Talk abstracts for CIDNET14
(alphabetical order, seminar AND workshop) *July 2, 2014*

Order patterns in time series and models of 1/f noise

Bandt, Christoph
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Permutation entropy is widely used to evaluate the complexity of time series of moderate length. For long time series, multiscale analysis of all order patterns will give more information, as we shall demonstrate with examples from medicine, wheather, internet traffic, and music.
A very interesting case is pink noise where frequencies of order patterns do not depend on the scale, We analyse several models and applications of pink noise and present a simple new model.

Information flow and phase transitions in complex systems

Barnett, Lionel
(University of Sussex, Sackler Centre for Consciousness Science, Department of Informatics, Brighton, United Kingdom)

The impact of network structure on criticality in cortical circuits

Beggs, John M.
(Indiana University, Department of Physics, Bloomington, USA)

Cortical circuits have been hypothesized to operate near a critical point for optimality. Previous evidence supporting this largely came from bulk field potential signals that did not show individual neuron activity. Using a 512 electrode array, we recorded hundreds of spiking neurons in vitro at sub-millisecond temporal resolution for 1 hour or more. Using a multi-delay version of transfer entropy (Ito, Hansen, Heiland et al., 2011) we constructed information transfer networks among hundreds of cortical neurons. We found three main things: (1) Avalanche shapes can be collapsed onto a universal scaling function, a key indicator of criticality (Freidman et al., 2012); (2) A simple algebraic expression constrains how three of the critical exponents must relate to each other; (3) The network structure of information transfer strongly influences the critical exponents of the system. Taken together, this work raises a new question: How do networks of cortical neurons change synaptic strengths during learning, yet still manage to satisfy the constraints of criticality?

Harmful algal blooms and the prediction of extreme events in networks

Bialonski, Stephan
(Max Planck Institute for the Physics of Complex Systems, Dresden, Germany)

Symbolic Causation Entropy

Cafaro, Carlo
(Clarkson University, Mathematics, Potsdam, NY, USA)

Transfer entropy is a causality inference measure of directed time-asymmetric information transfer between joint processes originally introduced by Schreiber in Ref. [Schreiber, T. Measuring information transfer. Phys. Rev. Lett., 2000, 85, 461]. Despite its undisputed success, causal relationship inferred by transfer entropy can be misleading when the underlying complex system contains indirect connections, dominance of neighboring dynamics, or anticipatory couplings. Inspired by the concept of transfer entropy, Sun and Bollt have recently introduced in Ref. [Sun, J.; Bollt, E. M. Causation entropy identifies indirect influences, dominance of neighbors and anticipatory couplings. Physica D, 2014, 267, 49] the notion of causation entropy, a generalization of transfer entropy, which works well also for time-dependent complex networks where, for instance, indirect interactions between subsystems can occur.

In this Contribution, we propose to estimate causation entropy by means of symbolic computational techniques. Specifically, we present both theoretical and numerical investigations in order to address its implementation, its computational speed, and its robustness against noise in applications to both synthetic and real-world time series data. Finally, merits and limitations of symbolic causation entropy in inferring cause-effect relations from observations are emphasized.

Noise focusing: the emergence of coherent activity in neuronal cultures

Casademunt, Jaume
(Univeristat de Barcelona, Faculty of Physics, Estructura i Constituents de la Matèria, Barcelona, Spain)

At early stages of development, neuronal cultures in vitro spontaneously reach a coherent state of collective firing in a pattern of nearly periodic global bursts. Although understanding the spontaneous activity of neuronal networks is of chief importance in neuroscience, the origin and nature of that pulsation has remained elusive. By combining high-resolution calcium imaging with modelling in silico, we show that this behaviour is controlled by the propagation of waves that nucleate randomly in a set of points that is specific to each culture and is selected by a non-trivial interplay between dynamics and topology. The phenomenon is explained by the noise focusing effect—a strong spatio-temporal localization of the noise dynamics that originates in the complex structure of avalanches of spontaneous activity. A detailed explanation of the phenomenon is provided together with an accurate characterization of avalanches with power-las statistics. The emergence of a complex hierarchical functional network out of the underlying metric network is discussed. Finally, a coarse-grained continuum model is introduced to describe neuronal tissues in terms of an effective excitable medium subject to unusual noise dynamics.

Edge Localized Modes (large scale energy release events) in magnetically confined plasmas for fusion: coincidence, causality, predictability or synchronization?

Chapman, Sandra
(University of Warwick, Centre for Fusion, Space and Astrophysics, Physics, Coventry, United Kingdom)

Fast reconfiguration of high-frequency human brain networks in response to surprising changes in auditory input

Chapman, Sandra
(University of Warwick, Centre for Fusion, Space and Astrophysics, Physics, Coventry, United Kingdom)

S. C. Chapman [1,2,3], R. Nicol[4] , P. Vertes[5], P. Nathan[5,6], M. Smith[7], Y. Shtyrov[8], E. Bullmore [5,6]
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We measured rapid changes in functional human brain network organization in response to brief, discrete, changes in auditori stimulii. We estimated network topology and distance parameters in the immediate response, < 1 s, following auditory presentation of standard, repeated tones interspersed with occasional 'surprising' tones, using MEG to measure synchronization of high frequency (gamma band 33-64 Hz) oscillations in healthy volunteers. We found that global small-world parameters of the networks were unchanged between the standard and surprising tones. However, auditory surprises were associated with local changes in clustering of connections between temporal and frontal cortical areas, and with increased interlobar, long-distance synchronization. This work maps the dynamic network response that corresponds to the well-known evoked response time domain signature of this mismatch-negativity paradigm and is the first step towards a clinical diagnostic. Extracting the dynamic network of physical signals from multiple sensors, with non-uniform sensor response functions and time varying signal/noise presents significant challenges which will also be discussed.

The brain at the edge

Chialvo, Dante R.
(Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), , Argentina)

It is well known that dynamical systems posed near a second order phase transition generate a bewildering variety of robust and flexible behavior, associated with the abundance of metastable states at the critical point. This universal feature led us to argue, since the last millennium, that the most

fundamental cognitive properties of the functioning brain are only possible because it is spontaneously located at the border of such instability. These results will be discussed at the light of recent theoretical efforts to understand which aspects of the mind dynamics can be usefully explained in terms of the brain (statistical) physics.

Pitfalls in Partial Mutual Information and beyond

Davidsen, Jörn
(University of Calgary, Department of Physics and Astronomy, Complexity Science Group, Calgary, Alberta, Canada)

Structural and funktional networks in nerve cell cultures and the brain

Davidsen, Jörn
(University of Calgary, Department of Physics and Astronomy, Complexity Science Group, Calgary, Alberta, Canada)

Geometric approaches to detecting coupling directions and synchronization - A complex network perspective

Donner, Reik
(Potsdam Institute for Climate Impact Research (PIK), Research Domain IV - Transdisciplinary Concepts & Methods, Potsdam, Germany)

Recently, a variety of approaches have been introduced for transforming time series into complex network representations and analyzing their dynamical properties in terms of graph characteristics. Specifically, recurrence networks encoding proximity relationships between sampled state vectors in the phase space of dynamical systems allow linking network topology with distinct aspects of nonlinear dynamics and attractor geometry. Beyond the solid mathematical theory establishing the geometric interpretation of recurrence network properties (Donges et al., 2012), recently there have been first attempts to generalizing this viewpoint for studying coupled dynamical systems.

This presentation will describe recent results and highlight some open challenges to establishing a rigorous theoretical framework of multivariate recurrence network analysis. Numerical investigations of paradigmatic model systems demonstrate good capabilities for numerically detecting coupling directions (Feldhoff et al., 2012) as well as signatures of generalized synchronization (Feldhoff et al., 2013) from bi- and multivariate time series data. Remarkably, both methods again rely on geometric information rather than temporal structures encoded within the time series under study.

This contribution is dedicated to the commemoration of our PhD student Jan Feldhoff, who developed the two approaches to multivariate recurrence network analysis during his master thesis. He passed away unexpectedly on 1 March 2014.

Causal Inference from Multivariate Time Series: Principles and Problems

Eichler, Michael
(Maastricht University, School of Business and Economics, Department of Quantitative Economics, Maastricht, Netherlands)

In time series analysis, inference about cause-effect relationships among multiple time series is commonly based on the concept of Granger causality, which exploits temporal structure to achieve causal ordering of dependent variables. One major and well known problem in the application of Granger causality for the identification of causal relationships is the possible presence of latent variables that affect the measured components and thus lead to so-called spurious causalities. This raises the question about whether Granger causality is an appropriate tool for causal learning; indeed, there are many researchers that deny any such claim.

To answer the question in more depth, we present a graph-theoretic approach for describing and analysing Granger-causal relationships in multivariate time series that are possibly affected by latent variables. It is based on mixed graphs in which directed edges represent direct influences among the variables while dashed edges---directed or undirected---indicate associations that are induced by latent variables. We show how such representations can be used for inductive causal learning from time series and discuss the underlying assumptions and their implications for causal learning. Finally we will discuss non-Markovian constraints imposed by latent variable structures and how these can be exploited for causal inference.

Network Inference from Irregular Time Series

Elsegai, Heba
(University of Aberdeen, Institute of Complex System and Mathematical Biology, Mathematical Sciences , Aberdeen, United Kingdom)

Mutual information: estimation & applications to inference of gene interaction networks and phylogenetic trees

Grassberger, Peter
(Forschungszentrum Jülich, John von Neumann Institute for Computing, Jülich, Germany)

TIME-SERIES BASED PREDICTION OF DYNAMICAL SYSTEMS AND COMPLEX NETWORKS

Grebogi, Celso
(University of Aberdeen, Institute for Complex Systems and Mathematical Biology (ICSMB), King's College, Aberdeen, United Kingdom)

TIME-SERIES BASED PREDICTION OF DYNAMICAL SYSTEMS AND COMPLEX NETWORKS

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Evolutionary games model a common type of interactions in a variety of complex, networked, natural systems and social systems. Given such a system, uncovering the interacting structure of the underlying network is key to understanding its collective dynamics. Based on compressive sensing, we develop an efficient approach to reconstructing complex networks under game-based interactions from small amounts of data. The method is validated by using a variety of model networks and by conducting an actual experiment to reconstruct a social network. While most existing methods in this area assume oscillator networks that generate continuous-time data, our work successfully demonstrates that the extremely challenging problem of reverse engineering of complex networks can also be addressed even when the underlying dynamical processes are governed by realistic, evolutionary-game type of interactions in discrete time.

Network reconstruction based on evolutionary-game data via compressive sensing, W.-X. Wang, Y.-C. Lai, C. Grebogi, and J. Ye, Phys. Rev. X 1, 021021 (2011)
Predicting catastrophe in nonlinear dynamical systems by compressive sensing, W.-X. Wang, R. Yang, Y.-C. Lai, V. Kovanis, and C. Grebogi, Phys. Rev. Lett. 106, 154101 (2011)
Forecasting the future: Is it possible for adiabatically time-varying nonlinear dynamical systems?, R. Yang, Y.-C. Lai, and C. Grebogi, Chaos 22, 033119 (2012)
Optimizing controllability of complex networks by minimum structural perturbations, W.-X. Wang, X. Ni, Y.-C. Lai, and C. Grebogi, Phys. Rev. E 85, 026115 (2012)

Predicting and triggering long jumps and sticks in molecular diffusion

Hallerberg, Sarah
(MPIDS Göttingen, Network Dynamics, Göttingen, Germany)

Diffusion can be strongly affected by ballistic flights (long jumps) as well as long-lived sticking trajectories (long sticks). Using statistical inference techniques in the spirit of Granger causality, we investigate the appearance of long jumps and sticks in molecular-dynamics simulations of diffusion in a prototype system, a benzene molecule on a graphite substrate. We find that specific fluctuations in certain, but not all, internal degrees of freedom of the molecule can be linked to either long jumps or sticks. Furthermore, by changing the prevalence of these predictors with an outside influence, the diffusion of the molecule can be controlled. The approach presented in this proof of concept study is very generic, and can be applied to larger and more complex molecules. Additionally, the predictor variables can be chosen in a general way so as to be accessible in experiments, making the method feasible for control of diffusion in applications. Our results also demonstrate that data-mining techniques can be used to investigate the phase-space structure of high-dimensional nonlinear dynamical systems.

Co-occurrence of symbols in a sequence

Hernandez Lahme, Damian Gabriel
(Instituto Balseiro and Centro Atomico Bariloche, CNEA and CONICET, Centro Atómico Bariloche, The Statistical and Interdisciplinary Physics Group, Bariloche, Argentina)

Unveiling latent variables through triplet analysis

Hernandez Lahme, Damian Gabriel
(Instituto Balseiro and Centro Atomico Bariloche, CNEA and CONICET, Centro Atómico Bariloche, The Statistical and Interdisciplinary Physics Group, Bariloche, Argentina)

Using computational models to relate structural and functional brain connectivity.

Hlinka, Jaroslav
(Academy of Sciences of the Czech Republic, Institute of Computer Science, Department of Nonlinear Dynamics and Complex Systems, Prague, Czech Republic)

Modern imaging methods allow a non-invasive assessment of both structural and functional brain connectivity. This has lead to the identification of disease-related alterations affecting functional connectivity. The mechanism of how such alterations in functional connectivity arise in a structured network of interacting neural populations is as yet poorly understood. Here we use a modeling approach to explore the way in which this can arise and to highlight the important role that local population dynamics can have in shaping emergent spatial functional connectivity patterns. The local dynamics for a neural population is taken to be of the Wilson-Cowan type, whilst the structural connectivity patterns used, describing long-range anatomical connections, cover both realistic scenarios (from the CoComac database) and idealized ones that allow for more detailed theoretical study. We have calculated graph-theoretic measures of functional network topology from numerical simulations of model networks. The effect of the form of local dynamics on the observed network state is quantified by examining the correlation between structural and functional connectivity. We document a profound and systematic dependence of the simulated functional connectivity patterns on the parameters controlling the dynamics. Importantly, we show that a weakly coupled oscillator theory explaining these correlations and their variation across parameter space can be developed. This theoretical development provides a novel way to characterize the mechanisms for the breakdown of functional connectivity in diseases through changes in local dynamics.

Importance of Randomness in networks: A Random matrix theory framework

Jalan, Sarika
(IIT Indore, Physics, Indore, India)

Random matrix theory, initially proposed to understand the complex interactions in nuclear spectra, has demonstrated its success in diverse domains of science ranging from quantum chaos to galaxies. We demonstrate the applicability of random matrix theory for networks providing a new dimension to complex systems research. We show that in spite of huge differences these interaction networks (representing real world systems) bear from random matrix models, the spectral properties of these networks follow random matrix theory bringing them into the same universality class. The talk would highlight importance of randomness in interactions in deducing crucial properties of underlying system, and potential of this framework to understand efficient information transmission in biological networks.

Unstable neuronal network dynamics precedes transition to seizure and seizure termination.

Jiruska, Premysl
(Academy of Sciences of the Czech Republic, Institute of Physiology, Department of Developmental Epileptology, Prague, Czech Republic)

Seizures are traditionally viewed as sudden and unpredictable shifts in brain dynamics. However, growing experimental evidence suggests that seizures can be preceded by detectable changes in the dynamics of neurons and neuronal populations. In our study we have examined neuronal and network behaviour during seizures and periods between them to determine the nature of these seemingly sudden transitions.

Experiments were performed in vitro in rat hippocampal slices perfused with artificial cerebrospinal fluid containing low-calcium (0.2 mM). Field potentials from the hippocampal CA1 region were recorded using multiple extracellular electrodes. Temporal profile of the early warning signals of critical transitions were examined together with active perturbation of the neuronal dynamics by application of electric fields and antidromic stimulation.

Results demonstrated that the dynamics of both transition to seizure and seizures was characterized by progressive increase in lag-1 autocorrelation, shift to low-frequencies and spatial expansion of synchrony. Approaching seizure was preceded by progressive increase of the sensitivity of the CA1 neuronal network to external perturbations.

Obtained results suggest that the dynamics of the CA1 hippocampal networks is characterized by switching between two different dynamical states. Progressively, each state becomes unstable and results in the shift to the other regime. Transition between each of these two regimes displays features of critical slowing down.

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The reconstruction of dynamical physiological networks from time series

Kantelhardt, Jan W.
(Martin-Luther-Universität Halle-Wittenberg, Institute of Physics, Halle, Germany)

The human organism is an integrated network where complex
physiological
systems, each with its own regulatory mechanisms, continuously interact,
and where
failure of one system can trigger a breakdown of the entire network.

Identifying and quantifying dynamical networks of diverse systems with different types of interactions is a challenge. Time-delay stability analysis is presented as a tool to probe interactions among diverse systems and identify a physiological network from recorded time series data. Different physiological states are characterized by specific network structures, demonstrating a robust interplay between network topology and function. Across physiological states, the network undergoes topological transitions associated with a fast reorganization of physiological interactions on time scales of a few minutes. The signs of the corresponding non-zero time delays might be considered as hints towards the causality of the interactions.

Causality versus predictability

Kantz, Holger
(Max Planck Instititute for the Physics of Complex Systems, Dresden, Germany)

Dynamic causal modelling for magneto- and electroencephalography

Kiebel, Stefan
(Max-Planck-Institut für Kognitions- und Neurowissenschaften, Neurologie, Leipzig, Germany)

Experimental research in cognitive neuroscience increasingly focuses on the connectivity among brain areas when human subjects perform specific tasks. Here, I will motivate and describe a hypothesis-driven approach for the analysis of effective connectivity: Dynamic Causal Modelling (DCM) for EEG and MEG data. This approach is based on a combination of nonlinear dynamical system with Bayesian inference techniques and can be applied to several data types like evoked responses, induced and evoked power data or phase responses. I will illustrate the use of DCM using evoked response potentials acquired under the mismatch negativity paradigm and show how the technique can easily be applied to other auditory experimental paradigms. In particular, DCM uses Bayesian model comparison which allows one to identify the model which best explains the data, both for single- and multi-subject data.

Epidemic spreading on complex networks

Kocarev, Ljupco
(Macedonian Academy of Sciences and Arts, Skopje, Macedonia, the Former Yugoslav Republic of)

Many contagions or infections spread over various types of communication networks and their spreading dynamics have been extensively studied in the literature.

In this talk, I will discuss recently proposed model for the concurrent spread of an arbitrary number of contagions in complex networks. The model is stochastic and runs in discrete time, and includes two widely used mechanisms by which a node can change its state. The first, termed the decay mechanism, is spontaneous transition to another state, while the second, termed the growth mechanism, describes acquiring other infections due to contact with the neighbors. Our work is among the first to approach the reactive discrete time process with time steps of finite size for spreading of multiple concurrent contagions, without neglecting the possibility of multiple infecting events in a single time step.

Next, I discuss both an upper and a lower bound for the probability that a particular node is infective in a susceptible-infective-susceptible model for two cases of spreading processes: reactive and contact processes. The bounds are derived by considering the n-hop neighborhood of the node; the bounds are tighter as one uses a larger n-hop neighborhood to calculate them. Consequently, using local information for different neighborhood sizes, we assess the extent to which the topology influences the spreading process, thus providing also a strong macroscopic connection between the former and the latter. Our findings are complemented by numerical results for a real-world email network. A very good estimate for the infection density is obtained using only two-hop neighborhoods, which account for 0.4% of the entire network topology on average.

Finally, I will present an analytical solution for the susceptible infectious susceptible (SIS) model in a network with heterogenous susceptibility and recovery probabilities, and show that the basic reproductive number of an infection is equal to the eigenvalue of a topology-infection matrix, which we approximate when information about the topology of the network is limited. Our results show that the incorporation of differential susceptibility to the SIS model makes networks more vulnerable to the spread of diseases and that this increased vulnerability is enhanced when individuals are more likely to connect with others that have similar susceptibility and/or recovery probabilities (the network is segregated).

Data-driven network inference: What's next?

Lehnertz, Klaus
(University of Bonn, Dept of Epileptology, Bonn, Germany)

Abstract: Complex networks have been recognized to be powerful representations of spatially extended systems and can advance our understanding of their dynamics. A large number of analysis techniques is now available that aim at inferring the underlying network from multivariate recordings of system observables. Despite great successes in various scientific fields, there still exist a number of problems, both conceptual and methodological, for which there are currently no satisfactory solutions.
In this talk, I will present some of these problems and will discuss possible research directions that may help to find better solutions.

Large-scale epileptic networks (Colloquium)

Lehnertz, Klaus
(University of Bonn, Dept of Epileptology, Bonn, Germany)

More than 50 million individuals worldwide approximately 1 % of the worlds population suffer from epilepsy.
Epileptic seizures are the cardinal symptom of this multi-facetted disease and are usually characterized by
an overly synchronized firing of neurons. Seizures cannot be controlled by any available therapy in about 25%
of individuals, and knowledge about mechanisms underlying generation, spread, and termination of the extreme event seizure in humans is still fragmentary. There is now increasing evidence for the existence of large-scale epileptic networks in which all constituents can contribute to the generation, maintenance, spread,
and termination of even focal seizures as well as to the many pathophysiologic phenomena seen during the
seizure-free interval. In this talk, I will provide an overview of the progress that has been made in understanding the dynamics of large-scale epileptic networks and will discuss challenging issues associated
with the inference of weigthed and directed functional networks from multivariate recordings of brain dynamics.

Synergy, and a Novel Maximum Entropy Estimator

Martin, Elliot
(University of Calgary, Physics and Astronomy, Calgary, Canada)

Testing the robustness of functional network methods, and novel information theoretic techniques

Martin, Elliot
(University of Calgary, Physics and Astronomy, Calgary, Canada)

Graph Theorical analysis of EEG on focal onset seizures: Extra- and Intra-cranial Recordings

Marín, Arlex
(Universidad Autonoma del Estado de Morelos, Faculty of Science, Computational Modelling, Cuernavaca, Mexico)

Graph theoretical analysis of functional networks of the brain have provided useful information on the dynamics that underlie on several pathological and non-pathological processes on the human brain. In this study we apply a set of graph-theoretical measures on extra- and intracranial peri-ictal recordings of focal onset seizures. Both local and global properties of these complex networks are analyzed, giving insight on the neurophysiological processes that might govern the structural changes in correlation patters found in different phases of the peri-ictal EEG. In particular we discuss possible mechanism of seizure offset.

Sleep, criticality and information processing in the brain

Meisel, Christian
(Universitätsklinikum Carl Gustav Carus, Klinik und Poliklinik für Neurologie, Dresden, Germany)

The general idea that both the computational capabilities of a system and its complexity are maximized at or nearby critical states related to phase transitions or bifurcations (Langton 1990) led to the hypothesis that neuronal networks in the brain may operate at or close to a critical state. Moroever, without sleep optimal brain functioning such as responsiveness to stimuli, information processing or learning may be impaired. Therefore one could hypothesize that sleep deprivation will change the brain dynamics into a less critical state and sleep is necessary to restore criticality. In the talk I will present results from joint work with Christian Meisel and Peter Achermann on changes of signatures of critical brain dynamics during sustained wakefulness in humans and discuss them in the context of recent experimental findings on "critical brain dynamics" on the one hand side and theories about the function of sleep on the other side.

Are epileptic seizures condensed sleep?

Müller, Markus
(Universidad Autonoma del Estado de Morelos, Facultad de Ciencias , Departamento de Física, Cuernavaca, Mexico)

It is well known that seizures may disturb sleep architecture, but also that sleep disruption and sleep deprivation predispose to seizures even in healthy subjects. There is undoubtedly a strong interrelation between sleep and seizures. Seizures occur with higher probability during a drowsy state, or even during sleep. On the other hand, seizures during wakefulness are often followed by so called post-ictal sleep. Instead of estimating probability distributions of the likelihood for the occurrence of seizures we focus in this study on the comparison of dynamical changes during sleep and seizures. Univariate properties like the evolution of power spectra as well as multivariate aspects as given by the graph theoretical analysis of the functional network are considered. We find multiple qualitative similarities in the evolution of brain activity during focal onset seizures and sleep cycles, although the time scales as well as the magnitude of the dynamical changes are different for both phenomena. Our results lead to the hypothesis that the physiological function of seizures is the compensation of sleep-deficiencies and that they may be interpreted as a kind condensed sleep on small time scales.

How to orchestrate a football team?

Müller, Markus
(Universidad Autonoma del Estado de Morelos, Facultad de Ciencias , Departamento de Física, Cuernavaca, Mexico)

Predictive information, adaptation, criticality, and all that

Nemenman, Ilya
(Emory University, Department of Physics, Theoretical Biophysics Lab, Atlanta, USA)

Predictive information, or information between past and future of a time series, allows to build bridges among very distinct branches of science. I will introduce this quantity, and discuss its properties. Then I will show how it unites the concepts of adaptation in evolutionary biology and physiology, by providing an upper bound on the growth of adaptive populations. I will further explain how predictive information allows to recast the theory of critical phenomena in physics in an information-theoretic or a learning-theoretic language.

Information theoretic approaches to complex systems

Olbrich, Eckehard
(Max Planck Institut für Mathematik in den Naturwissenschaften, Leipzig, Germany)

(research overview talk)

Information transfer across scales and levels

Olbrich, Eckehard
(Max Planck Institut für Mathematik in den Naturwissenschaften, Leipzig, Germany)

The transfer entropy introduced by Schreiber (2000) used conditional mutual information to operationalize the concept of Granger causality for nonlinear systems (see e.g. Barnett et al. 2009). Already in the original paper Schreiber demonstrated that the direction of the information transfer could depend on the observational scale. Nevertheless, in this case the observational scale was the same for both observed processes.
In this talk I will argue that instead of observing two processes at the same scale one could also consider the information transfer between different scales in a single process. In particular we will use the information flow between scales to identify specific observational levels (coarse grainings) that allow for a self-sufficient description of the process.

Transfer Entropy reconstruction of neuronal networks from calcium imaging data

Orlandi, Javier
(Universitat de Barcelona, Estructura i Constituents de la Materia, Spain)

Neuronal dynamics are fundamentally constrained by the underlying structural network architecture, yet much of the details of this synaptic connectivity are still unknown even in neuronal cultures in vitro. In this talk I will present a new reconstruction method, a generalization of Transfer Entropy, to the reconstruction of structural connectivity of neuronal networks from calcium imaging data, both in vivo and in silico. I will show how our method manages to reconstruct the network connectivity from very noisy signals and disentangles causal influences from spurious correlations. I will also show how the method can be adapted to work with both excitatory and inhibitory connections at the same time. Due to the model-free nature of the developed measure, both kinds of connections can be reliably inferred in silico.

Homoclinic bifurcations in low-Prandtl number Rayleigh-Bénard convection

Pal, Pinaki
(National Institute of Technology Durgapur, Mathematics, Durgapur, India)

We present the results of investigation of homoclinic bifurcations and pattern dynamics near the onset of convection of low-Prandtl number fluids. Rayleigh-Bénard geometry with free-slip boundary conditions has been considered for the study. Detailed direct numerical simulations (DNS) of the three dimensional governing equations have been performed for the investigation. DNS validated low dimensional models have also been used for the study.

Cross-scale information transfer: atmospheric dynamics

Palus, Milan
(Academy of Sciences, Institute of Computer Science, Dept. of Nonlinear Dynamics and Complex Systems , Prague 8, Czech Republic)

The complex dynamics of the Earth atmosphere and climate evolve on a wide range of temporal and spatial scales. Analyses of the low-frequency variability on seasonal to decadal time scales have led to detection of oscillatory phenomena possibly possessing a nonlinear origin and exhibiting phase synchronization between oscillatory modes extracted either from different types of climate-related data or data recorded at different locations on the Earth [1-4]. We study nonlinear interactions between dynamics on different temporal scales in about a century long records of daily mean surface air temperature from various European locations using conditional mutual information together with the Fourier-transform and multifractal surrogate data methods [5]. Information transfer from larger to smaller scales has been observed as the influence of the phase of slow oscillatory phenomena with periods around 6-11 years on amplitudes of the variability characterized by smaller temporal scales from a few months to 4-5 years. The overall effect of the slow oscillations on the inter-annual temperature changes within the range 1-2 K has been observed in large areas of Europe [6].

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Bridging the gap between self-organized criticality and the dynamics of neural activity in vivo

Priesemann, Viola
(Max-Planck-Institute for Dynamics and Self-Organization, Non-linear Dynamics, Göttingen, Germany)

Self-organized criticality (SOC) has been proposed to govern neural activity, because neural activity in vitro shows power-law distributions. However, for spiking activity in vivo, evidence for SOC is still lacking. Therefore we analyzed highly parallel spike recordings from rats, cats and monkeys and compared these to spike activity from an established SOC neural model. We showed fundamental differences between the neural activity and SOC. These differences could be overcome by eliminating the separation of time scales (STS) from the SOC model, and by making the model slightly sub-critical. The same results were obtained for avalanches from local field potentials in humans. Our results show that neural activity is better approximated by a slightly sub-critical regime that is driven (i.e., without a STS), than by a SOC state proper. Potential advantages are faster information processing capacities due to the loss of STS, and a safety margin from super-criticality, which has been linked to epilepsy.

Reconstructing effective phase connectivity of oscillator networks from observations

Rosenblum, Michael
(Potsdam University, Physics and Astronomy, Statistical Physics / Theory of Chaos Group, Potsdam, Germany)

We present a novel approach for recovery of the directional connectivity of a small oscillator network by means of the phase dynamics reconstruction from multivariate time series data.
The main idea is to use a triplet analysis instead of the traditional pair-wise one.
Our technique reveals effective phase connectivity which is generally not equivalent to structural one.
We demonstrate that by comparing the coupling functions from all possible triplets of oscillators, we are able to achieve in the reconstruction a good separation between existing and non-existing connections, and thus reliably reproduce the network structure.

Network inference from time-series measurements

Rubido, Nicolas
(University of Aberdeen, Institute for Complex Systems and Mathematical Biology (ICSMB), Department of Physics, Aberdeen, United Kingdom)

Inferring the underlying network of a complex system from observed data is nowadays the object of intense research. In order to infer the underlying network, usually, the observed data comes from time-series recorded at the different units composing the complex system. Then, a direct link between units is assumed depending on how interdependent these observations are. However, the limits for the inference of direct links in real-world systems composed by interacting dynamical units are still not fully understood. Here, I am going to make a brief overview of the inference of networks from time-series measurements, focusing on two of the most commonly used statistical tools: the Pearson Cross-Correlation and the Mutual Information.

Causality & information theory

Runge, Jakob
(Potsdam Institute for Climate Impact Research, Transdisciplinary Concepts & Methods - Research Domain IV, Potsdam, Germany)

Quantifying causal interactions from time series of complex systems

Runge, Jakob
(Potsdam Institute for Climate Impact Research, Transdisciplinary Concepts & Methods - Research Domain IV, Potsdam, Germany)

This talk deals with the problem of detecting the existence and quantifying the strength of causal interactions from time series of complex systems. I address this topic from an information-theoretic perspective, but will develop the framework also using linear measures.
In the first part of the talk, the primary goal is to infer the existence of causal interactions including time lags which will be approached using a causal algorithm that alleviates the curse of dimensionality commonly faced in such multivariate settings. The second part focuses on the problem of defining meaningful measures of the strength of these interactions based on a physical intuition and substantiated by some rigorous mathematical results.
The potential of the novel approach will be illustrated by studying mechanisms in the climate system like the Walker circulation in the tropical Pacific.

Reconstruction of causality from short, unevenly sampled environmental time series

Röder, Heidelinde
(Carl von Ossietzky University of Oldenburg, Institute for Chemistry and Biology of the Marine Environment (ICBM), Oldenburg, Germany)

Network inference from spike trains and time series

Sauer, Tim
(George Mason University, Mathematics, USA)

We consider parametric and semiparametric methods for inferring network structure from dynamical data. For multivariate spike trains, we discuss the Cox method from survival analysis and evaluate its success in determining network links. For multivariate time series, we implement a realtime method based on data assimilation that fits connection strengths as parameters. Since the data assimilation approach is model-based, we investigate the role of model error, and suggest a new approach to reconstructing poorly modeled and unmodeled variables.

Chimera States in Coupled Oscillator systems

Sethia, Gautam
(Institute for Plasma Research, Nonlinear Physics Division, Nonlinear Center, Gandhinagar, India)

Assessing the Strength of Directed Influences Among Neural Signals: An Approach to Noisy Data

Sommerlade, Linda
(University of Aberdeen, Institute for Complex Systems and Mathematical Biology, Physics, Aberdeen, United Kingdom)

Measurements in the neurosciences are afflicted with observational noise. Granger-causality inference typically does not take this effect into account. We demonstrate that this leads to false positive conclusions and spurious causalities. State space modelling provides a convenient framework to obtain reliable estimates for Granger-causality. Despite its previous application in several studies, the analytical derivation of the statistics for parameter estimation in the state space model was missing. This prevented a rigorous evaluation of the results. We derive the statistics for parameter estimation in the state space model, and demonstrate in an extensive simulation study that our novel approach outperforms standard approaches and avoids false positive conclusions about Granger-causality. The application to mice electroencephalogram data demonstrates the immediate applicability of our approach.

Understanding the grammar behind genome

Srivastava, Shambhavi
(University of Aberdeen, Institute of Complex System and Mathematical Biology, Physics, Aberdeen, United Kingdom)

Chromatin-based regulation: A computational interpretation and the role of ncRNAs

Stadler, Peter
(Universität Leipzig, Institute of Institute of Mathematics and Computer Science, Bioinformatics, Leipzig, Germany)

Chromatin regulation is one of the fundamental modes of gene regulation in eukaryotic cells. We argue that the basic proteins that determine the chromatin architecture constitute an evolutionary ancient layer of transcriptional regulation common to all three domains of life. We explore phylogenetically, sources of innovation in chromatin regulation, focusing on protein domains related to chromatin structure and function, demonstrating a step-wise increase of complexity in chromatin regulation.

Eukarya secondarily acquired mechanisms for "writing" chemical modifications onto chromatin that constitute persistent signals. The acquisition of reader domains enabled decoding of these complex, signal combinations and a decoupling of the signal from immediate biochemical effects. Interestingly, large non-coding RNAs appear to have a key function in organizing and targeting of at least parts of the chromatin modification machinery. The coupling of reading and writing, which is most prevalent in crown-group Eukarya, could have converted chromatin into a powerful computational device capable of storing more information than pure cis-regulatory networks and enabling the processing of this information in a discrete, ``digital'' fashion. If such mechanisms are indeed as prevalent as the available data lead us to think, we will have to profoundly rethink our view of the gene regulatory system.

Non-coding RNAs appear to play a crucial role in interfacing classical modes of gene regulation with a chromatin-based processes. Recent data demonstrate that the genome of higher multicellular organims are dominated by long non-coding RNAs that may be key to the rise of phenotypic complexity.

This is joint work with Sonja J. Prohaska

Cellular Inference

Stumpf, Michael
(Imperial College London, London SW7 2AZ, United Kingdom)

Cells need to sense a multitude of signals and cues respond to their environment appropriately. Molecular reaction networks process these signals and marshal the appropriate cellular response. They are themselves, however, affected by many other processes inside the cell and this affects their ability to process any signal reliably.
I will discuss some of the rich behaviour that can be observed for biological signal transduction systems. I will draw to roughly equal measure on recent experimental studies and analysis of the stochastic dynamics of molecular signalling processes to highlight some of the general features. In particular I will show how we can pinpoint sources of noise and study the interplay between molecular noise and the dynamics of signalling systems. These different factors need to be considered jointly from the outset in order to gain an appreciation of how cells (or single cell organisms) draw inferences about their environment.

Causal Network Inference by Optimal Causation Entropy

Sun, Jie
(Clarkson University, Mathematics, Potsdam, USA)

The broad abundance of time series data, which is in sharp contrast to limited knowledge of the underlying network dynamic processes that produce such observations, calls for an general and efficient method of causal network inference. Here we develop mathematical theory of Causation Entropy, a model-free information-theoretic statistic designed for causality inference. We prove that for a given node in the network, the collection of its direct causal neighbors forms the minimal set of nodes that maximizes Causation Entropy, a result we refer to as the Optimal Causation Entropy Principle. This principle guides us to further develop computational and data efficient algorithms for causal network inference. Analytical and numerical results for Gaussian processes on large random networks highlight that inference by Optimal Causation Entropy outperforms previous leading methods including Conditional Granger Causality and Transfer Entropy. Interestingly, our numerical results also indicate that the number of samples required for accurate inference depends strongly on network characteristics such as the density of links and information diffusion rate and not on the number of nodes.

Quantifying the Complexity of Population Structure

Tal, Omri
(MPI MIS Leipzig, Leipzig, Germany)

Can we provide measures of the underlying complexity of high-dimensional population-genetic data?

One perspective is to associate complexity with measures of population 'clusteredness'. Motivated by Shannon's axiomatic approach in deriving a unique information measure for communication, I identify a set of intuitively justifiable criteria that any such quantitative measure should satisfy, where the notion of communication noise can be made analogous to sampling noise. I show that standard information-theoretic measures such as mutual information or relative entropy cannot satisfactorily account for this sense of information, necessitating methods from statistical-learning. I also review recent empirical work of biologists to assess the 'population signal' from genetic samples.

A comparison between the resting state of the brain and the brain in a language task

Tapia, Luis
(Universidade Estadual de Campinas, Instituto de Física "Gleb Wataghin", DRCC, Campinas, Brazil)

A study of the resting state of the brain using fMRI and NIRS

Tapia, Luis
(Universidade Estadual de Campinas, Instituto de Física "Gleb Wataghin", DRCC, Campinas, Brazil)

Insight into earthquake sequencing: A graph theoretic approach to modified Markov chain model

Vasudevan, Kris
(University of Calgary, Geoscience, Calgary, Canada)

We construct a directed graph to represent a Markov chain of global earthquake sequences and analyze the statistics of transition probabilities linked to earthquake zones. For earthquake zonation, we consider the simplified plate boundary template of Kagan, Bird, and Jackson (2010). We generalize this Markov chain of earthquake sequences by including the recurrent events in space and time for each event in the record-breaking sense. The record-breaking recurrent events provide the basis for redefining the weights for the state-to-state transition probabilities. We use a distance-dependent look-up table for each zone to assign the distance-dependent weights for the recurring events. From this modified Markov chain, we obtain a time-series of state-to-state transition probabilities. Since the time-series is derived from non-linear and non-stationary earthquake sequencing, we use known analysis methods to glean new information. We apply decomposition procedures such as ensemble empirical mode decomposition (EEMD) to study the state-to-state fluctuations in each of the intrinsic mode function. We subject the intrinsic mode functions, the orthogonal basis set derived from the time-series using the EEMD, to a detailed analysis to draw information-content of the time-series. Also, we investigate the influence of random-noise on the data-driven state-to-state transition probabilities. We consider a second aspect of earthquake sequencing that is closely tied to its time-correlative behavior. Here, we extend the Fano factor and Allan factor analysis to the time-series of state-to state transition frequencies of a Markov chain. Our results support not only the usefulness the intrinsic mode functions in understanding the time-series but also the presence of power-law behaviour exemplified by the Fano factor and the Allan factor.

(A presentation co-authored with Dr. Micahel Cavers of the Department of Mathematics and Statistics)

Time continuous linear Granger causality

Wahl, Benjamin
(University of Oldenburg, Institute for Chemistry and Biology of the Marine Environment, Theoretical Physics/Complex Systems, Oldenburg, Germany)

Wind farm measurements and ECoG signals

Wahl, Benjamin
(University of Oldenburg, Institute for Chemistry and Biology of the Marine Environment, Theoretical Physics/Complex Systems, Oldenburg, Germany)

Comparison of modern causality measures: PDC, TE, MIME and PMIME

Wan, Xiaogeng
(Imperial College London, Imperial College London, Mathematics, London, United Kingdom)

Modern causalities are developed to detect causal effect between interacting units. Many of them are generalized from the notion of Granger causality, but target the causal detection problem from different angles. In this paper, we present a thorough comparison study among different causality measures, namely, the partial directed coherence (PDC), transfer entropy (TE), conditional mutual information from mixed embedding (MIME) and partialized MIME (PMIME). We use various time series model from theoretical maps to analytical models and real EEG data, in order to test the effectiveness and efficiency of measures. From this study, we conclude with property comparison of linearity, directness, computation speed and applications, as well as suggestion of parameter choice for future applications.

Transfer of information between cardiac time series

Wejer, Dorota
(The University of Gdańsk, Institute of Theorethical Physics and Astrophysics, Gdańsk, Poland)

From network dynamics to network structure and back

Zochowski, Michal
(University of Michigan, Physics, 1440 Randall Lab , Ann Arbor, USA)

Interaction of nodal and network connectivity properties in neuronal networks

Zochowski, Michal
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