30-15:30

Session: Complex Fluid Dynamics 1/2

- **OC.015** Navier-Stokes meets Synchronization - Numerical Simulation of Aeroacoustical Coupled Organ Pipes
- **OC.034** Helical mode interactions and spectral transfer processes in magnetohydrodynamic turbulence
- **OC.058** Suppression of long-range pressure contributions due to screening in turbulent flows
- **OC.033** Effects of fluid mechanics on the dynamics of compressed/expanded surfactant monolayers
- **OC.052** Phase synchronization of Kármán vortices

2.3.8 Parallel 3: 13:30-15:30

Session: Biophysics 2/2

- **OC.061** Route to chaos via torus destruction in models of dengue fever epidemiology and implications for time series analysis in Thailand dengue notification data
- **OC.089** Complex Solutions OF Nonlinear Optimal Control Problems
- **OC.079** Dissipation in noisy chemical systems: The role of deficiency
- **OC.093** When a reaction contributes to the generation of its reactant or to the destruction of its product
- **OC.010** Transition between segregation and aggregation : the role of environmental constraints

2.3.9 Parallel 4: 13:30-15:30

Session: Hybrid Systems/Complex Dynamics

- **OC.071** Delay-Induced Dynamics of Localized Structures in Systems with Spatial Inhomogeneities

- **OC.063** A Generalized Form of Disorder-Induced Resonance
- **OC.064** Wavefront Propagation in Two-Dimensional Optical Bistable Device under Patterned Light Irradiation
- **OC.038** Bifurcating small chimera states in a network of coupled lasers
- **OC.026** Neighborhoods of periodic orbits and the stationary distribution of a noisy chaotic system

2.4 Thursday 9th June

2.4.1 Plenary 6: 8:30-9:30

Yannis Kevrekidis, Mathematics for data-driven modeling The science of crystal balls

2.4.2 Paralell 1: 10:00-12:00

MS.02 New Trends in Chimera States 1/2

- **MS.02.01** Tweezer control for chimeras in small networks
- **MS.02.02** Controlling chimera states through pinning
- **MS.02.03** Intermittent chaotic chimeras for coupled rotators
- **MS.02.04** Alternating chimera states and other peculiar coherence-incoherence patterns in globally coupled oscillatory media
- **MS.02.05** Coherence-resonance chimeras in a network of excitable elements

2.4.3 Paralell 2: 10:00-12:00

MS.05 Assembly of Non-Spherical Particles 1/2

- **MS.05.01** Designing polyhedral particles for targeted self-assembly
- **MS.05.05** Curvature-driven flows explain where Martian river flows
- **MS.05.03** Particle-based simulation of powder application in additive manufacturing under consideration of geometrically complex particles
- **MS.05.02** Packings and flows of non-spherical particles

2.4.4 Paralell 3: 10:00-12:00

MS.13 Time Series, Networks and Applications 1/2

- **MS.13.01** Pairwise mutual information - a good interaction approximation?
- **MS.13.02** Determining the sub-Lyapunov exponent from chaotic dynamics of photonic delay systems

- **MS.13.03** Detecting redundancy and synergy with Granger causality
- **MS.13.04** Inferring Networks from Data: Recent Challenges and Advances
- **MS.13.05** Constructing networks from time series with k-nearest neighbours - how and why

2.4.5 Paralell 4: 10:00-12:00

Session: Complex Systems 2/2

- **OC.060** Toward new general-purpose processor with nonlinear transient computing
- **OC.025** Gas-like economic models: strategy and topology effects
- **OC.035** Linear Stability and the Braess Paradox in Coupled Oscillators Networks and Electric Power Grids
- **OC.075** Dynamical Voltage-Current Characteristics of Superconductor / Normal Metal / Superconductor Junctions
- **OC.081** Rotational Diffusion of a Molecular Cat

2.4.6 Plenary 7: 13:30-14:30

Laurette Tuckerman, Turbulent-laminar patterns

2.4.7 Parallel 1: 15:00-17:00

MS.02 New Trends in Chimera States 2/2

- **MS.02.06** Delayed-feedback chimera states: Forced multiclusters and stochastic resonance
- **MS.02.07** Linked and knotted chimera laments in oscillatory systems
- **MS.02.08** Twisted chimera states and multicore spiral chimera states on a two-dimensional torus
- **MS.02.09** Self-propelled chimeras
- **MS.02.10** SQUID chimeras: lions, goats and snakes

2.4.8 Parallel 2: 15:00-17:00

MS.05 Assembly of Non-Spherical Particles 2/2

- **MS.05.11** Dancing screw-nuts: Assembly of hexagonally shaped disks with attractive interactions
- **MS.05.07** Mean-field approach for random close packings of spherical and non-spherical particles
- **MS.05.08** The structure of non-spherical particle packings
- **MS.05.09** Liquid-crystal patterns in vibrated quasi-monolayers of rods
- **MS.05.10** Rotation and ordering of elongated particles under shear

2.4.9 Parallel 3: 15:00-17:00

MS.13 Time Series, Networks and Applications 2/2

- **MS.13.06** Comparing Density Forecasts in a Risk Management Context
- **MS.13.07** Information theoretic causal network structure of nancial data series
- **MS.13.08** Impact of external perturbations is dependent on the dynamical state of epileptic networks
- **MS.13.09** A creative brain is well-connected: functional networks of the creativity process in resting state
- **MS.13.10** Distributional Clustering of Multivariate Time Series

2.4.10 Parallel 4: 15:00-17:00

Session: Environmental/ Ecological Dynamics 1/2

- **OC.013** Diversity emerging from the interplay between dispersion and competition
- **OC.037** Harmful algal blooms: Extreme events in a coastal ecosystem
- **OC.076** Spatial effects for food webs in patch landscapes
- **OC.102** Melancholia States in the Climate System: Exploring Global Instabilities and Critical Transitions

2.4.11 Parallel 1: 17:30-19:30

Session: Complex Fluid Dynamics 2/2

- **OC.003** Asymptotic reduction of exact solutions of shear flows
- **OC.049** Precessionally-forced rotating cylinder flow: nutation angle effects
- **OC.065** Geometric Mixing, Peristalsis, and the Geometric Phase of the Stomach
- **OC.087** Steady streaming in standing waves
- **OC.017** Torsions as a new dynamic feature in 2D plasma crystals

2.4.12 Parallel 2: 17:30-19:30

MS.07 Noisy Dynamics in Biological Networks 1/2

- **MS.07.01** Correlations of fluctuations in recurrent networks of spiking neurons are strongly colored
- **MS.07.02** Chimera patterns under the influence of noise
- **MS.07.03** Amplitude and Phase Chimera States in a Ring of Nonlocally Coupled Chaotic Systems
- **MS.07.04** Role of noise and emergence of various patterns in networks
- **MS.07.05** Noise-induced coupling in neuronal networks with spike timing-dependent plasticity

2.4.13 Parallel 3: 17:30-19:30

Session: Chaos/Pattern Formation 1/2

- **OC.078** Frequency Synchronization and Localized Dynamics in Symmetric Networks of Coupled Phase Oscillators
- **OC.051** Multiheaded scroll wave chimeras
- **OC.029** Experimental Study of Chimeras in Small Ensembles of Phase Oscillators

- **OC.024** Collective behavior patterns in a ring of Kuramoto-type rotators with time-delay
- **OC.067** Bifurcation of spiral-shaped patterns in the phase space of a nonlinear delayed electro-optic system
- **OC.032** Activation process in systems of excitable units with multiple noise sources

2.4.14 Parallel 4: 17:30-19:30

Session: Neurodynamics 2/2

- **OC.012** Effect of Stimulation Frequency and Intensity on Long-Lasting Anti-Kindling
- **OC.022** Cell Assembly Dynamics of Sparsely-connected Inhibitory Networks
- **OC.074** Modelling of glissando patterns in the small neuronal circuit
- **OC.036** Chimera States in Leaky Integrate-and-Fire Networks
- **OC.090** Chimera states in two populations with heterogeneous phase lag

2.5 Friday 10th June

2.5.1 Plenary 8: 8:30-9:30

Lorenz Thomas, The expanding world of dynamical systems: Nonsmooth shapes and robustness refuse the minus !?

2.5.2 Parallel 1: 10:00-12:30

MS.07 Noisy Dynamics in Biological Networks 2/2

- **MS.07.06** Noisy synapses in the brain: A way to optimise neural computations?
- **MS.07.07** Interplay of Noise and Intelligence in Intracellular Gene-regulatory Networks
- **MS.07.08** Multiple time scales signalling in recurrent neural network driven by noise
- **MS.07.09** Bifurcations in open quantum systems

2.5.3 Parallel 2: 10:00-12:30

Session: Nonlinear Time series Analysis

- **OC.018** Robustness and reliability of the fitting of extreme value distributions and its results
- **OC.030** Non-admissible complex wavelets: an effective tool for spectral analysis of relaxation non-linear oscillations
- **OC.077** A Bayesian approach to dynamical noise reduction
- **OC.088** Detection of structural changes from connectivity analysis

2.5.4 Parallel 3: 10:00-12:30

Session: Environmental/ Ecological Dynamics 2/2

- **OC.020** Linear stability analysis of the coevolution of shallow marine clouds and rain

- **OC.057** Behavior of a Predator-Prey System under Strong Periodic Forcing
- **OC.101** Nonlinear Dynamics and Bifurcations in a forest-grassland ecosystem
- **OC.100** Seismicity Mopeling and Analysis of the 2009 L'Aquila Earthquake using complex networks
- **OC.104** Control-based continuation of pedestrian flows

2.5.5 Parallel 4: 10:00-12:30

Session: Chaos/Pattern Formation 2/2

- **OC.019** Formation of a periodic sequence of stabilized wave segments in excitable media
- **OC.072** Rayleigh-Plateau Instabilities of Thin Liquid Ridges
- **OC.056** Dynamical aperture and complex patterns in a strong localization approach
- **OC.055** Orbital motion in multipole fields via multiscales

3 Plenary talks

Plenary 1: 6 June 8:30-9:30

Modelling cell movement dynamics in biology

Philip Maini *(University of Oxford)*

We will review a number of areas in biology in which cells move in response to different chemical and physical cues. Examples will include neural cell crest invasion, movement in epithelial sheets, and invasion in heterogeneous media. The mathematical models used range from partial differential equations, to discrete cell-based and hybrid cellular automata.

Plenary 2: 6 June 13:30-14:30

Tracking unstable phenomena in experiments and complex simulations

Sieber Jan *(University of Exeter)*

The talk will give a few demonstrations where we systematically tracked families of periodic orbits in experiments. The methods combine ideas by Siettos et al (2004), time-delayed feedback control ideas and classical Newton iteration based numerical continuation to apply control in a non-invasive manner. We apply this experimental technique to track more complex unstable phenomena, such as chimeras in a ring of phase oscillators, in simulations. In these cases the control is non-invasive only in the mean or in the continuum limit.

Plenary 3: 7 June 8:30-9:30

Breaking Universality in Non-Equilibrium Statistical Physics

Jurgen Vollmer *(University of Goettingen)*

Universality is a key concept in statistical physics and dynamical systems theory. In the latter it is expressed by normal forms of bifurcations and in routes to chaos. In the former it has potent applications in the theory of critical phenomena: symmetries of the Hamiltonian uniquely select the set of critical exponents governing power-law divergences of correlation functions and response properties.

Breath figures are droplet patterns that grow on surfaces facing supersaturated steam. A characteristic example is dew. The droplets grow in time, giving rise to a self-similar droplet size distribution. Patterns at later time are reminiscent to those at earlier times, up to a rescaling of the size of the largest droplets. Hence, renormalization group theory was employed to determine the non-trivial exponent characterizing the size distribution. The derivation assumes that the exponent is universal. Scaling relations connect the exponent to the fractal dimension of the area that is not covered by droplets. However, this fractal dimension depends in a subtle way on the prescription of building the fractal, i.e. on microscopic details selecting the positions where new droplets are nucleated and on non-universal aspects of their growth. The exponent is not universal.

Granular flow undergoes jamming when the particle density is increased. The transition is governed by a critical point that arises at random close packing and zero shear rate. Concepts developed in renormalization group theory of equilibrium phase transitions form a very powerful tool in the analysis of this transition. However, the values of scaling exponents depend on specific details of short-range interactions, and the fluctuations close to the critical point differ fundamentally from those close to classical critical points. They are not universal. I conclude that there is a new field of research emerging here. In non-equilibrium systems short-range, microscopic interactions break the Hamiltonian phase space dynamics. Some thermodynamic properties survive this perturbation, others in particular the universality of scaling exponents are affected in a non-trivial way. Dynamical systems theory provides the tools to clarify how the qualitatively new properties arise.

Plenary 4: 7 June 13:30-14:30

Complex networks from multivariate time series: estimation and limitations

Kugiumtzis Dimitris *(Aristotle University of Thessaloniki)*

In the study of complex dynamical systems, such as brain dynamics and financial market dynamics, from multivariate time series, a main objective is the estimation of the inter-dependence structure of the observed variables (or subsystems), where inter-dependence is also referred to as coupling, information flow or Granger causality. A number of measures have been developed to estimate the driving-response connections among the observed variables and form the complex network (called also connectivity or causality network), having nodes the observed variables and connections the estimated inter-dependences. I will review the methodology on this topic and discuss the limitations in identifying the true complex network. In particular, I will focus on the following settings met often with real data: (a) large number of observed variables, (b) an important node is not observed (hidden source), (c) the observed variables have undergone transforms. Case studies from neuroscience and finance will be presented.

Plenary 5: 8 June 8:30-9:30

Dynamics of buoyancy-driven flows in the Earths subsurface and in the ocean

Cardoso Silvana *(University of Cambridge)*

Chemical and physical disequilibrium in the ocean, atmosphere and in the Earths subsurface can lead to gigantic convective flows of methane and carbon dioxide. Examples in the atmosphere and oceans include the turbulent plumes formed during the Icelandic volcanic eruption (2010), the BP oil spill in the Gulf of Mexico (2010), and the large number of methane plumes found recently in the Arctic Sea (2013). In the sub-surface, when carbon dioxide dissolves in the water contained in the porous rock, the heavy CO2-rich fluid sinks driving vigorous laminar convection. A further example is the flow of dissolved methane under osmotic forces in the porous rock near mud volcanoes on the seabed. In this talk, we focus on the non-linear interaction between hydrodynamics and chemistry, including chemical reaction or dissolution/precipitation, in such flows. Using complementary theoretical, numerical and experimental approaches, we quantify the spatiotemporal development of the flow pattern caused by ongoing chemical processes and mixing in the fluids.

Plenary 6: 9 June 8:30-9:30

Mathematics for data-driven modeling - The science of crystal balls

Kevrekidis Yannis *(Princeton University)*

In mathematical modeling one typically progresses from observations of the world (and some serious thinking!) to equations for a model, and then to the analysis of the model to make predictions. Good mathematical models give good predictions (and inaccurate ones do not) but the computational tools for analyzing them are the same: algorithms that are typically based on closed form equations. While the skeleton of the process remains the same, today we witness the development of mathematical techniques that operate directly on observations -data-, and circumvent the serious thinking that goes into selecting variables and parameters and writing equations. The process then may appear to the user a little like making predictions by looking into a crystal ball. Yet the serious thinking is still there and uses the same -and some new- mathematics: it goes into building algorithms that jump directly from data to the analysis of the model (which is never available in closed form) so as to make predictions. I will present a couple of efforts that illustrate this new path from data to predictions. It really is the same old path, but it is travelled by new means.

Plenary 7: 9 June 13:30-14:30

Turbulent-laminar patterns

Laurette Tuckerman *(PMMH-ESPCI, Paris)*

The transition to turbulence is characterized by coexistence of laminar and turbulent regions. In plane Couette and Poiseuille flow, this coexistence takes the form of statistically stationary alternating oblique bands of turbulent and laminar flow whose wavelength and orientation with respect to the streamwise direction are fixed. Since the wavelength of these astonishing patterns is much larger than the gap, they were first discovered in very large aspect ratio experiments. We study these patterns via full direct numerical simulation and reduced models.

This is joint work with Mat Chantry and Dwight Barkley

Plenary 8: 10 June 8:30-9:30

The expanding world of dynamical systems: Nonsmooth shapes and robustness refuse the minus !?

Lorenz Thomas *(RheinMain University)*

Dynamical systems have proved to be a flexible and very useful approach for modelling phenomena in nature, economics and engineering. Most standard examples are expressed in terms of ordinary differential equations, and several extensions to partial differential equations are well established (like evolution equations).

Applications in shape optimization and robust control problems, however, reveal a joint weakness of these infinitesimal approaches: They require an underlying linear space. Shapes in three-dimensional space, for example, are just compact subsets without an obvious linear structure if any a priori assumptions about regularity are avoided.

This talk focuses on how the notion of ordinary differential equations can be extended to metric spaces. Various examples show that the underlying idea provides the starting point for extending dynamical systems to a broad class of infinitesimal evolutions. In particular, conditions for well-posedness are then directly available for systems whose components are of completely different mathematical type.

4 Minisymposium talks

MS.01 The Kuramoto Model with Inertia in Complex Networks
8 June 10:00-12:00 (Parallel 1)

The second-order Kuramoto model has increasingly been brought to higher attention recently. The double minisymposium is dedicated to review the model from different points of view. From a methodological standpoint, the first minisymposium will be concerned to the description of the collective behavior of sets of coupled Kuramoto oscillators with inertia using mean-field analysis, mainly focusing on the study of emergent phenomena, such as chimera states and traveling waves. The second minisymposium will be dedicated to the investigation of the model in the presence of time delays and noise, besides the evaluation of the stability of networks of coupled oscillators in terms of the basin of attraction of the synchronized state against large perturbations. The rich potential for applications is discussed for special fields from engineering to neuroscience, with special attention to power grids.

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MS.01.01.Synchronization of Pendula: from Huygens to Chimeras

We recall the famous Huygens experiment which gave the first evidence of the synchronization phenomenon. We consider the synchronization of two clocks which are accurate (show the same time) but have pendula with different masses. It has been shown that such clocks hanging on the same beam can show the almost complete (in-phase) and almost antiphase synchronizations. By almost complete and almost antiphase synchronization we defined the periodic motion of the pendula in which the phase shift between the displacements of the pendula is respectively close (but not equal) to 0 or π. We give evidence that almost antiphase synchronization was the phenomenon observed by Huygens in XVII century. Additionally we discuss the synchronization of a number of different pendulum clocks hanging from a horizontal beam which can roll on the parallel surface. It has been shown that after a transient, different types of synchronization between pendula can be observed; (i) the complete synchronization in which all pendula behave identically, (ii) pendula create three or five clusters of synchronized pendula. We derive the equations for the estimation of the phase differences between phase synchronized clusters. The evidence, why other configurations with a different number of clusters are not observed, is given.

The phenomenon of chimera states in the systems of coupled, identical oscillators has attracted a great deal of recent theoretical and experimental interest. In such a state, different groups of oscillators can exhibit coexisting synchronous and incoherent behaviors despite homogeneous coupling. Here, considering the coupled pendula, we find another pattern, the so-called imperfect chimera state, which is characterized by a certain number of oscillators which escape from the synchronized chimera's cluster or behave differently than most of uncorrelated pendula. The escaped elements oscillate with different average frequencies (Poincare rotation number). We show that imperfect chimera can be realized in simple experiments with mechanical oscillators, namely Huygens clock. Finally, we uncover the mechanism of the creation of the chimera states by perturbations to the fully synchronized state. The mathematical model of our experiment shows that the observed chimera states are controlled by elementary dynamical equations derived from Newton's laws that are ubiquitous in many physical and engineering systems.

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MS.01.02.Solitary states in oscillatory networks

Two mechanisms of the coherence-incoherence transition in networks of coupled oscillators are discussed. One is the recently discovered chimera states which is characterized by spontaneous splitting the oscillators into two groups, one synchronized and the other desynchronized. The second possibility is via so-called *solitary states*[1], when the desynchronization starts with splitting off a single or a few oscillators, while all others remain synchronized. Under further variation of the control parameter more and more oscillators leave the coherent cluster manifesting eventually the phenomenon of *spatial chaos* . In the talk, the solitary state appearance is reported for Kuramoto model with attractive and repulsive interaction [1], for nonlocally coupled Kuramoto model with inertia [2-3], also for more realistic networks with both periodic and chaotic local dynamics[1] as well as in delayed-feedback systems ([4]).

[1] Y. Maistrenko, B. Penkovsky, and M. Rosenblum. Solitary state at the edge of synchrony in ensembles with attractive and repulsive interactions. *Phys.Rev. E* 89, 060901(R) (2014).
[2] T. Kapitaniak, P. Kuzma, J. Wojewoda, K. Czolczynski, Y. Maistrenko. Imperfect chimera states for coupled pendula. *Scientific Reports* 4, 6379 (2014).
[3] P. Jaros, Yu. Maistrenko, and T. Kapitaniak. Chimera states on the route from coherence to rotating waves. *Phys. Rev. E* 91, 022907 (2015)
[4] V. Semenov, A. Zakharova, Yu. Maistrenko, and E. Schöll. Delayed-feedback chimera states: Forced multiclusters and stochastic resonance.
arxiv.org/pdf/1511.03634.pdf (2015)

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MS.01.03.Nonlinear transient waves in coupled phase oscillators with inertia

Like the inertia of a physical body describes its tendency to resist changes of its state of motion, inertia of an oscillator describes its tendency to resist changes of its frequency. In this talk, I present a simple idea: finite inertia of individual oscillators enables nonlinear phase waves in spatially extended coupled systems. The ability to exhibit traveling waves is a generic feature of such systems and is independent of the details of the coupling function. I show how a continuum approximation of an oscillator lattice with nearest-neighbor coupling is able to describe the key features of wave propagation in the long-wavelength limit.

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MS.01.04.Dynamics of fully coupled rotators with unimodal and bimodal frequency distribution

We analyze the synchronization transition of a globally coupled network of N phase oscillators with inertia (rotators) whose natural frequencies are unimodally or bimodally distributed. In the unimodal case [1], the system exhibits a discontinuous hysteretic transition from an incoherent to a partially synchronized (PS) state. For sufficiently large inertia, the system reveals the coexistence of a PS state and of a standing wave (SW) solution. In the bimodal case [2], the hysteretic synchronization transition involves several states. Namely, the system becomes coherent passing through traveling waves (TWs), SWs and finally arriving to a PS regime. The transition to the PS state from the SW occurs always at the same coupling, independently of the system size, while its value increases linearly with the inertia. On the other hand the critical coupling required to observe TWs and SWs increases with N suggesting that in the thermodynamic limit the transition from incoherence to PS will occur without any intermediate states. Finally a linear stability analysis reveals that the system is hysteretic not only at the level of macroscopic indicators, but also microscopically as verified by measuring the maximal Lyapunov exponent.

[1] S. Olmi, A. Navas, S. Boccaletti and A. Torcini, "Hysteretic transitions in the Kuramoto model with inertia", Physical Review E, 90(4), p.042905.
[2] S. Olmi and A. Torcini, "Dynamics of fully coupled rotators with unimodal and bimodal frequency distribution", Control of Self-Organizing Nonlinear Systems. Springer International Publishing, 2016. 25-45.

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MS.01.05.Finding the role of time delays

Time delays are omnipresently observed in many nature and artificial systems including physical, biological, and chemical systems. Naturally, two kinds of questions arise: How to identify the time delays when a certain amount of datasets are obtained from the experiments or real world systems? and How to characterize the intrinsic roles of time delays that are played in coupled network systems? In this talk, we introduce recent works that address the previous two questions, and show the significance of time delays in dealing with various systems of physical/biological significance.

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MS.01.06.Nonequilibrium first-order phase transitions in the Kuramoto model in presence of inertia and noise

The Kuramoto model of coupled nonlinear oscillators serves as a prototype to study spontaneous synchronization in biological and physical systems. The original model involves overdamped motion of globally coupled oscillators of distributed natural frequencies. I will discuss the model by including inertial terms and thermal noise in the dynamics, and show for unimodal frequency distributions that the dynamics exhibits a non-trivial nonequilibrium first-order transition from a synchronized phase at low parameter values to an unsynchronized phase at high values. In proper limits, we recover the known continuous phase transitions in the Kuramoto model and in its noisy extension, and an equilibrium continuous transition in a related model of long-range interactions. By interpreting the model as a system of particles interacting through long-range potential and driven out of equilibrium by quenched external forces, I will further discuss how one may adopt a statistical physics perspective to study the dynamics, different from the existing dynamical systems perspectives.

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MS.01.07.Impact of network topology on synchrony of oscillatory power grids

The severity of power grid failures is often measured by the number of affected consumers. Data from real-world power grids show that the probability to disconnect more than a certain number of consumers often decays like a power law [1]. Here we are using an oscillatory power grid model [2] to model cascading failures, induced by the failure of single transmission lines. We analyze the effect of different cascading failures by counting the number of affected consumers for both artificial regular topologies and the topology of the German power grid. We show that depending on parameter values different distributions of disconnected consumers can be found. Furthermore we analyze the effect of different cluster sizes of generators and consumers and determine the vulnerability of small and large clusters against cascading failures.

[1] I. Dobson et al., Chaos **17**, 026173 (2007)
[2] M. Rohden et al., Chaos **24**, 013123 (2014)

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MS.01.08.The 2nd order Kuramoto model in a future power grid

The questions to what extent increasing shares in variable renewable energy sources influence power grid stability and what market instruments may be used to incentivize grid stabilizing prosumer behavior are subject to a controversial public debate. The energy transformation shifts the production from great centralized power plants with well predictable power output to smaller renewable generation units with highly intermittent power production schemes. This leads to a few challenges we want to address in this talk: first, it is necessary to build models of the dynamics of renewable energy sources (RES) to understand how grid stability is affected and second, what measures can be taken to reinforce dynamic stability. Models for RES are still in the exploratory phase compared with the well known synchronous machine models for conventional generators which are available in different model detail. In our previous research we identified the the 2nd order Kuramoto m model to be sufficiently detailed for transient stability assessment [1]. Now, is it also possible to rely on modfications of 2nd order Kuramoto to model RES? Wind and solar power plants are connected to the grid via power electronics, namely inverters, that do do not react inertially to grid disturbances as rotating masses do but need measurement times to take pre-defined programmed control actions. This introduces delays in action changing the overall system dynamics which we analyzed in [2]. Additionally, their intermittent power input needs to be modeled by Poisson compound processes including Jump processes as Levy flights. We will discuss the challenges in changing our understanding of dynamic stability assessment for a frequency evolution subject to a combination of 2nd order Kuramoto with stochastic differential equations. On the basis of this research, we will show how a novel decentral smart grid approach is one possible measure for incentivizing consumers to support grid stability [2].

[1] S. Auer, K. Kleis, P. Schultz, J. Kurths, F. Hellmann, ArXiv:1510.05640, Accepted by EPJ (2016).
[2] B. Schafer, C. Grabow, S. Auer, D. Witthaut, M. Timme. Accepted by EPJ (2016).

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MS.01.09.Uncovering stability from sync basin in the Second-order Kuramoto model

The second-order Kuramoto model has increasingly been brought to higher attention recently, partially thanks to the increased interest in the synchronization of power grid systems. In this talk, I present our results in terms of the basin stability concept applied to the evaluation of the robustness of power grids against large perturbations. In the one-node model, we focus on assessing the volume of the attracting basin of the synchronized state. In the scenarios of networked systems, we extend the concept in order to quantify the local interaction between nodes (groups), while disregarding the dynamics of others, evaluating, in this way, the direct perturbation influence between different elements.

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MS.02.New trends in chimera states
9 June 10:00-12:00 and 15:00-17:00 (Parallel 1)

Chimera states in dynamical networks consist of coexisting domains of spatially coherent (synchronized) and incoherent (desynchronized) behavior. They are a manifestation of spontaneous symmetry-breaking in systems of identical oscillators, and occur in a variety of physical, chemical, biological, technological, or socio-economic systems. We focus on recent developments with future promising perspectives that go beyond the classical Kuramoto phase oscillators, for instance, coupled phase and amplitude dynamics, complex coupling topologies like hierarchical connections, chimeras in small-size networks, chimera patterns in 2D and 3D, noise-induced chimera effects like stochastic resonance of chimeras or coherence resonance chimeras, and control methods for stabilizing chimera states.

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MS.02.01.Tweezer control for chimeras in small networks

Chimera states consist of coexisting domains of spatially coherent and incoherent dynamics in systems of nonlocally coupled oscillators. Chimeras are generally difficult to observe in small networks due to their short lifetime and erratic drifting of the spatial position of the incoherent domain. We propose a control scheme which can stabilize and fix the position of chimera states in small networks. Like a tweezer, which helps to hold tiny objects, our control has two levers: the first one prevents the chimera collapse, whereas the second one stabilizes its lateral position. The control scheme might be useful in experiments, where usually only small networks can be realized.

I. Omelchenko, O. Omel'chenko, A. Zakharova, M. Wolfrum, and E. Schöll, arXiv:1512.04275 (2015).

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MS.02.02.Controlling chimera states through pinning

During the last decade, chimera states in coupled dynamical systems have been the subject of intense studies aiming to understand the peculiarities of this intriguing phenomenon, as well as the key ingredients for its onset. Recently, experiments able to show chimera states in different systems have been also proposed, from coupled chemical oscillators to coupled map lattices, mechanical oscillators and populations of coupled neurons. One of the common features of the chimera states is their dependence from the initial conditions, so that the spatial position of the coherent or of the non-coherent domain is not fixed. This has lead to the problem of controlling the onset of the chimera state and the position of one of the domains: techniques based on feedback control of a global parameter of the system or of the coupling strength, on local changes in the coupling kernel, or on the introduction of inhomogeneities in the dynamics of some of the units have been used for this purpose. In our work, we investigate the suitability of pinning control for eliciting chimera states and controlling the coherent (incoherent) domain position. In particular, we focus on non-locally coupled structures and validate our approach with two different types of oscillators, FitzHugh-Nagumo neurons and Kuramoto oscillators. As a prerequisite for the control, we require that the proposed technique is non-invasive, i.e., only applied for a short period of time, and localized on adjacent sites of the structure. This latter requirement is motivated by the purpose of controlling spatially extended structures where only some spatial regions are accessible to exert the control action. Our results pointed out that pinning a region of the spatial structure considered is effective to control the onset of chimera states and the position of either the coherent or incoherent domain. To induce the incoherent domain in the pinned region, we used a stochastic control signal of appropriate intensity, while for the coherent domain we coupled the pinned nodes with an external reference unit with the same dynamics but slightly mismatched parameters. We have found that controlling the incoherent domain is easier than the coherent one, as it requires to pin a small number of nodes and still performs well with a high number of pinned nodes. On the contrary, the control of the coherent domain requires a finer tuning of its parameters (including the number of pinned nodes).

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MS.02.03.Intermittent chaotic chimeras for coupled rotators

Two symmetrically coupled populations of N oscillators with inertia m display chaotic solutions with broken symmetry similar to experimental observations with mechanical pendulums. In particular, we report evidence of intermittent chaotic chimeras, where one population is synchronized and the other jumps erratically between laminar and turbulent phases. These states have finite lifetimes diverging as a power law with N and m. Lyapunov analyses reveal chaotic properties in quantitative agreement with theoretical predictions for globally coupled dissipative systems [1].

[1] S. Olmi, E. A. Martens, S. Thutupalli, and A. Torcini, "Intermittent chaotic chimeras for coupled rotators", Phys. Rev. E 92, 030901(R) (2015)

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MS.02.04.Alternating chimera states and other peculiar coherence-incoherence patterns in globally coupled oscillatory media

Chimera states, i.e. intriguing dynamical patterns composed of synchronized and incoherent regions in otherwise isotropic systems were originally observed in non-locally coupled ensembles of phase oscillators. Meanwhile, they are well known to also exist under global coupling in ensembles of Stuart- Landau oscillators with non-constant amplitudes. In the talk we will demonstrate that the latter chimera states might undergo transitions to more complex coherence-incoherence patterns when the global coupling acts in an oscillatory medium, i.e. when the oscillators are also subject to diffusive coupling. Among these peculiar patterns are alternating chimera states in which synchronized and desynchronized domains interchange repeatedly in characteristic time intervals. Moreover, both, desynchronized and synchronized parts may exhibit further symmetry breaking leading to coexistence patterns of three or more distinct regions with different behaviors. We will discuss conditions for their existence as well as bifurcations leading to these states. Furthermore, we elucidate that there is also a special type of chimera state, termed localized turbulence, which requires the combined action of global and diffusive coupling.

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MS.02.05.Coherence-resonance chimeras in a network of excitable elements

In a network of nonlocally coupled excitable systems we demonstrate the occurrence of chimera behavior in the presence of noise. This phenomenon is distinct from classical chimeras, which appear in deterministic oscillatory systems, and it combines temporal features of coherence resonance, i.e., the constructive role of noise, and spatial properties of chimera states, i.e., coexistence of spatially coherent and incoherent domains in a network of identical elements. *Coherence-resonance chimeras* are associated with alternating switching of the location of coherent and incoherent domains, which might be relevant in neuronal networks.

N. Semenova, A. Zakharova, V. S. Anishchenko, and E. Schöll (2016), arXiv:1512.07036v2

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MS.02.06.Delayed-feedback chimera states: Forced multiclusters and stochastic resonance

A single time-delayed feedback oscillator can be mapped onto a continuous space-time system or onto a network of coupled oscillators. In the present work a variety of spatio-temporal patterns including regular dynamics, spatio-temporal chaos, chimera states, and salt-and-pepper like solitary states are revealed by numerical simulation in a single nonlinear oscillator with negative time-delayed feedback. A scenario for the transition from complete coherence to complete incoherence via solitary states is identified when the nonlinearity parameter of the oscillator is varied. The control of the dynamics by external periodic forcing is demonstrated. It is shown that chimera states with controllable characteristics, e.g., a desired number of incoherent clusters can be induced by using external periodic driving. A generalized form of synchronization with the driving signal leads to Arnold tongues of multi-chimera states when the driving frequency obeys a resonance condition, independently of initial conditions. We also show that noise can play a constructive role for controlling the chimera state. Noisy modulation of the external forcing amplitude can induce chimeras in regimes where they do not exist without noise; this is reminiscent of stochastic resonance. The noise-induced formation of chimera states is accompanied by an increase of the peak of the power spectrum at the resonance frequency up to an optimum, followed by a decrease, with increasing the noise intensity. Such non-monotonic behavior as a function of noise intensity is also found in the signal-to-noise ratio.
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MS.02.07.Linked and knotted chimera filaments in oscillatory systems

While the existence of stable knotted and linked vortex lines has been established in many experimental and theoretical systems, their existence in oscillatory systems and systems with non-local coupling has remained elusive. Using the Kuramoto model of coupled phase oscillators as a paradigmatic example, we present strong numerical evidence that stable knots and links such as trefoils and Hopf links do exist if the coupling between the oscillators is neither too short-ranged nor too long-ranged. In this case, effective repulsive forces between vortex lines in knotted and linked structures stabilize curvature-driven shrinkage observed for single vortex rings. In contrast to real fluids and excitable media, the vortex lines correspond to scroll wave chimeras — synchronized scroll waves with spatially extended (tube-like) unsynchronized filaments, a prime example of spontaneous synchrony breaking in systems of identical oscillators. We finally show that stable knots also exist under similar conditions in more complex and chaotic oscillatory systems.

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MS.02.08.Twisted chimera states and multicore spiral chimera states on a two-dimensional torus

Chimera states consisting of domains of coherently and incoherently oscillating oscillators in a two-dimensional periodic array of nonlocally coupled phase oscillators are studied [1], focusing on two types of two-dimensional structures: twisted chimera states and spiral wave chimera states. Particular attention is paid to the dynamics present in the core region of spiral chimeras. The properties of these states, including stability, are studied using an evolution equation for a complex order parameter and the results compared with numerical simulations.

[1] J. Xie, E. Knobloch and H.-C. Kao. Phys. Rev E 92, 042921 (2015)

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MS.02.09.Self-propelled chimeras

We report the appearance of chimera states in a minimal extension of the classical Vicsek model for collective motion of self-propelled particle systems. Inspired by earlier works on chimera states in the Kuramoto model, we introduce a phase lag parameter in the particle alignment dynamics. Compared to the oscillatory networks with fixed site positions, the self-propelled particle systems can give rise to distinct forms of chimeras resembling moving flocks through an incoherent surrounding, for which we characterize their parameter domains. More specifically, we detect localized directional one-headed and multi-headed chimera states, as well as scattered directional chimeras without space localization. We discuss canonical generalizations of the elementary Vicsek model and show chimera states for them indicating the universality of this novel behavior. A continuum limit of the particle system is derived that preserves the chimeric behavior.

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MS.02.10.SQUID chimeras: lions, goats and snakes

Superconducting QUantum Interference Device (SQUID) metamaterials are artificial media whose function relies both on their geometry and the extraordinary properties of superconductivity and the Josephson effect. Recent experiments on one- and two-dimensional radio-frequency (rf) SQUID metamaterials have revealed their wide-band tuneability, significantly reduced losses, dynamic multistability, and tunable broadband transparency. The simplest version of an rf SQUID involves a superconducting ring interrupted by a Josephson junction; this device is a highly nonlinear resonator with a strong response to applied magnetic fields. SQUID metamaterials exhibit peculiar magnetic properties such as negative diamagnetic permeability, predicted both for the quantum and the classical regime. The applied alternating fields induce (super)currents in the SQUID rings, which are therefore coupled through dipole-dipole magnetic forces. This interaction is weak due to its magnetic nature. From the dynamical point of view, the SQUID device is a highly nonlinear oscillator with a second derivative term (inertia) and a strong response to external periodic forcing. Previous works report on the emergence of chimera states with very long life-times in nonlocally coupled SQUIDs, where the coupling falls-off as the inverse cube of the distance between them. It has been shown that single and double-headed chimera states coexist with solitary states and patterns of traveling incoherent domains. The synchronization level and the metastability of these states were calculated through appropriate measures. Recently, we have found that multi-headed chimera states can also emerge in SQUID oscillators with purely *local* coupling. The key ingredient for the occurrence of these particularly robust states lies in the high multistability of the individual oscillator. By means of stability analysis, we show that for given system parameters, the resonance curve of the single SQUID exhibits a "snake-like" form where multiple stable and unstable periodic orbits coexist or collide through saddle-node bifurcations of limit cycles. For two coupled SQUIDS this resonance curve becomes even more complicated and additional stable and unstable branches appear. Stroboscopic phase portraits reveal that the incoherent regions in the chimera state involve periodic small-amplitude oscillators coexisting with weak chaotic attractors. Our findings provide a deeper insight in the criteria for the existence of chimera states. Finally, given that one-dimensional SQUID metamaterials have been already fabricated and investigated in the lab, experimental verification of SQUID chimeras could in principle be realized with already available set-ups.

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MS.03.Structure and Dynamics of Future Energy Systems: Power Grids as Complex Dynamical Systems
7 June 10:00-12:00 and 15:00-17:00 (Parallel 1)

The climate conference in Paris set the global goal to reduce CO_2 emissions and shift energy production towards renewable and sustainable sources. However, how a future energy system has to look like remains unclear. This interdisciplinary symposium merges various perspectives from control theory, energy economics, statistical physics and complex networks research. It addresses important questions on the way towards a sustainable energy supply network, e.g.: Where should production take place? How do we deal with fluctuations inherent to solar and wind production? Who is in control of the power grid? What are sustainable power market designs?

Session Organization
Session I (4 talks à 30 min):
Martin Greiner, Takashi Nishikawa, Antonio Scala, Dirk Witthaut
Session II (5 talks à 20 min and additional time for general discussion):
Tom Brown, Katrin Schmietendorf, Mario Mureddu, Paul Schultz, Benjamin Schäfer

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MS.03.01.Design of a simplified highly renewable European electricity system - challenges for system engineering, applied mathematics and physics of complex networks

Based on high-resolution meteorological and electrical load data, data-driven spatio-temporal modeling, and the physics of complex networks, fundamental properties of a simplified European electricity system with a high share of renewables are determined. Amongst such characteristics are the optimal mix of wind and solar power generation, the optimal combination of storage and balancing, the optimal extension of the transmission grid, as well as the optimal ramp down of conventional power generation during the transitional phase. These results indicate that the pathways into future energy systems will be driven by an optimal systemic combination of technologies, and that economy and markets have to be carefully designed to follow the system-technological optimum.

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MS.03.02.Synchronization stability and control in power-grid networks

An imperative condition for the functioning of a power-grid network is that its power generators remain synchronized. Disturbances can prompt desynchronization, which is a process that has been involved in large power outages. In this talk, I will present a study of spontaneous synchronization of power generators, which leads to a potential real-time control strategy that keeps the network optimized for maximum synchronization stability. Using a power-grid model in which the dynamics of the generators are coupled through a network of effective interactions, we derive a condition under which the desired synchronous state is stable and use the condition to identify tunable parameters of the generators that are determinants of spontaneous synchronization. This analysis gives rise to an analytical method to specify parameter assignments that can enhance synchronization of any given network, which I will demonstrate for a selection of both test systems and real power grids. We also show that further enhancement of synchronization stability is possible through numerical optimization. The analytical parameter assignments can be realized through very fast control loops, and this may help devise new control schemes that offers an additional layer of protection, thus contributing to the development of smart grids that can recover from failures in real time.

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MS.03.03.Statistical Physics for Power Grids

Electric grids, telecommunication networks, railways, health care systems, financial circuits, etc. are infrastructures that are critical for functioning and the welfare of our countries. Most of such infrastructures – for historical reasons – have been developed and designed according to engineering paradigms that are staring to become inadequate to cope with their increasing complexity. Much of this complexity is simply due to increased system size: as statistical physics teaches us, collection of interacting objects exhibit emergent phenomena (like phase transitions) that goes beyond to the properties of the single objects and have peculiar characteristics in the infinite size limit. Moreover, the increase of interdependencies among the infrastructures (think as an example of the interdependence among communication networks and electric grids) is adding a further element of complexity. Hence, the statistical physics' approach can enlarge the understanding of the fragilities and vulnerabilities of such critical infrastructures.

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MS.03.04.Prediction, detection and spreading of failures in supply networks

The robust supply with electric power is fundamental for economy, industry and our daily life. In periods of high loads the breakdown of a single transmission line can cause a global cascade of failures implying large-scale outages with potentially catastrophic consequences. Such periods of high loads are expected to become more likely in the future, as electric power from renewable sources is often generated far away from the consumers. In this talk I will discuss the stability of power grids to transmission line failures from a network science perspective, addressing the following questions: Which links are indispensable for network operation? How does a failure spread, i.e., which parts of a network are affected by the initial failure? How can we efficiently detect those failures with few measurements?

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MS.03.05.Reducing Complexity in Energy System Optimizations with High Shares of Renewables

To find the most cost-effective way to reach ambitious CO_2 reduction targets requires highly complex optimization. Capturing the variability of renewable resources such as wind, solar and hydroelectricity requires models with high spatial and temporal resolution. In this talk we present ways to preserve model detail while reducing complexity, so that the optimization computations can be run in a reasonable time. Furthermore, knowing where complexity can be reduced can tell you important information about the sensitivity of the results to the inputs, which provides invaluable information when designing our future energy system.

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MS.03.06.Impact of intermittent feed-in fluctuations on the dynamics of power grids

The progressive integration of fluctuating renewable energy sources poses one of the major challenges to future power grids. Understanding and handling the system under fluctuating feed-in is a prerequisite for the success of the energy transition. We focus on the short-term fluctuations induced by wind power, which is known to exhibit strongly non-Gaussian, intermittent statistics. Therefore, we use a Langevin-type model mimicking the main features of wind power time series and implement it into a Kuramoto-like power grid. We investigate the influence of intermittent feed-in fluctuations on the power systems dynamics and stability and contrast the results to Gaussian feed-in scenarios.

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MS.03.07.Forecasting the electricity balancing markets volumes and sizes in presence of a high share of renewable energy sources

Over the last years, the increasing production from renewable energy sources (RES) completely changes the paradigms underlying energy production, transmission and distribution. To manage RES power output, various control features had to be introduced into the system to improve the efficiency and reliability of the power system, in the attempt to control the increasing impact of this new power sources intermittent power output. In order to limit such impact from both an economic and operative point of view, different solutions have been implemented at different time scales, including electricity spot and balancing markets for medium and long time scales, and automatic frequency control for short time scales. In this talk, I will introduce a novel methodology able to describe the effects of RES power fluctuations on the electricity balancing markets. The proposed methodology uses a statistical mechanics approach for the evaluation of the market volumes and an agent based model for the forecast of the associated energy prices. This way it is possible to identify and characterize possible issues that can arise from an increased share of renewables, and to propose and test possible solutions.

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MS.03.08.Stability Measures for High-Dimensional Multi-Stable Systems

Given a random initial condition, what is the likelihood that the transient behavior of a deterministic system leaves a certain region of desirable states? Given a distribution of perturbations, how likely is it that a system returns to a certain attractor asymptotically? We investigate these problems in the context of high-dimensional multi-stable dynamical systems applying the methods of basin stability and survivability, respectively. The paragon of such systems are power grids, where we discuss the influence of network topologies on the two stability measures. Furthermore, we investigate potential limitations to the numerical estimation procedure and methodological challenges in power grids with stochastic renewable in-feed.

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MS.03.09.Taming Instabilities in Power Grid Networks by Decentralized Control

Stable operation of modern power grids requires to balance supply and demand – with specific challenges due to the increasing fraction of renewable energy sources. Common smart grid concepts to achieve such balance suggest to collect consumer demand and provider supply data, centrally evaluate them and send price incentives back to customers. Besides open questions regarding cyber security, privacy protection and large required investments, it remains unclear how such central smart grid options guarantee overall collective stability. Here we propose the concept of *Decentral Smart Grid Control* where the local grid frequency provides decentral pricing incentives. In principle, the deviations from the standard grid frequency (50Hz) contains all necessary information for decentral control. We analyze the dynamic stability given such control and determine its stability conditions both for elementary systems and key power grid motif network. Finally, we derive analytical results for the resilience of this system with respect to fluctuations.

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MS.04.Emergent Dynamics of Out-of-Equilibrium Colloids
8 June 10:00-12:00 (Parallel 2)

Generic out-of-equilibrium dissipative systems subjected to a time-dependent energy injection often develop nontrivial collective dynamics and structures, which are far more complex than their equilibrium counterparts. The origin of such emergent behavior is the multi-body interactions among colloids, their hydrodynamic coupling, and the nature of the driving force. Understanding the principles governing non-equilibrium organization will facilitate a systematic development of novel strategies for self-assembly, functional fluid flows, and active materials design.

The goal of this minisymposium is to encourage further interest in this rapidly developing area of research, which offers ample opportunities for experimentalists and theorists to contribute to the discovery and understanding of the rich variety of possible emergent phenomena.

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MS.04.01. The Collective Behaviors of Self-Propelled Particles and Drops through hydrodynamic interactions

Self-propelsion of particles and drops has attracted lots of attention in the last decades for its potential application to a smart control of biological systems and industrial materials. The system is far away from equilibrium states and the fundamental understandings of such systems are challenging. Recently, several experiments showing spontaneous motion driven by chemical reactions have been proposed and revealed the underlying mechanism of the motion. Accordingly, several simple theoretical models have been extensively studied such as active Brownian particles, squirmers, self-thermophoretic swimmers and so on. We have theoretically derived a set of nonlinear equations showing a bifurcation between stationary and motile states driven away from an equilibrium state due to chemical reactions. A particular focus is on how hydrodynamic flow destabilizes an isotropic distribution of a concentration field. This symmetry-breaking mechanism of the self-propulsion also leads to deformation of a spherical drop; it elongates perpendicular to the direction of motion.

The assemblage of such self-propelled particles gives rise to collective behaviors such as motility-induced phase separation, global polar state, and dynamic clustering. The question is how such variety of patterns appear from interactions between the individual elements. Our understandings are still primitive, but I shall try to clarify how hydrodynamic interactions and the interaction mediated by a concentration field lead to the collective behaviors.

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MS.04.02.Emergent collective dynamics in ensembles of magnetic colloidal rollers and spinners

Strongly interacting colloids driven out-of-equilibrium by an external periodic forcing often develop nontrivial collective dynamics. Emergent dynamics and self-assembly in driven colloidal systems are often assisted and facilitated by spontaneous symmetry breaking phenomena. Ferromagnetic colloidal micro-particles suspended over a water-air interface and energized by a single-axis alternating magnetic field applied in-pane of the interface revealed a rich variety of out-of-equilibrium dynamic self-assembled phases (in particular, ”wires”, ”rotators”) emerging in such systems in a certain range of excitation parameters. The studies revealed strongly non-Maxwellian nature of velocity statistics for both subsystems: single particles and self-assembled rotators.

Ferromagnetic micro-particles immersed in water and driven by a single-axis homogeneous alternating magnetic field applied perpendicular to the surface supporting the particles develop nontrivial collective dynamics. Upon application of the alternating magnetic field the magnetic torque on each particle is transferred to the mechanical torque giving rise to a rolling motion of the particle. Experiments reveal a rich collective dynamics of magnetic rollers in a certain range of excitation parameters. Flocking and spontaneous formation of steady vortex motion have been observed. The effects are fine-tuned and controlled by the parameters of the driving magnetic field.

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MS.04.03.Topological protection of multiparticle dissipative transport

Topological protection in Hamiltonian systems allows robust transport of localized phenomena such as quantum information, solitons, and dislocations. Here we extend topological protection to a new class of non-Hamiltonian driven dissipative systems. We experimentally demonstrate and theoretically explain the topologically protected motion using colloidal particles above a periodic hexagonal magnetic pattern. By driving the system with periodic modulation loops of an external and spatially homogeneous magnetic field, we achieve total control over the motion of diamagnetic and paramagnetic colloids. We can transport simultaneously and independently each type of colloid along any of the six crystallographic directions of the pattern via adiabatic or deterministic ratchet motion. Both types of motion are topologically protected. As an application, we implement an automatic topologically protected quality control of a chemical reaction between functionalized colloids. Our results are relevant to other systems with the same symmetry.

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MS.04.04.Hydrodynamic self-organization and mixing in suspensions of micro-rotors

Self-organization of active units has attracted considerable attention recently, especially in the context of living systems. While self-propelled active objects have been extensively investigated, the collective behavior of rotating active particle has received limited attention. To elucidate the transition to collective behavior and especially the role of multi-body hydrodynamic interactions, we numerically study systems of co- and counter-rotating spheres by varying the mixture ratio as well as the total volume fraction. With increasing volume fraction, we observe the emergence of intriguing patterns such as lanes, vortices of same-spin rotors as well as dynamic crystals composed of both types of rotors. We consider how the motion of the rotating particles and the collectively-generated flows affect the transport, diffusion and clustering of inert sphere particles in the system for various mixture proportions.

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MS.04.05.Complex Magnetic Fields Breathe Life into Fluids

There are many areas of science and technology where being able to generate vigorous, noncontact flow would be desirable. We have discovered that three dimensional, time-dependent electric or magnetic fields having key symmetries can be used to generate controlled fluid motion by the continuous injection of energy [1-13]. Unlike natural convection, this approach does not require a thermal gradient as an energy source, nor does it require gravity, so space applications are feasible. The result is a highly active material we call a vortex fluid. The homogeneous torque density of this fluid enables it to climb walls, induce ballistic droplet motion, mix vigorously, even in such complex geometries as porous media, and effect highly efficient heat transfer. This vortex fluid can also exhibit a negative viscosity, which can immeasurably extend the control range of the ?smart fluids? used in electro- and magnetorheological devices and can thus significantly increase their performance. Because the applied fields are uniform and modest in strength, vortex fluids of any scale can be created, making applications of any size, from directing microdroplet motion to controlling damping in magneto-rheological dampers that protect bridges and buildings from earthquakes, feasible. We will discuss how field symmetry permits fluid vorticity, present a particle-based theory of vorticity, and will demonstrate that such fields can animate fluids in remarkable ways that resemble living systems. Acknowledgments: Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy?s National Nuclear Security Administration under contract DE-AC04-94AL85000.

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MS.05.Assembly of non-spherical particles
9 June 10:00-12:00 and 15:00-17:00 (Parallel 2)

Each grain of sand has a unique shape. This minisymposium focuses on how the shape of particles influences their collective behaviors: From static problems such as the packing of jammed particles to dynamic ones such as phase transitions and rheological behaviors. In addition, we discuss possible pathways to control the collective behavior via shape design, e.g., creating patchy particles with tunable maximum coordination number. The goal is to unveil intrinsic laws governing the self-organization of non-spherical particles and provide guidelines for shape design, in order to shed light on the widespread applications of particulate systems.

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MS.05.01.Designing polyhedral particles for targeted self-assembly

Isolating the role of building block shape for self-assembly provides insight into the ordering of molecules, the crystallization of colloids, nanoparticles, proteins, viruses, and the organization of granular matter. Polyhedral particles have proven a good model to understand how assembly arises solely from anisotropic shape and demonstrated a remarkably high propensity for thermodynamic self-assembly and structural diversity. This contribution discusses how to design polyhedral shapes to yield desired target structures.
Specifically, we report of our search for particle shapes that lead to homochiral colloidal crystals, which are candidates for photonic metamaterials. Using Monte Carlo simulations we show that chiral polyhedra can be made to self-assemble into three-dimensional enantio-selective crystals. Tuning the directionality of entropic forces by means of particle rounding or the use of depletants allows for reconfiguration between achiral and homochiral crystals.
We also investigate Voronoi particles, which are space-filling polyhedra in the shape of Voronoi cells of a target crystal. Although Voronoi particles stabilize their target structure in the limit of high pressure by construction, the stabilization of the same structure at moderate pressure is not guaranteed. Indeed, a more symmetric crystal is often preferred due to additional entropic contributions arising from configurational or occupational degeneracy. We characterize the assembly behavior of Voronoi particles in terms of the symmetries of the building blocks as well as the symmetries of crystal structures. Controlling the degeneracies through a modification of particle shape and field-directed assembly can significantly improve the assembly propensity.

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MS.05.02.Packings and flows of non-spherical particles

In this work, we present an experimental and numerical study of the influence that particle shape has on the mechanical and structural properties of granular packings and flows. For instance, it is know that flat faces strongly effect those systems' behavior. We show that square particles deposited in a silo tend to align with a diagonal parallel to the gravity, giving rise to a deposit with very particular properties. Moreover, we explore the effect of the filling mechanism on the packing morphology of faceted particles. In particular, we modify the volume fraction of the initial configuration from which the grains are poured. Starting from a very dilute case, increasing the volume fraction results in an enhancement of the disorder in the final deposit characterized by a decrease of the final packing fraction and a reduction of the number of particles oriented with their diagonal in the direction of gravity. However, for very high initial volume fractions, the final packing fraction increases again. This result implies that two deposits with the same final packing fraction can be obtained from very different initial conditions, and even though the final volume fraction is the same, their micromechanical properties notably differ. Additionally, we also present experimental and numerical results of the effect that a partial discharge of the silo has on the morphological and micro-mechanical properties of non-spherical, convex particles in a silo. The comparison of the particle orientation after filling the silo and its subsequent partial discharge reveals important shear induced orientation, which strongly affects stress propagation.

We also examine the role of particle curvature and surface shape evidencing the importance of such parameters on both, the packing morphology and stress transmission. Generally, we observe that rough and curved particles have a stronger tendency for interlocking leading to the formation of dense packing structures. In addition, we show that elongated particles have a high preference for horizontal alignment that is reduced when increasing particle curvature.

Finally, we study dry, frictional, steady-state granular flows of non-spherical particles down an incline. We prove that the macroscopic fields, obtained from microscopic data by time-averaging and spatial smoothing (coarse-graining) are perfectly consistent with the conservation laws of continuum theory.

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MS.05.03.Particle-based simulation of powder application in additive manufacturing under consideration of geometrically complex particles

The development of reliable strategies to optimize part production in additive manufacturing technologies hinges, to a large extent, on the quantitative understanding of the mechanical behavior of the powder particles during the application process. Since it is difficult to acquire this understanding based on experiments alone, a particle-based numerical tool for the simulation of powder application is required. In the present work, we develop such a numerical tool and apply it to investigate the characteristics of the powder layer deposited onto the part using a roller as the coating system. In our simulations, the complex geometric shapes of the powder particles are taken explicitly into account. Our results show that increasing the coating speed leads to an increase in the surface roughness of the powder bed, which is known to affect part quality. We also find that, surprisingly, powders with broader size distributions may lead to larger values of surface roughness as the smallest particles are most prone to form large agglomerates thus increasing the packing's porosity. Moreover, we find that the load on the part may vary over an order of magnitude during the coating process owing to the strong inhomogeneity of interparticle forces in the granular packing. Our numerical tool can be used to assist — and partially replace — experimental investigations of the flowability and packing behavior of different powder systems as a function of material and process parameters.

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MS.05.04.Cornerstones for discrete element methods of non-spherical particles

While the Discrete Element Methods has become an established method, many actual codes still use a combination of unphysical approaches and parameters. Spherical particles will roll down even minimally inclined planes, a problem which is then “mended” in many DEM-codes by specifying unphysically high rolling resistance.

This work will outline elements, approaches and parameters which are necessary, those which are beneficial, which are “negotiable” and which are downright damaging.

While historically the interest centered on single-particle properties like the coefficient of restitution or the exponents (for ”penetration depth” in the elastic force law or the velocity in the damping term), for sufficiently high densities, simulation outcomes with different methods become undistinguishable.

As the time-integration uses finite-difference methods which require “smooth enough” force inputs, the force model must be sufficiently smooth, and that means, with respect to force magnitude, to force direction, and with respect to the force point. It turns out that the naive approach to ”single-particle properties”, e.g. with a “linear force model”, already violates these smoothness requirement, if the necessary cutoffs are not implemented. Results are unnecessarily small time steps (or time step recommendations), effects like “break failure” which are actually artifacts and occasional “explosions” in the simulation. In particular, the stable choice of representations for the degrees of freedom will be discussed.

On the other hand, it is not allways necessary to use tabulated material parameters like Young moduli. For rough grain surfaces, the contacts between realistic granular materials are only point-wise, and these “thinned out” contacts can be modeled by decreased Young’s moduli.

Next, the modelization of shapes will be discussed, including the drawbacks and advantages of various methods. Some shapes which look useful, like ellipses, may lead to numerical problems. Others, like composition of piecewise arcs, may turn out to be computationally awkward.

The dynamics of granular materials is determined by the competition of sliding and rolling at the grain contacts. If there is no realistic static friction, neither realistic bulk density nor strength parameters will be obtained, because this balance is misrepresented. A suitable physical test for the physicality of a DEM-simulation is whether heaps on smooth surfaces can be formed: If not, the granular strength also for particle agglomerates between walls will not be realistic. New results on the parameter-free implementation of friction will be shown and discussed.

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MS.05.05.Curvature-driven flows explain where Martian river flows

In a recent study [1] we claimed that the rounded pebbles on the pictures taken by NASA'a Curiosity Rover may have travelled as much as 30 miles on the planet's surface. Combined with earlier estimates based on global morphology, this is so far the most compelling evidence of the existence of an extended river system on ancient Mars.

This estimate was based on extensive laboratory and field data collected under terrestrial circumstances. Nevertheless, the faith in the result's validity has much deeper roots which reach as far as the Poincar-conjecture. In this talk I will outline the existing theory for the shape evolution of pebbles and point out some of its ties to mathematics, physics and geomorphology.

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MS.05.06.Smart particle assemblies at liquid-air interfaces

Self-assembly of particles along a liquid-air interface is of interest for microfabricating elaborated systems. It is indeed possible to generate complex structures without the help of manipulators. Two promising ways to self-assemble structures are presented in this talk :

1. Designing building blocks to obtain a desired mesoscopic structure is a scientific challenge. We show that it is possible to shape the particles with a low cost 3D printer, for composing specific mesoscopic structures. Our method [1] is based on the creation of capillary multipoles inducing either attractive or repulsive forces. Since capillary interactions can be downscaled, our method opens new ways to low cost microfabrication.

2. When magnetic particles are suspended at air-water interfaces in the presence of a vertical magnetic field, dipole-dipole repulsion competes with capillary attraction such that 2d structures are self-assembling. The complex arrangements of such floating bodies are emphasized. The equilibrium distance between particles exhibits hysteresis when the applied magnetic field is modified. Irreversible processes are evidenced. By adding a horizontal and oscillating magnetic field, periodic deformations of the assembly are induced. We show herein that pulsating particle arrangements start to swim at low Reynolds number. The physical mechanisms and geometrical ingredients behind this cooperative locomotion are identified. These physical mechanisms can be exploited to much smaller scales, offering the possibility to create artificial and versatile microscopic swimmers. [2,3].

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MS.05.07.Mean-field approach for random close packings of spherical and non-spherical particles

Random packings of objects of a particular shape are ubiquitous in science and engineering. However, such jammed matter states have eluded any systematic theoretical treatment due to the strong positional and orientational correlations involved. Here, a mean field theory based on a statistical treatment of the Voronoi volume is discussed, which allows for the calculation of the random close packing fractions of spherical as well as non-spherical particles [1]. This approach captures in particular the density peaks observed in simulations of different classes of non-spherical shapes. A phase diagram is presented that describes packings of elongated shapes such as spherocylinders and dimers in terms of an analytic continuation from the spherical random close packing [2].

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MS.05.08.The structure of non-spherical particle packings

Packing problems are of high relevance in engineering and physics. This talk discusses disordered packings of non-spherical particles which are an important model for disordered granular matter and can shed light on geometric features and structural transitions. Many studies have focused on sphere packings, but spheres are only the simplest model with differences to the possible anisotropic shapes found in nature, like sand or stones. The study of aspherical particle packings offers the possibility to assess the effect of the particle shape.

This talk focuses on geometric features of jammed static packings of ellipsoidal particles. Experimental packings of frictional particles recorded by X-ray tomography as well as simulated packings generated by a Discrete Element Method simulation are analysed and compared. The pore space of the packings is assigned to the particles by using a Set Voronoi construction, a generalisation of the Voronoi Diagram for spheres [1]. An interesting result is that the width of the local packing fraction distribution is independent of the aspect ratio of the particles. A recently developed approach for characterizing structures are Minkowski Tensors [2-4] which provide information about the local structure in these packings. We use this geometrical quantities to characterise the Voronoi cells. The average cell shape differs substantially in dense and loose ellipsoid packings, but is very similar in sphere packings of different packing fraction.

This analysis immediately extends to packings of arbitrarily-shaped particles. First results will be presented for tomography experiments with samples of Ottawa sand.

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MS.05.09.Liquid-crystal patterns in vibrated quasi-monolayers of rods

Quasi-monolayers of elongated granular rods form ordered patterns when vibrated vertically. These patterns have liquid-crystal symmetries, and are similar to those found in equilibrium systems governed by thermal fluctuations. In this contribution we present the results of recent experiments with monodisperse and bidisperse rods of different elongations. Steady-state patterns possess properties (order parameters, phase segregation, clustering effects) remarkably similar to those of equilibrium models for hard interactions. This indicates that, despite being dissipative in nature, vibrated granular rods obey some kind of entropic interactions coming from excluded-volume effects. Also, dynamic properties have some features in common with thermal systems.

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MS.05.10.Rotation and ordering of elongated particles under shear

Ordering and alignment of elongated objects in shear flows can be observed at all length scales, in log jams on rivers, in seeds, nanorods, viruses, and even at molecular scales in nematic liquid crystals. We have shown [1-3], that for simple dry granular materials in steady shear flow the time and ensemble averaged direction of the main axis of the particles encloses a small angle with the streamlines. This shear alignment angle is independent of the applied shear rate, and it decreases with increasing grain aspect ratio. The effective friction of the granular material is considerably reduced due to the alignment. At the grain level the steady state is characterized by a net rotation of the particles, as dictated by the shear flow. Several features of the shear induced alignment are similar to the behaviour of flow aligning nematic liquid crystals.

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MS.05.11.Dancing screw-nuts: Assembly of hexagonally shaped disks with attractive interactions

Sand on the beach can be easily sculptured into almost any shape, which is different from sand ripples or dunes in the desert with a well defined angle of repose. This feature arises from the formation of capillary bridges or liquid clusters that effectively hold sand grains together. As we are living in a world largely covered with water, it is necessary to consider the influence of a wetting liquid on the static and dynamical behaviors of granular materials in applications. The cohesive force arising from the formation of capillary bridges depends strongly on the contact area: For two spherical particles with a point contact, the cohesion is typically much weaker in comparison to the case of a surface contact between two polyhedra. Based on this feature, we design shaped particles with tunable maximum coordination number, i.e. maximum number of contact points to its neighbors, in order to investigate the influence of the so called patchy number on the assembly of shaped particles.

Here, we focus on the assembly of hexagonally shaped disks confined in a monolayer and agitated vertically against gravity. The particles are partially wet so as to introduce short ranged attractive interactions at the contact points. In contrast to agitated spheres, hexagonally shaped particles exhibit a strong tendency to spin around its vertical axis, i.e., acting as rotors. This motion hinders the binding of particles with capillary bridges and hence gives rise to dramatically different dynamics towards clustering and crystallization. We investigate the time evolution into various non-equilibrium stationary states (NESS) and the diffusivity of individual particles. Based on the local structures of the particles identified with the pair correlation functions and bond orientational order parameters, we determine the NESS of the system and present them in a stability diagram.

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MS.06.Reservoir Computing and Laser Dynamics
7 June 10:00-12:00 (Parallel 2)

The proposed mini-symposium aims at presenting some recent theoretical and experimental progresses on reservoir computing (RC) and laser dynamics, including some related topics. Extensive studies in last decades have shown the high performance information processing by RC implemented by laser systems. In view of this situation, it is our intention to arrange a meeting and discussion between theorists of recurrent networks and experimentalists of lasers, and moreover to stimulate further studies on these topics.

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MS.06.01.Physical reservoir computing from a dynamical systems point of view

Reservoir computing (RC) was first proposed as a framework to train recurrent neural networks. In this framework, a low-dimensional input is projected to high-dimensional dynamical systems, which are typically referred to as a reservoir. If the dynamics of the reservoir involve adequate nonlinearity and memory, emulating nonlinear dynamical systems only requires adding a linear, static readout from the high-dimensional state space of the reservoir. Because of its generic nature, RC is not limited to digital simulations of neural networks, and any high-dimensional dynamical system can serve as a reservoir if it has the appropriate properties. The approach using a physical entity rather than abstract computational units as a reservoir is called physical reservoir computing (PRC). Its various engineering applications, such as soft robotics, nanotechnology, and optoelectronics, have been proposed recently.

In this presentation, several novel platforms based on PRC are introduced using physical substrates. These platforms include soft materials (e.g., silicone-based soft robotic arm) and faraday waves generated on the water surface (which we call, "physical liquid state machines"), and they illustrate the potentials of the framework through a number of experiments. The focus will particularly be on how dynamical system aspects can provide a novel view of the PRC framework, including the relevance of noise-induced phenomena or random dynamical systems. For example, in quasiperiodically driven nonlinear systems, Strange Non-chaotic Attractors (SNAs) are frequently observed. SNAs are geometrically fractal, but the dynamics is not chaotic (the largest Lyapunov exponent is zero or negative), and they have been found in a number of diverse experimental situations such mechanical and electronic systems. If the time permits, we will present our recent explorations on the possibility of exploiting SNAs as reservoirs. Finally, we will demonstrate how the physical and dynamic properties of the materials are reciprocally related to the information processing capacity of the entire system.

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MS.06.02.Efficient signal processing in random networks that generate variability in contrast to externally generated variability

The source of cortical variability and its influence on signal processing remain an open question. We address the latter, by studying two types of randomly connected networks that produce irregular spontaneous activity patterns: The first network is a deterministic network with strong synaptic interactions that actively generates variability by chaotic dynamics (internal noise) and the second network is a stochastic network that has weak synaptic interactions but receives noisy input (external noise), e.g. by stochastic vesicle releases. Despite the difference in their sources of variability, spontaneous activity patterns of these two models are indistinguishable unless majority of neurons are simultaneously recorded. Despite the close similarity in the spontaneous activity, the two networks exhibit remarkably different sensitivity to external stimuli. Input to the former network reverberates internally and can be successfully read out over long time. Contrarily, input to the latter network rapidly decays and can be read out only for short time. The difference between the two networks is further enhanced if input synapses undergo activity-dependent plasticity, producing significant difference in the ability to encode external input. We show that this difference naturally leads to distinct performance of the two networks to perform probabilistic computation. Unlike its stochastic counterpart, the deterministic chaotic network activity can serve as a reservoir to perform near optimal Bayesian integration and Monte-Carlo sampling from the posterior distribution.

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MS.06.03.Reservoir Computing with Photonic Delay Systems

To learn and mimic how the brain processes information has been a major research challenge for decades. Despite many efforts, little is known on how we encode, maintain and retrieve information. One of the hypothesis assumes that transient states are generated in our intricate network of neurons when the brain is stimulated by a sensory input. Based on this idea, powerful computational schemes have been developed. These schemes, known as machine-learning techniques, include artificial neural networks, support vector machine and reservoir computing, among others. In this talk, I concentrate on the reservoir computing technique using delay systems. Unlike traditional reservoir computing, where the information is processed in large recurrent networks of interconnected artificial neurons, I present a minimal design, implemented via a simple nonlinear dynamical system subject to a self-feedback loop with delay. Even though this design is not intended to represent an actual brain circuit, it is sufficient to develop an efficient information processor. This simple scheme not only allows to address fundamental questions but also permits simple implementations in photonic hardware. By reducing the neuro-inspired reservoir computing approach to its bare essentials, it is found that nonlinear transient responses of the simple dynamical system enable the processing of information with excellent performance and at unprecedented speed. This talk explores different photonic hardware implementations and, by that, addresses the role of nonlinearity, noise and system responses. Besides the relevance for the understanding of basic mechanisms, this scheme opens direct technological opportunities that could not be addressed with previous approaches.

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MS.06.04.Brain-inspired processors based on lasers with Optical Feedback

A brain-inspired processor also called reservoir computing is an efficient approach for signal processing which has been introduced a decade ago. These tools are able to solve tasks such as pattern recognition, time series prediction and classification. State of the art capabilities have already been demonstrated with both computer simulations and physical implementations using nonlinear systems with delay. The use of lasers to implement these novel computational tools appears to be a promising solution for ultrafast and parallel nontrivial computing tasks. In my presentation, we will discuss how a laser subject to optical delayed feedback can be used for implementing a reservoir computing system. In particular, I will show that, thanks to the parallelism offered by multi-mode lasers, several independent machine learning tasks can be performed simultaneously. Also, I will point out some limitations of these systems and how they can be overcome.

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MS.07.Noisy dynamics in biological networks
9 June 17:30-19:30 and 10 June 10:00-12:30 (Parallel 2 and Parallel 1)

Fluctuations and noise arise naturally in various complex systems and networks. Biological processes on various levels are inevitably affected by internal and external random perturbations. In particular, oscillatory behavior of the interacting elements can be significantly influenced by the interplay of noise and network topology. Since noise can lead to irregular behavior or the increase of coherence, resulting in dynamical switching or qualitatively new regimes, it can be used to induce and control different synchronization patterns. This minisymposium will provide an insight into recent trends in the research on noisy dynamics in neural networks, chemical reaction networks or gene expression networks. These include models for subcellular genomic or epigenetic processes, neural models at single-cell or multiple-cell level, and many forms of abstract networks with different topologies.

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MS.07.01.Correlations of fluctuations in recurrent networks of spiking neurons are strongly colored

The analysis of spiking neural networks is thought to be instrumental in understanding synchronization, oscillations, and fluctuations seen in different areas of the brain.In my talk I discuss how slow (strongly correlated) fluctuations in the neural activity can emerge in a network of elements with fast dynamics provided they are coupled sufficiently strongly. I introduce a single-neuron simulation scheme that allows to determine the spike train power spectrum of cells in the recurrent network in a self-consistent manner. This scheme can also be used to analyze the amplification of low-frequency fluctuations for strong synaptic coupling. Our results illustrate that determining the firing statistics of a neuron in the presence of a strongly colored noise is an essential task in understanding the dynamics of recurrent networks.

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MS.07.02.Chimera patterns under the influence of noise

Chimera states are intriguing hybrid patterns in networks of identical oscillators consisting of coexisting domains of spatially coherent and incoherent behavior. They occur in a variety of systems and are of particular importance for the life sciences. For instance, they may account for the observation of partial synchrony in neural activity, like unihemispheric sleep, or the termination of epileptic seizures. Here we investigate the robustness of these patterns under the influence of Gaussian white noise. We use a network model of Stuart-Landau oscillators with nonlocal topology and symmetry-breaking coupling, where two types of chimera states occur [1], going beyond the classical phase chimeras: *Amplitude chimeras* are characterized by chimera behavior with respect to amplitude dynamics rather than the phase, i.e., partially coherent and partially incoherent amplitude dynamics; they are long-living transients. *Chimera death* states generalize chimeras to stationary inhomogeneous patterns (oscillation death), which combine the features of chimera states (coexisting incongruous coherent and incoherent domains) and oscillation death (oscillation suppression). We analyze the impact of random perturbations, addressing the question of robustness of chimera states in the presence of white noise, and the influence of noise upon the lifetimes of amplitude chimeras [2].

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MS.07.03.Amplitude and Phase Chimera States in a Ring of Nonlocally Coupled Chaotic Systems

We report the bifurcation transition from coherence to incoherence in a ring of nonlocally coupled logistic maps. It is firstly shown that two types of chimera states, namely, amplitude and phase, can be found in the network. We reveal a bifurcation mechanism by analyzing the evolution of space-time profiles and the coupling function with varying coupling coefficient. We show that the vertical front of the snapshot profiles and the chaotic behavior of the coupling function are the necessary and sufficient conditions for realizing the phase chimera states in the ensemble. The amplitude chimera states can be observed in the network when the coupling function demonstrates highly developed chaotic behavior.

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MS.07.04.Role of noise and emergence of various patterns in networks

We show that occurrence of noise during evolutionary time, both in the coupling strength as well as in the behavior of the interactions, leads to formation of various structural patterns in the underlying network. Using Darwinian evolutionary approach, by maximizing the stability of a system in terms of the largest eigenvalue of its adjacency matrix, we demonstrate that inclusion of noise in the coupling strength leads to disassortativity in the underlying networks. Further inclusion of the noise in the coupling behavior, termed as mutation, governs the degree of saturation in the disassortativity coefficient revealing the origin of wide range of disassortativity present in biological networks. We extend this evolutionary technique to systems having multiplex network architecture in order to understand existence of structural patterns which support coherent dynamical behavior of the system.

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MS.07.05.Noise-induced coupling in neuronal networks with spike timing-dependent plasticity

Stimulation of synchronized neurons by independent noise might be expected to have a powerful desynchronizing effect. Such an approach can be important in medicine for the treatment of neurological disorders characterized by abnormal neuronal synchronization like Parkinsons disease, epilepsy or tinnitus. We however show that for oscillatory neural populations with adaptive synaptic weights, the desynchronizing impact of noise can effectively be counteracted by the spike timing-dependent plasticity (STDP) which is a fundamental adaptation mechanism of the nervous system. The noise stimulation can induce an antagonistic response of the neurons, which organize themselves into a state of stronger coupling. This makes the system much more resistant against noise. We investigate this phenomenon in detail for small systems of two coupled phase oscillators and Hodgkin-Huxley neurons as well as for large networks. Noise can stabilize a strong bidirectional coupling, which is not present in the systems without noise. Furthermore, noise stimulation can induce a multistability of several coupling regimes, where some regimes are not found in the stimulation-free systems. In large neuronal ensembles the mean synaptic coupling increases dynamically in response to the increase of the noise intensity. There is an optimal noise level, where the amount of synaptic coupling gets maximal in a resonance-like manner as found for the stochastic or coherence resonances, although the mechanism in our case is different. Our results suggest a possible homeostatic mechanism of how the brain may counteract external perturbations and noise in order to preserve the existing level of neural synchrony, which may contribute to a deeper understanding of why maskers and noisers show limited efficacy in the treatment of tinnitus.

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MS.07.06.Noisy synapses in the brain: A way to optimise neural computations?

Individual nerve cells in our brain handle multiple inputs of information carried by afferent fibres and transformed by synapses into postsynaptic receptor currents. In a canonical case, spatiotemporal summation of such currents by the cell generates the sequence of spikes representing a computational outcome of the data input. Whilst this basic scenario has laid foundations for neural network theories, its key aspects in real brain circuits have remained enigmatic. A successful synaptic discharge in response to an action potential is a stochastic event which boosts the signal "noise" in the system. However, it appears that synaptic response fluctuations could actually reduce the error in transmitting spiking input to the synapse while boosting the overall information transfer, by employing what is termed the variance coding. Similarly, it has been suggested that the stochastic nature of the key synaptic signalling event, activity-induced calcium rise in postsyna! ptic dendritic spines, should provide more accurate translation of the presynaptic message compared to what has traditionally been thought as pre-determined calcium elevations. These emerging considerations provide us with some intriguing clues as or whether the synaptic current variability has an effective "informational" value.

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MS.07.07.Interplay of Noise and Intelligence in Intracellular Gene-regulatory Networks

I will discuss results of theoretical modelling in very multi-disciplinary area between Systems Medicine, Synthetic Biology, Artificial Intelligence and Applied Mathematics. Multicellular systems, e.g. neural networks of a living brain, can learn and be intelligent. Some of the principles of this intelligence have been mathematically formulated in the study of Artificial Intelligence (AI), starting from the basic Rosenblatts and associative Hebbian perceptrons and resulting in modern artificial neural networks with multilayer structure and recurrence. In some sense AI has mimicked the function of natural neural networks. However, relatively simple systems as cells are also able to perform tasks such as decision making and learning by utilizing their genetic regulatory frameworks. Intracellular genetic networks can be more intelligent than was first assumed due to their ability to learn. Such learning includes classification of several inputs or the ability to lea! rn associations of two stimuli within gene regulating circuitry: Hebbian type learning within the cellular life. However, gene expression is an intrinsically noisy process, hence, we investigate the effect of intrinsic and extrinsic noise on this kind of intracellular intelligence. During the talk I will also include brief introductions/tutorials about Synthetic Biology, modelling of genetic networks and noise-induced ordering.

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MS.07.08.Multiple time scales signalling in recurrent neural network driven by noise

The dynamics of the recurrent network of synaptically connected bistable neuronal oscillators are studied. Driven by noise in the form of uncorrelated Poisson pulse trains the network can exhibit one of two stable states with either high or low level of its total spiking activity depending on the parameters of the noise. To investigate metastable dynamics of the network we calculate distributions of escape times from the metastable states. Interestingly, that the escape time distributions exhibit two clearly separated time scales. Using phase maps analysis we investigate the mechanisms of the metastable states formation. It is shown that the bistability of the single units and synaptically-based synchronization underlie the observed transitions.

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MS.07.09.Bifurcations in open quantum systems

Currently, there is a growing interest in quantum effects that may underpin the key biological processes, such as photosynthesis, transfer of excitation energy and even information processing. The inherently strong coupling to environment there dictates the description in the framework of open quantum systems. We demonstrate that noise and concurrent dissipation do not simply destroy the coherent quantum states but lead to formation of the novel limiting states, which we coin quantum attractors. These attractors are subject to qualitative changes with parameters of the system that, as we propose, can be appropriately described and understood as quantum bifurcations.

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MS.08.Consistency and chaos in complex photonic systems
6 June 17:30-19:30 (Parallel 2)

Laser dynamics reveals abundant complex phenomena and has received wide attention in the field of nonlinear dynamical systems. In particular, semiconductor lasers with optical feedback represent excellent test beds for the study of high-dimensional chaos in nonlinear delay-coupled systems. This photonic system is also a paradigmatic example for the study of consistency in nonlinear dynamical systems. Consistency relates to the capability of a dynamical system to reproduce a response when repeatedly driven by similar inputs.
This minisymposium aims at introducing recent theoretical and experimental progresses on complex dynamical phenomena in lasers, relating the relevant topics of consistency and chaos synchronization. We thereby present a state-of-the-art overview in this field.

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MS.08.01.Reservoir computing based on consistency of a semiconductor laser driven by a chaos mask signal

Reservoir computing (RC) has been proposed as a new approach of information processing system. The concept of RC is based on a mapping of an input signal into a high dimensional space in order to facilitate classification and time-series prediction. In 2011, delay-based RC using a single nonlinear system has been proposed [1]. Since then, several implementations of delay-based RC have been reported. Semiconductor lasers with time-delayed feedback are very promising for high-speed implementation of RC and high dimensional transformation of the input signal [2]. In RC, a temporal mask is applied to each input data in order to introduce complex transient response under consistency conditions, where the same response output can be observed by using a repeated drive signal [3]. In most cases, a binary random signal is used as the input temporal mask, consisting of a piecewise constant function with a randomly-modulated binary sequence. Some studies on the design of the input mask signal have been reported in RC, such as a six-level digital mask [4] and a binary mask with optimized combination [5] to reduce the influence of noise. It is expected to improve the performance of RC by using a more complex mask signal, such as a chaos mask, since the laser dynamics induced by the chaos mask signal could be more complex than those induced by the binary mask signal. In this study, we investigate RC based on the consistency of a semiconductor laser subjected to optical delayed-feedback and injection in numerical simulations. We introduce a chaos mask signal as an input temporal mask for reservoir computing and perform a time-series prediction task. The prediction is successful in the consistency region of the response laser. We also compare the errors of the prediction task for the chaos mask signal with those for other digital and analog mask signals. The performance can be improved by using the chaos mask signal when the characteristic frequency of the mask is close to the relaxation oscillation frequency of the response laser under optical injection.

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MS.08.02.Consistency in Chaotic Systems Driven by Time-Delayed Feedback

Consistency refers to the property of an externally driven dynamical system to respond in similar ways to similar inputs [1]. In a delay system, the delayed feedback can be considered as an external drive to the undelayed subsystem, typically if the delay time is sufficiently large. A completely consistent response has been related to weak chaos, whereas strong chaos implies a certain degree of inconsistency. We analyze the degree of complete consistency in a general chaotic system with delayed feedback by means of the auxiliary system approach, in which an identical copy of the system is driven by exactly the same signal as the original. This scheme verifies complete consistency via complete synchronization. For stationary time series of the two driven units, we analytically derive relationships between characteristic correlation signatures of the cross-correlation function and the two auto-correlation functions. We introduce the concept of consistency correlation and transformation correlation. We further present two different experimental realizations of consistency testing schemes with semiconductor lasers and fiber optics. The first one is a direct implementation with two carefully selected and adjusted laser diodes as well as matched coupling. The second scheme consists of a single laser with two delay loops of different length, between which we switch such that only one is active at a time. The short loop serves as original feedback to generate the chaotic dynamics, whereas the second one is a much longer loop which serves as optical memory in order to generate a precise replay of the short loop optical drive of the laser [2]. The similarities and differences between the two experiments will be analyzed, and correlation functions in dependence of parameters will be discussed. We finally compare the experimental correlation signatures with the analytical framework and discuss the physical interpretation of the individual measures and their relationships.

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MS.08.03.Global and cluster synchronization in multi-nodal semiconductor laser network

Bidirectional coupling of semiconductor lasers (SLs) through optical signals is an engrained methodology to generate broadband chaotic signals. The inherent dynamics of such coupled systems may be useful to several applications in sensing and secure communications. In this work we investigate the potential of a large number of DFB SLs to synchronize, through broadband chaotic signals. It is shown that the coupling architecture and conditions, as well as the properties and operational conditions of the SLs determine the dynamic types of the emitted signals. We show experimentally that the synchronization among the lasers that participate in the coupled network is also affected by the signals' detected bandwidth. When considering an 8-GHz signal bandwidth, all lasers are pairwise cross-correlated with values from 0.86 to 0.93. Smaller signal bandwidth at the GHz range may result in global synchronization with averaged cross-correlation values over 0.97 in most of the SL nodes, rejecting higher frequencies that are not optimally synchronized. Strict frequency matching (¡200MHz) of the optical emitted signals allow synchrony at configurations with even a few identical SLs. De-synchronization events that are almost always apparent - especially when emitted signals include power dropouts - are diminished under optimized coupling and SLs matching conditions. Frequency shifting of some of the nodes emission wavelength can convert the global synchrony into a cluster synchrony. In such multiplexed wavelength operation, it is shown that the network can maintain intra-cluster but not inter-cluster synchrony. Even with SLs set at a spectral distance of only 50pm, the above property is validated. These properties of the coupled-SL networks could be exploited towards multi-channel hardware authentication protocols in fiber-based installations with ultra-dense channel allocation.

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MS.08.04.Quantitative relationship between phase response and chaos bandwidth enhancement in semiconductor lasers subject to optical feedback and injection

Chaotic signals with broad bandwidth are useful for fast chaos encryption and fast random bit generation. While the bandwidths of chaos generated by lasers are typically limited by their relaxation oscillation, it has been proven that the combination of delayed feedback and optical injection can be applied to lasers as an efficient way to significantly enhance the bandwidth of the chaos generated by these lasers without modifying their structures. In particular, it has been qualitatively shown that the bandwidth enhancement is a result of beating between the injected field and the chaotic laser field provided that the injected light is detuned towards the edge of the SL's optical spectrum. In my talk, I will discuss the quantitative relationship between the chaos bandwidth enhancement and fast phase dynamics in semiconductor lasers with optical feedback and optical injection. I will show that the injection increases the coupling between the intensity and the phase leading to a competition between the relaxation oscillation frequency and the intrinsic frequency response of the phase. For large feedback strengths, the chaos bandwidth is determined by the intrinsic phase response frequency.

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MS.08.05.Photonic memories using time-delayed neuromorphic optoelectronic resonators

Recent progresses in multidisciplinary fields including semiconductor physics, photonics, nonlinear dynamics, computing and networks yielded the possibility to emulate some elementary functions of the brain. Neuromorphic inspired systems offer great promise for implementing compact, low-power artificial neuron-like computing systems with real-time learning abilities. In this work, we report our recent advances in neuron-inspired optoelectronic integrated chips aiming at the development of new photonic memories capable of emulating the biophysics of real spiking neurons and dynamic synapses. The key component of our bio-inspired memory is a high-speed nanoscale semiconductor nonlinear device, the resonant tunneling diode photo-detector (RTP-PD), that uses the electron tunneling quantum effect to produce a region of negative differential conductance in its current-voltage characteristic (I-V). It also incorporates a photosensitive semiconductor layer for photodetection at $\sim$1550 nm. Due to the I-V pronounced nonlinearity and photodetector capabilities, sub-nanosecond spiking electrical responses are excited whenever the RTD-PD is perturbed by either optical or electrical signals above a certain threshold [1], that is, a dynamical excitable mechanism underlying all-or-none responses typically observed in biological systems (e.g. neurons). In order to implement the regenerative photonic memory [2], a laser diode operating at $\sim$1550 nm is directly modulated by the RTD-PD excitable response. Then, by reinjecting into the RTD-PD a delayed replica of the spiking excitation using an optical fiber loop, a regenerative memory is achieved as a result of the time-delayed feedback of the excitable response of the system onto itself. We experimentally demonstrate writing, reshaping and storing of photon packets of information at speeds much faster than the typical responses of neurons. Notably, it is found that the information is stored in the delay line as an ensemble of coherent structures which possess all the functional properties of localized structures, a phenomena often observed in spatially extended and out-of-equilibrium nonlinear systems. This ubiquitous property allow us to easily address, create and destroy individual localized patterns of information, ensuring additional robustness and flexibility of the memory. Furthermore, the experimental neuromorphic memory is well described by the FitzHugh-Nagumo model with time delay, making a complete link to the paradigm of neuronal activity and anticipating the development of novel neural-inspired photonic memories operating at Gb/s speeds.

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MS.09.Advanced time-series analysis: Novel tools for studying dynamical networks and complex systems
6 June 10:00-12:00 (Parallel 1)

Time series analysis is crucial for understanding dynamical systems because it links experiments and field data with theory and computer simulations. Current challenges are data from complex systems with a wide range of spatial and temporal scales, like spatio-temporal chaos or network dynamics. In fact, many complex systems consist of networks of interacting dynamical elements (e.g., neurons). Reconstructing network topology from (limited, noisy) data sampled at (few) nodes of the network is a major task. This topic as well as other parameter estimation issues constitute the focus of this Minisymposium with leading experts in network inference and data analysis.

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MS.09.01.Macroscopic reliability of high-dimensional chaos in recurrent neural networks

Neural activity in the brain is composed of the combination between spontaneous dynamics and responses to the external sensory inputs. In the present study, we investigate how a recurrent neural network exhibiting high-dimensional chaos is reliable against the external inputs. We find that macroscopic variables extracted by using an approach based on canonical correlation analysis (CCA) show a clear reliability, i.e., the time series of these macroscopic variables generated from different initial conditions coincides with each other against the same input signal, whereas microscopic variables do not show any such a reliability. We will also report that the EEG signals measured from the human brains show reliable responses to noisy visual inputs.

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MS.09.02.Network inference from time-series measurements

Inferring the underlying network of a complex system from observed data is nowadays the object of intense research. This network inference is usually made by analysing the data of time-series recorded at the different units that compose the complex system. Namely, a link between units is assumed depending on how interdependent these observations are. Hence, a network of interconnections between the units is retrieved. However, the limits of network inference in real-world systems composed by interacting dynamical units are still not fully understood. Here, we focus on critically comparing the most commonly used statistical tools for network inference: Pearson Cross-Correlation (CC) and Mutual Information (MI) using ordinal patterns. In particular, we test these methods on various coupled maps in terms of time-series length, presence of noise, network size, and parameter heterogeneity. We quantify their success based on their efficiency, robustness, and reliability to infer the underlying network. Shockingly, our findings show that there are dynamical regimes where we could infer exactly the underlying network for both methods. Although, in general, MI outperforms CC in terms of robustness and reliability. Consequently, we believe these findings to be relevant for the inference and interpretation of functional networks such as those coming from brain or climate data.

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MS.09.03.Inferring Network Connectivity From Time Series

How can we infer physical interactions between units of a network from only knowing the units' time series? Here we present a dynamical systems' view on collective network dynamics, and propose the concept of a dynamics' space to reveal interaction networks from time series. We present two examples: one, where the time series stem from standard ordinary differential equations, and a second, more abstract, where the time series exhibit only partial information about the units' states. We apply the latter to neural circuit dynamics where the observables are spike timing data, i.e. only a discrete, state-dependent outputs of the neurons. These results may help revealing network structure for systems where direct access to dynamics is simpler than to connectivity, cf. [1,2,3].

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MS.09.04.Time-series similarity analysis of coupled nonlinear oscillators and application to climate data.

Systems composed by interacting dynamical elements are ubiquitous in nature. In many situations, such systems are modelled as networks of oscillators, where the nodes represent the individual units and the links represent the interactions among them. These interactions are often unknown, and a popular method for inferring the underlying connectivity of a system (i.e., the structural network) is based on a statistical similarity analysis of the time-series collected from the dynamics of the nodes. In this presentation I will discuss our recent work on inferring network connectivity from observed data. I will present results obtained with synthetic data (simulations of Kuramoto phase oscillators) and with empirical data (Rössler electronic chaotic circuits), which are coupled with known network topology [1]. I will show that, under adequate conditions, the structural network can be perfectly inferred, i.e., no mistakes are made regarding the presence or absence of links. Then, I will discuss the application of this inference method for detecting main climate teleconnections from the analysis of observed climatological datasets.

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MS.09.05.Using delay coordinates for specifying non-observable and redundant model parameters.

In data driven system identification values of parameters and not observed variables of a given model of a dynamical system are estimated from measured time series. We briefly revisit synchronization and optimization based state and parameter estimation methods [1,2]. Then we address the question of observability [3,4,5], that is, whether unique results can be expected for the estimates or whether, for example, different combinations of parameter values would provide the same measured output. This question is answered by analysing the null space of the linearized delay coordinates map [6]. Examples with zero dimensional, one dimensional, and two dimensional null spaces are presented including the Hindmarsh-Rose model, the Colpitts oscillator, and the Rössler system.

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MS.10.Front evolution in active fluid flows
6 June 10:00-12:00 and 15:00-17:00 (Parallel 2)

Many physical phenomena evolve via fronts, separating distinct phases, that propagate through an active flowing fluid. Examples of both fundamental and applied interest include chemical reactions in microfluidic devices, plankton blooms in ocean currents, waves within plasmas, epidemics in moving populations, flame fronts in combustion, growth of the atmospheric ozone hole, and bacterial swimmers. The interplay between front growth and the underlying fluid flow leads to novel dynamical phenomena. This minisymposium brings together researchers studying front growth within flows from a variety of perspectives, including experiments, dynamical systems theory, numerical PDEs, and analytics.

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MS.10.01.Experimental studies of reaction front barriers in laminar flows

We present studies of the effects of vortex-dominated fluid flows on the motion of reaction fronts produced by the excitable Belousov-Zhabotinsky reaction. The results of these experiments have applications for advection-reaction-diffusion dynamics in a wide range of systems including microfluidic chemical reactors, cellular-scale processes in biological systems, and blooms of phytoplankton in the oceans. To predict the behavior of reaction fronts, we adapt tools used to describe passive mixing.In particular, the concept of an invariant manifold is extended to account for reactive burning. Burning invariant manifolds (BIMs) are predicted as one-way barriers that locally block the motion of reaction fronts. These ideas are tested and illustrated experimentally in a chain of alternating vortices, a spatially-random flow, vortex flows with imposed winds, and a three-dimensional, time-independent flow composed of the superposition of horizontal and vertical vortices. We also discuss the applicability of BIM theory to the motion of bacteria in fluid flows.

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MS.10.02.Calcium Carbonate Mineralization in a Confined Geometry

Injection of carbon dioxide in porous aquifers, where mineralization takes place via chemical reactions, is one possible long-term solution considered for storage of this greenhouse gas. However, such a flow-driven precipitation may dramatically change the porosity and permeability of the host medium, possibly leading to pore clogging. This mineralization is investigated here experimentally in a confined geometry, mimicking porous medium, by injecting radially an aqueous solution of carbonate into a solution of calcium ions to produce solid calcium carbonate. Various precipitation patterns like spirals, fingers, tubes, etc. are observed during injection due to the coupling of chemistry and hydrodynamics [Schuszter et al.; Env. Sci. Tech. Lett.; DOI: 10.1021/acs.estlett.6b00074 (2016)]. They bear analogies with similar patterns observed in the growth of chemical gardens in confined geometries [Haudin et al.; PNAS; Vol 111, No 49, 17367 (2014)]. The pattern properties are quantified to analyze the influence of growth conditions on mineralization. We show the existence of critical concentrations of reactants, which are functions of flow rate, above which the amount of precipitate drops significantly even if the reactant concentrations are large in the vicinity of reaction zone. The efficiency of the reaction is investigated by analyzing the spatial distribution of precipitate, its total amount, and the ratio of injected and consumed reactants.

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MS.10.03.Selection of Frozen Fronts in simple flow and Avalanches Dynamics in Reaction Fronts in Disordered Flow.

Autocatalytic reaction fronts between two reacting species, propagate as solitary waves. The coupling between autocatalytic reaction front and forced hydrodynamic flow may lead to stationary fronts whose velocity and shape depend on the underlying flow field. We focus on the issue of the chemo-hydrodynamic coupling between forced advection opposed to these self-sustained chemical waves. which can lead to static stationary fronts, i.e Frozen Fronts, FF.

We perform experiments, analytical computations and numerical simulations with the autocatalytic Iodate Arsenious Acid reaction (IAA) over a wide range of flow velocities around a solid disk. Over a wide range of flow velocity , we have been able to observe static stationary fronts, i.e Frozen Fronts, FF. For the same set of control parameters, we do observe two types of frozen fronts: an upstream FF which avoid the solid disk and a downstream FF with two symmetric branches emerging from the solid disk surface. We delineate the range over which we do observe these Frozen Fronts. We also address the relevance of the so-called eikonal, thin front limit to describe the observed fronts and to select the frozen front shapes.

For the more complex and disordered flow inside a porous medium, we report on numerical studies of the dynamics of the front for the same IAA autocatalytic reaction front. The front propagation is controlled by the adverse flow resulting in fronts propagating either upstream or downstream, or remaining frozen FF. Focusing on front shape, we have recently identified three different universality classes associated with this system by following the front dynamic experimentally and numerically. Here, using numerical simulation, in the vicinity of the depinning transition between FF and upstream fronts, we find power-law distributions of avalanche sizes, durations and lateral extensions. The related exponents are compared with the so-called $qKPZs$ theory that describes the front dynamic.

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MS.10.04.Effective dimensions and chemical transients in closed fluid flows

We investigate chemical activity in hydrodynamical flows in closed containers. In contrast to open flows, in closed flows the chemical field does not show a well-defined fractal property; nevertheless, there is a transient filamentary structure present. We show that chemical activity in such flows can be understood as the outcome of three basic effects: the stirring protocol of the flow, the local properties of the reaction, and the global folding dynamics. We show that the effect of the filamentary patterns on the chemical activity can be modeled by the use of time-dependent effective fractal dimensions. We derive a new chemical rate equation, which is coupled to the dynamics of the effective dimension, and predicts an exponential convergence to the asymptotic chemical state.

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MS.10.05.Optimal stretching for growth in reaction-diffusion-advection systems

Extended systems subjected to the combined effects of reaction, diffusion, and advection exhibit rich dynamics and are difficult to forecast. An improved understanding would enable prediction of phytoplankton growth in Earth's oceans, prediction of construction and deconstruction of cellular scaffolding in crawling cells, and–if feedback could be included–prediction of combustion. In reaction-diffusion-advection experiments, my team and I find that rapid growth can reliably be predicted in regions where advective stretching has values within an optimal range. Stretching, defined as the maximum eigenvalue of the right Cauchy-Green strain tensor, measures local deformation of the medium. Gentler stretching supplies reactants more slowly, reducing growth, whereas stronger stretching dilutes catalysts, effectively blowing out the reaction. I will share a few ideas about using optimal stretching to forecast ecological niches for marine phytoplankton, and ask whether there exists an optimal stretching for reaction-diffusion-advection systems that are not excitable.

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MS.10.06.Burning Lagrangian Coherent Structures and pattern formation in advection-reaction-diffusion dynamics

Front propagation in advection-reaction-diffusion systems gives rise to rich geometric patterns. We review recent results from dynamical systems theory that relate these patterns to invariant manifolds of periodic orbits of the front element dynamics. These manifolds—termed burning invariant manifolds (BIMs)—are one-sided dynamical barriers to the propagation of reaction fronts. As originally introduced, BIMs were defined only for time-independent or time-periodic fluid flows. We shall discuss recent research extending the BIM concept to arbitrary fluid flows, where the fluid velocity data is prescribed over a given finite-time interval, with no assumption on the time-dependence of the flow. In this context, we identify prominent one-sided barriers—termed burning Lagrangian Coherent Structures (bLCSs)—as locally the most repelling or attracting fronts over the given time interval. We illustrate these concepts using numerical computations of a time-varying fluid "wind" in a double-vortex channel flow.

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MS.10.07.Chemically Induced Finger Instabilities

Finger instabilities appear under different conditions, sometimes involving some density gradients in a gravitational field or viscosity differences when no gravity is present. Nevertheless in natural processes, convective mechanisms are mostly played by chemically active substances. Here, we experimentally analyze finger instabilities induced by some chemical reaction taking place at the interface. Different reactions were considered ranging from Belousov-Zhabotinsky reaction to pH oscillators. For the cases considered, the hydrodynamic instability was initiated by some chemical reaction taking place at the interface. These reactions trigger some changes in the physical properties of the fluids involved and, thus, initiate the instability. In particular, we will focus on a very interesting situation when diffusion processes are of the same order of magnitude as the convective ones involved. Under these circumstances, interesting competition happens and new hydrodynamic instabilities, finger-like, are observed. The induction mechanism as well as their properties will be analyzed.

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MS.10.08.Three-dimensional convection-driven fronts in autocatalytic systems

Horizontally propagating autocatalytic reaction fronts in fluids are often accompanied by convective motion in the presence of gravity. We experimentally and numerically investigate the stable complex three-dimensional pattern arising in the exothermic chloritetetrathionate reaction as a result of the antagonistic thermal and solutal contribution to the density change. By particle image velocimetry measurements, we construct the flow field that stabilizes the front structure. The calculations applied for incompressible fluids using the empirical rate-law model reproduce the experimental observations with good agreement. In a thin solution layer unusual cellular patterns develop when significant amount of autocatalyst is bound to a polyelectrolyte with low mobility: both oscillatory and stationary patterns evolve as a result of the interaction between the reaction front and the superposed gravity current. The concentration of the polyelectrolyte regulating the velocity of front propagation serves as a bifurcation parameter for switching between the two basic patterns.

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[2] G. Schuszter, G. Pótári, D. Horváth, Á. Tóth, CHAOS, 25, 064501 (2015).

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MS.10.09.Harmful algal blooms: combining excitability, competition and hydrodynamic flows

Harmful algal blooms (HABs) are rare events which are characterized by a sudden large abundance of potentially toxic plankton species which can alter the dynamics of the whole ecosystem. Since as a consequence of climate change, the frequency of HABs is increasing, there is a strong need in understanding the possible causes for such bloom events. We discuss a model, which is based on the idea of an excitable activatorinhibitor system in which two activators (toxic and non-toxic phytoplankton) compete with each other and the inhibitor (zooplankton) has a certain preference for a specific activator. We show how the interplay of the competition and environmental factors like increasing nutrient input due to upwelling result in a sudden growth of toxic species. Hydrodynamic flows are also important determinants for the emergence and the spread of HABs in the real ocean. Analzying data from observations in the Southern California Bight we demonstrate, that particularly mesoscale hydrodynamic vortices are of crucial importance for the spread of HABs. Moreover, such vortices can lead to heterogeneous dominance patterns of different plankton species in the ocean. We illustrate the mechanism of the emergence of spatially localized HABs using a simplified kinematic flow. Furthermore we demonstrate the importance of the interplay between biological and hydrodynamic time scales for the formation of blooms.

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MS.10.10.Dynamics of dilute and dense bacterial suspensions under flow

The vast majority of microorganisms experience fluid flow, whether turbulent flow in aquatic and industrial systems, or laminar flow in the human body and medical devices. Common to all flow regimes is hydrodynamic shear, which generates forces and torques on cells. In the absence of shear, motile bacteria explore their environment with random-walk swimming patterns, resulting in diffusive transport, but little is known about the effects of fluid flow on their navigation and spatial distribution. Using microfluidics, I will show that bacteria can be trapped in regions of high shear, where the hydrodynamic torque preferentially aligns them in the flow direction, quenching their migration across streamlines. This is a robust phenomenon, which can result in depletion of cells from the low-shear regions of the flow within only a few seconds and which does not require any cell-surface interaction to induce the observed heterogeneous distributions. I will rationalize the physical mechanism underlying this phenomenon using both a Langevin and a Fokker-Planck model, whose predictions and scaling analysis capture the experimental observations very accurately, revealing the competing roles of cell aspect ratio and stochasticity in cell alignment with the flow and the consequent emergence of maximal trapping at intermediate shear rates. In addition, I will present experiments in which concentrated bacterial suspensions were flown through narrow microchannels and the velocity statistics of the flowing suspension were accurately quantified with a recently developed velocimetry technique. This revealed a robust intermittency phenomenon, whereby the average velocity profile of the flowing suspension oscillated between a plug-like flow and a parabolic flow. Vortex-tracking methods revealed that the origin of the intermittency resides in the constructive interference between organized bacterial motility and ambient flow.

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MS.11.Data-based methods for complex dynamical systems
6 June 15:00-17:00 and 17:30-19:30 (Parallel 1)

This minisymposium will explore the interplay between dynamical systems and exciting new ideas in high dimensional sampling, data assimilation, and manifold learning. The focus will be on data-driven methods that are able to extract features from complex dynamical systems, and on novel sampling methods that expand the traditional understanding of large scale systems.

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MS.11.01.On the Computation of Attractors for Delay Differential Equations

In this talk we will introduce a numerical method which allows to approximate (low dimensional) invariant sets for infinite dimensional dynamical systems. We will particularly focus on the computation of attractors for delay differential equations. The numerical approach is inherently set oriented - that is, the invariant sets are computed by a sequence of nested, increasingly refined approximations -, and does not rely on long term simulations of the underlying system.

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MS.11.02.A spectral clustering approach to coherent Lagrangian vortex detection

One of the ubiquitous features of real-life turbulent flows is the existence and persistence of coherent vortices. Here we show that such coherent vortices can be extracted as clusters of Lagrangian trajectories. To this end, we extract coherent vortices from a graph built from trajectory data, using tools from spectral graph theory. Our method is able to recognize the number of present coherent vortices as well as their location without a priori knowledge. We illustrate the performance of our technique by identifying coherent Lagrangian vortices in several two- and three-dimensional flows.

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MS.11.03.Matching algoritms for sampling in multiscale simulations

In many multiscale simulations, the system state is described at just two scales: microscopic and macroscopic. At the microscopic scale, modeling can be very detailed, leading to high-dimensional models with multiple time scales. At the macroscopic level, one usually reduces the number of state variables and eliminates the fast degrees of freedom. Various techniques exist for combining the two system descriptions to yield simulations that are faster than a naive microscopic simulation yet more accurate than using the approximate macroscopic model. Coarse projective integration and micro-macro parallel-in-time methods are only two examples. The difficulty in such methods usually lies in the coupling between the two descriptions, in particular finding an appropriate microscopic state given the macroscopic state.

When the microscopic model is an ensemble of particles advected by an SDE and the macroscopic model is a low-dimensional Fokker-Planck equation, finding a microscopic state corresponding to a given macroscopic state is essentially a sampling problem. In this presentation, I will demonstrate that it is vital to obtain this microscopic state by minimizing perturbations with respect to a given (previous) microscopic state. We then generalize this procedure, which we call matching, to the case where the microscopic model is a system of interacting particles. This complicates the sampling as reweighting and/or cloning particles has grave consequences for the further simulation.

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MS.11.04.The design of numerical methods for statistical simulation in high-dimensional dynamical models

Dynamical systems with many degrees of freedom arise in molecular and other particle systems as well as through discretization of time-dependent continuum models. The challenge in simulation is typically to extract some type of statistical information, e.g. stationary thermodynamic averages, time-dependent ensemble averages, diffusion rates or transition times. In this talk I will discuss some of the challenges in building numerical schemes that flexibly address these different aims.

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MS.11.05.Spectral analysis of flows using radial basis functions

The most expensive part of the transfer operator approach to a spectral analysis of flows is the construction of the operator itself. We present a numerical method based on radial basis function collocation and apply it to a recent transfer operator construction that has been designed specifically for purely advective dynamics. The construction is based on a "dynamic" Laplacian operator and minimises the boundary size of the coherent sets relative to their volume. The main advantage of our new approach is a substantial reduction in the number of Lagrangian trajectories that need to be computed, leading to large speedups in the transfer operator analysis when this computation is costly.

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MS.11.06.Tensor-based data-driven analysis of complex dynamical systems

In this talk, we will present tensor-based and data-driven methods for the analysis of complex dynamical systems. The main goal is to rewrite methods such as Dynamic Mode Decomposition (DMD) or Extended Dynamic Mode Decomposition (EDMD), which have been recently developed for analyzing the global behavior of dynamical systems, for identifying low-order dynamics, and for computing finite-dimensional approximations of the Koopman operator associated with the underlying system, in terms of tensors. Due to the curse of dimensionality, analyzing high-dimensional systems is often infeasible using conventional methods since the amount of memory required to compute and store modes and eigenfunctions grows exponentially with the size of the system. This can be mitigated by exploiting low-rank tensor approximation approaches. We will show how a tensor-based reformulation of EDMD can be used to approximate the eigenfunctions of the Koopman operator or Perron-Frobenius operator and illustrate the results using simple molecular dynamics examples.

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MS.11.07.Detecting coherent sets with spacetime diffusion maps

Intuitively, coherent sets are subsets of the configuration space that stay together under the (possibly chaotic) dynamics. Many different approaches for making this notion precise exist in the literature. For example, one approach defines coherent sets via spectral properties of the transfer operator, and another defines coherent sets as tight bundles of trajectories by specifying a euclidean distance metric in spacetime. We show that these two approaches can be reconciled: By replacing the Euclidean distance in spacetime with an augmented version of the distance used in diffusion maps, one can make contact with the transfer operator notion of coherence in the infinite data limit. The resulting numerical method, which can be used to extract coherent sets directly from trajectory data, is related to similar methods that have been discussed in the past. We demonstrate its performance on several examples.

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MS.11.08.Transfer Operator Families and Coherent Sets

In this talk we present a way to compute finite-time coherent structures in time variant dynamical systems via considering the system at all time instants. This is done by analysing a corresponding transfer operator family as a whole. We furthermore discuss different discretizations, some of them leading to recently developed, purely data-driven algorithms and so providing a set oriented justification for those.

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MS.11.09.Coherent Families: Spectral Theory for Transfer Operators in Continuous Time

The decomposition of the state space of a dynamical system into metastable sets is important for understanding its essential macroscopic behavior. The concept is quite well understood for autonomous dynamical systems, and recently generalizations appeared for non-autonomous systems: coherent sets. Aiming at a unified theory, in this talk we present connections between the measure-theoretic autonomous and non-autonomous concepts. We will do this by considering the augmented state space, and our results will be restricted to systems with time-periodic forcing.

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MS.11.10.Information barriers and robustness of reduced-order models, with application to optimal control of diffusions

Many models in science and engineering are characterized by their high dimensionality, the presence of vastly different characteristic spatial and temporal scales and the importance of stochastic effects. Noise is ubiquitous in these models and can be due to thermal fluctuations, noise in control parameters or imprecise knowledge of the system state. Well known examples of complex multiscale systems with stochastic effects are the atmosphere/ocean system, biomolecular systems, or energy networks. A wealth of analytical, computational and statistical techniques have been developed in recent years for the study of complex multiscale dynamical systems. These techniques enable us to obtain low dimensional effective dynamics that capture accurately the evolution of a few appropriately selected variables at the length and time scales of interest. Prominent examples are the singular perturbation approximation or projection-based model order reduction techniques, which both can be made rigorous under the assumption of scale separation, but this assumption is rarely met or verifiable in reality. An important development in recent years therefore has been the systematic use of data in the derivation and validation of the reduced-order models, and various closure schemes have been proposed that include available data in the construction of the models [1]. Given suitable coarse-grained or macroscopic variables that capture the effective behaviour of a complex system, it is often the case that there are many different, but equally plausible reduced models. It has been pointed out recently that, although a reduced model may be very good in approximating certain equilibrium properties of the full system, such as statistical equilibrium distributions, energy functionals or steady states, they may be unstable under perturbations and perform badly in cases when, for example, the original model or the data are perturbed [2]; another example in which a reduced model may fail is in the context of (feedback) control and optimization, due to a lack of backward stability [3].

In this talk we will survey recent results on the robustness and backward stability of model order reduction techniques, with a special focus on feedback-controlled diffusions, and explain how information-theoretic concepts such as entropy or statistical divergences can be helpful to improve model fidelity, robustness and backward stability of the reduced models.

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MS.12.Nonlinear Waves: Modeling, Methods and Applications
7 June 10:00-12:00 and 15:00-17:00 (Parallel 3)

The goal of this meeting is to survey recently developed methods and novel results on the subjects of the formation and the dynamics of Nonlinear Waves and related applications. A wide range of physical systems will be discussed including optics and photonics, metamaterials, Bose-Einstein condensates and granular chains. Analytical and numerical methods will be presented for the study of continuous and discrete, integrable or nonintegrable, systems modeling wave propagation in nonlinear media, under the presence of effects such as medium inhomogeneity, gain/loss, nonlocality and others.

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MS.12.01.Comb solitons in micro-ring resonators

An overview of the recent results by the author and collaborators on nonlinear effects and soliton formation in optical micro-ring resonators used to generate frequency combs for metrology applications will be presented. In particular, the influence of Raman scattering and higher order dispersions on the soliton combs will be discussed. The Raman effect introduces a threshold value in the resonator quality factor above which the frequency-locked solitons cannot exist, and instead, a rich dynamics characterized by generation of self-frequency-shifting solitons and dispersive waves is observed. A mechanism for broadening the Cherenkov radiation through Hopf instability of the frequency-locked solitons and various analytical and semi-analytical approaches to the problem will be discussed.

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MS.12.02.Propagating quantum breathers in superconducting qubit lattices

Quantum bits or qubits are at the heart of quantum information processing schemes. The possibility of achieving quantum coherence in macroscopic circuits comprising Josephson junctions, envisioned by Legett in the 1980s, was demonstrated for the first time in a charge qubit; since then, the exploitation of the macroscopic quantum effects in low-capacitance Josephson junction circuits allowed for the realization of several kinds of superconducting qubits. Furthermore, coupling between qubits has been successfully realized that was followed by the construction of multiple-qubit logic gates and the implementation of several algorithms. Here it is demonstrated that induced qubit pulse coherence as well as two remarkable quantum coherent optical phenomena, i.e., self-induced transparency and Dicke-type superradiance, may occur during light-pulse propagation in quantum metamaterials comprising superconducting charge qubits. The qubit pulse generated forms a compound quantum breather that propagates in synchrony with the electromagnetic pulse.

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MS.12.03.Time-asymmetric quantum physics and Gamow vectors in nonlinear waves

We will review our results on the application of time-asymmetric quantum physics in nonlinear propagation and, in particular, in nonlocal optical propagation. We show that states belonging to a rigged Hilbert space with quantized decay rates form dispersive shock waves and provide a global description of wave-breaking phenomena, in quantitative agreement with experiments.

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MS.12.04.Discrete breathers in granular chains

Granular chains made of aligned beads interacting by contact (e.g. Newton's cradle) are widely studied in the context of impact dynamics and acoustic metamaterials. While much effort has been devoted to the theoretical and experimental analysis of solitary waves in granular chains, there is now an increasing interest in the study of breathers (spatially localized oscillations) in granular systems. Due to their oscillatory nature and associated resonance phenomena, static or traveling breathers exhibit much more complex dynamical properties compared to solitary waves. Such properties have strong potential applications for the design of acoustic metamaterials allowing to efficiently damp or deviate shocks and vibrations. In this talk, we review recent results and open problems concerning the dynamics of breathers in granular systems and their approximation through modulation equations.

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MS.12.05.Coherence and Decoherence in Superconducting Metamaterials

Superconducting metamaterials that rely on the Josephson effect which renders them nonlinear, have attracted considerable interest owing to their extraordinary properties both in the classical and the quantum regime. It is demonstrated that superconducting metamaterials comprising SQUIDs (Superconducting QUantum Interference Devises), i.e., superconducting rings interrupted by one or more Josephson junctions, exhibit novel flux localization properties as well as counter-intuitive dynamic flux states. The latter, referred to as chimera states, emerge due to dynamic multistability of individual SQUIDs that results in attractor crowding for the SQUID metamaterial, the strong response to externally applied magnetic fields, and the nonlocal coupling between the metamaterial elements. It is also demonstrated that those metamaterials undergo synchronization-desynchronization transitions. In the quantum regime, it is demonstrated that Josephson-based (charge qubit - loaded) superconducting transmission lines exhibit quantum coherence effects well known from optics, such as self-induced transparency and Dicke-type superradiance. Moreover, self-induced transparent electromagnetic pulses induce quantum coherence in the qubit chain, in the form of population inversion Lorentzian pulses with significant coherence times. These findings may open a new pathway to potentially powerful quantum computing.

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MS.12.06.Integrable nonlocal nonlinear Schrodinger equation

An integrable nonlocal nonlinear Schrodinger equation has been recently introduced that possesses a Lax pair and an infinite number of conservation laws and is PT symmetric. The inverse scattering transform and scattering data with suitable symmetries are discussed. A method to find pure soliton solutions is given. An explicit breathing one soliton solution is found. Key properties are discussed and contrasted with the classical nonlinear Schrodinger equation.

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MS.12.07.Compactons in a nonlinear evolutionary PDE and its discrete analog

We consider nonlinear evolutionary PDE deduced from systems of ODEs, describing dynamics of chains of pre-compressed granular media. The PDE is shown to possess a family of traveling wave (TW) solutions, describing bright and dark compactons. Stability tests for compactons are accomplished. Qualitative studies are backed by direct numerical simulations, revealing that both bright and dark compactons demonstrate the behavior reminding that of the "true" solitons. The results obtained within the continual model are compared with the numerical simulation of the dynamics of the source model of granular media. The numerical results obtained for both models endowed with the same initial conditions occur to be in a good qualitative agreement.

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MS.12.08.Instabilities in Non-hermitian Photonic Structures

Following the recent advances on Parity-Time (PT)-symmetric photonics, we will examine the fundamental phenomenon of modulation instability in a general class of non-hermitian photonic structures. In the framework of nonlinear Schrodinger equation (NLSE), this family of optical potentials contains gain and loss and supports nonlinear constant-intensity solutions (CI-Waves). We are going to present results regarding the linear stability of CI-waves on (PT)-symmetric photonic lattices, as well as, on the modulation instability of vector CI-waves (two coupled NLSE of Manakov type) for both signs of Kerr nonlinearity.

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MS.12.09.Dynamics of wave propagation in nonlinear photonic structures with unbalanced gain and loss

The combination of lossy dielectrics, metals and active parts in modern photonic structures introduces an inhomogeneous gain-loss landscape which, along with the conservative inhomogeneity corresponding to refractive index modulations, determines the dynamics of wave propagation. In a large variety of such structures, gain and loss are not balanced, as in the typical case where high-gain active parts (hot-spots) of small extent are introduced in order to compensate losses due to more extended lossy parts. In this work we study conditions for stable localized beam propagation in such unbalanced structures. The conditions refer to the relation between the gain-loss and the refractive index profiles enabling efficient wave trapping and stable propagation for a wide range of beam launching conditions such as initial power, angle of incidence, and position. The stability of propagation is a consequence of an underlying dynamic power balance mechanism that is related to a conserved quantity of the wave dynamics.

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MS.12.10.Adiabatic perturbation theory for vector nonlinear Schrodinger equation with nonvanishing boundary conditions

We use the adiabatic perturbation theory in vector NLS equations. We derive analytical the systems of ODEs concerning the dynamics of dark-bright solitons for vector NLS. Adopting a mean-field description for a 2-component atomic Bose-Einstein condensate, dark-bright solitons are studied in the presence of impurities and show that, counter intuitively, an attractive (repulsive) delta-like impurity induces an effective localized barrier (well) in the effective potential felt by the soliton; this way, dark-bright solitons are reflected from (transmitted through) attractive (repulsive) impurities. Analytical results for the small-amplitude oscillations are found to be in good agreement with results obtained via a Bogoliubov-de Gennes analysis and direct numerical simulations.

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MS.13.Time Series, Networks and Applications
9 June 10:00-12:00 and 15:00-17:00 (Parallel 3)

For time series, appropriate measures of inter-dependence are required to explore the underlying dynamics from the data and models can be built capturing these interactions. The inter-dependence structure of the system regarding the observed variables can be studied in terms of networks, assigning the variables to nodes and the estimated correlation or causality to the respective connections. The network analysis can reveal system properties, distinguish between different system regimes and track the system evolution. The minisymposium will cover recent advances in these topics and concentrate on applications, basically in neuroscience and finance. So, the minisymposium will be divide in two parts: the first part with first five talks on the methodology, and the second part with next five talks on applications.

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MS.13.01.Pairwise mutual information - a good interaction

Characterizing the interaction structure within a complex system is a key challenge across many scientific disciplinces. A matrix of mutual informations is a straightforward generalization of a linear correlation matrix for nonlinear systems, describing the structure of bivariate dependencies in a multivariate probability distribution. However, a question emerges: is the given probability distribution sufficiently described by the bivariate dependences? To answer the question, one principled approach lies in assessing the difference between the observed distribution and a maximum entropy distribution with the observed bivariate dependence structure. As conditioning on the full bivariate marginal distributions is prohibitively difficult, and approximate approach is needed in practice; conditioning on the first and second moments has been proposed in [1]. In the current contribution, we describe an alternative approach, taking into account explicitly the nonlinearity of the system, introduced by Martin et al. [2,3]. In particular, instead of conditioning on correlations, we propose to assess whether (and to what extent) does the observed distribution differ from a maximum entropy distribution consistent with the observed bivariate mutual informations (and univariate entropies). Importantly, a relatively tight upper bound for this deviation can be obtained by an effective algorithm based on linear programming. In the presentation, we shall describe the approach in more detail and give an example of application on human neuroimaging data, discussing also the relation to bivariate (non)linearity[4]. We shall also discuss the possible generalization to causal networks.

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[4] Jaroslav Hlinka, Milan Palu, Martin Vejmelka, Dante Mantini, Maurizio Corbetta. Functional connectivity in resting-state fMRI: Is linear correlation sufficient? NeuroImage, 2011, 54, 2218-2225

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MS.13.02.Determining the sub-Lyapunov exponent from chaotic dynamics of photonic delay systems

Chaos is likely to occur in a network of oscillators with time-delayed couplings. Lyapunov exponents are a typical measure to characterize the chaotic dynamics. In contrast to the spectrum of Lyapunov exponents of the entire system, conditional exponents (or sub-Lyapunov exponents, sub-LE) provide information about the response of an individual node to the input from its network environment. For instance, it was shown that a positive (negative) sub-LE corresponds to strong (weak) chaos, which is reflected by the scaling of the maximum LE with the delay time, and in particular by the synchronizability of multiple nodes. We investigate a minimal network configuration, namely a single node with self-feedback. In particular, we aim at the extraction of the sub-LE from the chaotic dynamics of a semiconductor laser with fiber-optical feedback, where we focus on two approaches. First, we present an algorithm for the determination of the sub-LE spectrum from time series only [1]. This algorithm combines previous methods developed for the calculation of conditional LE in systems coupled without delay, and for the determination of the full Lyapunov spectrum for a delay system. We introduce our method step by step, first for a discrete map, then for a scalar continuous system, where we apply the algorithm to experimental data, and finally for numerical time series from the Lang-Kobayashi model of a laser with feedback, where a direct comparison with the true spectrum of sub-LE is possible. Second, we present an experiment, in which a replay of the delayed feedback is realized via a second much longer delay loop [2]. By switching between the primary short loop and the long memory loop, an auxiliary system test is realized with a single node, thus minimizing mismatches. The difference signal between short loop and long loop dynamics exhibits a power-law distribution, which is caused by the finite-time fluctuations of the sub-LE that act as multiplicative noise. The power-law exponent is directly related to the sub-LE. This exponent shows a clear dependency on system parameters, also indicating transitions between strong and weak chaos. We confirm the proportionality between the extracted exponent and the sub-LE by numerical simulations of the corresponding system.

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[2] N. Oliver, T. Jüngling, and I. Fischer, Consistency Properties of a Chaotic Semiconductor Laser Driven by Optical Feedback, Phys. Rev. Lett. 114, 123902 (2015)

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MS.13.03.Detecting redundancy and synergy with Granger causality

We develop a framework for the analysis of synergy and redundancy in the pattern of information flow between subsystems of a complex network. The presence of redundancy and/or synergy in multivariate time series data renders difficult to estimate the neat flow of information from each driver variable to a given target. We show that adopting an unnormalized definition of Granger causality one may put in evidence redundant multiplets of variables influencing the target by maximizing the total Granger causality to a given target, over all the possible partitions of the set of driving variables. Consequently we introduce a pairwise index of synergy which is zero when two independent sources additively influence the future state of the system, differently from previous definitions of synergy. We report the application of the proposed approach to resting state fMRI data from the Human Connectome Project, showing that redundant pairs of regions arise mainly due to space contiguity and interhemispheric symmetry, whilst synergy occurs mainly between non-homologous pairs of regions in opposite hemispheres. Redundancy and synergy, in healthy resting brains, display characteristic patterns, revealed by the proposed approach. The pairwise synergy index, here introduced, maps the informational character of the system at hand into a weighted complex network: the same approach can be applied to other complex systems whose normal state corresponds to a balance between redundant and synergetic circuits.

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MS.13.04.Inferring Networks from Data: Recent Challenges and Advances

Recent years have seen a large increase in the availability of data. In fact, increasing amounts of data play a key role in every aspect of our lives, including but not restricted to physics, such as for the Large Hadron Collider (CERN) and the Square Kilometre Array (South Africa), biology, e.g. genomic data, medicine, e.g. functional magnetic resonance imaging or electroencephalography, and data mining in the social sciences or digital economies.

Dealing with these data sets efficiently determines the success of the projects, treatments, assessments, and analyses. This necessity to better understand and analyse data has led to an outburst of research into advanced methods of data analysis. The inference of networks underlying complex systems is of utmost importance. Especially when dealing with complex data sets the algorithms for network inference have to fulfil certain fundamental requirements: (i) they need to deal with truly multivariate data, i.e. they must distinguish between direct and indirect influences, (ii) they have to account for various concurrent noise sources, (iii) they need to addresses both linear and non-linear systems, (iv) provide results for each sampling point, (v) and estimate the strengths of the directed interactions. Finally, (vi) they need to provide a rigorous statistical framework to allow their evaluation and (vii) be numerically efficient.

A multitude of algorithms has been developed to address these extremely challenging requirements, but until now only very few can address them simultaneously. This is partly due to the fact that a rigorous mathematical framework, i.e. a theory of a suitable highly versatile class of mathematical models to comprise all of these features, is challenging. In this talk, the challenges will be introduced and means to address these will be discussed. Various methods will be compared and their abilities and limitations will be discussed. This results in a comprehensive overview of techniques that exists to tackle one of the key challenges of data based modelling: The detection of direct directed interactions from time series.

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MS.13.05.Constructing networks from time series with k-nearest neighbours - how and why

Several network transform algorithms have recent been proposed to construct, from time series, networks which exhibit certain useful properties of the underlying dynamical systems. Of these methods, two are based on phase space reconstruction - the k neighbour approach and an epsilon ball method. The later is equivalent to treating the recurrence matrix of a recurrence plot as a binary adjacency matrix of a network. The k-neighbour method is more subtle and that subtlety has meant that, until now, it has been not clear exactly what is going on and why it should be useful. In this talk we will explain the so-called time series super-family phenomena (whereby the dynamics of the original system are completely classified by the network motif superfamily) and then show that the overall network structure is equivalent to a proper embedding. We do this by constructing an inverse map from the network to a space that is topologically equivalent to the embedded time series.

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MS.13.06.Comparing Density Forecasts in a Risk Management Context

This paper develops a testing framework for comparing the accuracy of competing densities of aggregated marginal variables in the downside part of the support. Three proper scoring rules including conditional likelihood, censored likelihood and penalized weighted likelihood are used for assessing the predictive ability of (out-of-sample) densities, closely related to the Kullback-Leibler information criterion (KLIC). We consider distributions in the framework of skew-elliptical family which is analytically traceable under affine transformations. The common practice of forecast comparison in high-dimensional space is problematic because a better forecast in multivariate evaluation does not necessarily correspond to a better portfolio return forecast; as illustrated by examples in the paper. An application to the daily returns of three US stocks suggests that the Student-t outperforms the Normal, Skew t and Skew Normal assumptions in the left tail of the portfolio return. The visualized dynamics of our test statistic provides a side proof for regime change over the last thirty years. In the second application, techniques for distribution selection based on the scoring rules are applied and the one-step-ahead VaR estimates from dynamic-selected distributions show better results than the fixed distributions.

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MS.13.07.Information theoretic causal network structure of financial data series

We analyse high frequency financial time series. Each time series is considered to be a node in a network. The (directed) edges between the nodes are representing (information theoretic) causal interdependencies between the the time series. We compare network structures derived by use of different theoretical causal measures including the Mutual Information Mix Embedding measure introduced by Vlachos and Kugiumtzis [PRE **82**, 016207 (2010)]. We are interested in identifying nodes which play a systemic role in the networks. As a way to assess how the causal connections identified by MIME may relate to a potentially hidden strength of interaction, we have repeated the analysis on time series produced by the fully stochastic Tangled Nature model of co-evolution between interacting species. In this case we know the interacting matrix responsible for the interdependence between the degree of occupancy of different species. Hence we are able to compare the actual interaction strength to the MIME causality. We are particularly concerned with relating the structural evolution of the networks to stability and ultimately to forecasting. Our experience from forecasting of transitions in the Tangled Nature model [See PRL **113**, 264102 (2014)] suggests that the dynamics of the causal network structure can provide information relevant to forecasting.

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MS.13.08.Impact of external perturbations is dependent on the dynamical state of epileptic networks

Understanding of the mechanisms responsible for transition to seizure represents key step for development of new tools how to effectively control seizures. Previous studies have demonstrated that seizures do not occur suddenly but they are preceded by detectable changes in dynamics of epileptic neuronal networks. In this study we have examined impact of external perturbations interictal epileptiform discharges on the process of slow transition to seizure. The experiments were performed in vitro in rat hippocampal slices perfused with artificial CSF containing high potassium (¿8 mM). Population and neuronal activity was recorded from the hippocampal CA1 and CA3 regionsusing multiple extracellular electrodes. By monitoring neuronal activity in CA1 we have demonstrated that seizures were preceded by increase in overall neuronal firing which has manifested in extracellular recordings by buildup of low-amplitude high-frequency activity at 200 Hz. Interictal discharges were generated in CA3 regions and propagated via excitatory pathways to CA1 region where they interfered with the dynamics of high-frequency activity and seizure initiation. In CA1 each interictal discharge induced transient increase in high-frequency activity followed by its suppression lasting 0.5 s. Block of these excitatory perturbations resulted in shortening of inter-seizure period which suggested that the may have seizure postponing effect. However, if interictal discharge occurred immediately before seizure onset then it facilitated transition to seizure. This study demonstrate the dual nature of external excitatory perturbations on seizure generating areas when character of the response to perturbations was determined by the dynamical state of the epileptic neuronal networks.

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MS.13.09.A creative brain is well-connected: functional networks of the creativity process in resting state

The study of functional brain network has proved useful to give insight into brain function both in healthy controls and in subjects suffering from different neurophysiological pathologies. Even in the case of sensor level EEG studies, which are known to be affected by issues such as volume conduction and the recording reference, the patterns of functional connectivity change between and within groups depending on different variables. Yet the relationship between such patterns and, e.g., the behavioural data characterizing different cognitive functions is poorly understood. In this work we analysed, in a large simple of subjects, the correlation between resting state functional brain networks, as derived from scalp EEG, and performance of each subject in a set of commonly used test of creativity. The results demonstrate that, albeit weak, there exists a significant correlationship between different features of the networks and the outcomes of the tests, which are topographically and frequency-specific. We think that such correlationship can be exploited not only to better understand brain function, but also as a proxy to determine the effectiveness of different types of stimuli to enhance creativity.

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MS.13.10. Distributional Clustering of Multivariate Time Series

A frequent problem encountered in the modeling of time series is the presence of two very different time scales; one defined implicitly by the data acquisition or sampling rate and the other one given by the time scale of stationarity of the dynamical system under study. Clearly, data analysts are interested only in the latter, as the former is to be considered a necessary artifact of the measurement setup.

Difficulties arise when one tries to formulate models for sequential data that are independent of sampling rate. In switching autoregressive (SAR) models for example, an observed datum at time tn depends on its predecessors at times $t_{n-1}, \ldots, t_{n-O}$, the order O of which must be increased in proportion to an increase in sampling rate. Thus, without downsampling it is not possible to choose a rate independent model complexity. Moreover, it is not guaranteed that the assumption of linearity underlying the SAR model is plausible for the specific dynamical system under study. Finally, in the multivariate case the SAR approach suffers from bad scaling w.r.t. the number of adaptable parameters, which is proportional D^2O, where D is the number of time series (variables). One solution to these problems is to take a step back and temporally divide the set of time series into windows -whose length corresponds to the time scale of stationarity- and to consider temporal dependencies only *between* but not *within* windows. The data of each window is hereby condensed into an empirical distribution, which is thus considered as some high-dimensional vector on the probability simplex. In effect this corresponds to feature extraction, crucially however the resulting feature (= probability vector) does not require transformation of the original data.

By defining a specific type of emission distribution for probability vectors, we here show how a Hidden Markov based, soft clustering model for such windowed data can be found. We present results from systems identification in artificial data, as well as results obtained from intracranial EEG data of epilepsy patients. In the latter case, our model is able to correctly predict the likely prevention of seizures for 6 out of 7 patients, when the resection of those channels is simulated, whose actual, surgical resection has rendered the patient seizure free (= class I on the Engel scale). Moreover, these results are robust, as a Monte-Carlo analysis shows the actually resected channels to perform significantly better than random sets of channels.

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MS.14.Nanoscale thermal and thermoelectric transport: A dynamical systems approach
8 June 10:00-12:00 (Parallel 3)

The possibility to manipulate heat currents represents a fascinating challenge for the future, especially in view of the need of providing a sustainable supply of energy and limiting the environmental impact of the combustion of fossil fuels. In this respect, nanodevices are emerging as one of the key technologies. On the one hand, heat management at the nanoscale could dramatically reduce the energy cost requirements for operating electronic devices. On the other hand, nanoscale thermal engines might be able to efficiently convert part of the waste heat into electric work. Dynamical systems offer a new perspective to the challenging problems of controlling the heat flows and improving thermoelectric efficiency. Understanding from first principles and nonlinear dynamics simulations the microscopic mechanisms that can be implemented to control heat and charge flows might prove useful for designing new efficient thermal and thermoelectric devices. The purpose of this Minisymposium is to discuss the most recent developments in our understanding of coupled heat and charge transport in nanoscale systems.

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MS.14.01.Increasing thermoelectric efficiency: Dynamical models unveil microscopic mechanisms

The understanding of energy conversion in complex systems is a fundamental problem, also of practical interest in connection with the challenging task of developing high-performance thermoelectric heat engines and refrigerators. A rather abstract perspective of non-equilibrium statistical mechanics and dynamical systems theory is taken to view at this very practical problem. Recently discovered general mechanisms of optimizing the figure of merit of thermoelectric efficiency are discussed, in connection to momentum-conserving interacting systems, to the breaking of time-reversal symmetry by an applied magnetic field, and to multiterminal steady-state quantum thermal machines.

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MS.14.02.Studying thermoelectricity using efficiency fluctuations

At small scales thermometric devices operate far from equilibrium beyond the linear regime. They are also subjected to strong fluctuations. As a result, we propose to use the concept of efficiency fluctuations to accurately asses their performance. The theory of efficiency fluctuation and its application to simple device will be presented.

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MS.14.03.The discrete nonlinear Schröedinger equation out of equilibrium

We discuss the nonequilibrium properties of the one-dimensional discrete nonlinear Schrödinger equation. Due to the presence of two conserved quantities, energy and norm (or number of particles), the model displays coupled transport in the sense of linear irreversible thermodynamics. Monte Carlo and Langevin thermostats are implemented to impose a temperature and/or chemical potential gradients. At high-enough temperature Onsager coefficients are finite in the thermodynamic limit, i.e. transport is normal. At lower temperatures signatures of anomalous transport are observed. Application of the model to macrospin system is discussed throughout.

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MS.14.04.Phononic heat transport and thermal rectification

Recent progresses in manufacturing nanoscale electrical and mechanical devices have motivated deep understanding of heat transport in low dimensional systems and introducing new mechanisms for heat managements. More interestingly, it has been shown that thermal transport in many cases, e.g. carbon based nanostructures, is phonon dominated, indicating that phonons can be manipulated similarly to electrons for controlling heat transport at all temperatures. Thermal rectification, the thermal counterpart of electrical diodes corresponding a better thermal conductance in one direction rather than the opposite one, can also play an important role in nanoscale heat management. Here, utilizing either molecular dynamics simulation and/or density functional theory calculation, we investigate heat transport in low dimensional systems. Phononic thermal transport in different nanoscale systems, the effect of functionalization in graphene, the importance of anisotropy in phosphorene and arsenene as well as the effect of strain on heat transport in silicene, will be discussed.

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MS.14.05.Towards the laws of thermodynamics for non-Markovian quantum machines

Do quantum machines that convert heat into work (or vice versa) obey the classical laws of thermodynamics? This is a central question of the field of quantum thermodynamics. If it turned out the answer was "no", it would have huge ramifications for future energy production. For machines weakly coupled to the reservoirs of heat and work, the machine's dynamics is Markovian (described by a Lindblad equation) and much is known. In many cases, one can show that these systems do obey the classical laws of thermodynamics, and respect fluctuation relations such as the Crooks equality. However, weak coupling to the reservoirs automatically implies that the machine's power output is small.

Thus there is strong interest in understanding the physics of machines that are strongly coupled to their reservoirs. However, this means dealing with non-Markovian quantum dynamics. We will present a method capable of doing this, and will give preliminary results indicating that such systems also obey the classical laws of thermodynamics.

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5 Contributed talks

OC.001.Hub dynamics in complex networks
6 June 10:00-12:00 (Parallel 3), Session: Neurodynamics

We present some recent developments in dynamics of complex networks motivated by neuronal dynamics. We consider hubs (well-connected nodes) in scale-free networks (as a model for neuronal networks) and show that under idealised circumstances, where individual disconnected nodes have strongly chaotic dynamical properties and in the presence of (arbitrarily) weak diffusive noise, exact equations for hubs can be derived that reduce the description of hubs to that of random dynamical systems. This effective model for hub dynamics can be used to study coherent behaviour, like hub-synchronisation, liking to the recent surge in activity regarding the development of a bifurcation theory for random dynamical systems.

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OC.002.Accuracy of the non-relativistic approximation to relativistic momentum diffusion at low speed
8 June 10:00-12:00 (Parallel 3), Session: Chaos/Complex Systems

Newtonian mechanics is the standard theory used to study low-speed momentum diffusion in nonlinear Hamiltonian systems. However, the accuracy of this approximation to special-relativistic mechanics has not yet been studied. Here, the Newtonian and special-relativistic predictions for low-speed momentum diffusion, which are calculated using the same parameter and the same initial ensemble of trajectories, are compared for a prototypical system - the periodically-delta-kicked particle. We show there is no breakdown of agreement between the predictions of the two theories for the mean square momentum displacement if the initial ensemble is a non-localized semi-uniform ensemble. However, if the initial ensemble is a sufficiently-localized Gaussian, the special-relativistic prediction is not always well-approximated by the Newtonian prediction as expected and the breakdown of agreement can occur rapidly. Our finding suggests that, in general, it must not be assumed that the Newtonian prediction for low-speed momentum diffusion will always be close to the special-relativistic prediction.

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OC.003.Asymptotic reduction of exact solutions of shear flows
9 June 17:30-19:30 (Parallel 1), Session: Complex Fluid Dynamics

In subcritical shear flow configurations, exact solutions are formed at a finite value of the Reynolds number *Re* through a saddle-node bifurcation. The lower branch solution emerging from this bifurcation acts as an attractor on the separatrix between laminar and turbulent flows and the corresponding upper branch solution reproduces low-order statistics of turbulence. The lower branch states are comprised of a small number of dominant streamwise Fourier modes having a well-defined asymptotic behavior in *Re*. We use these observations to derive a reduced model for parallel shear flows and apply it to a cousin of plane Couette flow. The lower branch states are not only captured at large values of the Reynolds number but also away from the asymptotic regime. The upper branch states are also computed as well as pattern forming bifurcations. Analysis of these solutions reveals intriguing features and applies to other parallel shear flows.

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OC.004.Exploring the Applications of Fractional Calculus: Anomalous Diffusion of Hierarchically-Built-Polymers

8 June 10:00-12:00 (Parallel 3), Session: Chaos/Complex Systems

Expressions involving fractional derivatives have a long history in the theory and modelling of viscoelastic materials. Here polymers are very challenging, since they may show vast viscoelastic domains, in which anomalous behaviors occur. This is already evident for polymer chains, which in the Rouse domain display anomalous diffusion with an exponent of 1/2. More complex polymeric architectures are classically modeled based on the theory of generalized Gaussian structures (GGS), and are related to fractional generalized Langevin equations of non-Markovian nature [1]. For fractals the corresponding anomalous patterns display exponents which depend on the underlying structure.

The situation is, however, even more general, since such scaling laws persist even when local restrictions (say, constraints on the bonds' lengths and on the angles between bonds close to each other) are implemented, leading to semiflexible behavior. As we have shown, such restrictions can be readily incorporated into the GGS formalism, while still allowing for a largely mathematical-analytical study. As examples we will focus on semiflexible dendrimers and on semiflexible regular hyperbranched structures [2]. Remarkably, it turns out that the form of the potential energy for semiflexible treelike polymers (STP) stays very simple. This allows us to readily determine (among others) the mechanical and dielectric relaxation of several STP, and to display their corresponding anomalous behavior.

Of particular importance in applications is the non-Markovian character of these models in the study of chemical reactions: Thus, in quite recent publications we have investigated the formation of cycles in fractal-built polymers [3].

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[2] Dolgushev, M. and Blumen, A. 2009 J. Chem. Phys. 131, 044905; 2013 J. Chem. Phys. 138, 204902.
[3] Dolgushev, M., Guérin, T., Blumen A., Bénichou, O. and Voituriez, R., 2014 J. Chem. Phys. 141, 014901; 2015, Phys. Rev. Lett. 115, 208301.

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OC.005.Farey sequence and the largest Lyapunov exponent analysis in the ac driven Frenkel-Kontorova model

6 June 10:00-12:00 (Parallel 3), Session: Chaos

Dynamics of the dc+ac driven dissipative Frenkel-Kontorova model with deformable substrate potential is examined by using largest Lyapunov exponent computational technique. Obtained results show that comparing to the usual way where behavior of the system in the presence of external forces is examined by analyzing its dynamical response function, the largest Lyapunov exponent analysis often represents a better tool to estimate the system dynamics. Due to deformation, large fractional and higher order subharmonic steps appear in the response function of the system. Computation of the largest Lyapunov exponent as a way to verify their presence led to the observation of the Farey sequence. The appearance of subharmonic steps between the large harmonic steps, and their relative sizes follow the Farey construction. The largest Lyapunov exponent analysis not only offers the most accurate way to detect the presence of Shapiro steps but completely reflects the amplitude dependence of the step size and the critical depinning force. Largest Lyapunov exponent as a function of the ac amplitude calculated in the pinned regime represents a mirror image of the amplitude dependence of critical depinning force obtained from the dynamical response function when both forces are applied. The obtained results have also shown that regardless of the substrate potential or deformation, there was no chaos in the system.

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OC.006.Influence of Hopf bifurcations on the external cavity modes for a laser subject to phase-conjugate feedback

6 June 15:00-17:00 (Parallel 3), Session: Nonlinear Dynamics/Bifurcation Theory

We investigate the Hopf bifurcations of a semiconductor laser subject to a phase-conjugate feedback (PCF). From this analysis we deduct the frequency of the external cavity modes (ECMs) expected. In the PCF configuration, the ECMs are self-pulsing solutions at frequencies close to harmonics of the external cavity frequency. Numerical simulations confirm our results. After that, we introduce a filter in our equations and find the steady states and Hopf bifurcation conditions. We then compare our results with the one of the model without filter. From the Hopf bifurcation analysis, we predict the disappearance of ECMs at critical values of the filter width. This phenomenon is explained by successive coalescence of Hopf bifurcations as the filter width decreases. In the limit of a narrow filter, we then demonstrate that the problem is similar to an injection laser problem where the effect of the delayed feedback is averaged on the long time scale of the relaxation.

L. Weicker, T. Erneux, D. Wolfersberger, and M. Sciamanna: *Laser diode nonlinear dynamics from a filtered phase-conjugate optical feedback*, Phys. Rev. E 92, 022906 (Aug 2015).

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OC.007.Auditory neural burst formation through spike synchronization in the cochlea

6 June 10:00-12:00 (Parallel 4), Session: Neurodynamics

The ear transforms an input acoustic sound wave into a mechanical traveling wave on the basilar membrane of the cochlea which is then triggering neural spikes. Thereby the frequencies are oredered along the basilar membrane from high frequencies at the oval window to low frequencies at the cochea staple. Contrary to the frequencies, their phases are not treated with such care. In terms of these phases, as the acoustic input frequencies may have any phase relations, the output of all nerves are maily consistent bursts, like those found throughout the brain. To examine this, a time dependent Finite-Difference model of the basilar membrane is performed, transfering the mechanical wave energy on the moving basilar membrane into neural spike activity. It shows strongly enhanced phase synchronization in the spike pattern leaving the cochlea. This synchronization happens due to the nonlinear transition mechanism from mechanical waves on the basilar membrane govermed mainly by an inhomogeneous but linear differential equation into electrical spikes, and leads to a synchronization of random phases in the acoustic sound leading to consistent bursts. Neural mechanisms enhancing this phase synchronization even further have already empirically been found in the nucleus cochlearis and the trapezoid body, the two adjacent neural nuclei further up the neural pathway. This synchronization may help to explain fundamental properties of auditory perception, like the binding of many harmonic frequencies into one perceived pitch which only happens with harmonic sounds and not with inharmonic frequency spectra. As pitch is the fundamental component of music, the synchronization may be the perceuptual cause of music based on tones. Another phenomena which may be caused by this synchronization is the unability of listeners to hear phase relations in a static sound.

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OC.008.Frobenius–Perron eigenstates for asymmetric backscattering in deformed microdisk cavities

6 June 10:00-12:00 (Parallel 3), Session: Chaos

Optical microcavities with boundary deformations are weakly open systems that show pronounced aspects of non-Hermitian physics: The backscattering of clockwise and counter-clockwise propagating waves is in general asymmetric. Therefore, optical modes come in nearly degenerate pairs, where in contrast to the closed system dynamics both modes are non-orthogonal and have the same preferred sense of rotation, which is quantified by a finite chirality. At so-called exceptional points colinear modes indicate a full asymmetry in the backscattering and strongest deviation from Hermitian time evolution. We investigate the asymmetric backscattering phenomena with ray dynamics. For this purpose, we construct a finite approximation of the Frobenius–Perron operator, which describes the time evolution of intensities in phase space. Eigenstates of the Frobenius–Perron operator nicely reflect the non-orthogonality, copropagation and finite chirality of optical modes. Our method is demonstrated at a cavity system with a smooth asymmetric boundary deformation.

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OC.009.Chaos synchronization by resonance of multiple delay times
6 June 15:00-17:00 (Parallel 3), Session Complex Networks

Chaos synchronization may arise in networks of nonlinear units with time delayed couplings. We study complete and sub-lattice synchronization generated by resonance of two large time delays with a specific ratio. As it is known for single delay networks, the number of synchronized sublattices is determined by the Greatest Common Divisor (GCD) of the network loops lengths. We demonstrate analytically the GCD condition in networks of iterated Bernoulli maps with multiple delay times and complement our analytic results by numerical phase diagrams, providing parameter regions showing complete and sublattice synchronization by resonance for Tent and Bernoulli maps. We compare networks with single and multiple delays for the same GCD, and we investigate the sensitivity of the correlation to detuning between the delays in a network of coupled Stuart-Landau oscillators. Moreover, the GCD condition also allows to detect time delay resonances leading to high correlations in non-synchronizable networks. Specifically, GCD-induced resonances are observed both in a chaotic asymmetric network and in doubly connected rings of delay-coupled noisy linear oscillators.

M.Jimenez Martin, O. D'Huys, L. Lauerbach, E. Korutcheva and W. Kinzel, Phys Rev E 93, 022206 (2016)

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OC.010.Transition between segregation and aggregation : the role of environmental constraints
8 June 13:30-15:00 (Parallel 3), Session: Biophysics

Interactions between sub-groups (species, strains) have been reported in many species among many taxae. We propose a generic model based on earlier experiments accounting for both conspecific (or between individuals of the same strains) and heterospecific (or between strains) interactions. The model predicts different collective behaviors without any change of individuals algorithm by varying some key generic parameters such as the carrying capacity, the number of individuals involved and an inter-attraction parameter between sub-groups. A key result is the possibility for sub-groups to segregate between patches and for transition between different patterns without any active agonistic behavior. The model can be viewed as a network of feedbacks that is independent of the signals or cues involved in mixed groups interactions. Its predictions are therefore applicable to a wide spectrum of situations including social insects (inter castes interaction) and provides insights on possible mechanisms that can be at work.

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OC.011.Phase dynamics of delay-coupled electronic clocks with filter-induced memory effects

7 June 15:00-17:00 (Parallel 4), Session: Complex Systems

We study the phase dynamics in networks of delay-coupled analogue and digital electronic clocks with internal signal filtering. Our research has demonstrated that synchronization concepts discovered in biological systems can be transferred to electrical engineering. Inspired by the underlying principles of synchronization of delay-coupled biological clocks we devised a phase model that captures the dynamic properties of networks of mutually delay-coupled electronic clocks, so called phase-locked loops (PLLs). We have shown that in such systems, self-organized synchronization of spatially distributed clocks can be established in the presence of significant communication delays arising from finite signal transmission speed.

In this contribution we discuss the role of the characteristic integration time related to signal filtering in the PLLs. This integration time leads to memory effects that generate inertia-like behavior. We show that for digital systems closed analytical expressions for the frequencies of synchronized states can be provided, in contrast to implicit expressions for the frequencies of the synchronized states in analogue systems. Furthermore, we present results for the frequencies and stability of different synchronized states obtained from Matlab/Simulink simulations and experiments on prototype networks of coupled digital PLLs. These are in excellent qualitative and quantitative agreement with the predictions of our theoretical model. This synchronization concept has relevance in particular for applications operating in the terahertz frequency regime and in mobile communication systems, e.g., massive MIMO antenna arrays.

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OC.012.Effect of Stimulation Frequency and Intensity on Long-Lasting Anti-Kindling

9 June 17:30-19:30 (Parallel 4), Session: Neurodynamics

Several brain diseases are characterized by abnormally strong neuronal synchrony. Coordinated Reset (CR) stimulation was computationally designed to specifically counteract abnormal neuronal synchronization processes by desynchronization. In the presence of spike timing-dependent plasticity (STDP) this leads to a decrease of synaptic excitatory weights and ultimately to an anti-kindling, i.e. unlearning of abnormal synaptic connectivity and abnormal neuronal synchrony. The long-lasting desynchronizing impact of CR stimulation has been verified in pre-clinical and clinical proof of concept studies. However, as yet it is unclear how to optimally choose the CR stimulation frequency, i.e. the repetition rate at which the CR stimuli are delivered. This work presents a first computational study on the dependence of the long-term outcome on the CR stimulation frequency in neuronal networks with STDP. For this purpose, CR stimulation was applied with Rapidly Varying Sequences (RVS) in a wide range of stimulation frequencies and intensities. Large and robust anti-kindling effects were achieved for: (i) short (9 and 10 ms) stimulation ON cycles (independent of the used stimulation intensities) and (ii) for weak to intermediate stimulation intensities in combination with stimulation ON cycles of maximal 24 ms. A similar survey is also performed with different type of CR signals, i.e. the Slow Varying Sequences (SVS) where although, in some cases, the outcome is different, the overall picture and message remains the same. From a clinical standpoint this may be relevant in the context of both invasive as well as non-invasive CR stimulation.

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OC.013.Diversity emerging from the interplay between dispersion and competition

9 June 15:00-17:00 (Parallel 4), Session: Environmental/ Ecological Dynamics

To understand the factors leading to the extinction, survival, or coexistence of competing species, is a main aim in population ecology. The formation of patches has been shown to be one of the key promoters for species diversity. Cluster and patch formation, with its influence on competition processes, is affected by the dispersal of individuals. On the basis of the dispersal of the organisms, interacting Brownian and Levy bug models have been proposed. In these models the competition is taken into account assuming that demographic processes depend on population density. For appropriate parameters, a salient property of these models is the formation of a spatially periodic clustering of individuals.

In this presentation we investigate the ecological diversity emerging from the interplay between dispersal and competition for resources that are the basic factors determining the quantity and distribution of organisms in nature. Namely, we study the competition between ecologically similar species that use the same resources and differ from each other only in the spatial motion they undergo.

We first consider a system in which initially half of the organisms are characterized by Brownian motion whereas the other half are characterized by Levy flights, being otherwise identical. For example, one can think of the foraging behavior of two types of organisms, competing for the same resource and whose spatial motion is consistent either with Brownian or Levy random walks. Our goal is to determine which of the two species survives, and if coexistence is possible. We show that survival is mediated by the clustering, so that forming stronger clusters provides better chances for survival. A similar competitive advantage would occur between walkers of the same type but with different diffusivities if this leads also to different clustering. Species coexistence is also observed under certain conditions.

Considering, instead, that initially the system consists of N otherwise identical organisms that all move according to the same type of motion, however, each of them is characterized by a different diffusion coefficient, we observe that the average value and the width of the initial distribution of the diffusivities determine the final diversity of the system, i.e., the number of families/species that manage to survive and coexist.

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OC.014.Multistability of Phase-Locking and Topological Winding Numbers in Locally Coupled Kuramoto Models
6 June 15:00-17:00 (Parallel 4), Session: Complex Networks

Determining the number of stable phase-locked solutions for locally coupled Kuramoto models is a long-standing mathematical problem with important implications in biology, condensed matter physics and electrical engineering among others. Investigating Kuramoto models on networks with various topologies, it can be shown that different phase-locked solutions are related to one another by loop currents. The latter take only discrete values, as they are characterized by topological winding numbers. This result is generically valid for any network, and also applies beyond the Kuramoto model, as long as the coupling between oscillators is antisymmetric in the oscillators' coordinates. Similarities between these loop currents and vortices in superfluids and superconductors as well as persistent currents in superconducting rings and two-dimensional Josephson junction arrays can be pointed out. In this talk, motivated by these results, we will further investigate loop currents in Kuramoto-like models.

To begin with, we will consider loop currents in nonoriented n-node cycle networks with nearest-neighbor coupling. Amplifying on earlier works, we will give an algebraic upper bound for the number of different, linearly stable phase-locked solutions. Stable solutions with a single angle difference exceeding $\pi/2$ emerge as the coupling constant K is reduced, as smooth continuations of solutions with all angle differences smaller than $\pi/2$ at higher K. Furthermore, we will show that in a cycle network with nearest-neighbor coupling, phase-locked solutions with two or more angle differences larger than $\pi/2$ are all linearly unstable.

We will then investigate how the results for single-loop networks may be extended to multiple-loops networks and emphasize the issues arising from such a generalization.

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OC.015.Navier-Stokes meets Synchronization - Numerical Simulation of Aeroacoustical Coupled Organ Pipes

8 June 13:30-15:30 (Parallel 2), Session: Complex Fluid Dynamics

A new approach to investigate the aeroacoustical interaction of two extended sound sources – organ pipes – which lead to synchronization is presented. By solving the compressible Navier-Stokes equations under suitable boundary and initial conditions numerically, it is possible to retrace the experimentally observed phenomenon of synchronization. It is shown that the synchronization phenomenon can be mapped numerically in excellent accordance with the experimental results. The presented approach allows to study synchronization of sound sources in a new degree of extraordinary detail and it enhances to understand the underlying first principles of sound generation, sound propagation and mutual aeroacoustical coupling.

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OC.016.Studies on integrability using higher variational equations, and applications
6 June 10:00-12:00 (Parallel 3), Session: Chaos

Higher-order variational equations VE_{ϕ}^{k} are satisfied by terms in the Taylor expansion of the flow along particular solution ϕ. A simple process transforms systems $\{\mathrm{VE}_{\phi}^{k}\}_{k\geq 1}$ into one infinite-dimensional linear system. It is here that they become interesting on a twofold capacity.

On one hand, all obstructions to Hamiltonian integrability found by Ziglin, Morales-Ruiz and Ramis were extended by the study of Galois groups of the linearised VE_{ϕ}^{k}, by the latter two authors and Simó. Their work theorised the use of linearisation but resorted to jet analysis in its workings and proofs. However, recent work by the author made strong inroads into a practical implementation after explicitly finding the linearisation described in the first paragraph–one expressible in a single infinite-block equation (LVE_{ϕ}) after simple tensor constructions.

On the other hand, the *dual* system $(\mathrm{LVE}_{\phi})^{\star}$ is also relevant: it is satisfied by Taylor blocks of certain first integrals for the original system. This was already studied by the author, Weil et al. for an earlier, non-compact form of individual blocks in (LVE_{ϕ}), but the formulation later developed by the author simplified those results significantly and is the subject of a current study of the effect of global transformations on the formal first integrals that can be solutions to the dual system. Unlike the previous paragraph, *the original system need not be Hamiltonian.*

This is a study of chaos and non-integrability from the algebraic and complex analytical viewpoint. In the presentation we introduce the topic via work by the author encompassing both applications of (LVE_{ϕ}) and $(\mathrm{LVE}_{\phi})^{\star}$ as seen in the above two paragraphs: monodromy-oriented obstructions to integrability, and additional formal first integrals. This will be a prelude to new results on two problems in Physics and Astrophysics using the latter approach on $(\mathrm{LVE}_{\phi})^{\star}$ and formal integrals.

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OC.017.Torsions as a new dynamic feature in 2D plasma crystals
9 June 17:30-19:30 (Parallel 1), Session: Complex Fluid Dynamics

Complex plasmas represent the plasma state of soft matter. They consist of a weakly ionized gas where small particles of solid matter are dispersed. Particles charge up and interact with each other through the screened Coulomb potential. They can form various ordered structures including monolayer (2D) crystalline lattices. As any kind of crystal, 2D plasma crystals support various collective excitations, some of them generic and others plasma-specific. Examples include phonons excited by particle thermal motion, hybrid modes generated by mode-coupling instability, and dislocations generated by excessive shear stress. In this presentation, we report on a new type of collective excitation in 2D plasma crystals, a spinning pair of particles, which we call a “torsion” [1]. It is a dissipative structure where energy input is provided by the flow of ions and energy dissipation is through the neutral gas friction on particles. Non-reciprocal attraction between the particles in a torsion is due to the plasma wake effect.

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OC.018.Robustness and reliability of the fitting of extreme value distributions and its results
10 June 10:00-12:30 (Parallel 2), Session: Nonlinear Time series Analysis

Extreme value statistics has become an important tool in today's data analysis. A lot of disciplines like hydrology, meteorology or risk assessment for insurance companies heavily rely on its results. Despite of its common use we found serious problems in the parameter fit of the generalized extreme value (GEV) distribution and the robustness and reliability of the inferred results. We present the cause of those problems, give some suggestions to improve the fitting and demonstrate our findings on both artificial data and observed temperature series.

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OC.019.Formation of a periodic sequence of stabilized wave segments in excitable media

10 June 10:00-12:30 (Parallel 4), Session: Chaos/Pattern Formation

Wave segments represent an interesting and important example of spatio-temporal pattern formation in a broad class of nonlinear dynamic systems, so-called excitable media. They have been observed, for instance, in cardiac and cortex tissue, catalytic surface reactions, concentration waves in thin layers of the Belousov-Zhabotinsky reaction or during cell aggregation of Dictyostelium discoideum [1]. For a given excitability a medium supports propagation of a wave segment with a selected size and shape, which is intrinsically unstable. In order to make this solution observable it has to be stabilized by an adequate noninvasive feedback control. For the case of a solitary propagating wave segments a universal selection rules have been found by use a free-boundary approach [2-4].

The main aim of our study is to generalize these results on a case of a periodic sequence of wave segments, which is much more common in many known experimental situations. To this aim the translational motion of a stabilized wave segment in an excitable medium is numerically studied by use of a generic reaction-diffusion model with nonlinear activator-inhibitor kinetic. In addition, the free-boundary approach is applied to determine the wave segment shape and the speed as functions of the medium parameters. Despite of a relative simplicity of the free-boundary approach, not only the shape and the velocity of the segment sequence, but also the existence domain can be predicted with a high accuracy.

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OC.020.Linear stability analysis of the coevolution of shallow marine clouds and rain
10 June 10:00-12:30 (Parallel 3), Session: Environmental/ Ecological Dynamics

The coevolution of shallow marine clouds and rain, was shown to be captured by a set of dynamical equations with a delayed sink term. Modeling these equations yields a bifurcation point, which marks the system shifts from a stable fixed point to oscillations. In the steady state the rain consumes the cloud in the exact rate of the cloud replenishment, whereas in the oscillations state the stronger rain depletes the cloud that created it, and therefore fades until the next generation cloud is thick enough to reform rain. Here we explore theoretical aspects of this system. Linear stability analysis describes the transition from steady to a limit-cycle state analytically, showing how it depends on the systems properties. Our results reveal interesting links between the environmental and microphysical parameters, that could shed new light on transitions from open to closed cellular cloud cells in nature. Moreover, we show that when the system shifts from a stable fixed-point regime to oscillations, the decrease in the average cloud height over a period is proportional to the oscillations variance. Such insight is tested on satellite data, showing a negative trend between the variance and the regional average, suggesting that indeed the variance consumes part of the average cloud thickness.

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OC.021.Jittering regimes in rings of pulse oscillators with delayed coupling

6 June 15:00-17:00 (Parallel 4), Session: Complex Networks

We consider rings of pulse oscillators with unidirectional delayed coupling. In the case of symmetrical connections and equal natural frequencies, the basic regimes demonstrated by the system are regular equidistant spiking regimes. Particular examples of such regimes are the globally synchronized solution and the splay state. We perform the stability analysis of such the solutions and show that under certain conditions on the PRC function they may destabilize in quite a peculiar manner. All the multipliers of the characteristic equation become critical simultaneously, and a number of new, irregular spiking regimes emerge. These regimes are characterized by unequal inter-spike intervals of the oscillators which differ not only for different oscillators, but also in time for the same oscillator. The emergent, the so-called jittering regimes, are periodic with a period proportional to the delay in the system. Moreover, the number of different regimes appearing at the bifurcation point grows combinatorial with the delay. Thus, there is a sequence of bifurcation points in the parameter space as the delay grows, and the bifurcations at these points become more and more complex. The results are corroborated by numerical simulations and extend previou findings on multistable jittering in a single oscillator with delay (Klinshov et al, Phys. Rev. Lett. 2015). They suggest that jittering instability may be generic for pulse-coupled systems with delays.

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OC.022.Cell Assembly Dynamics of Sparsely-connected Inhibitory Networks
9 June 17:30-19:30 (Parallel 4), Session: Neurodynamics

The striatum, plays an important role in motor control and reward based learning, and the disruption of information signaling at striatal level is at the base of disorders such as Parkinson's (PD) and Huntington's (HD) diseases. The striatum is formed by a sparsely and weakly connected circuit of GABAergic Medium Spiny Neurons (MSNs), and its dynamics is organized in groups of neurons firing coherently within a family while firing in an anti-correlated way with other groups of neurons. Some detailed models have been proposed to account for striatal activity, we show here that a minimal model of pulse coupled LIF neurons is able to reproduce the most relevant aspects of striatal dynamics. By proposing a novel indicator, we single out the role of synaptic transmission parameters in shaping the striatal-like dynamics. Furthermore we demonstrate that the formation of assemblies is closely related with the underlying topology of the network, where groups of neurons sharing smaller number of connections than the expected value for the network, group together as an assembly. We discover that the range of parameters at which the network exhibits the desired behavior (connectivity values, lateral inhibition strength and post-synaptic duration), closely corresponds to experimental values for the MSN. Also, the MSN-like activity emergence seems to be related to the presence of weak chaos. We find that the inhibitory post-synaptic potential (IPSP) time scale is fundamental for the emergence of bursting dynamics. Reducing the IPSP drives the neurons to a Poisson like behavior and consequently to a reduction of the cell assembly structure, as observed in HD symptomatic mice. We are able to reproduce general experimental features of striatal dynamics *in-vitro* reported in [*Journal of neurophysiology* **99**, 1435 (2008)]. In this paper the authors describe the response of the striatum in presence of NMDA as the alternating activity of a few number of cell assemblies, as we observed in our model. In the same study, the effect of reduced inhibitory coupling is characterized by the emergence of a dominant assembly, and this effect is also captured with our model. Reduced inhibitory coupling is related to Parkinsonian striatum, where the disruption of dopamine release, diminishes the strength of lateral inhibition among MSNs.

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OC.023.Information Spread in Networks: Search Engines vs. Word-of-Mouth

7 June 15:00-17:00 (Parallel 2), Session: Complex Networks

The spread of information in society has a significant political, social, and economic impact. The following work compares two fundamental methods of modern information spread in networks, where multiple beliefs compete on recognition in a society. In both methods, a choice of an opinion by a person which did not yet formed his/her own personal opinion, is based on herd behavior as a social force. That is, the likelihood of a person to adopt a certain belief is proportional to the rate of adoption of this belief by his/her "friends" which the person tends being influenced from.

We compare two spreading methods: (1) word-of-mouth (WOM), where information solely spreads through the links of the social network, and (2) a spread of information through web pages and search engine (WEB), where ideas are published on the internet, then are read by users that find these ideas while using a search engine.

Simulations of the WEB spread include two principles: (i) the PageRank scoring method, and (ii), the users "tendency" to click on higher positions in the search engine results, also known as the Search Engine Result Page (SERP) function.

The simulations show that opinions would be more homogeneous in populations solely relying on search engine for information search, as compared to word of mouth.

These simulative results were validated by an experiment, in which two groups of users were requested to find an answer to similar questions. The first group was requested to answer these questions by asking their local social circle (WOM), while the second group was asked to search these questions on Google (WEB).

This experiment revealed that users searching information by word-of-mouth included a higher diversity of opinions, as compared to users solely using a search engine, in which conformity in opinions was substantially higher.

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OC.024.Collective behavior patterns in a ring of Kuramoto-type rotators with time-delay
9 June 17:30-19:30 (Parallel 3), Session: Chaos/Pattern Formation

We investigate emerging collective behavioral patterns in a ring of identical Kuramoto-type rotators with time delayed coupling. The observed collective modes are dynamic stationary states of the system, which can also be interpreted as rotating waves or generalized synchronization modes. These states are discrete, characterized by various rotation frequencies and phase-shifts between the neighboring rotators. Their number equals the number of rotators in the ring. It is shown that for random initial conditions, their appearance probability follows a normal distribution, having basins of attraction of nontrivial structure in the high-dimensional phase space of the system. By extended computer simulations we study the dynamics of the system for various parameter values, and we give an empirical formula for the time-interval that is needed for the system to select its final synchronization mode.

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OC.025.Gas-like economic models: strategy and topology effects
9 June 10:00-12:00 (Parallel 4), Session: Complex Systems

In this communication, some economic models for random conservative markets where agents trade by pairs are addressed. The time evolution of the wealth distribution in these systems can be modeled by nonlinear functional mappings. Some asymptotic results for different models are presented. Simulations and implementations of these systems in different topologies are also investigated.

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OC.026.Neighborhoods of periodic orbits and the stationary distribution of a noisy chaotic system
8 June 13:30-15:30 (Parallel 4), Session: Hybrid Systems/Complex Dynamics

We deal here with the problem of evaluating long-time averages, such as diffusion coefficients, decay of correlations, escape rates, or Lyapunov exponents of chaotic systems, in the presence of white, additive noise.

In classical chaos, a dynamical average should be weighed by the natural (invariant) measure of the state space, which is, however, impractical to compute directly in most cases. One valid alternative is that to weigh the average by properly partitioning the state space, and defining a suitable symbolic dynamics, as a way to recognize the most important (i.e. most often visited) regions. In particular, unstable periodic orbits constitute the skeleton of the dynamics, and can be a valuable tool to chart the state space.

Additional background noise, which is always present in any realistic model, calls for a substantial change in the way we think partitions due to the element of randomness: fractals are smoothed out, periodic orbits no longer exist, precious symmetries are broken. Thus, novel ideas, formalisms, and algorithms are to be developed accordingly.

We follow the evolution of densities in the state space via Fokker-Planck equation, whose smooth, locally invariant solutions around periodic orbits of the deterministic flow constitute the building blocks of our partition algorithm.

In a recent spew of publications, we have fully developed and tested this novel method in the framework of one- and two-dimensional hyperbolic maps. Due to the asymptotic balance between deterministic, exponential shrinking of neighborhoods around longer and longer periodic orbits, and the smearing effect of noise, a *finite* resolution is found for the state space. As a consequence, the Fokker-Planck equation is replaced by a *finite-dimensional* evolution operator that yields estimates of long-time observables (escape rate and Lyapunov exponent), which are found in agreement with the outcomes of blind-grid ('Ulam') discretizations.

In perspective, the proposed optimal partition hypothesis applies to high-dimensional dynamical chaotic systems, such as turbulent fluid flows or weather models, where direct numerical simulations are costly, and sharp criteria are needed to determine when a sufficient number of modes have been computed.

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OC.027.Inter-layer synchronization in multiplex networks
7 June 10:00-12:00 (Parallel 4), Session: Complex Networks

In the last few years, and taking advantadge of the increased resolution in databases, real complex systems, like online social networks, are benefiting from a representation of several layers of networks interrelated between them. When the layers are composed of the same nodes and the only interrelations are those between the same nodes in the different layers, the multilayer structure is called a multiplex. Such a representation helps understanding, for instance, the spreading of an epidemic process due to social interactions occurring at different levels, like the physical and online levels. As far as the emergence of collective dynamical pheomena is concerned, we focus here on a yet unnoticed phenomenon in a multiplex network: inter-layer synchronization, where each constituent in a given layer of a system undergoes a synchronous evolution with all its replicas in other layers, regardless of whether or not it is synchronized with the other units of the same layer. In particular, we derive the conditions for the existence and stability of such a solution and inspect its robustness by means of numerical simulations and experiments with multiplexes of nonlinear electronic circuits. Our finding actually gives novel hints towards understanding how, for instance, biological systems can collectively organize in a redundant way, so that their effective functioning

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OC.028.Stochastic Detection of an Interaction-Range in Non-Equilibrium Traffic and Granular Flows

8 June 10:00-12:00 (Parallel 4), Session: Chaos/Complex Systems

Self-organized patterns revealed in many granular, social or socio-physical systems (like vehicular traffic, pedestrian flows) indicate the presence of mutual interaction-forces among individuals. Although there exist several successful researches dealing with theoretical estimations of agent repulsions/attractions, quantitative description of interaction-range for those virtual forces is, without any doubt, a much more difficult task. As is well known, for the afore-mentioned purposes any analysis of correlation coefficients is highly ineffective. Therefore, instead of it we present a novel analytical method for deciding how many immediately neighboring agents (particles, drivers, walkers) influence decision-making procedures of a given agent. Such a method is based on the novel Stochastic Perturbation Theory that quantitatively analyzes deviations between multi-headway distributions calculated for uncorrelated and correlated agents. Applicability of the SPT method will be demonstrated on an extensive set of vehicle-by-vehicle data recorded at the Expressway R1 in Prague (in cooperation with The Road and Motorway Directorate of the Czech Republic).

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OC.029.Experimental Study of Chimeras in Small Ensembles of Phase Oscillators

9 June 17:30-19:30 (Parallel 3), Session: Chaos/Pattern Formation

Chimeras — a popular and interesting phenomenon in the oscillator system [?], which are mainly studying by computer simulation. Experimental study of chimeras, in particular, in small ensembles requires special experimental setups. The active wireless network [?] is used as such experimental equipment in the report. Experiments were carried out with small ensemble of coupled oscillators. Ensemble of six phase oscillators [?] was used as the study system:

$$\dot{\theta}_{i+3j} = \omega + \sum_{k=1}^{3} [g(\theta_{i+3j} - \theta_{k+3j}) + \epsilon g(\theta_{i+3j} - \theta_{k+3j+3})] \tag{1}$$

where $g(\phi) = -sin(\phi - \alpha) + rsin(2\phi)$ is coupling strength function, $i = 1, ..., 3$, $j = 0, 1$. Thus, the ensemble consists of two groups of three oscillators, the oscillators within the group connected with coupling coefficient equal to 1 and oscillators of the various groups — with coupling coefficient ϵ. This ensemble demonstrates chimeric state in which one part of the oscillators is synchronized in frequency, and the other part of the oscillators — no [?]. Each active node in the wireless network is implemented as a pair of ultra-wideband wireless transceiver and the connected actuator. The actuator is a card equipped with a microcontroller, as a calculating device, and multi-color LEDs as a visualization tool. To simulate an ensemble of coupled oscillators, each oscillator in the experiments of the ensemble is associated with a node is an active network. The equations of the oscillator are integrated on the microcontroller, the communication between the oscillators are realized through wireless channels, and the oscillator phase is visualized by means of colored LEDs. This approach allows an arbitrary network topology and a visual demonstration of dynamic patterns of the ensemble. The report examines the technique of modeling with the help of the active wireless network, the experimental results of the observation of different dynamic regimes of the ensemble and their analysis.

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OC.030.Non-admissible complex wavelets: an effective tool for spectral analysis of relaxation non-linear oscillations

10 June 10:00-12:30 (Parallel 2), Session: Nonlinear Time series Analysis

The complex wavelets ψ, which have a relatively small number of oscillations over the interval of support, are known as best adjusted to localize sharp pulses. Due to this property, they found their application for fitting of short-time signals, e.g. in the problems of echo-pulse ultrasound acoustics, A-wave impulse noises, etc. On the other hand, a possibility to apply such a functions for the frequency analysis was disputable since they do not satisfy so called admissibility condition in the frequency space, i.e. $\int_R |\hat{\psi}(\omega)|^2 \omega^{-1} d\omega \to \infty$.

The recent work [1] reveals an algorithm, which evades this principal difficulty and opens perspectives for practical applications.

The special focus of this presentation will be on the spectral analysis of spike-like oscillations, which are typical for highly non-linear biophysical oscillations. For example, the new algorithm mentioned above combined with the previous analysis of synchronization phenomena [2] allows for obtaining and processing the global spectrum of optic nerve impulse activity of limnetic snails. The corresponding signals comprise a set highly non-linear oscillations of a set of interconnected cells placed in the background of a strong noise. In addition to the global spectrum, the new reconstruction formula for the time-period wavelet transform provides an opportunity to distinguish and reconstruct these individual spikes of different oscillators from the time-frequency diagram obtained after the continuous wavelet transform with the non-admissible Morlet wavelet with the extremely low central frequencies ($\omega_0 \leq \pi$).

Finally, we discuss the interconnections of the complex wavelet transform with the non-admissible Morlet wavelets with the new method of scale parameter regression [3], which is robust with respect to the noise with large amplitude outliers. They spectra indicate α-stable distributions and attract a attention in the context of spread and relaxation processes in complex intracellular medium.

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OC.031.Optimal Target Control of Complex Networks
7 June 10:00-12:00 (Parallel 4), Session: Complex Networks

We consider the problem of defining an optimal strategy to control a dynamical complex network, optimal in terms of a general cost function. Here we show that by controlling a network's output rather than the state of every node, the required energy to control the network can be reduced substantially. In particular, by only targeting a subset of the nodes of the network, the energy requirements exponentially decay. We also show that the minimum energy well approximates the energy required for a large family of cost objectives so that the benefits of target control extend beyond the minimum energy control scheme considered in previous work. We validate our conclusions in model and real networks to arrive at an energy scaling law to better design control objectives regardless of system size, energy restrictions, state restrictions, driver node choices and target node choices.

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OC.032.Activation process in systems of excitable units with multiple noise sources
10 June 10:00-12:30 (Parallel 4), Session: Chaos/Pattern Formation

We consider the activation process in cases of a single and two interacting units [1], as well as the assembly of class II excitable units [2] influenced by two independent sources of noise, which may be interpreted as external and internal noise. For all three analyzed systems, we determine the most probable activation paths around which the corresponding stochastic trajectories are clustered.

In case of a single unit, the theoretically most important point lies in introducing the terminating boundary set relevant for class II excitability, which can immediately be generalized to scenarios involving two coupled units. We examine how the properties of the activation process depend on the particular type of noise, as well as the linear or nonlinear character of interactions [1].

In case of an assembly, we first apply the mean-field approach to explicitly show that the assembly of excitable units can itself exhibit macroscopic excitable behavior. In order to allow for the comparison between the excitable dynamics of a single unit and an assembly, three distinct formulations of the assembly activation event are introduced. Each formulation treats different aspects of the relevant phenomena, including the threshold-like behavior and the role of coherence of individual spikes [2]. The activation processes of individual units are analyzed in light of the competition between the noise-led and the relaxation-driven dynamics.

We also consider how the statistical features of the activation process, such as the mean time-to-first pulse and the associated coefficient of variation, are influenced by the coaction of two noise sources. An intriguing fact is that the statistical features turn out to be qualitatively analogous for all three formulations of the assembly activation event, whereby these further resemble the results for a single and two interacting units. We demonstrate that such a universal behavior generically derives from the fact that the considered systems undergo a stochastic bifurcation from the stochastically stable fixed point to continuous oscillations [1,2].

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OC.033.Effects of fluid mechanics on the dynamics of compressed/expanded surfactant monolayers
8 June 13:30-15:30 (Parallel 2), Session: Complex Fluid Dynamics

The study of monolayer rheology has a great number of applications ranging from polymer physics to colloid and interface science, biology, biochemistry, and biophysics. Surfactant dynamics may involve anysotropy and viscoelastic effects, solubility in the bulk phase, and other non-equilibrium phenomena, depending on various spatio-temporal scales, which makes both understanding the phenomena and designing/predicting/explaining experimental measurements fairly subtle.

Interfacial rheology can be meassured by mechanical relaxation methods, which allow to determine rehological properties from changes in the surface tension of the monolayer produced by variations in the fluid surface area. The typical experimental set up consists in a shallow liquid layer whose free surface is subject to periodic compression/expansion, moving two (slightly immersed) solid barriers, which vary the enclosed free surface area in a controlled manner. In order to minimize the fluid dynamics and other non-equilibrium effects, the modulation is very slow. Nevertheless, the surfactant concentration dynamics exhibits some unexpected features such as irreversibility, suggesting that the motion is not slow enough. We present a long wave theory that takes fluid mechanics and symmetries into account. A nonlinear difusion equation for surfactant concentration coupled to the free surface deformation shows that fuid dynamics is an important source of irreversibility and help explain experimental observations. The main conclusion is that the fluid dynamics has to be accounted for in the analysis of these experimental devices.

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OC.034.Helical mode interactions and spectral transfer processes in magnetohydrodynamic turbulence
8 June 13:30-15:30 (Parallel 2), Session: Complex Fluid Dynamics

Spectral transfer processes in homogeneous magnetohydrodynamic (MHD) turbulence without a mean field are investigated analytically by decomposing the velocity and magnetic fields in Fourier space into positive and negative helical modes. In 1992, Waleffe (Phys. Fluids A, 4:350 (1992)) used the helical decomposition to construct a system of equations which describes the evolution of a triad of helical modes in homogenous, isotropic hydrodynamic turbulence. From this, he established whether or not a given triad interaction would contribute to a forward or reverse transfer of energy. When a magnetic field is coupled to the velocity field, the dynamics become even more complex as any triad interaction involves six, rather than three, modes. Inspired by Waleffe's analysis, we determine steady solutions of the dynamical system which governs the evolution of the helical modes and carry out a stability analysis of these solutions, the interpretation being that unstable solutions lead to energy transfer between the interacting modes. We find that the possible energy and helicity transfers depend not only on the combination of positive and negative helical modes in a triad interaction, but in certain cases also on the magnitude and cross-helicity of the magnetic and velocity fields. As expected from the inverse cascade of magnetic helicity in 3D MHD turbulence, mode interactions with like helicities lead to the transfer of energy and magnetic helicity to smaller wavenumbers. However, some interactions of modes with unlike helicities also contribute to an inverse energy transfer. As such, an inverse energy cascade for non-helical magnetic fields is shown to be possible. Furthermore, we find that high values of the cross-helicity may have an asymmetric effect on forward and reverse transfer of energy, where forward transfer is more quenched in regions of high cross-helicity than reverse transfer. This agrees with recent observations of solar wind turbulence. For specific helical interactions the relation to dynamo action is established. The analysis provides new theoretical insights into physical processes where inverse cascade and dynamo action are involved, such as the evolution of cosmological and astrophysical magnetic fields and laboratory plasmas.

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OC.035.Linear Stability and the Braess Paradox in Coupled Oscillators Networks and Electric Power Grids
9 June 10:00-12:00 (Parallel 4), Session: Complex Systems

We investigate the influence that adding a new coupling has on the linear stability of the synchronous state in coupled oscillators networks. Using a simple chain model we show that, depending on its location, the new coupling can lead to enhanced or reduced stability. We extend these results to electric power grids where a new line can lead to four different scenarios corresponding to enhanced or reduced grid stability as well as increased or decreased power flows. Our analysis shows that the Braess paradox may occur in any complex coupled system, where the synchronous state may be weakened and sometimes even destroyed by additional couplings. We further note that the addition of couplings which create loops in the network can stabilize new solutions, labeled by winding numbers, which are related to each other by circulating power flows.

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OC.036.Chimera States in Leaky Integrate-and-Fire Networks.
9 June 17:30-19:30 (Parallel 4), Session: Neurodynamics

We study a network of non-locally coupled neurons focusing primarily on synchronization phenomena related to the functioning of the human brain. For the dynamics of single neurons the Leaky Integrate-and-Fire model (LIF) is used, taking into account the refractory period of the neuron. Single neurons are linked into a 2D square lattice with periodic boundary conditions, in a torus like configuration. Each neuron is connected either non-locally with its neighbours or with a group of other neurons hierarchically (fractally) arranged on the 2D lattice. As control parameters for our investigation we use the connectivity range, coupling strength and lattice size. For a wide range of parameter values a variety of synchronization phenomena is observed. In particular, we explore the parameter range where phase seperation is demonstrated and the parameter regions where chimera states (coexistense of synchronous and asynchronous domains) are found.

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OC.037.Harmful algal blooms: Extreme events in a coastal ecosystem
9 June 15:00-17:00 (parallel 4), Session: Environmental/ Ecological Dynamics

Harmful Algal Blooms (HABs) are extreme events that threaten human health and fishery industries, causing financial losses and large-scale marine mortality incidents. Since climate change will likely render such extreme events to occur more frequently and with larger magnitudes in the future, a better understanding of mechanisms leading to blooms is highly desirable and may inform the development of prevention strategies. We studied the spatio-temporal patterns of occurrences of HABs in the Southern California Bight, an area for which blooms are well documented. Using cross-correlation analyses together with Lagrangian particle simulations, we aimed at disentangling various factors which decisively shape the spatio-temporal sequence of occurrences of blooms [1]. Our results indicate that local environmental conditions as well as transport phenomena influence the occurrences of blooms. In particular, we observed connectivity patterns that can be interpreted as a temporal directed network in which different regions (nodes) are temporarily connected via ocean flows (links). We speculate that deeper insights into the complex interaction between hydrodynamics and population dynamics will pave the way for methods with increased power to predict harmful algal blooms.

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OC.038.Bifurcating small chimera states in a network of coupled lasers
8 June 13:30-15:30 (Parallel 4), Session: Hybrid Systems/Complex Dynamics

Chimera states were first observed in a ring-network of identical phase oscillators with non-local coupling. Due to the apparently paradoxical incorporation of both coherent (synchronized) and incoherent (unsynchronized) parts, chimera states are intriguing both from a pattern formation and a network dynamics perspective. Follow-up research has since revealed some possible creation mechanisms of these states and deepened the understanding of their features. They have subsequently been found in many systems, both in theory and experiment.

We have recently reported the appearance of small chimera states for the limit of vanishing delays in a numerically simulated laser network (*Boehm et al.*, Phys. Rev. E **91**, 4, (2015)). These chimera states can be characterized by their high degree of multistability, many of which are multistable with the fully synchronized state. Here, we present a second type of small chimera state, which develops from the fully synchronized state by a succession of Andronov-Hopf and symmetry breaking bifurcations. These second type of chimera states apparently lack multistability. We compare these two types of chimera states in terms of their creation mechanisms, scalability and temporal behaviour.

Our system is a small globally delay-coupled laser network with a minimum of four units. Using the established theory for semiconductor lasers subject to injection and feedback, the nodes of our network each possess three dynamical degrees of freedom: the inversion N of the carriers of the gain medium and the complex electric field amplitude E. These are described by the Lang-Kobayashi differential equations, which we numerically integrate with an Euler-type delay equation solver. The four lasers of our network are delay-coupled to all other units via their electric fields E, with an additional self-feedback term included. Both the feedback and the coupling have the same time delay τ, coupling strength κ and phase shift C_p. The small chimera states that can develop in this system can be observed in all three degrees of freedom, i.e. intensity, optical phase and inversion.

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OC.039.Multistability in an erbium-doped fiber laser: photonic applications
7 June 15:00-17:00 (Parallel 4), Session: Complex Systems

Erbium-doped fiber lasers under sine-wave pump modulation present a rich nonlinear dynamics including bifurcation, chaos and multistability phenomena. Multistability is particularly interesting for potential applications such as switches and memories. This work consists of four stages. First, a laser has been mounted and its characteristic parameters have been measured by methods previously developed by us. Second, a numerical study has been carried out in order to predict the ranges of control parameters (modulation frequency, average pump power and modulation depth) in which the laser may exhibit multistable behavior. Specifically, the study makes use of a model which requires accurate values of the laser characteristic parameters, determined in the first stage. Calculation of the laser response is carried out for a multitude of cases combining the different control parameters and various initial conditions. Third, methods for causing different initial conditions in the laser have been tried in the lab, so that a number of the multistable ranges identified in the second stage have been experimentally found. And fourth, after selecting a particular bistable range, control of the system state is found to be possible by varying an external CW signal coupled to the laser cavity. Two phenomena observed in this stage are particularly remarkable for their potential applications: one takes place after the external signal is switched off. It is found that depending on the previous external power, the system state can be chosen. This way, the system behaves as a binary memory. The other phenomenon is observed under smooth variations of the external power, controlled by means of the external source power knob. Once it exceeds a certain threshold, the system stays there no matter how power evolves, provided that no sudden changes take place. Therefore, the system behaves as a photonic pilot lamp.

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OC.040.Timing of Transients: Quantifying Return Times and Transient Behavior in Complex Systems

7 June 15:00-17:00 (Parallel 4), Session: Complex Systems

Several methods, including Basin Stability [5,4] and more integrative quantifiers e.g. from Hellmann et al.[3] and Mitra et al.[6], have been developed to estimate notions of stability for shocks, i.e. non-infinitesimal perturbations, and thus complement the Linear Stability paradigm [2] for nonlinear complex systems that can be described in terms of ODEs. While the work focuses on the stability of the attractor, a further analysis on the transients after a shock seems due and important questions to tackle are: HOW "LONG" DOES IT TAKE TO RETURN TO THE ATTRACTOR AND HOW "FAR AWAY" DOES THE TRANSIENT LEAD US?

The fundamental problem is that for a large class of systems the actual return time to the attractor is infinite and as such we need more complex methods to quantify it. Traditional methods, e.g. characteristic times and definitions using ϵ-neighborhoods, depend strongly on the representation of the system and the choice of the method's parameters. Therefore, they are rather hard to interpret physically. To properly quantify the transient time we propose two observables called *Regularized Return Time* (RRT) and *Area Under Distance Curve* (AUDiC) that address precisely the aforementioned problems from two different points of view.

RRT is defined as the difference of the return time of a state with respect to a chosen reference state. That way relative statements (of qualitative and quantitative nature) can be made, i.e. what state returns "faster" than another and by how much. Particularly when using centered statistics of RRT over inital condition distributions, this proves to be very useful.

AUDiC is the distance to the attractor integrated over time. With that it captures properly the transient of the trajectory while measuring time from a different perspective also.

We analyze their rich individual interpretations as return times, stability measures and early-warning signals, showing how they capture different features of the system. We start with conceptual models of the global carbon cycle [1] and generators in a power grid [4] and finally show that these ideas work also in chaotic systems like the Rössler attractor [7], differentiating between multiple phases of the chaotic regime and proving their focus on the transient dynamics.

Furthermore, we show that both are Lyapunov functions and use properties derived from that to develop efficient algorithms for computing them.

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OC.041.Network Inference in the Presence of Latent Confounders: The Role of Instantaneous Causalities
6 June 15:00-17:00 (Parallel 4), Session: Complex Networks

Detecting causal interactions in multivariate systems, in terms of Granger-causality, is of major interest in the Neurosciences. Typically, it is almost impossible to observe all components of a measured system. Missing certain important components can lead to the appearance of spurious interactions. The aim of this study is to demonstrate the effect of these spurious interactions and to demonstrate that distinction between latent confounders and volume conduction is possible in some cases.

Our new method uses a combination of renormalised partial directed coherence to detect directed interactions and analysis of the (partial) covariance matrix of residual noise process to detect instantaneous instantaneous, both spurious and non-spurious. Sub-network analyses are then performed to infer the true network structure of the underlying system.

We provide evidence that it is possible to distinguish between instantaneous interactions that occur as a result of a latent confounder and those that occur as a result of volume conduction.

Our novel approach demonstrates to what extent inference of unobserved important processes as well as the distinction between latent confounders and volume conduction is possible. We suggest a combination of measures of Granger-causality and covariance selection models to achieve this numerically.

Sub-network analyses enable a much more precise and correct inference of the true underlying network structure in some cases. From this it is possible to distinguish between unobserved processes and volume conduction when measuring, among other things, biological oscillatory systems such as EEG networks. Our approach is straightforwardly adaptable to various measures of Granger-causality emphasising its ubiquitous successful applicability.

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OC.042.Asymptotic stability criteria and the localization method of compact invariant sets
6 June 17:30-19:30 (Parallel 4), Session: Nonlinear Dynamics/Bifurcation Theory

Conditions for asymptotic stability and global asymptotic stability of an equilibrium point of autonomous system are formulated in terms of compact invariant sets and positively invariant sets. To verify these conditions the localization method [1] of compact invariant sets is applied. The localizing sets arising from this method contain all compact invariant sets of the system. The localization method explains the behavior of trajectories outside a localizing set [2] can be used to prove the asymptotic stability and global asymptotic stability of an equilibrium point.

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OC.043.Kuramoto-Sakaguchi model as an extended system : chimera, puffs and spatio-temporal intermittency
6 June 10:00-12:00 (Parallel 3), Session: Chaos

Nonlocally coupled oscillators on a ring are known to display not only synchrony, but also chimera states, characterised by spatial coexistence of synchrony and asynchrony [1]. The Kuramoto-Sakaguchi is perhaps the simplest model exhibiting such multistable behaviour in a network of N identical phase oscillators. Recent work has been devoted to the continuous limit of this system on a one-dimensional ring as N goes large [2]. This notion of continuous limit has to be distinguished from that of thermodynamic limit, in which both the observation time and N go large but the spatial density of oscillators remains constant. Such a system has been investigated in the case of finite-range coupling as a function of the phase lag between neighbouring oscillators and of the coupling range. While synchrony and multiple twisted states [3] are assumed to be the only attractors in the system, we unveil a variety of metastable dynamical behaviour for decreasing coupling range: multi-headed chimera states [4] but also spatio-temporal intermittency ("laminar-turbulent flow") and solitary defects ("puffs") propagating on a background of twisted states. Statistical characterisation of the fraction of synchrony reveals interesting features typical of spatiotemporal systems with mutiple absorbing states.

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OC.044.Spiral wave chaos: Tiling, local symmetries, and asymptotic freedom

6 June 10:00-12:00 (Parallel 3), Session: Chaos

Excitable systems can generate dynamics ranging from solitary waves in 1D to spiral/scroll wave chaos in 2D/3D. Complex spatiotemporally chaotic dynamics featuring spiral waves are associated with phenomena such as cardiac arrhythmias (e.g., fibrillation) and seizures (epilepsy). Understanding the nature of spatiotemporal chaos in excitable systems therefore is not only of fundamental interest, but also of high practical importance. This talk will give an overview of recent progress in understanding the dynamical mechanisms that initiate and maintain spiral wave chaos featuring multiple interacting spiral waves that repeatedly break up and merge.

Periodic orbit theory, which aims to describe chaotic dynamics using the properties of unstable periodic solutions embedded in the chaotic attractor, produced a lot of insight into the dynamics of low-dimensional systems, starting with the work of Poincare on celestial mechanics. Recently, a similar approach has been applied rather successfully to spatiotemporal chaos in a range of systems (complex Ginzburg-Landau, Kuramoto-Sivashinsky, and Navier-Stokes equation). In excitable systems, however, it fails rather spectacularly due to a special property of spiral waves: they have extremely short spatial correlations.

Although it is tempting to associate the relevant length scale with the wavelength of a spiral wave, the former is instead defined by the width of the adjoint eigenfunctions associated with the dominant modes of the linearization. For typical models of excitable dynamics these eigenfunctions are exponentially localized around the spiral core, with the width much smaller than the wavelength. Hence, interaction between two spiral waves falls off exponentially, and the dynamics of individual spirals become effectively independent once the separation between the spiral cores exceeds this length scale (spiral waves become asymptotically free).

As a result, typical multi-spiral states break the global Euclidean symmetry of the problem, but respect local symmetries (translations and rotations in 2D). Local symmetries imply that time-periodic solutions are extremely rare due to the slow relative drift in the position and orientation of individual spirals. This drift can be understood by partitioning the domain into tiles, each of which supports a single spiral wave. The dynamics of each spiral can then be understood completely based on the shape of the corresponding tile and the position of the spiral core. This formalism produces a number of specific predictions that are fully supported by numerical simulations and offers a novel way to understand and describe spiral wave chaos.

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OC.045.Asynchronous networks & a modularization of dynamics theorem

7 June 10:00-12:00 (Parallel 4), Session Complex Networks

We have developed a theory of asynchronous networks and event driven dynamics. This theory gives a theoretical and conceptual framework for the study of network dynamics that takes account of features encountered in networks from modern technology, engineering, and biology, especially neuroscience. For these networks dynamics can involve a mix of distributed and decentralized control, adaptivity, event driven dynamics, switching, varying network topology and hybrid dynamics (continuous and discrete). The associated network dynamics will generally only be piecewise smooth. Nodes can evolve independently of one another, be constrained, stop, and later restart, and the interactions between different components of the network may depend on time, state, and stochastic effects. Potential applications range from power grids and transport networks to neuroscience. In this talk we describe the motivation and basic structure of asynchronous networks and give a factorization of dynamics theorem that addresses the question of modularization of dynamics addressed by Alon in the introduction to his book on systems biology "Ideally, we would like to understand the dynamics of the entire network based on the dynamics of the individual building blocks".

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OC.046.Identifying Dynamical Instabilities in Supply Networks Using Generalized Modelling
7 June 15:00-17:00 (Parallel 2), Session Complex Networks

Disruptions in supply networks have significant economic impact. For instance, in year 2000, Ericsson suffered losses of $400 million due to supply shortages. While this particular case may have been due to an external trigger, supply networks are known to exhibit intrinsic self-organised instabilities. Therefore, increasing effort is made to identify the most sensitive and influential organisations in a network regarding these instabilities. The objective of this work is to investigate the local stability of large ensembles of supply network models and to identify the sensitive and influential organisations. For this purpose we use tools from dynamical systems theory, e.g. generalised modelling. We start by analysing a small example network to introduce these tools to supply networks, before considering large real world networks. Our results show that the central suppliers are the most influential and sensitive. In addition, suppliers that are far away from the prime company are highly sensitive to instabilities, but have low influence. More importantly, we were able to identify cyclic relationships in supply networks as highly destabilising. Such instabilities occur due to coordination problems in the organisation that supply several different parts, which can result in oscillatory or divergent instabilities. In conclusion, our approach can help to gain information on sensitivity to and influence of instability from the network topology alone.

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OC.047.Transition States and Invariant Manifolds
6 June 17:30-19:30 (Paralell 4), Session: Nonlinear Dynamics/Bifurcation Theory

Transition State Theory (TST) plays a central role in chemical reactions as it provides a simple answer to two of the most important tasks in Chemistry, namely: which is the reaction rate and which is the reaction mechanism responsible of that reaction.

In this contribution, we will revisit some of the last advances on TST based on the identification of the geometrical structures (the invariant manifolds) that determine the rate constant in systems that interact strongly with their environments [1, 2].

[1] T. Bartsch, F. Revuelta, R. M. Benito, F. Borondo, Reaction rate calculation with time-dependent invariant manifolds, *J. Chem. Phys.* 136:224510, 2012.
[2] F. Revuelta, T. Bartsch, R. M. Benito, F. Borondo, Transition state theory for dissipative systems without a dividing surface *J. Chem. Phys.* 136:091102, 2012.

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OC.048.Robustness of oscillatory behavior in correlated networks
7 June 15:00-17:00 (Parallel 2), Session: Complex Networks

From its beginnings, network robustness has been one of the central issues in complex network theory. Since networked systems rely on interactions of the network units, failures of the network units and/or their interactions can lead to a large-scale breakdown in the entire network. For instance, power-line accidents in power grids can cause large-scale blackouts, or cell necrosis in biological networks can induce disorders in living things.

To get an insight into how to prevent such enormous damages on a widespread scale in the real-world networked systems, two theoretical frameworks for understanding network robustness and vulnerability have been developed. The structural robustness indicates the failure tolerance of the networks connectivity evaluated by the giant component, i.e., the size of the largest connected component. This framework has been applied to networks consisting of static nodes. On the other hand, the dynamical robustness focuses on the failure tolerance of dynamical behavior on networks where dynamical processes play important roles in their functions.

The structural and dynamical robustness of complex networks has been studied in comparison between homogeneously and heterogeneously connected networks with different forms of degree distributions. However, the degree distribution does not uniquely specify the network topology. Namely, networks with the same degree distribution can have different kinds of network topology. Among the several quantities to measure such a difference, here we focus on the network assortativity. The network assortativity indicates how the degree of a node is correlated with the degrees of its neighboring nodes.

We study [1] the dynamical robustness of correlated (assortative and disassortative) networks consisting of diffusively coupled oscillators. Numerical analyses for the correlated networks with Poisson and power-law degree distributions show that network assortativity enhances the dynamical robustness of the oscillator networks but the impact of network disassortativity depends on the detailed network connectivity. Furthermore, we theoretically analyze the dynamical robustness of correlated bimodal networks with two-peak degree distributions and show the positive impact of the network assortativity.

Sasai T, Morino K, Tanaka G, Almendral JA, Aihara K.
Robustness of Oscillatory Behavior in Correlated Networks.
PLoS ONE 10(4):e0123722 (2015). doi:10.1371/journal.pone.0123722

OC.049.Precessionally-forced rotating cylinder flow: nutation angle effects.

9 June 17:30-19:30 (Parallel 1), Session: Complex Fluid Dynamics

Precessing flows consist of a fluid-filled body rotating about an axis with rotation vector ω_0 that is itself rotating (precessing) about another rotation vector ω_p, where the angle between the two rotation vectors is α. Examples of precessionally forced flows are plentiful in astrophysics and geophysics, and also in industrial applications.

Weakly precessing flows tend to be dominated by triadic resonances; these have been observed experimentally, analyzed theoretically, and simulated numerically. For the most part, these investigations in cylindrical geometries have used small nutation angles α in order to be in the weak precessional forcing regime. Experimentally, as α is increased above about 4°, the system is observed to suffer a catastrophic transition to small scale apparently disorganized flow, usually reported as being turbulent. This regime, and the transition to it, have not been accessible using existing theories, and flow visualization experiments have been inadequate for examining the flow dynamics. Despite over a century of study, there are still many open questions. However, with recent advances in numerical simulations of the full governing equations, insight into some of these intriguing problems has become accessible.

The flow in a rapidly rotating cylinder forced to precess through a nutation angle α is here investigated numerically, keeping all parameters constants except α, and tuned to a triadic resonance at $\alpha = 1°$. When increasing α, the flow undergoes a sequence of well-characterized bifurcations associated with triadic resonance, involving heteroclinic and homoclinic cycles, for α up to about 4°. For larger α, we identify two chaotic regimes. In the first regime, with α between about 4° and 27°, the bulk flow retains remnants of the helical structures associated with the triadic resonance, but there are strong nonlinear interactions between the various azimuthal Fourier components of the flow. For the larger α regime, large detuning effects lead to the triadic resonance dynamics being completely swamped by boundary layer eruptions. The azimuthal mean flow at large angles results in a large mean deviation from solid-body rotation and the flow is characterized by strong shear at the boundary layers with temporally chaotic eruptions.

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OC.050.Geometric Constraints and Scaling Laws in Spatial Networks 7 June 10:00-12:00 (Parallel 4), Session: Complex Networks

Geometric constraints impact the formation of a broad range of spatial networks, from amino acid chains folding to protein-structures to rearranging particle aggregates in ferrofluids. In this presentation, we introduce and analyze a class of spatial network formation processes, where random connections are added to a closed chain of unit discs, such that no two units intersect. By introducing a mapping from geometric to graph-theoretic constraints, we study the resulting networks in direct numerical simulations and mean-field calculations. We find an algebraic scaling law for the diameter of the resulting networks with system size, in contrast to logarithmic scaling known for networks without constraints (such as Watts-Strogatz networks). Intriguingly, the exponent falls between those of self-avoiding random walks and space filling arrangements, consistent with experimentally observed scaling for protein tertiary structures.

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OC.051.Multiheaded scroll wave chimeras
9 June 17:30-19:30 (Parallel 3), Session: Chaos/Pattern Formation

We report the appearance of multple scroll wave chimera states in the Kuramoto model of coupled phase oscillators in the 3D grid topology

$$\dot{\varphi}_{ijk} = \omega + \frac{K}{P^3} \sum_{(i',j',k') \in B_P(i,j,k)} \sin(\varphi_{i'j'k'} - \varphi_{ijk} - \alpha),\ i,j,k = 1,...,N,$$

where φ_{ijk} are phase variables, indexes i, j, k are periodic mod N. The coupling is assumed to be long-ranged and isotropic: each oscillator φ_{ijk} is coupled with equal strength K to all its nearest neighbors $\varphi_{i'j'k'}$ within a range P. i.e. to those oscillators falling in the 3D ball-like neighborhood

$$B_P(i,j,k) := \{(i',j',k'){:}(i'-i)^2 + (j'-j)^2 + (k'-k)^2 \leq P^2\}.$$

The phase lag parameter α is assumed to belong to the attractive coupling range from 0 to $\pi/2$, the second control parameter is the coupling radius $r = P/N$.

Different types of chimera states for the Kuramoto model were obtained recently in [1,2]. In the talk, we demonstrate that number of the incoherent domains (chimera's "heads") such as rolls, trefoils and Hopf links can multiply under appropriate choice of the system parameters. Cascades of these kinds scroll wave chimeras are obtained, examples are visualized for chimeras with 2, 4, 6, 8, 10, 12, 14, 16, 64, 256, and 1024 heads. Respective parameter regions in the parameter space (r, α) are obtained, which demonstrate a huge multistability of the chimeric system dynamics. Simulations where performed for the network of N^3 oscillators with $N = 100, 200$, and 400. The presentation comprises video illustrating the origin and evolution of different types multiheaded chimera states.

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OC.052.Phase synchronization of Kármán vortices
8 June 13:30-15:30 (Parallel 2), Session: Complex Fluid Dynamics

The Kármán vortex street is a typical nonlinear oscillation of fluid flow, where vortices are periodically emitted from an obstacle in the flow. In this study, we analyze synchronization dynamics of a periodically oscillating Kármán vortex street using the phase reduction theory, which is a general method for analyzing weakly perturbed limit-cycle oscillators. In the phase reduction theory, the phase response property of the limit-cycle oscillator to weak perturbation is essential. However, the phase sensitivity function of the Kármán vortex street has not been calculated so far. In this study, we propose a numerical method to calculate the phase sensitivity function of the oscillatory flow field described by the Lattice Boltzmann Method and apply it to the Kármán vortex street. The obtained phase sensitivity function characterizes the phase response properties of the Kármán vortex street to weak external perturbations and gives a simple one-dimensional phase equation describing the flow. Using the reduced phase equation, we analyze phase synchronization of the Kármán vortex street by weak periodic forcing, and identify the location in the flow where the synchronization takes place efficiently.

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OC.053.Dynamics of second-order equation with large delay
6 June 17:30-19:30 (Parallel 4), Session: Nonlinear Dynamics/Bifurcation Theory

Consider second-order nonlinear equation

$$\frac{d^2x}{dt^2} + \sigma \frac{dx}{dt} + x = ax(t-T) + F(x(t-T))$$

with large delay ($T \gg 1$). Here $x \in R$, $\sigma > 0$ and F is smooth nonlinear function. Let study the stability of zero equilibrium and its bifurcations.

Its stability depends of location of roots of characteristic equation

$$\lambda^2 + \sigma\lambda + 1 = a\exp(-\lambda T).$$

There are two types of critical cases. At the critical case of first type ($\sigma > \sqrt{2}$, $a = \pm 1$) infinite number of roots tend to imaginary axis when delay tends to infinity. At the second one ($\sigma < \sqrt{2}$, $a = \pm a(\sigma)$) each root has the limit in left complex half-plane, but for sufficiently large delay there are exist root λ with small real part. The number of such λ is unbounded. So, all critical cases have infinite dimension.

In critical cases the method of research based on method of normal forms. The main idea is to built special equations (we call it quasinormal forms) with help of some asymptotic substitution. These equations describes behaviour of solutions of initial problem. In the both critical cases quasinormal forms are parabolic equation without small or large parameters.

In the critical of first type, equilibrium state loss stability and periodic solutions may born during bifurcation. The number of such solutions may be any for sufficiently large T. In the critical case of second type again periodic solutions may born, but the frequency of these solutions is asymptotically large.

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OC.054.The impact of the newly licensed dengue vaccine in endemic countries
6 June 17:30-19:30 (Parallel 3), Session: Biophysics

Epidemic models have been important in understanding the spread of infectious diseases and to evaluate the introduction of intervention strategies like vector control and vaccination.

Dengue disease and transmission shows large fluctuations of disease incidence and multi-strain models try to explain the irregular behaviour of disease epidemics. Dengue fever is caused by four antigenically related but distinct serotypes (DENV-1 to DENV-4). Infection by one serotype confers life-long immunity to that serotype and a temporary cross-immunity period (TCI) to other serotypes. Epidemiological studies support the association of severe disease with secondary dengue infection, due to a process described as antibody-dependent enhancement (ADE), where the pre-existing antibodies to previous dengue infection do not neutralize but rather enhance the new infection.

Mathematical modeling describing multi-strain interactions have shown deterministic chaos in a wider parameter region, where the combination of TCI and ADE is the most important feature to drive the complex dynamics in the system. The minimalistic model developed by Aguiar et al. is able to describe the large fluctuations observed in empirical outbreak data, where a rich dynamic structures, with bifurcations (Hopf, pitchfork, torus and tangent bifurcations) up to chaotic attractors in unexpected parameter regions was found (see Aguiar et al. (MMNP 2008, JTB 2011, Ecol. Complex. 2013)).

Treatment of uncomplicated dengue cases is only supportive, and severe dengue cases require hospitalization. The dengue vaccine candidate most advanced in clinical development is a live attenuated tetravalent dengue vaccine developed by Sanofi Pasteur (CYD-TDV, named Dengvaxia). Phase III trials were successfully completed in the Asian-Pacific region and in Latin American countries, reducing dengue disease prevalence in 66% in Latin America (and 60% in Asian-Pacific Region) of a subset of 9 16 year olds. However, a significantly lower efficacy (including negative vaccine efficacy) for dengue infected individuals who were seronegative prior vaccination was observed. Among these individuals there is a high incidence of hospitalization, notably among children younger than 9 years of age.

In this talk, we present the vaccine efficacy estimation for hospitalized dengue cases during the Phase III trials, based on relative risk (only given) information in Hadinegoro et al. (NEJM 2015). Using the mathematical modeling approach from Aguiar et al., the impact of the newly licensed dengue vaccine in endemic countries is analyzed for different scenarios and the results are discussed.

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OC.055.Orbital motion in multipole fields via multiscales
10 June 10:00-12:30 (Parallel 4), Session: Chaos/Pattern Formation

We present applications of methods of nonlinear local harmonic analy- sis in variational framework for a description of multiscale representations for polynomial/rational approximations of (nonlinear) models of beam motion in arbitrary n-pole fields. Our approach is based on the methods allowed to consider dynamical beam/particle localization in phase space and provided exact multiscale represention via nonlinear high-localized eigenmodes for observables with exact control of contributions to motion from each underlying hidden scale.

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OC.056.Dynamical aperture and complex patterns in a strong localization approach
10 June 10:00-12:30 (Parallel 4), Session: Chaos/Pattern Formation

We present the applications of the multiresolution analysis approach in the constrained variational framework for calculation of dynamical aperture for particle/beam motion in high-energy accelerators. We construct an exact multiscale representation by decomposition via nonlinear high-localized eigenmodes, which allows to control contributions to motion from the whole underlying hidden multiscale structure. It provides the explanation for self-organization in the complex system and corresponding pattern formation. We consider also a qualitative approach to the aperture problem based on the analysis of smoothness classes in the underlying functional space.

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OC.057.Behavior of a Predator-Prey System under Strong Periodic Forcing
10 June 10:00-12:30 (Parallel 3), Session: Environmental/Ecological Dynamics

The effects of large-amplitude seasonal effort harvesting on a species in a continuous predator-prey model (Rosenzweig-MacArthur) is investigated. Such strong periodic forcing of nonlinear oscillators typically results in richly diverse and complicated bifurcation structures involving chaos, which can be understood through numerical studies and classification of generic bifurcation sequences. High-order return maps are utilized to interpret mechanisms for some of the characteristic flow behaviors, including distinctive phase-locking regions, chaotic transients and local chaotic attractors. These return maps are constructed similarly to Poincaré maps, and they can reduce the essential flow behavior to the behavior of noninvertible scalar maps.

Some implications for the prediction and wildlife management of real biological populations is discussed.

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OC.058.Suppression of long-range pressure contributions due to screening in turbulent flows

8 June 13:30-15:30 (Parallel 2), Session: Complex Fluid Dynamics

The complexity of turbulent flows is deeply rooted in the non-locality and non-linearity of the governing Navier-Stokes equations. The former can be understood as the formal dependence of even the short-term evolution of a fluid element on the state of the entire system. The latter is responsible for the generation and interaction of multi-scale structures with different topologies: strain sheets and vortex tubes.

In incompressible hydrodynamics the governing Navier-Stokes equations encode non-locality through the kinematic pressure gradient. The pressure itself is formally determined by a competition between the *global* rate-of-strain and vorticity fields weighted by an algebraically decaying kernel. The question of the scale of locality of this dependence naturally follows: Is there a *local* neighborhood which contains the majority of the contributions to the pressure? This is intimately related to the two-point distribution of the strain and vorticity field throughout the flow.

We characterize the existence and the scale of locality of this neighborhood as a function of global parameters, e.g. the Reynolds number, and local flow properties, e.g. local topology, dissipation, etc. This is accomplished by investigation of a suite of high resolution data from direct numerical simulations of statistically stationary, homogeneous and isotropic incompressible turbulence under periodic boundary conditions.

Considered separately, both the strain and the vorticity fields have significant long-range influence on the pressure, with characteristic scales of the order of the integral scale. However, their combined effect is relatively local – it has a characteristic scale comparable with the Kolmogorov scale. This is explained by considering the relative distribution of the strain and vortex structures. They tend to arrange themselves in compact bundles and thus screen each other's influence at large scales. We discuss the implications of these findings for the turbulence closure problem as well as their impact on the decay of turbulent kinetic energy.

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OC.059."Backbones" in the parameter plane of the Hénon map
6 June 15:00-17:00 (Parallel 3), Session: Nonlinear Dynamics/Bifurcation Theory

We study accumulation loci in the parameter plane of the Hénon map, of curves of bifurcation for periodic sinks. Focus on two issues: first, monotone curves spanning the entire parameter plane (no singularity) and their accumulation curves. Second, when the dissipation parameter goes to zero, i.e. the jacobian goes to 1: onset of coexistence of attractors, renormalization schemes and convergence.

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OC.060.Toward new general-purpose processor with nonlinear transient computing
9 June 10:00-12:00 (Parallel 4), Session: Complex Systems

Nowadays sustaining Moore's law requires new information processing methods to be developed. On the other hand, modern applications tend to deal more and more with complex, computationally heavy tasks in one or another way related to machine learning. That includes major companies such as Google and Amazon which are already heavily relying on so-called big data analysis. On the other hand, with the growth of the number of smart devices, the volume of information, and thus, the demand of processing speed has dramatically increased. To address these and other related technology challenges we offer our perspective on brain-inspired processors.

Reservoir computing (RC) technique refers to a generalized machine learning approach for tasks of different complexity. Its strength is the possibility to deal with complex data such as images, sounds, time series and other 'fuzzy' logic where conventional computers' performance falls considerably or requires intricate algorithms to be developed.

Tasks RC is already capable of: high-speed pattern recognition and classification, forecasting and time series prediction, nonlinear control, etc. That is making wide potential area of use: automotive, robotics, aerospace, security, medicine, data servers, communications, smart houses, personal computers and smartphones, entertainment and game industries.

Here we present a hardware implementation of a reservoir computing device. Our autonomous implementation is based on FPGA (field-programmable gate array) reconfigurable integrated circuit. The FPGA approach makes it compact, decreases its costs and requires less energy comparing to CPU. This implementation is not only highly reconfigurable, but also works in real-time.

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OC.061.Route to chaos via torus destruction in models of dengue fever epidemiology and implications for time series analysis in Thailand dengue notification data

8 June 13:30-15:30 (Parallel 3), Session: Biophysics

Multi-strain models of dengue fever epidemiology display complex behaviour in large parameter regions, via Hopf, symmetry breaking pitchfork and torus bifurcations into chaos, where the bifurcation structure up to the torus is detected by continuation methods in AUTO and the chaos measured by positive Lyapunov exponents. Such models in their chaotic region describe well the fluctuations observed in empirical time series of dengue fever notification data in Thailand with more than 35 years of monthly data available for all provinces. We investigate the model performance on the empirical data via new statistical methods designed to describe chaotic dynamics especially in population biology, namely iterated particle filtering which uses the short term predictability of chaotic systems and overcomes the long term unpredictability gluing short pieces together with a simulated annealing procedure. We take not, as initially suggested by other groups, only observational noise into account for constructing the likelihood function estimation, but also dynamical noise, being able to perform well on test cases, which had been a problem for a long time. With these advances in parameter estimation, now short term predictions, up to two to three years ahead, are possible and intervention measures like the up-coming first dengue vaccine with its proven limited efficacy can be evaluated. This work is part of the EU-project DENFREE.

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OC.062.Vortex Currents in High Voltage AC Power Grids
6 June 15:00-17:00 (Parallel 4), Session: Complex Networks

Geographical formations such as mountain ranges or big lakes and inland seas often result in large closed loops in high voltage AC power grids. Sizable circulating power flows have been recorded around such loops, which take up transmission line capacity and dissipate but do not deliver electric power. Power flows in high voltage AC transmission grids are dominantly governed by voltage phase differences between connected busses, much in the same way as Josephson currents depend on phase differences between tunnel-coupled superconductors. From this previously overlooked similarity between Josephson junction arrays and AC power systems, we argue that these circulating power flows are analogous to supercurrents flowing in superconducting rings and in rings of Josephson junctions. AC power systems however differ from superconducting systems in at least two significant ways. First, in superconductors, vortices couple to magnetic fluxes so that it is easy to create them by simply applying an external magnetic field. Second, superconductors are dissipationless systems and it is not at all clear if the above analogy still holds in dissipative AC power grids. We investigate how circulating power flows can be created and how they persist in the presence of ohmic dissipation. We show how changing operating conditions generates vortices, how significantly more power is ohmically dissipated in their presence and how they are topologically protected, even in the presence of dissipation, so that they persist when operating conditions are returned to their original values.

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OC.063.A Generalized Form of Disorder-Induced Resonance

8 June 13:30-15:30 (Parallel 4), Session: Hybrid Systems/Complex Dynamics

We study some effects produced by "generalized disorder" on dynamical systems.

Here, by "generalized disorder" we mean disorder of a most general nature. This can mean *noise*, considered as a time-dependent form of disorder; e.g. a stochastic force acting on the system, *heterogeneity*, that is a quenched form of disorder affecting some parameters; or a *combination of the two types* above.

Our starting point are the well known phenomena of stochastic resonance [1] and diversity-induced resonance [2]. In these phenomena, the corresponding system presents an optimal response in correspondence to suitable values (or in a suitable range of values) of the disorder-related parameters, meaning temperature in the case of stochastic resonance and level of heterogeneity (measured e.g. by the spread of the parameter distribution) in the case of diversity-induced resonance.

We investigate numerically and analytically at a general level the constructive effects that the interplay of noise, diversity, and the multi-unit nature of a (complex) system can have in producing an optimal response to an external signal. We show that such an optimal response can in fact be obtained in a suitable range of the parameter space and that it outperforms the specific responses that would be obtained otherwise if only noise or diversity were present in the system. In this sense we refer to it as a "generalized disorder-induced resonance".

The results obtained, which confirm the constructive interplay between different forms of disorder, may explain why many biological and social systems have evolved toward states which are at the same time noisy and heterogeneous.

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[2] C.J. Tessone, C.R. Mirasso, R. Toral, J.D. Gunton, *Diversity-induced resonance*, Phys. Rev. Lett. 97, 194101 (2006).

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OC.064.Wavefront Propagation in Two-Dimensional Optical Bistable Device under Patterned Light Irradiation

8 June 13:30-15:30 (Parallel 4), Session: Hybrid Systems/Complex Dynamics

Wavefront propagation in a nonequilibrium system is attracting attentions in the field of natural computing. For example, Belousov-Zhabotinsky (BZ) reaction system in a two-dimensional space is one of such a system, and maze exploration using BZ reaction wave has been reported. We are investigating a two-dimensional thermo-optical bistable device for wavefront propagation, because of their controllability and stability. As a first step goal, we are aiming to realize maze exploration.

In this type of devices, optical bistability is realized through positive feedback between heat generated by photoabsorption and change in optical absorbance induced by temperature-dependent absorption coefficient. Under irradiation of bias light at an intensity in the bistable (hysteresis) region, the whole area can stay at "off" state without any perturbation. Once the light intensity is increased above the turn-on threshold at one location, the medium is locally triggered to turn on, and the "turn-on" wavefront expands two-dimensionally due to thermal diffusion in lateral direction. Theoretically, this device can be modeled using a thermal diffusion equation with heat loss at the device boundary and heat source originated from absorption of light. In the optical absorption term, temperature dependent absorbance is incorporated, resulting in bistability of the device. Using this theoretical model, we have performed a top-view two-dimensional numerical simulation, and demonstrated maze exploration.

Experimentally, temperature-dependent light absorption is realized using a combination of a layer of material with temperature-dependent optical transmission and a black layer which absorbs light by nearly 100%. Here we employ a liquid crystal 4-pentyl-4'-cyanobiphenyl (5CB) as the temperature-dependent optical transmission material: below 35 C, 5CB is in nematic phase with large optical scattering and therefore low optical transmission, and above this temperature it is in isotropic phase which is highly transparent. We performed cross-sectional numerical simulation to obtain temperature distribution in the device by the finite element method (FEM), and confirmed that required experimental conditions (temperature and light intensity) are realistic under actual materials properties and device structure. We have also fabricated devices, and experimentally demonstrated wavefront propagation. Under patterned light irradiation, wavefront triggered at one end of the pattern propagated through the pattern toward the other end. Experimental wavefront velocity was similar to that obtained by the numerical simulation.

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OC.065.Geometric Mixing, Peristalsis, and the Geometric Phase of the Stomach

9 June 17:30-19:30 (Parallel 1), Session: Complex Fluid Dynamics

Mixing fluid in a container at low Reynolds number — in an inertialess environment — is not a trivial task. Reciprocating motions merely lead to cycles of mixing and unmixing, so continuous rotation, as used in many technological applications, would appear to be necessary. However, there is another solution: movement of the walls in a cyclical fashion to introduce a geometric phase. We show using journal-bearing flow as a model that such geometric mixing is a general tool for using deformable boundaries that return to the same position to mix fluid at low Reynolds number. We then simulate a biological example: we show that mixing in the stomach functions because of the "belly phase", peristaltic movement of the walls in a cyclical fashion introduces a geometric phase that avoids unmixing.

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OC.066.Improving Network Inference of Oscillatory Systems: A Novel Framework To Reliably Identify the Correct Class Of Network
7 June 15:00-17:00 (Parallel 2), Session Complex Networks

Recently, many research groups have focused on the inference of networks from data such as brain networks from observed electroencephalography or functional magnetic resonance imaging data. In the example of the brain, this promises to disclose information about how the brain processes signals and how alterations thereof cause specific diseases. A key hypothesis is that important characteristics are not specific to individual subjects but rather common in a given population. This is reflected by the fact that brain networks but also other networks are typically classified into main prototypic networks, i.e., Erdos-Renyi, Small World and Scale Free Networks.

In the Inverse Problem, the challenge is to infer the network topology from data. Two challenges are particularly relevant: (i) to reliably obtain the links in the network once the nodes have been fixed, (ii) to use the characteristics above to uniquely determine the type of network.

For oscillatory systems several cutting-edge methods have been suggested in the literature to address problem (i). Usually these techniques rely on statistical inference. The correct reconstruction of networks is therefore hampered by mis-estimation of links due to statistical uncertainties, unobserved processes, noise contamination to name just a few. Mis-estimated links in a network typically alter the key characteristics; this makes it particularly difficult to infer the correct type of network and it is the challenge of problem (ii).

We investigate to which extent classical statistical approaches to estimate links in a network are reliable; furthermore, we investigate if common rules of type I and type II errors should be modified to achieve a reliable inference of the correct type of network. Our approach is based on the topological analysis of the detected networks taking into account the role of two important parameters: false positive and false negative decisions about the presence and absence of links.

We present simulation results which indicate that standard alpha values for statistical inference are suboptimal when for instance the degree distribution is to be estimated. We suggest a novel procedure to optimally balance false positive conclusions. This enables us to obtain, e.g., the best estimate for the average shortest path length or degree distribution for a given analysis technique. Based on these improved estimates we can infer the correct type of network with high probability.

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OC.067.Bifurcation of spiral-shaped patterns in the phase space of a nonlinear delayed electro-optic system
9 June 17:30-19:30 (Parallel 3), Session: Chaos/Pattern Formation

We report on experimental and theoretical analysis of a particular kind of complex dynamics generated by a bandpass nonlinear time-delayed optoelectronic oscillator. The observed waveform exhibits a slow-fast motion which reveals, within a reduced 2D delayed coordinate space, a spiral-like fast trajectory on top of a large amplitude slow limit cycle. This multiple time scale waveform belongs to the family of chaotic breathers, and it is shown to strongly depend on the nonlinear function shape involved in the delayed feedback. The slow compound of the motion emerges from a Hopf bifurcation, and it is found to further bifurcate at some higher nonlinear feedback strength. The dynamics then results in a fully developed chaos in which the slow frequency contributions is abruptly reduced. An energy-based approach is used to explain the evolution of the slow compound with an associated potential function within which the orbits are confined, until it bifurcates into fully developed chaos.

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OC.068.Extreme Events in Delay-Coupled FitzHugh-Nagumo Oscillators
7 June 15:00-17:00 (Parallel 4), Session: Complex Systems

The study of rare, recurrent, aperiodic events which have a large impact on dynamical systems — known as extreme events — has recently gained increasing attention due to its relevance in a wide range of fields. Extreme events are known to occur in economics, power grids, communication systems, geophysics and meteorology. Various mechanisms have been suggested in the literature which could explain the appearance of extreme events. Some of these include progressive spatial synchronisation and an interior crisis in networks of non-identical relaxation oscillators.

An important feature of many real-life networks is delay coupling. For instance, neural activities across different regions of the brain — whose synchrony may lead to epileptic seizures — are coupled by time delayed coupling. Moreover, as the flow of information in these networks might take different routes to travel from the source to the destination, a given pair of nodes might have multiple connections — each characterised by a different delay. We study the role of such multiple delays in the generation of extreme events. To this end, we investigate a system of two identical FitzHugh-Nagumo oscillators connected by diffusive couplings with multiple delays. We show that, this system can exhibit extreme events even in the absence of other known factors such as heterogeneity in parameters determining the dynamics of nodes. Using a simple phase measure, we also demonstrate that two different classes of extreme events might occur: in- or out of phase. Furthermore, the loss of synchrony in the second class of extreme events occurs much before the actual event. Hence the phase difference might be used as a predictor for such extreme events.

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OC.069.Bifurcation bridges in semiconductor ring lasers subject to delayed optical feedback
6 June 15:00-17:00 (Parallel 3), Session: Nonlinear Dynamics/Bifurcation Theory

Semiconductor Ring Lasers (SRLs) have attracted recent attention for their possible applications in photonic integrated circuits because their cavities do not require cleaved facets or gratings . Recently, SRLs subject to delayed optical feedback have been studied for their nonlinear response or as potential candidates for new applications. In particular, optical feedback allows the control of the multi-wavelengths emission of the laser for which an oscillatory instability is highly undesirable. This naturally leads to the need of finding such instabilities in parameter space.

Laser diodes subject to a delayed feedback are known to exhibit high-frequency intensity oscillations as a result of a beating between two external cavity modes. They emerge from a particular Hopf bifurcation mechanism and are referred to as bifurcation bridges. We show theoretically that a semiconductor ring laser subject to feedback exhibits a similar mechanism leading to anti-phase intensity oscillations in the two propagating directions of the circular cavity. Contrary to the diode lasers, the bifurcation bridges of the ring lasers are fully stable and motivate experimental investigations. Our experiments performed with an on-chip ring laser with feedback confirm the theoretical and numerical predictions. In particular, we highlight the role of the feedback phase on the apparition of the oscillatory instabilities.

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OC.070.Extreme orbits: the key of the global organization of complex sets in the parameter space

6 June 15:00-17:00 (Parallel 3), Session: Nonlinear Dynamics/Bifurcation Theory

We present the extreme orbits, trajectories that connect local maximum and minimum values of one dimensional maps, and show that they play a fundamental role in the parameter space of dissipative systems dictating the organization for the windows of periodicity, hence producing sets of Arnold tongues and shrimp-like structures. As applications, we solve three fundamental problems regarding the distribution of these sets for the circle and perturbed logistic maps and give: (i) their precise localization in the parameter space, even for sets of very high periods; (ii) their local and global distributions along cascades and; (iii) the association of these cascades to complicate sets of periodicity. The extreme orbits are proved to be a powerful indicator to investigate the organization of windows of periodicity in parameter planes and its formalism can be extended to many other different nonlinear and dissipative systems.

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OC.071.Delay-Induced Dynamics of Localized Structures in Systems with Spatial Inhomogeneities
8 June 13:30-15:30 (Parallel 4), Session: Hybrid Systems/Complex Dynamics

We are interested in the control of localized structures by time-delayed feedback in dissipative systems with spatial inhomogeneities. Therefore, a Swift-Hohenberg model that describes, e.g., the behaviour of transversal patterns in a passive cavity in two spatial dimensions is combined with an additional time-delayed feedback term and an inhomogeneous gaussian injection beam.

We show that varying the delay strength, the delay time and the shape of the injection beam leads to various dynamical solutions including drifting solutions, pinned oscillatory structures and the formation of spirals. The onset of these different instabilities can be predicted analytically in terms of a linear stability analysis of the delayed systems.

A special focus lies on the competing effects of the symmetry breaking inhomogeneity, which has a pinning effect on the localized structure, and the drift-inducing modes, which can be destabilized by time delayed feedback. The interplay of these competing effects leads to an oscillatory motion of the structure which is studied both numerically and analytically.

To this aim, the motion of the localized structure is modeled as the dynamics of an overdamped particle in a potential well generated by the inhomogeneity, driven by time-delayed feedback. We show that the results from the reduced potential well model are in good agreement with direct numerical simulations of the full model.

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OC.072.Rayleigh-Plateau Instabilities of Thin Liquid Ridges
10 June 10:00-12:30 (Parallel 4), Session: Chaos/Pattern Formation

We are interested in the statics and dynamics of thin liquid films forming ridges on homogeneous or (chemically) heterogeneous solid substrates. The local height of the liquid on the substrate is modeled by a thin film equation which is derived from a long-wave approximation of the Stokes equation and includes wettability of the substrate as well as capillarity. The chemical prepattern of the substrate is acounted for in terms of a spatially modulated disjoining pressure.
The Rayleigh-Plateau instability is well known as the surface tension driven instability of liquid jets, leading to a break-up into drops. The same phenomenon occurs for liquid ridges on a solid subtrate. This instability of liquid ridges is studied for various geometries in terms of linear stability analysis and 2D direct numerical simulations. For two weakly interacting ridges on adjacent prepattern stripes, the influence of their interaction on the linear instability modes is investigated. Furthermore, bridge-forming static solutions for the two-stripe system in dependence of the distance between two more wettable stripes are discussed. Finally, we compare our results concerning the Rayleigh-Plateau instabilities obtained for the thin film equation qualitatively with respective results from a stochastic kinetic Monte Carlo model and discuss possibilities of a quantitative mapping between the two models.

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OC.074.Modelling of *glissando* patterns in the small neuronal circuit
9 June 17:30-19:30 (Parallel 4), Session: Neurodynamics

Recently, it has been found a very special kind of neuronal activity during an epileptic seizure, so called *glissando* [1]. In addition to its neurophysiological importance, this phenomenon is a challenge for the theory of dynamical systems, which could model it. Glissando represents patterns of oscillations with a continuously growing frequency, the behaviour, which can not be reproduced by the single conventional non-linear oscillators typical for the problems of neuroscience.

Basing on the study of multiscale decompositions [2], which demonstrates the coexistence of several time scales , we propose a simple mathematical model of two parametrically coupled non-indentical oscillators resulting in glissando.

To describe glissando, we have constructed a simple model of neuron system comprising one fast-spiking and one slow-spiking cells, respectively. The cells are mutually electrochemically connected. The system is described by the coupled modied FitzHugh-Nagumo (FHN) equations, which well reproduce the dynamical behavior of dierent cells types. The period of isolated cell in FHN system is determined by the time-scale factor and could be interpreted as the ratio of dimensional relaxation times of ion currents, in particular sodium, potassium or specific currents and could be changed at the neuron interconnection. Therefore model includes dependence of time-scale factor on the membrane potential of interconnected cell, that results in the glissando-like behaviour. We suggest that phenomemon *glissando* rather occurs due to alteration of ion currents than additional diffusion coupling (electric junction).

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[2] E.B. Postnikov, E.A. Lebedeva, A.I. Lavrova, *Applied Mathematics and Computation* **282** (2016) 128

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OC.075.Dynamical Voltage-Current Characteristics of Superconductor / Normal Metal / Superconductor Junctions

9 June 10:00-12:00 (Parallel 4), Session: Complex Systems

We probe the dynamics of a Superconductor / Normal Metal / Superconductor junction (SNS: Nb / Al above its critical temperature / Nb) by measuring its voltage-current characteristics while applying an ac current of frequency in the range 1-200 MHz. We observe a dynamical phase transition as a function of the frequency and amplitude of the ac current. At low frequency there is a continuous change in the dynamical behavior of the junction, replaced an abrupt change and hysteresis at high frequency. The crossover frequency between the two regimes has a strong temperature dependence similar to that of the electron-phonon interaction rate.

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OC.076.Spatial effects for food webs in patch landscapes
9 June 15:00-17:00 (Parallel 4), Session: Environmental/ Ecological Dynamics

In ecology it is recognised that our environment is not evenly distributed, landscapes often comprise discrete patches of habitat. These landscapes can be represented by a network, where each node represents a patch and links between patches represent dispersal opportunities. The species that inhabit the same patch interact with each other through feeding relationships. These feeding relationships can also be described by a network, called a food web. In a food web each node represents a species and with links indicating feeding relationships. Combining the dispersal and feeding relationships the whole system can be represented by a network of networks.

Previous analysis of this network of networks model has shown that, for a simple set of feeding relationships represented by a food chain, the degree distribution of the landscape network has a large effect on species persistence. The focus on the degree distribution simplifies the landscape networks in a way that does not necessarily represent spatial settings.

However real landscape networks are spatial, and as a result often contain structure which cannot be captured by the degree distribution, for example is clustering. Further real networks of feeding interactions can contain patterns not included in a food chain, for example omnivores who feed on prey at multiple trophic levels.

Here we develop the networks of networks model further. We present analysis for various landscape networks and food web topologies that include omnivores. We find that clustering has a small effect on persistence of species in a food chain, but significantly increases the persistence of omnivores.

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OC.077.A Bayesian approach to dynamical noise reduction
10 June 10:00-12:30 (Parallel 2), Session: Nonlinear Time series Analysis

In this paper, a Bayesian nonparametric approach to dynamical noise reduction of a given dynamically noisy corrupted chaotic time series is presented. Under the assumption of known functional form for the deterministic part of the process, responsible for the noisy chaotic series, we introduce a stochastic model with which in parallel we fully reconstruct the unknown state space dynamic equations and at the same time a hidden part replicates the dynamics of the process under reduced noise level perturbations. We demonstrate the inference procedure of the Dynamical Noise Reduction Replicator (DNRR) model with synthetic time series generated by the stochastic versions of the logistic and the Hénon dynamical systems, when the nonparametric component is applied to additive errors.

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OC.078.Frequency Synchronization and Localized Dynamics in Symmetric Networks of Coupled Phase Oscillators
9 June 17:30-19:30 (Parallel 3), Session: Chaos/Pattern Formation

The emergence of collective behavior is a fascinating feature of interacting oscillatory units in nature and technology. We study systems of phase oscillators which provide an approximation for weakly coupled oscillators. Apart from full synchronization, solutions where a subset of localized oscillators are frequency synchronized have attracted an enormous amount of attention recently. Weak chimeras provide a rigorous notion to describe such dynamics and we discuss some recent results on the existence of weak chimeras. Moreover, we give some explicit examples of interaction functions that give rise to weak chimeras with chaotic dynamics. Finally, we consider some symmetry aspects since frequency synchronization of identical oscillators is equivalent to a nontrivial symmetry of the frequencies and relates to the overall symmetry of the system.

[1] C Bick and P Ashwin. *Chaotic Weak Chimeras and their Persistence in Coupled Populations of Phase Oscillators.* Nonlinearity, to appear, arXiv:1509.08824 (2016).
[2] C Bick. *Isotropy of Frequencies and Weak Chimeras with Broken Symmetry.* arXiv:1512.01321 (2016).

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OC.079.Dissipation in noisy chemical systems: The role of deficiency
8 June 13:30-15:30 (Parallel 3), Session: Biophysics

We study the effect of intrinsic noise on the thermodynamic balance of complex chemical networks subtending cellular metabolism and gene regulation. A topological network property called *deficiency*, known to determine the possibility of complex behavior such as multistability and oscillations, is shown to also characterize the entropic balance. In particular, when deficiency is zero the average stochastic dissipation rate equals that of the corresponding deterministic model, where correlations are disregarded. In fact, dissipation can be reduced by the effect of noise, as occurs in a toy model of metabolism that we employ to illustrate our findings. This phenomenon highlights that there is a close interplay between deficiency and the activation of new dissipative pathways at low molecule numbers.

Polettini, Wachtel, and Esposito. *J. Chem. Phys.* **143**, 184103 (2015), arXiv:1507.00058

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OC.080.Modelling Thermostatically Controlled Loads as Coupled Oscillators for Electricity Grid Balancing

8 June 10:00-12:00 (Parallel 4), Session: Chaos/Complex Systems

A key aspect of safe and secure operation of the electricity grid is the careful control of the frequency of the alternating current (grid frequency). Historically this was done using a few large generators which responded to fluctuations in grid frequency by increasing or decreasing their output to redress the underlying demand-supply imbalance causing the fluctuations. As countries incorporate far greater levels of less predictable and more volatile forms of generation such as wind and solar farms new solutions to the provision of frequency response are required.

One option is to use dynamic demand-side response. We consider the potential for a large number of very small thermostatically controlled loads (TCLs) such as fridges or hot water tanks to respond to changes in grid frequency without impacting the needs of users. We model the system as a population of coupled oscillators, inspired by the work of Kuramoto, Strogatz and others. This is a complex system in which each individual TCL is equipped with a simple deterministic control algorithm and is coupled to all other TCLs only through the impact of the total population power consumption on grid frequency. We seek the criteria for system stability given a heterogeneous population, and investigate the effect of diversity on the potential for stability.

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OC.081.Rotational Diffusion of a Molecular Cat

9 June 10:00-12:00 (Parallel 4), Session: Complex Systems

We analyze the classical dynamics of a simple spring-mass molecule connected by linear springs and suspended in free space. Similarly to a falling cat, such a molecule can rotate with zero overall angular momentum. The molecule manages this peculiar motion by making a cyclic deformation of its shape. Consequentially, overall rotation is obtained thanks to the nontrivial connection of the molecule's internal shape space. This nontrivial connection can be considered to be the result of angular momentum conservation coupled with the gauge freedom of defining the molecules orientation. In this system, the geometric nonlinearities arising from the non-zero rest-lengths of the springs connecting the masses suffice to break the integrability of the harmonic system and create chaotic dynamics in many regimes of the phase space. The two phenomena, chaotic dynamics in shape space and the spaces nontrivial connection, coupled together result in an angular random walk of the molecule. We study the properties and dynamics of this angular motion analytically and numerically. We observe the evolution of the type of motion from normal-mode-like motion, through anomalous diffusion to regular diffusion-like motion as the initial energy of the molecule is increased. Last, we show that if the system is embedded in a space of constant curvature then real-space diffusion is observed, despite conservation of overall linear momentum.

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OC.082.Dynamics and Thermodynamics of Chemical Reaction Networks
7 June 15:00-17:00 (Parallel 2), Session: Complex Networks

Driven Open chemical networks (DOCN) are large sets of coupled chemical reactions where some of the species are externally controlled. Cell metabolism and biochemical signal transduction networks are notable examples of DOCN. We present a rigorous nonequilibrium thermodynamical description of DOCN in terms of deterministic rate equations. Our description is inspired by Stochastic Thermodynamics and is based on Chemical Reaction Network Theory. The energy and entropy balances of DOCN are derived and a nonequilibrium Gibbs free energy is introduced. This latter is related to the chemical work necessary to control the network far from equilibrium. The relationship between the thermodynamics and the topology of DOCN is illustrated by considering detailed-balanced networks as well as complex-balanced networks. An application to oligosaccharides exchange dynamics performed by so-called D-enzymes is provided.

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OC.083.Asymptotic Analysis of a Target Mediated Drug Disposition Model: Algorithmic and Traditional Approaches
6 June 17:30-19:30 (Parallel 3), Session: Biophysics

A full scale analysis is reported of a multiscale pharmacokinetic model, simulating the interaction of a drug with its target, the binding of the compounds and the outcome of their interaction. The analysis is based on the algorithmic Computational Singular Perturbation (CSP) methodology. Among others, the analysis concludes that the partial equilibrium and the quasi steady state approximations (QSSA and PEA) are valid in two distinct stages in the evolution of the process. Similar conclusions are reached from the algorithmic criteria for the validity of the QSSA and PEA. The reactions in the model that (i) generate the fast time scales, (ii) generate the constraints in which the system evolves and (iii) drive the system at various phases are identified, with the use of algorithmic CSP tools. These identifications are very important for the improvement of the model and for the identification of ways to control the evolution of the process. The present analysis systematizes the findings in the literature and provides some new insights.

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OC.084.Colored noise as a driver of epileptiform dynamics in a mesoscopic neuronal model
6 June 10:00-12:00 (Parallel 4), Session: Neurodynamics

Epilepsy is a prevalent neurological disorder characterized by recurrence of spontaneous seizures, defined as hypersynchronous activity of neuronal assemblies. The seizures show as high-amplitude excessive activity in the EEG. Mechanisms of initiation of epileptic seizures are today elusive, they might involve local changes of neuronal tissue properties, as well as global interactions on the brain-network level. Here, we theoretically study how background activity of cortical network may initiate epilepticform activity in healthy and aberrantly excitable neuronal populations. To this end we employ a mesoscopic neuronal model receiving a stochastic, temporally correlated input, which combines rhythms from a wide range of frequencies, and stands for background activity of the brain network. By varying properties of this input we characterize conditions in which epileptic seizures are most likely to occur. Furthermore, we drive the model with plain harmonic rhythms in order to pinpoint essential mechanisms underlying observed phenomena.

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OC.085.Causal connectome of the human brain: how do the large-scale networks communicate?
6 June 10:00-12:00 (Parallel 4), Session: Neurodynamics

Over the course of last fifteen years, functional Magnetic Resonance Imaging (fMRI) research highly contributed to cognitive science. Today, this field is further developing, and has been recently pivoting around concepts such as spatio-temporal processes (Shen et al, NeuroImage 2014) and reverse inference (Poldrack, TiCS 2006). In the last few years however, the communication in large-scale brain networks became of interest. As spatial ICA reveals, the brain functionally divides into groups or regions who share common activity in the resting state, and have a biological meaning (Smith et al, PNAS 2009), known as 'resting state networks' (RSNs). RSNs can be further divided into smaller regions with hierarchical ICA protocols (van Oort et al, in prep). However, the causal patterns of communication between those regions have not been determined. Determining causal links between brain regions on the basis of BOLD fMRI encounters a few issues (Smith et al, NeuroImage 2011). Firstly, human haemodynamics is slow and therefore acts like a lowpass filter to a neuronal activity. Secondly, data acquisition is much slower than the intrinsic brain dynamics. Thirdly, the signal to noise ratio is low. In my current research, I am developing a new causal inference method which aims at overcoming these issues. I do not include regression in time into the analysis, and concentrate on systematic differences in the shape of the distribution of BOLD values between upstream and downstream regions in the brain. In order to create a data-informed but parameter free method, I simulate simple two-node networks using Dynamical Causal Modeling (Friston et al, NeuroImage 2003) forward model which emulates generation of BOLD fMRI from neuronal networks. I am testing the method on very high quality Human Connectome Project resting-state data. The resulting method outperforms the competitive methods both in terms of causal inference on synthetic datasets, and test-retest reliability on the true HCP datasets. The first causal maps in the brain give new insights into neuronal communication. So far, certain patterns of functional (undirected) connectivity were found in cognitive disorders, including schizophrenia (Lynall et al, J Neurosci 2014) or Major Depression (Greicius et al, Biol Psychiatry 2007). Now, this research can be extended to causal links between brain regions. In certain cognitive disabilities such as ADHD, reliable biomarkers still have not been found, therefore our results open a promising new field of research in psychiatry.

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OC.086.Investigating visual working memory in epileptic children with use of Spectral Granger Causality
6 June 10:00-12:00 (Parallel 4), Session: Neurodynamics

Using spectral Granger causality (GC) on a set of 19-channel EEG recordings, we identified distinct spatio-temporal patterns between the two groups of subjects (control and epileptic children) and the two conditions (GO and NOGO) of a one-back matching visual discrimination working memory task. We show that for the GO task, the highest brain activity in terms of the density of the CC networks is observed in alpha-band for the control group while for the epileptic group the CC network seems disrupted as reflected by the small number of connections. For the NOGO task, the denser CC network was observed in theta-band for the control group while widespread differences between the control and the epileptic group were located bilaterally at the left temporal-midline and parietal areas. In order to test the discriminative power of our analysis, we performed a pattern analysis approach based on fuzzy classification techniques. The performance of the classification scheme was evaluated using permutation tests. The analysis demonstrated that, on average, 87.6 and epileptic. Thus, our findings may provide a helpful insight on the mechanisms pertaining to the cognitive response of children with well controlled epilepsy and could potentially serve as functional biomarkers for early diagnosis.

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OC.087.Steady streaming in standing waves
9 June 17:30-19:30 (Parallel 1), Session: Complex Fluid Dynamics

We report the existence of recirculating eddies existing in the bulk of a liquid under the action of standing surface waves. This phenomenon results from the combined action of the nonlinearity and viscosity. The period of these secondary flows can be, say, one hundred times that of the wave, depending on the amplitude. Our measurements reveal strong disagrements with the theoretical predictions devised hitherto. In order to account for our results, we propose a new mechanism playing a major role in the formation of these rolls.

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OC.088.Detection of structural changes from connectivity analysis
10 June 10:00-12:00 (Parallel 2), Session: Nonlinear Time series Analysis

Structural change detection is evidently important for early warning and prediction in many applications. Granger causality measures have been extensively used in order to capture the connectivity structure of coupled systems and construct causality networks from multivariate time series. Subsequently, network indices are used to quantify characteristics of the causality networks. The aim of this study is to provide a procedure for the identification of changes in the connectivity structure of a high dimensional dynamical system observed through a multivariate time series using Granger causality and network indices. The connectivity structure is estimated on sliding windows on the multivariate time series using the information based Granger causality measure called partial mutual information from mixed embedding (PMIME). Then a large number of network indices, referred to as features, are computed on the estimated causality networks. The features that classify best different connectivity structures are found and the CUSUM (cumulative sum control chart) algorithm is applied to the profiles of these features in order to detect structural change points. Feature selection is also applied in order to select a small feature subset and improve classification efficiency. The proposed procedure was found to identify correctly sharp structural changes and with significant accuracy smooth structural changes in simulations with high dimensional dynamical systems. The same setting was applied to electroencephalogram (EEG) recordings to detect the starting and ending point of an epileptic seizure.

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OC.089.Complex Solutions OF Nonlinear Optimal Control Problems
8 June 13:30-15:30 (Parallel 3), Session: Biophysics

The purpose of this paper is to identify mechanisms implying complex trajectories in dynamic optimization problems. We study epidemic structures and social interactions of subpopulations such as peer effects or the impact of macro behavior to individual propensities. By applying bifurcation methods we are able to show how nonlinear effects may generate multiple equilibria, tipping points and stable limit cycles. The theory is applied to the US-American cocaine epidemic. In particular, we establish the existence of a tipping point. If the number of addicts exceeds this so-called SKIBA-threshold, it is optimal to accommodate between the damage and the costs for control the illicit drug consumption,while below that value eradication is recommended.

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OC.090.Chimera states in two populations with heterogeneous phase lag
9 June 17:30-19:30 (Parallel 4), Session: Neurodynamics

Networks of coupled oscillators are pervasive in natural and engineered systems. These systems are known to exhibit a variety of dynamical behaviors including uniform synchronous oscillation and chimera states, patterns with coexisting coherent and incoherent domains. We study the simplest network of coupled phase-oscillators exhibiting chimera states – namely two populations with disparate intra- and inter-population coupling strengths – and explore the effects of heterogeneous coupling phase lags between the two populations. Such heterogeneity arises naturally in various technological and biological settings. Together with the coupling strengths, differing phase lags can be used to introduce frustration similar to that which results from heterogeneous time-delay, to allow for excitatory-inhibitory interactions, and to model the amplitude and phase responses of oscillators with electrical or mechanical coupling. Breaking the phase-lag symmetry, we find in a variety of states with uniform and non-uniform synchronization, including in-phase and anti-phase synchrony, full incoherence (splay state), chimeras with phase separation of 0 or π between populations, and states where both populations remain desynchronized. These desynchronized states exhibit stable, oscillatory, and even a transition to chaotic dynamics [1]. We analyze the resulting system using symmetry considerations, numerical methods and perturbative approaches, and identify the bifurcations through which chimeras emerge. Our analysis demonstrates that stable chimeras states and novel desynchronized states emerge as a result of competition between synchronized in-phase, anti-phase equilibria and fully incoherent states when the phase lags are near $\pm\pi/2$ (cosine coupling). These findings elucidate previous experimental results involving a network of mechanical oscillators [2] and provide further insight into the breakdown of synchrony in biological systems.

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OC.091.Attractors of relaxation mappings with chaotic dynamics on a fast time scale

7 June 15:00-17:00 (Parallel 4), Session: Complex Systems

Relaxation oscillations, i.e., the processes with multiple time scales are quite common in various natural and technical systems. A distinctive feature for much of the relaxation systems previously considered is that they comprise epochs of slow regular motions alternating with rapid transitions between them. Even if the oscillations exhibited by such systems are chaotic, the chaos takes place due to random jumps between slow regular epochs. In this work we consider a new class of slow-fast systems where the chaotic behavior occurs on a fast time scale and hence the resulting oscillations consist of two types of epochs, one of slow regular and another of fast chaotic motions. Unlike traditionally studied slow-fast systems that have in the phase space smooth manifolds of slow motions and fast trajectories between them, in this new type one observes, apart the same geometric objects, areas of transient chaos. Alternating periods of slow regular motions and fast chaotic ones as well as transitions between them result in a specific chaotic attractor with chaos on a fast time scale. We examine the conditions for appearance of a corresponding relaxation attractor in the framework of discrete-time systems, study basic properties of geometric objects in the phase space underlying such dynamics, and illustrate our results by several examples. Finally, we provide an important application of such systems, the neuronal electrical activity in the form of chaotic spike-burst oscillations.

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OC.092.Stochastic Dynamics of Cancer Growth and Mutations: Modeling Lung Cancer Data
6 June 17:30-19:30 (Paralllel 3), Session: Biophysics

Cancer is a proliferative disease in which cell clones are proliferating and mutating, leading to local and distant invasion of tumors. Of multiple mutations discovered by sequencing cancer genomes, some, the so-called drivers, are under positive selection, while majority, the passengers, are selectively neutral. We extend the infinite-allele simple branching process of Griffiths and Pakes allowing the off spring to change types (due to driver mutations) and labels (due to passenger mutations). The model is developed and limit theorems are provided for the growth of the number of labels of a specific type (McDonald and Kimmel, J Appl Prob, 2015). The purpose of this model is to find a mathematical description of driver and passenger data ascertained from The Cancer Genome Atlas (TCGA), a repository of large numbers of genomes of individual tumors. Specifically, we mined the information in the TCGA lung adenocarcinoma (LUAD) data consisting of about 192018 somatic variants in 542 patients. We identified, using CHASM bioinformatics tool (and other similar tools), the driver and passenger mutations and compared their distributions with the predictions of our branching process. Based on our analyses, we propose a new classification of driver mutations in disjoint categories.

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OC.093.When a reaction contributes to the generation of its reactant or to the destruction of its product
8 June 13:30-15:30 (Parallel 3), Session: Biophysics

The dynamics of a multi-scale pharmacokinetic model are studied. The model simulates the interaction of (i) the drug with a biological target, (ii) their binding and (iii) the results of such an interaction. It is shown that an increase of the reaction rate constant of a reaction leads to an increased level of its reactant or to a decreased level of its product. This unexpected feature is analysed with the Computational Singular Perturbation (CSP) algorithm, which allows for the identification of the slow and fast dynamics and for the understanding of their interaction. With CSP it is possible to identify algorithmically the reactions that (i) generate the fast time scales, (ii) are responsible for the formation of the Slow Invariant Manifold (SIM) on which the multi-scale system evolves according to the slow scales and (iii) drive the system on the SIM. CSP constructs algorithmically the simplified model that is traditionally generated by the Singular Perturbation methodology and provides directions towards the proper use of the conventional approximations of Partial Equilibrium (PEA) and Quasi Steady State (QSSA).

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OC.094.Numerical methods for quasi-conservative systems
6 June 15:00-17:00 (Parallel 3), Session: Nonlinear Dynamics/Bifurcation Theory

Numerical methods exploit peculiar features of either conservative or dissipative systems. Systems with small dissipation, thus, need specific numerical techniques. Our *dribbling method* enabled us to continue periodic solutions avoiding highly degenerate bifurcation points, and follow sequences of periodic orbits with diverging period, for which we introduce a renormalization scheme.

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OC.096.Self-coupling in the FitzHugh-Nagumo model in the limit of short time-delays
6 June 17:30-19:30 (Parallel 4), Session: Nonlinear Dynamics/Bifurcation Theory

We analyze the FitzHugh-Nagumo equations subject to time-delayed self-feedback in the activator variable. Parameters are chosen such that the steady state is stable independent of the feedback gain and delay τ. We demonstrate that stable large amplitude τ-periodic oscillations can, however, coexist with a stable steady state even for small delays, which is mathematically counterintuitive. In order to explore how these solutions appear in the bifurcation diagram, we propose three different strategies. We first analyze the emergence of periodic solutions from Hopf bifurcation points for τ small and show that a subcritical Hopf bifurcation allows the coexistence of stable τ-periodic and stable steady state solutions. Second, we construct a τ-periodic solution by using singular perturbation techniques appropriate for slow-fast systems. The theory assumes $\tau = O(1)$ and its validity as $\tau \to 0$ is investigated numerically by integrating the original equations. Third, we develop an asymptotic theory where the delay is scaled with respect to the fast time scale of the activator variable. The theory is applied to the FitzHugh-Nagumo equations with threshold nonlinearity, and we show that the branch of τ-periodic solutions emerges from a limit point of limit cycles.

T. Erneux, L. Weicker, L. Bauer, and P. Hövel: *The short time-delay limit of the self-coupled FitzHugh-Nagumo system*, Phys. Rev. E **93**, 022208 (2016) .

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OC.097.Unstable modes in bounded slow manifolds

6 June 17:30-19:30 (Parallel 4), Session: Nonlinear Dynamics/Bifurcation Theory

The reactions contributing to the explosive time scale that characterises the autoignition of a homogeneous stoichiometric CH4/ air mixture are identified, using two different chemical kinetics mechanisms; the well known GRI-3 mechanism (53/ 325 species/ reactions with N-chemistry) and a mechanism developed recently (113/710 species/reactions without N-chemistry; Combustion and Flame 162 (2015) 315-330). Although the two mechanisms provide qualitatively similar results (regarding the ignition delay and the profiles of the temperature, of the mass fractions and of the explosive time scale), it is shown that the reactions responsible for the generation of the explosive time scale differ significantly. The present analysis aims in exploring the origin of the increasing accuracy provided by the kinetics mechanisms of increasing complexity.

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OC.098.Multimodal or coupled networks: just a matter of taste?
7 June 10:00-12:00 (Parallel 4), Session: Complex Networks

Populations of phase oscillators can display a variety of synchronization patterns. This depends on the coupling between oscillators and on intrinsic properties like the oscillators' natural frequency. If several populations with unimodal frequency distribution are coupled to one another, the resulting dynamics may resemble that of a single population with multimodally distributed frequencies; see, e.g., [3-5] for related conjectures. Using an Ott-Antonsen ansatz in the all-to-all coupled Kuramoto model [1], we have proven that in the case of two symmetric networks both the subpopulation approach and the bimodal approach are equivalent and lead to the same properties as regards stability, dynamics, and bifurcations [2].

This equivalence strongly suggests a generalization to more complicated set-ups. On the one hand, our findings for two populations seem to be robust when refraining from perfect symmetry assumptions, see, e.g., [5]. On the other hand, the step to more than two populations appears to be not trivial at all. Even in the case of three populations, the network dynamics cease from being analyzed by means of the Ott-Antonsen ansatz.

In our talk, we will address these three points step by step. First, we discuss the dynamics of two coupled symmetric populations of Kuramoto phase oscillators. It turns out that, compared to the bimodal network as has been studied by Martens and co-workers [3], an additional bifurcation parameter enters the system. However, we show that this parameter does not lead to new dynamical behavior, but both descriptions prove to be topologically equivalent. Second, we add asymmtry in the frequency distributions. A starting point here is the work by Pazó and Montbrió [5], which then will be compared against our results. Last, we give an outlook for investigating more than two populations, and discuss chances and problems when comparing the coupled subpopulation approach vis-à-vis the multimodal approach.

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OC.099.Agent-based modeling, forecasting and control of the Ebola Epidemic in Liberia and Sierra Leone
6 June 17:30-19:30 (Parallel 3), Session: Biophysics

Based on multiscale agent-based computations we model, analyse, forecast and design control policies for the Ebola epidemic that swept through Liberia and Sierra Leone within 2014 and 2015. Agents interact through a small-world social network that simulates the underlying transmission network. The model incorporates the main epidemiologic factors, including the effect of burial practices to virus transmission. Estimates of the epidemic variables and network characteristics were computed on the basis of real demographic data and the time series of the official cases as reported by the Centers for Disease Control and Prevention (CDC) with the aid of the Equation-Free approach. The assessment of different policy-control scenarios on population isolation are also provided. Our approach was able to forecast ahead of time the evolution of the Ebola epidemic in Liberia and Sierra Leone throughout the period of the outbreak.

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OC.100.Seismicity Modeling and Analysis of the 2009 L'Aquila Earthquake using complex networks

10 June 10:00-12:30 (Parallel 3), Session: Environmental/ Ecological Dynamics

The monitoring of statistical network properties could be useful for the short-term hazard assessment of the occurrence of mainshocks in the presence of foreshocks. Using successive connections between seismic events acquired from the earthquake catalogue of the Istituto Nazionale di Geofisica e Vulcanologia (INGV) for the case of the LAquila (Italy) mainshock of 6th April 2009, we provide evidence that network measures could potentially be exploited for forecasting purposes both in time and space.

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OC.101.Nonlinear dynamics and catastrophic shifts in a forest-grassland ecosystem
10 June 10:00-12:30 (Parallel 3), Session: Environmental/ Ecological Dynamics

Many ecosytems in nature are characterized by the coexistence of multiple stable states. In such systems sudden shift to one state or to another may manifest as consequence of external disturbances. The most simple cases are bistable systems where two stable states coexist and depending on the initial conditions or the external perturbations, the system may approach to one of the two stable states. Frequently the external disturbances in ecosystems are caused by the human interactions and understanding of the way disturbances influence the dynamics of ecosystems is very important for the prevention and control of ecological disasters which may manifest as a shift of the ecosystem to undesirable stable states. Forest-grassland mosaic ecosystems are typical examples of ecosystems where two species (forest and grass) compete for the same resource (soil, sunlight and space) [1-3]. Previous experimental observations as well as modelling research have shown that forestgrassland ecosystems behave like bistable systems where the bistability is mainly due to a feedback mechanism coming from the fire spreading [4-7]. In particular, it has been observed that if the fire frequency is above a certain threshold, the ecosystem can be maintained in a grassland state, conversely if the frequency is low, forest state is stable. Thus, understanding how the stability of these two state is affected by external perturbations is of primary importance for the management and the control of the forests. Indeed a common way to manage forests in order to prevent fires is for example the deforestation [8-10] which has been demonstrated to be able to maintain savanna in a stable grassland state. Thus human actions have a direct consequence on the dynamics of forest-grassland ecosystems. On the other hand, the evolution of the ecosystem itself influences the human perception of the environment and thus it influences the human activities. Because of these feedback mechanisms, various mathematical models have been developed which consider the human-enviroment interaction as a dynamical system [11,12]. In this work we perform the bifurcation analysis of the forest-grassland ecosystem model proposed by [12] which includes the human inference. The model couples a forest-grassland mosaic system to a dynamic model of rarity-driven perceptions of forest/grassland value.

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OC.102.Melancholia States in the Climate System: Exploring Global Instabilities and Critical Transitions
9 June 15:00-17:00 (Parallel 4), Session: Environmental/ Ecological Dynamics

In bistable systems perturbations may cause the system state to exit one basin of attraction entering the other one. The exit rate and the most probable path of exit are of primary interest. In the weak noise limit the large deviations approach can estimate these based on a quasi- or nonequilibrium potential characterizing the deterministic system. A relevant feature of this quasipotential is a saddle or plateau through which the exit path goes. In this contribution we construct numerically, by applying the edge tracking algorithm, the unstable state of a high-dimensional system belonging to the saddle. The system of our interest is the climate of Earth, which features the snowball-snowfree bistability due to the ice-albedo feedback. The time scale (of $o(10)$ years) of relaxation from the unstable state (upon a small perturbation) to a stable state is widely separated from that of the typical atmospheric dynamics (of $o(10)$ days). In an intermediate-complexity climate model we track down unstable climates in the range of bistability, and find that most of them feature a chaotic atmosphere, just like the warm climate. We find a bifurcation of the unstable climates with increasing solar strength whereby the system develops a large zonal variation pattern, with meridional warm and cold belts, rotating very slowly around the axis of rotation of Earth (taking of $o(100)$ years per revolution).

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OC.103.On Control-Based and Equation-Free Continuation
6 June 17:30-19:30 (Parallel 4), Session: Nonlinear Dynamics/Bifurcation Theory

By either control-based or equation-free continuation it is possible to obtain a numerical bifurcation analysis of macroscopic or low-dimensional quantities describing essential features of high-dimensional microscopic models or experiments. The presentation will focus mainly on the continuation of stable and unstable states. Pros and cons of both approaches are discussed and demonstrated with examples ranging from mechanical systems to traffic and pedestrian flow. The talk includes joint work with E. Bureau, C. Marschler, I. Panagiotopoulos, I. Santos, F. Schilder, J. Sieber and J. Thomsen.

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OC.104.Control-based continuation of pedestrian flows

10 June 10:00-12:30 (Parallel 3), Session: Environmental/ Ecological Dynamics

The behaviour of pedestrians on evacuation scenarios is investigated. Before exiting the facility, pedestrians have to manoeuvre around a triangular obstacle. The collective behaviour of the pedestrians is investigated systematically by changing the position of the obstacle. The macroscopic variable of interest is the difference of flux of pedestrians on each side of the obstacle. Bistability and a hysteresis behaviour is observed where the stable branches consist of the extreme cases where all pedestrians selected the same side of the obstacle. A control-based tracking of the unstable equilibria of the flux separating the stable branches is presented.

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6 Posters

PO.01.Random walk of bouncing particles

Bouncing of sand particles on a vibrating membrane is explored. Vertical movement of particles is accompanied by a transversal one that results in a formation of a Chladni pattern. Although the membrane vibration is harmonic, the generated bouncing of particles is random, and therefore, their horizontal drift represents a random walk.

The experiment is performed on a circular rubber membrane of radius $r_0 =$ 152mm and thickness 1mm. Its principal vibration mode of frequency $f = 36.8$Hz is excited by the air pressure from a speaker underneath the membrane. The distribution of membrane displacement is $z(r) = z_0\, J_0(2.4\, r/r_0)$, where z_0 is the amplitude and J_0 the Bessel function with the first zero at 2.4. The bouncing is excited inside a critical radius $r_c = 95$mm where the vertical acceleration is above g of gravity. In this case $z_0 = 2\, z(r_c)$ and the span of the relative amplitude above the critical level: $A(r) = z(r)/z(r_c) - 1$ is $[0 \leftrightarrow 1]$.

The experiment is performed by quartz particles of approximately tetrahedral form. The distribution of their heights χ is approximately normal with the mean value $\langle\chi\rangle = 1.55$mm and standard deviation $\Delta\chi = 0.38$mm. The kinematics of movement is characterized by trajectories of individual particles. A trajectory is recorded by a photo camera taking 45 successive images at time intervals of $1/3$ s.

From the ensemble of 30 trajectories the horizontal components of particle displacement vectors are determined. Their properties are characterized statistically. The experiment reveals that displacements are random and normally as well as symmetrically distributed around zero. The mean length of the horizontal displacement is approximately proportional to the vibration amplitude and about one fourth of the corresponding bounce height.

For the description of horizontal drifting of particles a model of vibration driven random walk is proposed that yields a good agreement between numerically simulated and experimentally determined data.

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PO.02.Analytical and numerical study of finite-size-induced transitions to synchrony in oscillator ensembles with nonlinear global coupling

In this study, we consider the Kuramoto model of finite number of phase oscillators coupled via a nonlinear mean field, specifically when it is proportional to the the square of the Kuramoto order parameter. Expressed in equation: $\dot{\phi}_k = \epsilon R^2 sin(2\Theta - 2\phi_k)$ where $Re^{i\Theta} = \frac{1}{N}\sum_{k=1}^{N} e^{i\phi_k}$. In many experimental setups, a model that allows for couplings which include higher harmonics is needed, such as electrochemical oscillators and ϕ-Josephson junctions. Moreover, coupling terms can be nonlinear functions of the order parameters. It has also been shown that such a model is microscopically equivalent to a fully connected hypernetwork where interactions are via triplets. As observed first by Komarov and Pikovsky, oscillators of identical frequency and zero noise under such a model form two asymmetrical clusters, and the asymmetrical distribution probability obeys scaling law of $N^{1/2}$. We discuss numerical and statistical approaches, allowing one to establish scaling observed by Komarov and Pikovbsky. Our starting point is to find the breaking point in a chain of phase oscillators when they are brought to synchrony under a conventional Kuramoto mean field. Analytically, we reformulate the Watanabe-Strogatz dynamical equations in complex notations, attempting to find the singularity which corresponds to the "breaking point" or the "unsynchable phase" in the Kuramoto model. Numerically we have been able to locate such a singularity in numerical simulations of all to all coupled oscillators when the unsynchable phase variable actively participates in the mean field. The location of such a phase via passive flow tracer-type variable is also being studied.

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PO.03.High-efficient THz time domain spectroscopy using laser chaos and super focusing with metal v grooved waveguide

A few decades, generation and detection of THz (terahertz) waves had been uncultivated region since simple THz emitters and detectors are not realized and only output power of THz wave can be detected by bolometer which require cooling by liquid helium. With development of femtosecond laser in the 1990s, generation and detection of THz waves have been enabled buy THz-TDS(THz-Time Domain Spectroscpy system). But in this system femtosecond laser which is high cost and its peak power fluctuates several percent is used. Then MLD-THz-TDS(Multimode Laser Diode THz-TDS) using commercially available low cost semiconductor laser was proposed. In this system output power of MLD is stable, however,generated THz waves are unstable and weak (about 10nw output power). And also they are line spectra which are correspond to a multiple of the frequency interval between the laser longitudinal modes and limited below 0.5 THz. In this study, generation of stable and broadband THz waves using laser chaos is investigated. Furthermore, instead of conventionally Si lens, THz electric fields are enhanced with MVG (Metal V Grooved waveguide) by super focusing effects on THz region. In this experience the off-axis focus length of parabolic mirriors are fixed to 4inch. We compere THz time series in which using (a) laser chaos and MVG, (b) CW laser and MVG, (c) laser chaos and Si lens and (d) CW laser and Si lens. Generated THz waves using CW laser ((b),(d)) are unstable and weak, however,using laser chaos ((a),(c)) THz signals are stable and amplitude is about 1.6 with MVG although THz waves are spread in the LT-GaAs substrate between PA and MVG and decrease more than one order.

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PO.04.Effect of light polarization on a signal mode class A laser chaos

The minimal condition for the onset of the deterministic chaos in a dissipative system with continuous variables is the presence of at least three degree of freedom, which was proved by Ruelle and Takens. With regard to laser dynamics, lasers are classified into class A B, and C on the basis of their relationship between decay rates of three relevant variables electric field, population inversion and polarization, which are given by the relaxation rates , // and , respectively. The dynamical behavior of the single mode laser is described by three equations for these three relevant variables that usually decay on very different time scales. Most experimental and theoretical investigations on chaotic dynamics for lasers have been carried out class B and class C lasers. Recently, as reported in our previous papers, the chaotic oscillation of a single mode class A standing wave laser has been observed by optical delayed feedback using an external resonator. The chaotic dynamics of a single-mode class A laser with optical delayed feedback has also been investigated theoretically. In that paper, we derived the equation and using this model, the characteristic frequency is deduced as the round-trip frequency. The characteristic frequency of a single mode class A laser with optical delayed feedback was investigated by using a long external resonator. In that paper, although the round trip frequency was observed but the spectrum is not broadened around the round trip frequency and it is broadened at approximately 10-100Hz. This result is not inconsistent with theoretical one. The population inversion may be effective even on a class A laser. Effects of optical polarization in a class A laser chaos are investigate by comparing the linear polarized and random polarized longitudinal single mode He-Ne laser(6328) in this paper. We observe time series, spectra, phase portraits and Lyapunov exponents for linear and random polarized lasers. The fluctuation of the linear polarized laser is notably larger than that of random one. The ratio of chaos threshold for random polarized laser to linear one is about 1.412=1/cos45which is correspond the average angle between the light polarization of laser output and that of delayed fed back light. It is indicate that the electric fields of the laser inside and delayed fed back laser light directly interact each other and the interaction via the population inversion is negligible small.

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PO.05.Long-term predictability in chaos

In many dissipative dynamical systems that exhibit chaos, one finds parameter regions, where it is hard to tell, whether the attractor is definitely chaotic. These attractors do not “fill-up”a considerable fraction of the phase space, but stay constrained to rather narrow areas, which correspond to formerly stable limit cycles. This is called *chaotic wandering around limit cycles*.

As the average maximum Lyapunov exponent becomes arbitrary small for these attractors, the standard classification for chaos is ambiguous, and it is hard to draw a distinction between chaotic and regular motion. Furthermore, the time-scale, on which two initially close trajectories diverge, is significantly longer than the time-scale of the chaotic motion itself.

In the present work we adress the challenges of characterising the type of chaos described above by theoretical considerations and by numerical simulations. Therefore we present a new method that is capable of distinguishing between chaos and limit cycles in $0-1$ fashion, even for small Lyapunov exponents. The method is both based on analytic work and validated by numerical simulation of well-known standard systems.

Furthermore, we show that for the described type of chaotic motion the finite-time long-term correlation does not vanish. On the one hand this means that we can partially predict the chaotic motion over long time-scales. And on the other hand we are able to differentiate between the partially predictable type of chaos and ordinary chaos by a qualitative aspect. All results are validated and presented for the well-known Lorenz system.

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PO.06.Resonance analysis of a vector soliton propagating an optical fiber with periodically modulated dispersion

The dynamics of a vector soliton that propagates along a fiber with periodically modulated dispersion, strong birefringence and Kerr nonlinearity is studied. The propagation is modeled by two Nonlinear Schrdinger Equations (NLS) coupled through the cross-phase modulation effect. Utilizing the variational approach yields a set of ordinary differential equations that describe a dynamical system of 2+1 degrees of freedom. By expanding the latter around the stationary point up to the third order, it becomes obvious that the dispersion modulation acts like an external drive, while the coefficients of various terms are time-dependent. Taking in to consideration the eigenfrequencies of the system, possible resonances (also parametric) can be uncovered. It is observed that in the case of resonance between the eigenfrequencies and the external drive the soliton is destroyed for very small values of the modulation strength. In comparison with neighboring values of the modulation frequency, in the case of resonance, the modulation strength necessary for soliton destruction is at a local minimum. A resonance between the two degrees of freedom is also uncovered.

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PO.07.Short-term synaptic plasticity generates complex activity patterns of cell assemblies in Hopfield-networks

Spatio-temporal patterns of cell assemblies are thought to be the neural correlates of cognitive information processing, short-term memory storage, and motor control. The relevant time scales of these processes are of the same order as of short-term synaptic plasticity (STP), i. e. a few hundreds of milliseconds.

Starting from Hopfield-type attractor neural networks we turn constant synaptic weights into dynamic variables, using the rules of short-term synaptic plasticity. In the absence of STP active cell assemblies are the stable fixpoints of the system, turning into attractor relicts as a result of synaptic depression. The emerging transient state dynamics consists of regular (limit cycle) and irregular (chaotic) sequences of activity patterns, in which the system revisits the former fixpoint attractors of the Hopfield network.

First we present a dynamical systems analysis of a 4-site symmetric network, showing the possible limit cycle and chaotic behaviours involving cell assemblies of two neurons. Furthermore, by considering random networks up to several hundreds of neurons, we find a large number of coexisting distinct and partially overlapping patterns of cell assemblies. The type of the generated dynamics then depends on the relative strength of excitatory (positive) and inhibitory (negative) synaptic weights. We argue that short-term synaptic plasticity might play an important role in the computational processes of the brain, which should be considered when building new models for this purpose.

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PO.08.Self Consistent Partial Synchronization in simple models

We show the existence of stable Self Consistent Partial Synchronization [SCPS] in a biharmonic Kuramoto-Daido model of globally coupled oscillators with identical frequency. The system is analysed both by evolving a large ensemble of oscillators and the corresponding self-consistent Liouville equation for the probability density. The linear stability analysis leads to an exact integral equation that is solved numerically to determine eigenvalues and eigenvectors. As a result, the region where SCPS is fully stable has been determined and shown to agree with the outcome of the microscopic simulations. Clustered states are also investigated.

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PO.09.A numerical study on the role of nonlinearity of activation function in reservoir computing

Extensive studies in last decades have shown a high information processing performance of reservoir computing (or echo state network). The reservoir computing typically employs the sigmoid function as its activation functions. However, the role of nonlinearity of activation function in the reservoir computing has not been clarified so far. It is expected that necessity of the nonlinearity depends on the type of task to be solved by reservoir computing. If we can clarify the dependency, we will be able to design the reservoir architecture more efficiently, e.g., to choose linear or nonlinear activation function appropriately depending on the task. Goudarzi *et al.* (2015) considered the Taylor expansion of sigmoid function, and showed that a cubic function approximation is enough to capture the computational power of the reservoir for some tasks. Here, we introduce a more direct measure that quantifies how the reservoir dynamics makes use of the nonlinearity of the activation functions. By using this measure, we discuss the role of nonlinearity in reservoir computing based on numerical experiments on some tasks.

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PO.10.Measures of spike train synchrony: Defining a minimum time scale for ISI and SPIKE-distances

Over the years many different methods have been developed in order to quantify spike train similarities. For example, Victor-Purpura [**1**] and Van Rossum [**2**] metrics describe spike train (dis)similarity based on user given time scales. The main drawback of these measures is the fixed time scale, since it sets a boundary between rate and time coding for the whole recording. This means that the result obtained depends on the user input and they do not perform well if the spike trains contain more than one time scale.

These drawbacks have been eliminated in time scale independent ISI [**3**] and SPIKE [**4**] distances by Kreuz et al., since these methods always adapt to the local firing rate. However, while the methods identify correctly the relative firing rate differences, they have no concept of actual time scales. Especially in the presence of bursts this may lead to situations, where the time scale independence identifies small deviations from perfect synchrony as highly dissimilar.

Here we propose an extension to the existing ISI- and SPIKE-distance measures that is based on using a minimum relevant time scale (MRTS). This new version starts to gradually ignore differences in ISI that are smaller than the MRTS. The MRTS can be a parameter, but we also introduce a method for estimating it directly from the data. We perform a pairwise analysis on a library of stereotypical spike trains to show that the correction addresses the shortcomings of the original measures without introducing any side effects.

In summary, our new extension allows for a more accurate estimation of similarity with certain types of data. Especially in the presence of bursts the new version has the advantage of being able to disregard the differences that are too small for the time scales of the underlying system.

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PO.11.SPIKE-order: A new method to sort spike trains from leader to follower

Measures of spike train synchrony (or inversely spike train distances) are estimators of the (dis)similarity between two or more spike trains. The terminology comes from neuroscience where spike train refers to a sequence of stereotypical neuronal action potentials (spikes). However, these measures can also be applied to many other sequences of discrete events.

Over the last years a wide variety of such measures have been introduced. Three recent proposals (ISI-distance, SPIKE-distance, SPIKE synchronization [**1,2,4**]) share the desirable property of being time-resolved and parameter-free (time-scale independent). However, their bivariate versions are symmetric and in consequence their multivariate versions are invariant to changes in the order of spike trains. None of these measures is designed to provide information about directionality.

Here we introduce a method (termed SPIKE order) that allows to sort multiple spike trains from leader to follower. This is meant purely in the sense of temporal sequence. The question asked is: Which are the spike trains that tend to fire first, and which are the ones that tend to fire last? Leader-follower dynamics are encountered frequently not only in neuroscience, but also in fields as wide-ranging as climatology, social communication, and human-robot interaction.

The algorithm uses the adaptive coincidence detection first proposed for the bivariate measure event synchronization [**3**] and then also employed in SPIKE synchronization to identify pairs of coincident spikes. For these pairs the consistency of the leader-follower relationship is quantified resulting in the final SPIKE order value.

Analyzing a spike train set with SPIKE order yields three kinds of results: How close is the original and how close is the optimal sorting to a synfire chain (consistent repetition of the same sequence of spikes), and which is the optimal sorting. The new method is distinguished by conceptual simplicity, flexibility, low computational cost, and universality (parameter-free and time-scale adaptive).

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[4] Source codes: http://www.fi.isc.cnr.it/users/thomas.kreuz/sourcecode.html; https://github.com/ma

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PO.12.Testing human mobility models with commuters data.

Empirical human mobility models have been proposed in the past by social scientist using an unproved analogy with gravitational attractions. Recently statistical physicists have derived well argued models based on some simple and reasonable assumptions. The radiation model [1] the intervening opportunities model [2], the uniform selection model [3] and the radiation model with selection [3] are only a few of such successful approaches. Here we test and comment the applicability of these models by processing a complete commuter and population database from Hungary.
[1] Simini F, Gonzlez MC, Maritan A, Barabási AL (2012); Nature 484: 96. [2] Stouffer SA (1940); American Sociological Review 5: 845867. [3] Simini F, Maritan A, Néda Z. (2013); PLoS One. 8(3):e60069.

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PO.13.Winding-number sequences for periodically driven oscillators

Bifurcation sets of periodically driven symmetric and asymmetric nonlinear oscillators are investigated and classified by means of winding numbers. It is shown that periodic windows within chaotic regions are forming winding number sequences on different levels. These sequences can be described by a simple formula that makes it possible to predict winding numbers at bifurcation points. Symmetric and asymmetric systems follow similar rules for the development of winding numbers within different sequences and these sequences can be combined into a single general rule. Examples are taken from the double-well Duffing oscillator, a special two-parameter Duffing oscillator, and a bubble oscillator.

[1] V. Englisch et al., Phys. Rev E 92, 022907 (2015)

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PO.14.Methods and applications for attractor comparison

We present and evaluate different approaches for comparing attractors in terms of distributions of points in (reconstructed) state space. The main goal of these methods is to quantify differences between attractors. Applications of this kind of attractor comparison are methods for estimating model parameters from time series and tools for detecting and identifying coexisting attractors in nonlinear systems analysis. Examples illustrating methods and applications will be given.

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PO.15.Velocity versus distance scaling in human travel

It is a well known fact that further we travel, the faster we go. This effect leads to nontrivial scaling-like relations between the average traveling velocity and travel distance on quite extended scales. Scaling is present for all mobility types taken together and also for a given type of mobility in part. Terrestrial, air traveling velocities, and even the propagation of digital information through the world wide web follows such universal laws. The characteristic exponents on the other hand does not prove to be universal and depends on the studied system. We offer a wide range of experimental results, investigating and quantifying this universal effect and its measurable causes. The increasing traveling speed with the travel distance arises from the combined effects of: choosing the most appropriate traveling type; the structure of the travel networks; the travel times lost in the main hubs, starting or target cities; and the speed limit of roads and vehicles.

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PO.16.Direct perturbation theory for dark-bright solitons: Application to Bose-Einstein condensates

We develop a direct perturbation theory for dark-bright solitons and derive evolution equations for the soliton parameters. In particular, first the linearization equation around the solitons is solved by expanding its solution into a set of complete eigenfunctions of the linearization operator. Then, suppression of secular growth in the linearized solution leads to the evolution equations of soliton parameters. The results are applied to a number of case examples motivated by the physics of atomic Bose-Einstein condensates, where dark-bright solitons have recently been studied both in theory and in experiments. We thus consider perturbations corresponding to (a) finite temperature induced thermal losses, and (b) the presence of localized (δ-function) impurities. In these cases, relevant equations of motion for the dark-bright soliton center are in agreement with ones previously obtained via alternative methods, including energy-based methods, as well as numerical linear stability analysis and direct simulations.

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PO.17.Amplitude death of identical oscillators in networks with direct coupling

Motivating the study is the fact that amplitude death is possible in networks of weakly coupled identical oscillators close to an Andronov-Hopf bifurcation if they interact via linear diffusive coupling links with time delay, yet amplitude death is impossible for such networks if the oscillators interact via direct coupling, where direct coupling refers to coupling functions that are entirely independent of the state of the receiving oscillator. In contradistinction to this previous work, we investigate networks with arbitrary coupling strengths. We consider systems where both the node dynamics and the coupling may include time delay. We find several interesting oscillation quenching mechanisms for delay-coupled nodes whose dynamics is described by first order delay differential equations and show that amplitude death in the strict sense arises for delay-coupled nodes of second-order delay differential equations.

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PO.18.Bifurcation analysis of coupled heterogeneous phase oscillators

Many biological systems such as heart cells show oscillating behavior. These systems can be modeled by using coupled self-oscillatory and excitable units, e.g., coupled phase oscillators. Biological systems often possess *excitability* that the system oscillates only when an external stimulus is injected into the system. A phase oscillator $\theta(t)$ which is defined as $\dot{\theta}(t) = f(\theta, \alpha, b) = 1 - b\sin(\theta(t) + \alpha)$, has excitability. Because this oscillator has a stable equilibrium point if $b > 1$, it cannot oscillate by itself. We have studied a system composed of these N excitable phase oscillator $\dot{\theta}_j(t) = 1 - b_j \sin(\theta_j + \alpha_j) + \frac{K}{N}\sum_{i=1}^{N} \sin(\theta_i - \theta_j)$, where $j = 1, \ldots, N$. We have found that the oscillation spontaneously occurs under a certain condition of parameters. We have also revealed that the condition is characterized by saddle-node bifurcation on invariant circle and heteroclinic bifurcation. In our presentation, we will report these findings in detail. This research was partially supported by JSPS KAKENHI Grant No. 26730127.

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PO.19.Fractal Dimension of Self-Affine Signals: Four Methods of Estimation.

In this study, four methods for analyzing a fractal signal were used to estimate the fractal dimension. The first of these is the Higuchi method for the fractal dimension (D) computation. The others are calculating of the spectral decay (β) and estimation of the generalized Hurst exponent (H) and detrended fluctuation analysis. In case of self-affine processes, there exists the next relationship between the fractal dimension, Hurst exponent, and spectral decay: $D = 2 - H = \frac{5-\beta}{2}$. Thanks to that, any of the computed characteristics can be used to estimate the fractal dimension. The aim of this study is to find out which of the four methods is the most accurate. For this purpose, two types of test data with known fractal dimensions ($D = 1.2, 1.4, 1.5, 1.6, 1.8$) were generated: the graph of the Weierstrass function and the fractional Brownian motion. Then the four methods were used to estimate the value of D. Critical impact of noise and the length of the data was also considered. Of all the methods discussed, the Higuchi method and the generalized hurst exponent were generally best, while the spectral decay gave the most biased results.

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PO.20.Modelling culture-dependent transcriptional dynamics of mouse Embryonic Stem Cells

Embryonic stem cells (ESCs) are pluripotent, which means they have the potential to differentiate into most other cell types. Also, ESCs can be kept in an undifferentiated state for multiple generations (self-renewal). The study of ESCs is a rapidly growing field of interest, with the potential to develop new regenerative medicine treatments. Although the scientific community is making rapid progresses in understanding ESCs, an in depth characterisation of the underlying processes is still missing.
In particular, it is crucial to define culture conditions optimised for pluripotency maintenance. Serum+LIF, the standard culture medium, promotes heterogeneous expression of pluripotency genes of mouse ESCs (mESCs); conversely, the recently proposed 2i+LIF medium forces mESCs into a selective and overall homogenous ground state of pluripotency (Ying et al., Nature 2008, Marks et al., Cell 2012).
We developed a novel mathematical model to describe the different transcriptional dynamic in the two culture conditions. Stochastic Differential Equations, based on Hill kinetics, were used to describe the interactions of the core pluripotency network genes (Oct4, Sox2 and Nanog), the inhibitors present in 2i+LIF (PD and Chiron), and genes identified from RNA sequencing of mESCs cultured in the two conditions (Marks et al., Cell 2012).
Our model reproduces the Nanog profile experimentally measured using a novel reporter cell line in the two media (Nanog Nd mESCs, Abranches et al, 2013), as well as the redistribution of populations upon sorting. Continuation analysis highlights the role of the inhibitors in the 2i+LIF medium and of each gene in regulating the system dynamics, ultimately suggesting experimental perturbations.

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PO.21.Pattern formation on a flame front

Nonlinear coupling between the flame front dynamics with the acoustic field of a system gives rise to a very interesting phenomenon called thermoacoustic instability. This phenomenon is widely studied in the fields of fluid dynamics, acoustics and combustion science research to obtain a deeper understanding of the occurrence of this phenomenon. The general approach is to understand the various physical mechanisms that are responsible for the onset of this nonlinear behavior and also to control or suppress this instability. The phenomenon is also an engineering problem as its unexpected occurrence in practical systems could cause fatal, large thermal and mechanical vibrations in the system.

These nonlinear oscillations that emerge from the coupling are highly complex; Bifurcations, scenarios and chaotic thermoacoustic oscillations have been previously identified. The source of nonlinearity is the flame/combustion process.

In experiments on a very simple thermoacoustic system, which involves a premixed flame, we have observed that nonlinear bifurcations are accompanied by spatio-temporal patterns on the flame front. As the bifurcation parameter of the system is gradually varied, the structure of the pattern also undergoes variation.

Motivated to shed light on the phenomenon, in this submission, I will report the observation of spatio-temporal flame surface patterns, their characteristics, and provide details that could help in explaining the observations.

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PO.22.Coherence Resonance leads to precursors to thermoacoustic instability

The phenomenon of thermoacoustic coupling arises in a practical systems such as gas turbine engines, aero-engines and industrial boilers is due to the time-delayed feedback coupling between the unsteady combustion process and the acoustics of the combustion chamber. Such real systems are inherently noisy due to the presence of highly turbulent flow conditions. Thermoacoustic systems are also nonlinear and the onset to the instability is characterized by Hopf—often subcritical—bifurcation. For a variety of nonlinear systems, it has been shown that noise can lead to non-trivial dynamics, particularly close to the bi-stable regime associated with subcritical Hopf bifurcation. Here, we experimentally investigate noise-induced dynamics in a model thermoacoustic system.

It has been shown, experimentally and analytically, that noise can induce transition to instability in thermoacoustic systems within the bi-stable region. Recently we have shown in laboratory experiments that noise influences the thermoacoustic system even prior to the bi-stable regime. We have demonstrated that the non-trivial noise-induced response of the system corresponds to coherence resonance, where an optimum coherence is induced at an intermediate level of noise intensity. The response is observed in acoustic variables as well as in flame intensity fluctuations, indicating that the thermoacoustic coupling process is involved in the observed noise-induced dynamics.

With this submission we would like to take further step and discuss the connection between previously reported precursors to onset of thermoacoustic oscillations and their characteristics and coherence resonance. This study will broaden the current understanding of the stochastic dynamics of thermoacoustic systems. The subject is one of the least well-understood aspects of thermoacoustic coupling.

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PO.23.Parameter estimation and tracking of the variables in a stochastic two-scale Lorenz 96 chaotic system

Researchers in some of the most active fields of science, including, e.g., geophysics or systems biology, have to deal with very-large-scale stochastic dynamic models of real world phenomena for which conventional prediction and estimation methods are not well suited. In this work we propose a novel probabilistic method to jointly track the dynamic variables and approximate the posterior probability density functions of the fixed model parameters of a stochastic version of the two-scale Lorenz 96 chaotic system. The two-scale Lorenz 96 system displays the basic features of atmospheric dynamics and, for this reason, the deterministic version of this model has been commonly used as a benchmark model for data assimilation and parameter estimation techniques in meteorology and climate science. The stochastic model that we consider preserves the essential dynamics of the original system but introduces some degrees of freedom that exploit for the tracking and approximation method. We illustrate the performance of the proposed scheme by means of computer simulations with 16 slow and 160 fast dynamic variables as well as several unknown parameters.

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PO.24.Convergence to the stationary state in the Hassell mapping

We investigate the convergence to the fixed point and near it in a transcritical bifurcation observed in a Hassell mapping. We considered a phenomenological description which was reinforced by a theoretical description. At the bifurcation, we confirm the convergence for the fixed point is characterized by a homogeneous function with three exponents. Near the bifurcation the decay to the fixed point is exponential with a relaxation time given by a power law. Although the expression of the mapping is different from the traditional logistic mapping, at the bifurcation and near it, the local dynamics is essentially the same for either mappings.

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PO.25.Multistability and noise induced switching in rings of reactively coupled oscillators

Multistability is a ubiquitous property of complex nonlinear systems with examples ranging from gene regulation to power grids and social systems. A multistable deterministic dynamical system settles in one of its stable attractors depending on the initial conditions; however, in the presence of noise the long-term behavior of the system is no longer characterized by deterministic attractors. Depending on the level of noise, the system fluctuates around an attractor, but it is occasionally kicked to the basin of attraction of a different attractor. This offers a coarse-grained description of the dynamics: we define an attractor switching network (ASN) where each node represents an attractor and the links connecting nodes represent the likelihood of switches. Recently, noise or external perturbation induced jumps in the ASN were suggested as a feasible strategy to control large scale non-linear systems. However, to design efficient control strategies the structural properties of the ASN have to be known.

Here, we contribute to this effort by investigating rings of reactively coupled limit cycle oscillators which have multiple stable states, each characterized by a rotating wave. The dynamics of our choice describe systems of coupled nanoscale mechanical oscillators – a subject of recent experiments. Setting up the analysis, we enumerate and describe all possible deterministic attractors, we determine the linear stability of the states and we provide a closed-form expression that predicts the systems response to small noise. We then study attractor switching via numerical simulations by preparing the system in a stable attractor of the deterministic dynamics and letting it evolve until the system switches to another state; we record the time needed to switch and the new state. We show that the tail of the switch time distribution is consistent with an exponential distribution, indicating that the typical time needed to switch is well characterized by its average. We systematically study the effect of number of oscillators, coupling strength and noise strength on the average switch time and the ASN. We show that the system spends disproportionately more time in states that are the most stable linearly.

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PO.26.Braess paradox in Complex Flow Networks

Flow networks support much of our technical infrastructure, like the electrical power grid; and many biological systems; like the flow of sap through leaf veins. Understanding and improving the stability properties of flow networks therefore have huge implications in various fields of science.

When a flow network is overloaded, for example, due to increased energy demand, adding more links is assumed to be the solution. However, it has been reported that [**?**, **?**] often adding a link may *decrease* the stability of a flow network rather than increase it. This phenomena is known as Braess paradox [**?**].

Here we present a statistical analysis of the occurence of such a phenomena in a variety of complex networks. We show that Braess paradox persists across a wide variety of network topologies.

We find that different random graph ensembles show different scaling behaviours in the percentage of Braessian edges with respect to network size.

We study the topological distribution of BE's in the network. We find that in Barasi-Albert networks, BE's are clustered in the close vicinity of the maximally loaded edge. But square lattices and Voronoi tesselated graphs do not exhibit this behaviour.

We also find that in Barabasi-Albert networks, BE's tend to form a large giant component, whereas in other network models they are more scattered throughout the network.

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PO.27.Stochastic dynamics of bipolar field resistive switching

We have considered a memristor-like model for the hysteretic modulation of the electric resistance of a transition metal oxide (TMO). Its functionality is determined by the electrode-TMO interface and the distribution of oxygen vacancies. We started with a one-dimensional lattice model, in which the vacancies hop between the lattice sites depending on the external voltage and the local resistance is proportional to the number of vacancies. Formulating the corresponding master equation and taking the continuum limit, we drew a generalized Burgers equation to interpret the dynamics of oxygen vacancies as nonlinear traveling waves. Further, by introducing a collateral scalar variable characterizing the distribution of the vacancies, we can build a connection to a analytically solvable nonlinear model based on the complementary resistive switch and the original Strukov memristor model, which we finally discuss for its dynamics.

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PO.28.Structural connectivity outlines recruitment networks in partial epilepsy

In partial epilepsy, seizures originate in a local network, the so-called epileptogenic zone, before recruiting other close or distant brain regions. Correctly delineating the epileptogenic and the propagation zone is essential for successful resective surgery. In particular the stereotaxic EEG (SEEG) is used to edge the zone to resect. However the propagation pathways of epileptic seizures are still largely unknown. Using a specific dynamical model for epilepsy [1], we then predict the recruitment network given the seizure origins and we try to understand the role played by the topology in constraining the recruitment process. The indentification of the minimal number of connections that allows the seizure to propagate and the choice of the optimal set of links to be cut in order to stop seizure propagation might reveal an approach to improve the success rate of epilepsy surgery.

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PO.29.SIQ epidemic model

Profound understanding of infection spread processes and the influence of local contact structure is of crucial importance not only in the medical sciences [1,4]. The systematic analysis of epidemics started with the famous model of Kermack and McKendrick [2], already emphasized the significance of infection duration and was recently extended to the network approach [3]. After the identification of critical delay time τ_∞ to prevent epidemic spread on networks with delayed transition of infecteds into isolation [5], the authors investigated the corresponding expressions in proposed collective dynamics. For $\tau < \tau_0$ isolation is particularly effective. For larger values of the delay, the isolation of individuals may still prevent an outbreak, but quite counterintuitively, the release after long time of isolation might cause the disease to reappear periodically for highly infectious diseases. In this case, the fast spread leads to many people taken into quarantine in a short time span. In turn, the release of this cohort from quarantine, causes a new outbreak.

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PO.30.Ripening with Volume Growth

The evolution of a particle size distribution under equilibrium thermodynamic conditions–Ostwald ripening–is commonly described by a set of non-linear coupled differential equations for the droplet radii. It can be derived in the appropriate continuum limit of a stochastic process (Becker-Döring theory). In the early 1960s Lifshitz, Slyozov and Wagner suggested that the size distribution function converges asymptotically towards a universal, self-similar scaling solution. In the early 2000s Niethammer and coworkers showed that this solution is not universal. Rather, there are multiple solutions with non-trivial domains of attraction in the space of size distribution functions.

Here, we generalize Niethammer's formulation of the dynamics to explore the impact of the overall particle growth. The additional terms in the dynamics involve the dimensionless parameter $k = 1+\xi/\sigma Dn$ where ξ is the growth rate of the droplet volume fraction, D the diffusion coefficient governing diffusive growth of the particles, n the particle number density and σ the Kelvin length, i.e. a length of the order of the thickness of the interface characterizing the particle surface. For $k = 1$ we recover classical Ostwald ripening, as expected for $\xi = 0$. Any initial condition with $0 < k - 1 \ll 1$ will involve droplet evaporation such that n decreases. Thus, k grows until evaporation ceases for $k > 3/2$. A new type of solutions emerge, where the size distribution becomes monodisperse and where the initial conditions have a persistant impact of the shape of the distribution function. There are no universal solutions any longer. In conclusion, classical Ostwald ripening is structurally unstable with respect to sustained, arbitrarily small perturbations of the equilibrium conditions.

We provide two examples where this fundamentally different dynamics must be accounted for: 1. nano-particle synthesis where the overall particle volume is not preserved but it grows due to precursor reactions or addition of material. 2. growth of rain droplets where slow adiabatic cooling of the cloud induces a net growth of the overall droplet volume.

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PO.31.Climate Modeling Considering Non-equilibrium Thermodynamics

By looking back the history of atmospheric dynamics development and by reviewing the climate dynamics progress, the present statue of climate dynamics and its existing problems are investigated. Thereby a new approach to climate modeling on the basis of non-equilibrium thermodynamics is suggested, and necessary and possibility of developing the thermo-oriented numerical model of the climate system are presented. The physical principle and mathematical formulation of the model, which emphasize on thermodynamic effects, are demonstrated, and hence we advocate the research and the design of the thermo-oriented numerical model afterward.

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PO.32.Scaling laws associated to a symmetry-break in the energy distribution in a set of dynamical systems: application to discrete mappings

In this project we investigate the dynamics of some systems described by mappings near two types of phase transition: (i) integrability to non-integrability; (ii) limited to unlimited energy diffusion (Fermi acceleration). Our main goal is to describe the behavior of the probability energy density for a set of particles moving in a chaotic way. The break of symmetry in the probability energy density leads to an additional scaling, up to now, described only phenomenologically. The first observation in a area preserving mapping was in Physical Review Letters 93, 014101 (2004), authored by Edson D. Leonel, Peter V. E. McClintock and Jafferson K. L. Silva. Considering the solution of the Diffusion Equation at the chaotic sea of the phase space, we may describe this behavior, caused by the symmetry-break, in an analytical approach, leading to scaling laws associated to the dynamics. It will be a new approuch for this kind of phenomenon in a set of dynamical systems described by discrete mappings. Furthermore, the generalization to time dependent billiard is immediate and is in the scope of the present project.

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PO.33.The effect of hidden source on the estimation of causality networks

In multi-variate dynamical systems and time series analysis the topic of Granger causality is of increasing interest. Many methods related to linear and nonlinear fitting, embedding, frequency, phase and information have been developed to assess the causal relationships between the system's variables based only on the information extracted from the time series. In many studies it has been a subject of research the degree to which these methods are able to capture the true underling connectivity structure using simulated dynamical systems where the ground truth is known. In regression as well as time series problems, models are built under the assumption of latent or hidden variables. Here, we consider the presence of unobserved variables that act as hidden sources for the observed high-dimensional dynamical systems. We study the effect of a hidden source on the estimation of the connectivity structure. The study examines the performance of different Granger causality measures on settings of unobserved source. For the simulations, the coupled Mackey-Glass and the neural mass model, each comprised of 25 subsystems at chain coupling structure and another subsystem driving all others. The results show that the causality measures estimate in general terms correct the existing connectivity in the absence of the hub (when the driving strength is zero or weak), yet fail to detect the actual relationships when a strong driving hub variable is present. An example from finance is also illustrated.

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PO.34.Epileptic seizures in the unfolding of a high codimension singularity.

Epileptic seizures can arise under a big variety of conditions. Despite this big variability there are some invariant features that consistently characterize their electrophysiological signature. Jirsa et al. 2014 investigated these universal properties in the light of dynamical system theory, and proposed a taxonomy of seizures based on Izhikevichs classification of fast-slow bursters. They also built a phenomenological model, the Epileptor, able to reproduce the main characteristics of the predominant class of human seizure (around 80% of cases), according to data from epileptic patients.

We generalize the Epileptor model in order to include other bursting classes of the taxonomy and we provide a framework to investigate the coexistence of different types of seizures in the same patient and to explain transitions among them.

To this goal we use a powerful approach proposed by Golubitsky et al. 2001, based on the idea that the bifurcations of the fast subsystem involved in bursting activity can be collapsed to a single local bifurcation, generally of higher codimension. Through the systematic investigation of the unfoldings of codimension 3 singularities we find most of the classes predicted by Izhikevich. We propose a model, based on the normal form of the unfolding of one of these singularities, that is able to produce bursting activity for all the identified classes. The Epileptor class belongs to this model, together with the classes that in Jirsa et al. 2014 could account for the remaining 20% of data. Furthermore, transitions between bursting classes are possible, together with transitions to regions in the parameter space in which bursting is not possible at all. Most importantly, using clinical cases, we find direct evidence in epileptic patients for the transitions predicted by the model. The possibility of describing different seizure types with a unique model, and thus with a unique set of variables and parameters, will also facilitate the search for physiological correlates for the model's elements.

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PO.35.Pattern formation in the Walgraef-Aifantis model for dislocation dynamics

It is well known that dislocations during plastic deformation are responsible for many instabilities that have been experimentally observed within metals. Dislocation patterning is a highly complex process which is the result of the interplay of multiple time and length scales ranging from the atomic and microscopic to meso and macroscopic ones. Despite this complexity, the resulting patterns are extremely well organized in the space and time [1]. This surprising behavior, which is very similar to many others observed in other complex systems, has suggested the adoption of methodologies coming from the complex systems theory for a system-level analysis (e.g. Self organized criticality, bifurcation theory, symmetry in PDEs, chaos theory, etc.). Indeed, scale-free behavior, symmetry breaking mechanisms and the presence of periodic regimes as well as regular spatial structures are just some of the dislocation dynamics ingredients which indicate the non linear nature and complexity of dislocation processes [1-3]. Theses instabilities,which manifest when the system is far from equilibrium [2, 3, 4,5] are particularly evident when the material is subjected to cyclic loading and are the consequence of the complex interplay between inherent nonlinearities, diffusion-like transport and creation-annihilation feedback mechanisms. Consequently, the use of non-linear dynamics techniques for systems-level modeling and analysis (bifurcation, stability) is necessary for a deeper understanding of the transitions which bring the system from equilibrium to dislocations patterning and oscillation. In this work, we study the dynamics of the well known WalgraefAifantis (W-A) model [2,3]. The system consists of two partial differential equations of reaction diffusion type with a polynomial nonlinearity of order two in the one dimensional finite domain. We study the nonlinear dynamics of the system as the diffusion coefficients are varied. First, we conduct a linear analysis by considering perturbations around the homogeneous state in time and space (that is the equilibrium). The conditions for complex spatial patterning (Turing instabilities) and time periodic oscillations (Hopf bifurcations) from the equilibrium are then extracted and we proceed to the bifurcation analysis of the PDEs [6-8].

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PO.36.Symmetry locking in a periodically switched ring network

We analyse transitions between symmetric and asymmetric regimes in a ring network with periodically forced connections. In particular, the network consists of a ring where the connections are periodically switched (ON/OFF) with a circular law. We consider, as an example, a sequence of n reactors where the feed position is periodically shifted according to a permutation law. We analyse the symmetry-breaking phenomena which are consequence of interaction between the natural and external forcing action. As the main parameters are varied due to the presence of Neimark-Saicker bifurcations, the system exhibits periodic regimes where the periods are exact multiples of the period of the forcing or quasi-periodic regimes. In addition to the standard phenomenon of frequency locking, we observe symmetry breaking transitions. While in a symmetric regime all the reactors in the network have the same time history, symmetry breaking is always coupled to a situation in which one or more reactors of the ring exhibit a greater temperature than the others. We found that symmetry is broken when the rotational number of the limit cycle, which arises from the Neimark-Saicker bifurcation, is an specific ratio. Finally, symmetry locking and resonance regions are computed through the bifurcational analysis to detect the critical parameters which mark the symmetry-breaking transitions.

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