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Institute for Advanced Study

Symposium

"Self-Organization in Complex Systems: The Past, Present and Future of Synergetics"

Delmenhorst, Nov. 13 – 16, 2012

Organizers:
PD Dr. Axel Pelster, HWK/Technische Universität Kaiserslautern
Prof. Dr. Günter Wunner, Universität Stuttgart

Program

Venue:

Hanse-Wissenschaftskolleg
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International Symposium
Self-Organization in Complex Systems: The Past, Present, and Future of Synergetics

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In numerous systems of both living and nonliving nature complex spatio-temporal or functional patterns of self-organization processes are ubiquitous. They are extremely important in physics, chemistry, biology, medicine, as well as in the engineering, and even in the social sciences. Understanding such self-organization processes over the past several decades has not only changed physics, but has also led to various improvements in our daily life. Hermann Haken, who is celebrating his 85th birthday this year, is an internationally recognized pioneer in this respect, having laid the mathematical-physical basis for describing and analyzing self-organization processes with his fundamental theory of synergetics. Haken successfully applied synergetic methods to investigations of the laser and other physical systems, as well as to studies of the brain. Since it was founded, this truly interdisciplinary field has experienced a rapid growth, both in terms of the mathematical-physical methodology and the success that has been achieved by applying it to a diversity of different fields of research. On all length scales and in all areas of human life - from the quantum level right up to the spread of disease over economic processes - self-organization and complex dynamics behavior have turned out to play a key role. A more in-depth understanding of these processes will allow the development of diverse methods of control with which we can attempt to master the complexity of these systems. The potential of practical applications can certainly be enhanced if the different disciplines share their advanced and sophisticated methods, as well as their experiences with each other. Therefore, this symposium aims to cover the research field synergetics as a whole, ranging from basic methods to concrete applications, by taking advantage of its interdisciplinary impact. Furthermore, by combining a historical review with a present status report the symposium is intended to give young scientists an understanding of the allure and potency of this branch of research as well as its applicability in the future. The symposium also aims at honoring one of the most important pioneers in this field of science, Hermann Haken, on the occasion of his 85th birthday. Thanks to a substantial support of the VolkswagenStiftung the symposium is kindly hosted at the Hanse-Wissenschaftskolleg in Delmenhorst, Germany.

Axel Pelster (Fellow, Hanse-Wissenschaftskolleg, Delmenhorst)

Günter Wunner (Universität Stuttgart)

Tuesday, November 13, 2012

16:00 – 17:00	***Arrival and Coffee/Tea***
17:00 – 17.15	Axel Pelster (Delmenhorst, Germany): *Opening*
17:15 – 18:00	Joachim Peinke (Oldenburg, Germany): *Stochastic models for turbulent and turbulence driven systems*
18:00 – 18:45	Siegfried Großmann (Marburg, Germany): *Flow organization in highly turbulent thermal convection*
18:45 – 19:00	Hermann Haken (Stuttgart, Germany): *Obituary for Rudolf Friedrich and Arne Wunderlin*
19:00 – 20:30	***Dinner***
20:30 – 22:00	Poster Session I

Wednesday, November 14, 2012

09:00 – 09:45	Fritz Haake (Duisburg-Essen, Germany): *Quantum chaotic equilibration – without dissipation*
09:45 – 10:30	Günter Mahler (Stuttgart, Germany): *Quantum-Thermodynamics: A case study for emergent behavior*
10:30 – 11:00	***Coffee Break***
11:00 – 11:15	Reto Weiler (Delmenhorst, Germany): *Welcome to the Hanse-Wissenschaftskolleg* *(Institute for Advanced Study, HWK)*
11:15 – 12:00	Cun-Zheng Ning (Tempe, USA): *Nanolasers: The current status of the trailblazer of synergetics*
12:00 – 12:45	Günter Wunner (Stuttgart, Germany): *Bose-Einstein condensates in PT-symmetric double-well potentials*
12:45 – 14:00	***Lunch***
14:00 – 14:45	Axel Pelster (Delmenhorst, Germany): *Ginzburg-Landau theory for bosons in optical lattices*
14:45 – 15:30	Martin Weitz (Bonn, Germany): *Bose-Einstein condensation of light*

15:30 – 16:00	***Coffee Break***
16:00 – 17:15	Poster Session II
17:15 – 18:00	Gerhard Roth (Bremen, Germany): *Personality development as a process of self-organization*
18:00 – 19:00	Hermann Haken (Stuttgart, Germany): *The brain as a synergetic and physical system* (All HWK Fellows are invited to this lecture.)
19:00 – 20:30	***Dinner with HWK Fellows***
20:30 – 21:15	Bernd Kröger (Stuttgart, Germany): *Hermann Haken – His roadmap to synergetics*

Thursday, November 15, 2012

09:00 – 09:45	Marko Robnik (Maribor, Slovenia): *Adiabatic invariants and some statistical properties of the time-dependent linear and nonlinear oscillators*
09:45 – 10:30	Axel Hutt (Nancy, France): *Additive noise tunes the stability of nonlinear systems*
10:30 – 11:00	***Coffee Break***
11:00 – 11:45	Viktor Jirsa (Marseille, France): *On the role of the space-time structure of couplings in synergetic networks*
11:45 – 12:30	Eckehard Schöll (Berlin, Germany): *Control of self-organizing complex systems and networks with time-delay*
12:30 – 13:15	Günter Schiepek (Salzburg, Austria): *Phase transitions and critical instabilities in the psychotherapeutic process: Converging results from repeated functional MRI and continuous self-report data from the synergetic navigation system*
13:15 – 14:30	***Lunch, Coffee/Tea***
14:30	Departure for Bremerhaven (bus)
16:30 – 18:00	Visit to the “Klimahaus Bremerhaven 8°Ost” followed by ***Dinner in Bremerhaven***
21:30	Departure from Bremerhaven to Delmenhorst (bus)

Friday, November 16, 2012

09:00 – 09:45	Peter Tass (Jülich, Germany): *Unlearning pathological neuronal synchrony by coordinated reset neuromodulation: treating brain diseases based on synergetic principles*
09:45 – 10:30	Andreas Daffertshofer (Amsterdam, The Netherlands): *On the dynamics of synchrony and information processing in the nervous system*
10:30 – 11:00	***Coffee Break***
11:00 – 11:45	Aneta Stefanovska (Lancaster, UK): *Introduction to chronotaxic systems – systems far from thermodynamic equilibrium that adjust their clocks*
11:45 – 12:30	Till Frank (Connecticut, USA): *Synergetic computer and physical intelligence*
12:30 – 13:15	Lisa Borland (San Francisco, USA): *The Physics of finance: Collective dynamics in a complex world*
13:15 – 13:30	*Günter Wunner (Stuttgart, Germany):* *Closing*
13:30 – 15:00	***Lunch, Coffee/Tea***
15:00	Departure

Talks

The Physics of finance: Collective dynamics in a complex world

Lisa Borland
Integral, San Francisco

Time series of financial data exhibit highly nontrivial statistical properties. What is quite fascinating is that many of these anomalous properties appear to be universal, in the sense that they are present in a variety of different asset classes, ranging for example from commodities such as wheat or oil, to currencies and individual stocks. Furthermore they are present across the geographical borders, and can be observed among others in US, European and Japanese markets.

Finding a somewhat realistic model of price variations that can capture the spectrum of interesting statistical features inherent in real data is a challenging task, important for many real-world reasons, such as risk control, the development of trading strategies, option pricing and the pricing of credit risk to name a few.

In this paper, we present and discuss nonlinear feedback models of price formation and asset price correlations which are simple and intuitive, yet capture many of the statistics and dynamics observed in reality. A common feature in all of our models is that the cooperative effects of collective behavior lie at the root of many of the interesting phenomena of the financial markets, very much in the spirit of synergetics. Finally, we show how these models have been successfully applied in the real world of finance and propose some interesting open questions.

On the dynamics of synchrony and information processing in the nervous system

Andreas Daffertshofer
MOVE Research Institute, VU University Amsterdam

The interplay between structural and functional brain networks has become a popular research topic in the past years. Topologies of structural and functional networks may disagree. Several modeling studies tried to address this issue more systematically as it can give insight into the way structural connectivity facilitates but also constrains information exchange. For instance, in a combined neural mass and graph theoretical model of the electroencephalogram, it was found that patterns of functional connectivity are influenced by, but not identical to those of the corresponding structural level [5]. Functional connectivity is often been defined through the synchronization between activities at different nodes. These activities are considered to stem from meso-scale neural populations that oscillate at certain frequencies with certain amplitudes. The amplitude of a neural population reflects the degree of synchronization of its members. Synchronization between two or more oscillatory neural populations is typically defined by their relative phase variance. It is usually assumed that amplitude variations take place on long time scales when compared to the phase dynamics and are therefore considered negligible. The coupling, which yields (or does not yield) synchrony between nodes, hence exclusively depends on the relative phase. Here we ask whether this assumption is valid and, by this, tackle if a sole focus on phase really covers all functional characteristics of networks.

In order to investigate how amplitude affects the phase dynamics in neural networks we approximate the dynamics of the node by defining neural populations as self-sustaining, weakly non-linear oscillators. This description allows for deducing the corresponding phase dynamics [1,5]. Dependent on the type of oscillator, the phase dynamics is influenced by the amplitudes of the individual oscillators, which can be shown analytically. We illustrate this using a network of neural oscillators $j = 1, 2, \ldots, N$. Each oscillator is characterized by its amplitude A_j and phase ϕ_j. The latter has a dynamics of a Kuramoto-like network [2,6]. Given a certain (structural) connectivity between the oscillators denoted by C_{ij} we discuss in detail how the connectivity between phases, D_{ij} explicitly depends on the oscillators amplitudes, i.e., $D_{ij} = D_{ij}(A_1, A_2, \ldots, A_N)$. It will be shown that phase dynamics and, hence, synchrony patterns should always be analyzed in conjunction with the corresponding amplitude changes [4]. This may have profound impact when linking neuro-anatomical and -imaging studies to modeling.

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Synergetic computer and physical intelligence

Till D. Frank
Department of Psychology, Center for the Ecological Study of Perception and Action, University of Connecticut, USA

Intelligence is a general ability with many facets. Among those facets are the ability to store knowledge and the ability to evaluate and judge. Intelligence is not an ability reserved to humans and animals. Artificial intelligence is concerned with algorithms that typically run on computers and exhibits key characteristics of intelligence. For example, pattern recognition algorithms evaluate input patterns on the basis of stored knowledge. Physical intelligence is about non-algorithmic, i.e., non-computational, processes that yield intelligent behavior. While human and animal intelligence is non-algorithmic in nature, the focus of physical intelligence is on physical systems without brains and in particular on systems of the in-animate world. How can pieces of matter show intelligent behavior? The synergetic computer introduced by Haken is a benchmark example in which observations in material physics have led to the development of algorithms used in the field of artificial intelligence. When looking in the opposite direction, i.e., from artificial intelligence to material physics, the development of the synergetic computer answers at least to a certain extent the questions about how pieces of matter can exhibit intelligence. I propose to use the synergetic computer to define a subclass of intelligent physical systems that will be called smart physical systems. In particular, I demonstrate that the aforementioned connections between human, artificial, and physical intelligence can be exploited to improve our understanding of intelligence in all three fields. Finally, the proposed approach based on the synergetic computer illustrates the feasibility to identify smart physical systems and candidate systems of physical intelligence.

Flow organization in highly turbulent thermal convection

Siegfried Grossmann, in cooperation with Detlef Lohse, Guenter Ahlers and others
Fachbereich Physik der Philipps-Universität, Marburg, Germany

Turbulent Rayleigh-Bénard convection has been the Drosophila of the physics of fluids for many decades, starting with the famous analytical calculation of the linear instability at the critical Rayleigh number $Ra_c = 1708$. Over the last decade experimental, theoretical, and numerical results have converged up to a Rayleigh number $Ra \approx 10^{12}$. Even for such large Ra the boundary layers are still of Prandtl-Blasius, i. e., of laminar type, though time dependent. In 2001 we had predicted that the transition to a turbulent boundary layer only occurs around $Ra = 10^{14}$ (for gases), cf. Grossmann, Lohse, Phys.Rev.Lett.86 (2001)3316. Recently Ahlers et al. (NewJ.Phys.11 (2009)123001) indeed have experimentally found this laminar-turbulent transition at this very high Ra. Here due to a sufficiently large shear the extremely thin boundary layers finally become turbulent leading to a much stronger increase of the heat transfer with increasing Ra as in the laminar, the “classical” range below. In Grossmann, Lohse, Phys.Fluids23 (2011) 045108, we have calculated an effective scaling law $Nu \sim Ra^{0.38}$ for this ultimate regime by extending the unified scaling theory (Grossmann, Lohse, J.FluidMech.407 (2000)27; Phys.Rev.Lett86 (2001)3316; Phys.Rev.E66 (2002) 016305, PhysFluids16 (2004)446), determining the scaling behavior of the heat current Nu as well as the thermal wind amplitude Re as functions of the control parameters Rayleigh and Prandtl number.

We now also look at the local flow properties such as the (vertical) temperature profile. This turns out to show logarithmic dependence with distance z from the heated bottom and the cooled top plates (Ahlers et al., Phys.Rev.Lett.108(2012)114501). This so called “law of the wall” and its properties in dependence of the control parameters, has been derived and analyzed in Grossmann, Lohse, Phys. Fluids, 2012, in press.

As a surprise we have also noticed the log-law in the classical regime below $O(10^{14})$ (cf. above Phys.Rev.Lett.108), apparently meaning that a turbulent bulk of thermal flow beyond the structure formation regime at lower Ra can coexist with still laminar boundary layers. The notion “laminar” has to be extended to time dependence on the gross convective scale (Zhou et al. Phys. Fluids 23(2011)125104).

In the talk some of these self-organized flow structures in strongly driven thermal convection will be detailed together with some overview.

Quantum chaotic equilibration - without dissipation

Fritz Haake
Universität Duisburg-Essen, Germany

The unitary quantum dynamics of a paradigmatic system – the Dicke model, a large spin coupled to an oscillator – can be described by a Fokker-Planck equation for a suitable quasiprobability density (the Glauber Q aka Husimi function). The drift terms herein represent the underlying classical Hamiltonian flow and the diffusion terms account for quantum fluctuations.

The classical Hamiltonian flow being chaotic, the four dimensional phase space can be parametrized by coordinates along one stable, one unstable, and two neutral directions. Phase space structures respectively shrink and expand exponentially in the stable and unstable directions; the stable directions, on the other hand, at most allow for subexponential change.

The quantum fluctuations, in turn, also distinguish four directions, related to the eigenvectors of the 4 x 4 diffusion matrix. Of the four eigenvalues two are positive while their negatives are the remaining two. The positive eigenvalues stand for genuine diffusion, i. e. stretching along the pertinent eigenvectors while the negative eigenvalues are associated with "antidiffusive" squeezing.

Antidiffusion can threaten the existence of quantum quasiprobabilities, due to second moments of certain coordinates going negative; not so here, since the Q function is guaranteed existence and positivity by its very definition.

The competition of classical chaotic and quantum diffusive stretching and squeezing entails effective equilibration in time. Whatever initial form Q may have, it will be smeared out over the pertinent energy shell towards effective uniformity (For initially sharp energy, Q approaches the microcanonical distribution). The disclaimer "effective" is unimportant: In principle, Q never becomes strictly stationary and uniform, but revealing the remaining fluctuations would require resolution of Planck cells.

Interestingly, quantum fluctuations have a net smoothing effect on Q, the existence of antidiffusive directions notwithstanding. Antidiffusion as well as diffusion can never take an exponential course in time. Therefore, the exponential classical stretching is negligibly modified by quantum fluctuations; the classical exponential shrinking in the stable directions, however, will eventually be overwhelmed by the diffusive part of the quantum fluctuations, and precisely that smoothing secures existence and positivity of Q forever.

While equilibration of long-wavelength observables in many-body systems is nowadays considered self-evident among physicists, the charm of the Dicke model with its only two degrees of freedom lies in the fact that it allows to follow that equilibration in detail. The technicalities of revealing equlibration involve a projection of the dynamics onto a co-moving Poincaré section (which might be appreciated only by the theoretical physicists in the audience and will therefore be put on stage but briefly).

The brain as a synergetic and physical system

Hermann Haken
Institute for theoretical physics 1, Center of Synergetics, Stuttgart, Germany

The human brain is the most complex system we know. It consists of about 10^{11} neurons, each of which may have up to 10^4 connections to other neurons. This network enables us to recognize patterns, to move, to think etc. Who or what steers the neurons so to produce all these mental processes in a meaningful manner? The answer that I gave some 30 years ago is: by means of self-organization. The scientific discipline that deals with this phenomenon from a unifying view is synergetics. After a very brief reminder of two typical examples from physics (laser, fluids), I will summarize basic concepts: control parameters, instability, order parameters, enslavement, circular causality. These considerations open the possibility to treat a complex system at the microscopic level as well as at the macroscopic (phenomenological) level, describable by order parameters. In biology, at the phenomenological level, Kelso´s finger experiments and the HKB model will be discussed. The observed phenomena hysteresis, critical fluctuations and critical slowing down indicate that the brain doesn´t function like a computer, but is selforganizing. Further examples are taken from psychophysics. A connection between the microscopic and the order parameter level is provided by the synergetic computer as applied to face recognition. As a step towards the modeling of “real”, i.e. spiking neurons, I represent my “lighthouse” model from which, depending on the situation, the synergetic computer algorithm and synchronization between spike trains can be derived. To proceed further, molecular processes in axons will be treated such as the motion of kinesin on microtubuli.
Finally, returning to the macroscopic level, I discuss some consequences for psychology and psychotherapy.

Additive noise tunes the stability of nonlinear systems

Axel Hutt
INRIA Nancy, France

The work studies the effect of additive noise on the stability of nonlinear multi-dimensional systems. The applied method is motivated by the slaving principle in stochastic systems studied in detail by Gregor Schoener and Hermann Haken[1] and extended by Xu and Roberts[2] on stochastic centre manifolds[3]. The technique exploits the separation of time scales close to instability points.
The first part of the presentation shows the study of an integral-differential equation equation of the type

$$\frac{\partial U(x,t)}{\partial t} = h[U(x,t)] + \int_{\Omega} \mathrm{d}y\,(K(x-y)S_K[U(y,t)] + L(x-y)S_L[U(y,t)]) + I(x,t).$$

which generalizes partial differential equation systems. Special cases are the Swift-Hohenberg Equation and Neural Field Equations. The external input *I(x,t)=I(t)* represents additive random global fluctuations uncorrelated in time and constant in time. After a reduction onto spatial interacting modes parameters are chosen such that the system evolves close to a Turing instability, see Fig.1 (left). The subsequent application of the stochastic centre manifold technique[4,5,6] shows that the instability occurs now at control parameters different from the deterministic critical control parameter (Fig. 1(right)).

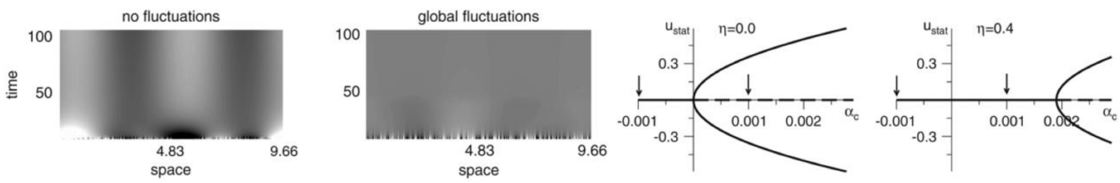

Figure 1 : (Left) Space-time simulation of Swift-Hohenberg equation with and without global flcutuations. (Right) Resulting bifurcation diagram of critical spatial mode.

Concluding this work, additive noise induces a stochastic bifurcation what has been known of multiplicative noise for several decades. The first example shows this effect in a infinite-dimensional (spatial) system. Then the question arises whether other infinite-dimensional systems exhibit this behavior as well, such as delayed systems.
The second and last part of the presentation shows the application of the stochastic centre manifold technique in delay systems[7], more specifically in the scalar delay differential equation

$$\frac{\mathrm{d}U(t)}{\mathrm{d}t} = -\alpha U(t) + K_0 S[U(t-\tau_0)] + E_0 + \xi(t).$$

with uncorrelated Gaussian noise $\xi(t)$ and delay τ_0. We find a noise-induced shift of the stability (Fig. 2) confirming that additive noise also affects the stability of delayed systems.

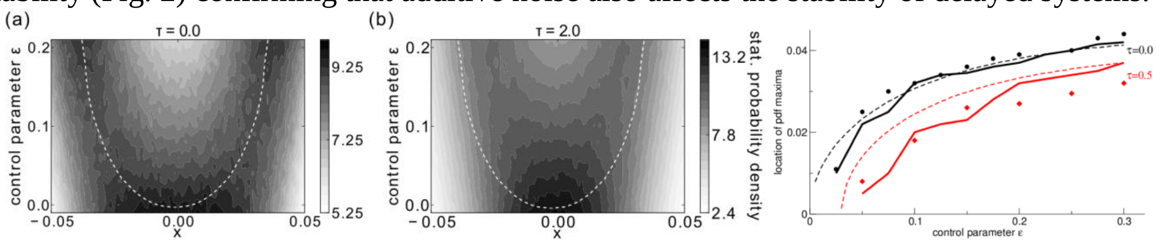

Figure 2 : (Left) Probability density function (pdf) of U without and with delay. (Right) The bifurcation diagram of the pdf maxima exhbiting a noise-induced shift in the presence of delays.

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On the role of the space-time structure of couplings in synergetic networks

Viktor Jirsa
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Brain systems are synergetic networks capable of exhibiting a rich spatiotemporal dynamics. In particular, the level of the full brain is attractive for investigation from the pattern formation perspective, since here the functional circuits are closed for the first time. But this perspective also poses its particular challenges. For instance expresses the brain network the full space-time structure of the brain's connectivity matrix, the so-called connectome. Here the anatomical connections of the connectivity matrix define the spatial components, whereas the time delays define the temporal components of the connectome. We discuss the relevance of the space-time structure for the emergent brain dynamics and illustrate first results obtained within The Virtual Brain platform.

Hermann Haken – his roadmap to synergetics

Dr. Bernd Kröger
Tübingen, Germany

During the last sixty years Hermann Haken has made numerous contributions to the scientific endeavor, not only to physics. The talk will cover the development of Hermann Hakens thoughts during the first thirty years of his career.

The time from 1950 to 1983 includes his early years at Erlangen University, where he was concentrating on solid state physics and the resulting invitation to the Bell Laboratories in 1960. After becoming Professor of Theoretical Physics at Stuttgart he developed the quantum-mechanical theory of the laser with the members of his “Stuttgart School” during the years 1962 to 1967. This was in strong competition with American researchers.

At the end of this period he and his pupil Robert Graham could show that the laser is an example of a nonlinear system far from thermal equilibrium that shows a phase-transition like behavior. This led to the formulation of Synergetics in 1970.

At that time the question how order arises through self-organization from an unordered state was strongly debated at different conferences. During the following years Haken was able to show analogies of the laser system with the Hypercycle-Ansatz of Manfred Eigen, the Bénard-Effect and the Lorenz-Equations of hydrodynamic flow. This was as early as 1975.

Influenced by his tremendous knowledge of the laser and the role of fluctuations in such systems far from thermal equilibrium he developed the mathematical tools for Synergetics, especially the Generalized Ginzburg-Landau equations and the slaving principle. The results were then published in two seminal books Synergetics (1977) and Advanced Synergetics (1983).

Quantum Thermodynamics: A case study for emergent behavior

G. Mahler
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Summary: Quantum thermodynamics is able to provide a foundation of conventional thermal behavior; it also allows to follow thermal behavior down to the nano-limit. Quantum measurements are needed as a link between classical and quantum descriptions. Quantum mechanics has been proven to be an extremely successful theory. Not only does it give rise to new and most exciting quantum features, it is believed to underly also the well-known classical phenomena. The way in which this happens, however, often appears rather vague.
The central question is, how a qualitatively different type of behavior may systematically emerge (as an effective description) from the underlying quantum substrate.
Surprisingly clear-cut answers have been found with respect to thermal behavior: During the last couple of years it has been realized that the partitioning of a closed quantum system into a smaller and a significantly larger part typically (i.e. for weak coupling) gives rise to thermal properties for the former part, even though the system as a whole continues to exhibit unitary motion [1,2].
This picture differs substantially from the classical (statistical) description: It is not the system as such, which is thermal; rather it is made thermal by its environment.
Based on entanglement, this feature may show up already for rather small total quantum systems, the dynamics of which can still be solved exactly! Furthermore, it allows for nano-thermodynamics, an entirely self-contradictory concept in the classical regime. Thermal behavior is thus "apparent" only, i.e. dependent on the way the observer chooses to look. A much "closer look" would make the thermal properties disappear -- just like a portrait will become unrecognizable after focusing on the individual pixels.
However, "looking" is inherently operational, it has to be included as part of the detailed physical modeling. In fact, observational quantum thermodynamics [3] establishes an intuitive link between quantum and classical description.

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Nanolasers: The current status of the trailblazer of synergetics

Cun-Zheng Ning
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Lasers have revolutionized modern science, technology, and our daily lives since they were invented 50 plus years ago. It was the study of lasers as a prototype of non-equilibrium systems that led to the birth of Synergetics [1,2], thus lasers are considered as trailblazer of Synergetics [3]. The field of laser science and technology today is as active and exciting as it has ever been. One of the constant themes of research in semiconductor lasers has been size miniaturization. This process has led to the invention of many microcavity lasers such as photonic crystal lasers, distributed feedback lasers, and nanowire lasers. But miniaturization using pure dielectric laser cavities encountered significant barrier due to the constraints of wavelengths. To reduce the size of semiconductor lasers further significantly, a surface-plasmon-polariton (SPP) waveguide as a mechanism for wave confinement was proposed [4,5] and demonstrated experimentally [6]. Since then, nanolasers based on SPP modes or metallic waveguides have attracted a great deal of attention [7-9]. Rapid progress has been made in various aspects of such nanoscale lasers [9-12].
In this talk, recent progress in experimental and theoretical studies of semiconductor nanolasers will be discussed [10-12]. The talk will start with a brief overview of the history of miniaturization and outline the challenges with the continuing size reduction. Results will be presented on the first experimental demonstration [12] of continuous wave operation of sub-wavelength cavity lasers at room temperature. Future prospects of the further size reduction and implication will be discussed.

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Stochastic models for turbulent and turbulence driven systems

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Quite often, the behavior of complex systems that are far from equilibrium can be traced back to rather simple laws, because there are self-organizing processes in complex systems. As well known from the research field of Synergetics [Haken 1983|, it is the challenge to achieve an understanding of interaction between microscopic subsystems, which may result in irregular fluctuations and the emergence of collective variables or order parameters. This consideration leads directly to the question whether the self-organizing processes of a system can be projected on two basic components, on the one hand noise, describing the fast irregular fluctuations, on the other hand some deterministic forces, describing the slow dynamics of the order parameters.

In this contribution, this synergetic approach is applied to turbulence, where the self-organization leads to a hierarchical interaction of subsystems on different scales. Thus the self-organization will be considered as a function of scales. In [Friedrich 1997] it could be shown that the multi-scale statistics of homogeneous isotropic turbulence can be described by a stochastic 'cascade' process of the velocity increment from scale to scale. For this approach to the turbulent cascade the underlying Fokker–Planck equation can be "measured" directly via the moments of conditional probabilities, i.e. via the estimation of the Kramers Moyal coefficients. The fundamental novelty of this approach is that it shows evidence of a three point closure for the complexity of turbulence. Consequently, this description can be extended to obtain the complete multi-point statistics of the velocity field, i.e. we achieved an explicit expression for the joint probability p(u(x1), u(x2), …, u(xn)), where u(xi) is the velocity at the spatial points xi.

Besides different new insights into details of turbulence, this method can also be used to analyze profoundly other complex spatio-temporal structures having either scale or time dependent complex structures. [Friedrich 2011] Thus it is a general method to handle noisy and turbulence driven systems.

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Ginzburg-Landau theory for bosons in optical lattices

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Spinless bosons in optical lattices reveal a generic quantum phase transition once the depth of the potential wells is tuned. When the on-site interaction energy is small compared to the hopping energy, the ground state is superfluid, as the bosons are delocalized and phase coherent over the whole lattice. In the opposite limit, where the on-site interaction energy dominates over the hopping energy, the ground state is a Mott insulator, as each boson is trapped in one of the respective potential minima.

In order to describe both thermodynamic and dynamic properties of this quantum phase transition we developed a Ginzburg-Landau theory [1,2]. To this end we started from the microscopic Bose-Hubbard model, applied diagrammatic techniques within a systematic strong-coupling expansion, and calculated the underlying effective action. Already the first beyond mean-field order exhibits for the boundary of the quantum phase transition in a three-dimensional cubic lattice a relative error of less than 3% when compared with most recent Quantum Monte Carlo simulations [1]. Higher orders turn out to be so accurate that they even allow for the calculation of critical exponents [3,4]. Furthermore, the Ginzburg-Landau theory yields excitation spectra both in the Mott and the superfluid phase, which agree qualitatively with recent experiments [5]. Finally, new calculations show that the Ginzburg-Landau theory is also suitable to investigate non-equilibrium problems via an analytic continuation. A quantitative analysis of the seminal collapse and revival experiments in the group of Immanuel Bloch shows convincingly that the observed decoherence of the condensate wave function stems from the inhomogeneous external trap.

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Adiabatic invariants and some statistical properties of the time-dependent linear and nonlinear oscillators

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We consider 1D time dependent Hamiltonian systems and their statistical properties, namely the time evolution of microcanonical distributions, whose properties are very closely related to the existence and preservation of the adiabatic invariants. We review the elements of the recent developments by Robnik and Romanovski (2006-2008) for the entirely general 1D time dependent linear oscillator and try to generalize the results to the 1D nonlinear Hamilton oscillators, in particular the power-law potentials like e.g. quartic oscillator. Furthermore we consider the limit opposite to the adiabatic limit, namely parametrically kicked 1D Hamiltonian systems. Even for the linear oscillator interesting properties are revealed: an initial kick disperses the microcanonical distribution to a spread one, but an anti-kick at an appropriate moment of time can annihilate it, kicking it back to the microcanonical distribution. The case of periodic parametric kicking is also interesting. Finally we propose that in the parametric kicking of a general 1D Hamilton system the average value of the adiabatic invariant always increases, which we prove for the power-law potentials. We find that the approximation of kicking is good for quite long times of the parameter variation, up to the order of not much less than one period of the oscillator.
We also look at the behaviour of the quartic oscillator for the case of the kick and anti-kick, and also the periodic kicking.

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The development of personality as a self-organizing process

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The development of human personality including its cognitive and emotional-psychic components is one of the most complex processes we know. Based on recent psychological and neurobiological studies a psycho-neural model of personality and its development emerges. It is characterized as a sequence of developing fundamental "psycho-neural" systems: (1) the stress management system, (2) the calming-down system, (3) the attachment and empathy system (4) the reward-motivation system(5) the impulse control system, (6) the reality awareness system. These systems develop on top of each other, but there are important feedbacks. They are based on the development of cortical and subcortical brain centers belonging to the limbic system in conjunction with the establishment of neuromodulatory systems like cortisol, serotonin, oxytocin, dopamine and acetylcholine. The entire process is determined by genes and epigenetic processes, prenatal (mostly harmful) events via the brain of the mother, positive and negative early childhood experience and events in later childhood and early adolescence, while later events rarely influence and modify personality to a greater extent. This model intends to solve the long-standing problem of nature-nurture.

Self-Organization in complex mental and neural systems: Application of synergetics to psychotherapy and psychiatry

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This lecture will give a short review on some successful applications of synergetics to psychology. Phenomena like perception, decision making, memory, and learning can be conceptualized as processes of order formation and order transition. Formal models as well as empirical data support synergetics models of complex mental phenomena.

One of the technical applications of synergetics to psychology is meanwhile a feedback-driven psychotherapy and counselling practice using an Internet-based ambulatory assessment device (Synergetic Navigation System). The monitoring of dynamic patterns and pattern transitions during human change processes supports therapeutic self-organization. We will report on empirical results and experiences from clinical practice.

Following the conceptualization of psychotherapy as a self-organizing, neuro-psychological dynamic system, a german-austrian cooperative study tested the hypothesis that in discontinuous order transitions mental (cognitive and affective) and brain dynamics are synchronized. The Synergetic Navigation System was used in the course of inpatient therapy in order to collect daily self-assessments (Therapy Process Questionnaire). A dynamic complexity measure was applied on the resulting time series. Critical phases of the change process were identified by the maxima of the varying complexity of the time-series. In addition, several fMRI measurements were conducted over the course of the therapy. The study was realized with 9 patients with obsessive compulsive disorder, mainly suffering from the subtype of washing/contamination fear, and 9 matched healthy controls. For symptom-provocative stimulation individualized pictures from patients‘ personal environments were used. The neuronal responses to these pictures were compared to the responses during standardized neutral and disgust-eliciting pictures. Results showed considerably larger changes of brain activity during critical phases than between fMRI measurements out of such critical phases (order transitions), as well as compared to healthy controls. The data indicate that order transitions play a crucial role in the psychotherapeutic process, supporting synergetic models of learning and human change processes.

In psychiatry, the prediction of suicidal attempts is still a big challenge and an unsolved problem. Goal is the development of an early warning system for rare and extreme events like suicidal attempts. If a suicidal crisis can be seen as a specific cognitive-emotional order state, critical instabilities and transitions in synchronisation patterns could be used as early markers of a suicidal quasi-hypnotic enslaving process.

Control of self-organizing complex systems and networks with time-delay

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Time delays arise naturally in many complex systems, for instance in neural networks or coupled lasers, as delayed coupling or delayed feedback due to finite signal transmission and processing times. Such time delays can either induce instabilities, multistability, and complex bifurcations, or suppress instabilities and stabilize unstable states. Thus, they can be used to control the dynamics [1]. We study synchronization in delay-coupled oscillator networks, using a master stability function approach, and show that for large coupling delays synchronizability relates in a simple way to the spectral properties of the network topology, allowing for a universal classification [2]. As illustrative examples we consider synchronization and desynchronization transitions in neural networks, in particular small-world networks with excitatory and inhibitory couplings [3], and group synchronization in coupled chaotic lasers [4].
Within a model of Stuart-Landau oscillators, which represents a generic expansion of any system near a Hopf bifurcation into a normal form, we demonstrate that by tuning the coupling parameters one can easily control the stability of different synchronous periodic states, i.e., zero-lag, cluster, or splay states. We show that adaptive algorithms of time-delayed feedback control can be used to find appropriate value of these parameters [5], and one can even self-adaptively adjust the network topology to realize a desired cluster state. Our results are robust even for slightly nonidentical elements of the network.

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Introduction to chronotaxic systems – systems far from thermodynamic equilibrium that adjust their clocks

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Living systems are characterised by time-dependent structures and functions. In this lecture we will concentrate on function. We will motivate the talk by experiments related to cellular, cardiovascular and brain dynamics and introduce a new class of dynamical systems which we name chronotaxic. The main characteristics of chronotaxic systems are that they are oscillatory and non-autonomous [1-4]. They maintain their frequencies within a certain range under external influence. They also maintain their coupling strengths to other systems, again within a certain range.

Chronotaxic systems undergo continuous perturbation, whereas self-sustained oscillators are most of the time in their limit-cycles. So, when we have a self-sustained oscillator and weakly perturb it we can describe it as a weakly non-autonomous self-sustained oscillator. This implies that a separation of phase and amplitude dynamics can be effected and that perturbation theory can be applied. Stronger and continuous perturbation can result in chronotaxicity. The system shows more complex dynamics; however it still exhibits self-sustained properties, and it is still capable of adjusting parameters so that stability is preserved. In response to the continuous perturbation the system sustains its stability by continuously adjusting its parameters. Stronger perturbation of a self-sustained oscillator can result in the system being driven – i.e. the intrinsic dynamics is overwhelmed by the dynamics of the external forcing. Again, perturbation theory cannot be applied.

Generally, perturbation theory with separation of phase and amplitude dynamics cannot be applied directly to chronotaxic systems. We can separate the fast from the slow dynamics, but we should bear in mind that the trajectories in phase space change continuously with time. When we do not know the properties of the external and the inherent dynamics, we can apply methods to study what is then an inverse problem. Numerically, we can analyse chronotaxic system by applying methods that allow for the study of time-evolution [5], such us time-phase, time-frequency (e.g. wavelets) and time-phase space methods. These will be discussed briefly, and results relevant to living systems will be illustrated. We will argue that the chronotaxic systems are often classified and treated as stochastic systems although most of the time they can be fully deterministic.

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Unlearning pathological neuronal synchrony by coordinated reset neuromodulation: Treating brain diseases based on synergetic principles

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A number of brain diseases, e.g. movement disorders such as Parkinsons disease, are characterized by abnormal neuronal synchronization. Within the last years permanent high-frequency (HF) deep brain stimulation became the standard therapy for medically refractory movement disorders. To overcome limitations of standard HF deep brain stimulation, we use a model based approach. To this end, we make mathematical models of affected neuronal target populations and use methods from synergetics, statistical physics and nonlinear dynamics to develop mild and efficient control techniques. Along the lines of a top-down approach we test our control techniques in oscillator networks as well as neural networks. In particular, we specifically utilize dynamical self-organization principles and plasticity rules. In this way, we have developed coordinated reset (CR) stimulation, an effectively desynchronizing brain stimulation technique. The goal of CR stimulation is not only to counteract pathological synchronization on a fast time scale, but also to unlearn pathological synchrony by therapeutically reshaping neural networks. This is achieved by shifting the neuronal system from a pathological attractor to a physiological attractor. According to computational studies, CR works effectively no matter whether it is delivered directly to the neurons' somata or indirectly via excitatory or inhibitory synapses.

The CR theory, results from animal experiments as well as clinical applications will be presented. MPTP monkey and human data will be shown on electrical CR stimulation for the treatment of Parkinsons disease via chronically implanted depth electrodes. Furthermore, acoustic CR neuromodulation for the treatment of subjective tinnitus will be explained. Subjective tinnitus is an acoustic phantom phenomenon characterized by abnormal synchronization in the central auditory system. In a proof of concept study it was shown that acoustic CR neuromodulation significantly and effectively counteracts tinnitus symptoms as well as the underlying pathological neuronal synchronization processes. Furthermore, CR normalizes the pathologically altered interactions between different brain areas involved in the generation of tinnitus.

Bose-Einstein condensation of light

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Bose-Einstein condensation, the macroscopic ground state accumulation of particles with integer spin (bosons) at low temperature and high density, has been observed in several physical systems, including cold atomic gases and solid state physics quasiparticles. However, the most omnipresent Bose gas, blackbody radiation (radiation in thermal equilibrium with the cavity walls) does not show this phase transition. The photon number is not conserved when the temperature of the photon gas is varied (vanishing chemical potential), and at low temperatures photons disappear in the cavity walls instead of occupying the cavity ground state. Here I will describe an experiment observing a Bose-Einstein condensation of photons in a dye-filled optical microcavity [1]. The cavity mirrors provide both a confining potential and a non-vanishing effective photon mass, making the system formally equivalent to a two-dimensional gas of trapped, massive bosons. By multiple scattering of the dye molecules, the photons thermalize to the temperature of the dye solution. In my talk, I will begin with a general introduction and give an account of current work and future plans of the Bonn photon gas experiment.

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Bose-Einstein condensates in PT-symmetric double wells

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The existence of PT(parity-time)-symmetric wave functions describing Bose-Einstein condensates in realistic one-dimensional and fully three-dimensional double-well setups is investigated theoretically. When particles are removed from one well and coherently injected into the other the external potential is PT-symmetric. We solve the nonlinear Gross-Pitaevskii equation using the time-dependent variational principle (TDVP). We show that the PT-symmetry of the external potential is preserved by both the wave functions and the nonlinear Hamiltonian as long as eigenstates with real eigenvalues are obtained. We find that indeed two branches of real eigenvalues exist up to a critical strength of the nonlinearity, at which the two solutions merge in a branch point. This behaviour is analogous to that found in studies of optical wave guides with loss and gain [1].
A surprising result, however, is that although there also appears a branch of two complex conjugate eigenvalues, which correspond to PT-broken solutions, the latter are not born at the branch point but at a lesser value of the strength of the nonlinearity where they bifurcate from the real eigenvalue branch of the ground state. This implies that there is a range of values of the nonlinearity where two real and two complex eigenvalues coexist. Obviously this is a consequence of the nonlinearity in this PT-symmetric system. It agrees with previous findings in studies of a Bose-Einstein condensate in a PT-symmetric delta-functions double well [2, 3] and of a PT-symmetric Bose-Hubbard dimer with loss and gain [4].
The applicability of the TDVP is confirmed by comparing its results with numerically exact solutions in the one-dimensional case. The linear stability analysis and the temporal evolution of condensate wave functions reveal [5] that the PT-symmetric condensates are stable and should be observable in an experiment.

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Posters

Self-Assembled organic nanowires

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Organic semiconductors from small molecules such as para-phenylenes or thiophenes promise a vast application potential as the active ingredient in electric and optoelectronic devices. Their growth and self-organization into organic nanowires adds a peculiar attribute, where mutually aligned entities are of interest. Different methods for nanowire formation have been pursued in the past such as filling of nanoporous templates, precipitation from solution, and organic molecular beam deposition (OMBD). Here nanowire OBMD growth is explored, where growth directions are determined by a combination of epitaxy, substrate surface symmetry, and packing of the molecules. As a second step the morphological stability of such wires with time and in the presence of gases and vapors is investigated, which is of major importance for their use in any device.

Chronotaxic systems as an inverse problem

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Chronotaxic systems are a newly-defined class of dynamical systems which are characterised as being oscillatory and non-autonomous. Despite continual external perturbations, the frequencies of their oscillations remain within a certain range and their dynamics is not chaotic [1].

The introduction of this new class poses questions about how we can obtain information related to the properties of these systems from their observed time series. Methods which have previously been applied for inverse problems of dynamical systems need to be reviewed. In particular, the apparent complexity of these systems is greatly increased when analysed in phase space so that they resemble stochastic systems, despite the fact that they are fully deterministic [1,2]. However, other methods such as those which act in the time-frequency domain do not face the same problems because they are able to track time-dependence in dynamical systems. Recent approaches are also able to resolve time-varying parameters from chronotaxic dynamics in interacting systems by applying Bayesian inference [3].

It is well known that living systems exhibit the characteristics of chronotaxic systems [4] but similar dynamics have also been measured in the currents of surface state electrons on liquid helium [5]. These measurements show oscillations occurring in the range 100–1000Hz which are modulated by a separate 10Hz component. The time series analysis methods discussed here are applied to this data in addition to simulated data from a theoretical chronotaxic system. The results motivate a new framework of analysis so that chronotaxic systems are correctly identified as such, rather than being misrepresented as either chaotic or stochastic systems.

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Coherence properties of semiconductor nanolasers

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The emission properties of semiconductor nanolasers are studied on the basis of microscopic theories going beyond simple atomic models. This allows us to investigate many-body effects and incorporates carrier-photon correlations, providing direct access to the statistical properties of the emission. The dynamical evolution of the system is described by means of density matrix approaches, or relies on cumulant expansion techniques where the first is numerically not possible. In particular we focus on nanostructures where quantum dots are used as active material. Multi-exciton effects of the quantum dot carriers play an important role, as well as the coupling to continuum states of the embedding semiconductor material.

Bose-Einstein Condensation in Compact Astrophysical Objects

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We work out in detail two possible applications of the theory of Bose-Einstein condensates (BEC) in astrophysical contexts, one being neutron stars and white dwarfs due to the formation of Cooper-like pairs of fermions, the other being BECs of bosonic dark matter.
There is a general consensus that the conditions in these astrophysical environments allow for BECs, and thus models featuring Bose-Einstein condensated particles are viable candidates to determine the physical properties of these astrophysical objects, see e.g. [1,2].
The framework of the calculations is that of a system of self-gravitating, uncharged particles subject to both contact interaction and gravitational interaction. The equation of state of the particle ensemble is found from the theory of Bose-Einstein condensation, and then inserted into an appropriate theory of gravity. We can identify three regimes of the physical properties of the system: non-relativistic particles with Newtonian or Einsteinian gravity [3], and relativistic particles in a general relativistic framework [4,5]. The three regimes are compared by investigating possible observable quantities as, for instance, the respective bounds for the maximum masses, their density profiles, or the specific heat of the compact objects.

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A cortico-thalamic feedback model to explain EEG during anesthesia

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General anesthesia (GA) is a neurophysiological state in which has many purposes including Analgesia, Amnesia, Immobility, Sleep, and Skeletal muscle relaxation. Although GA is commonly used in medical care for patient's undergoing surgery, its precise underlying mechanisms and the molecular action of anesthetic agents (AA) remain to be elucidated. A wide variety of drugs are used in modern anesthetic practice and this has been observed that for all AAs (except for midazolam), during the transition from consciousness to unconsciousness, many derived EEG variable show biphasic effects, that is an initial increase of the effect variable followed by a decrease at higher concentrations. The aim of our work is describe mathematically this bi-phasic behavior in the EEG-power spectrum by the study of a neuronal population model of a single thalamocortical module.

A longitudinal study of network dynamics in the human brain

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The brain is the ultimate self-organizing system. Evidence of this is offered by the ubiquitous presence of synchronized rhythmic activities which can define and redefine countless networks, often on a millisecond timescale. Oscillations, which can be apparently spontaneous or stimulus-induced, are associated with a multitude of faculties of the brain and body and are suggested to be essential to neuronal communication and brain function. The last two decades have witnessed intensive investigation into their possible functional significance for information coding, attributing a role to these phenomena in processes ranging from vision to memory to motor action. The emphasis of these studies, however, was to understand the coordination of various elements which led to emergent properties that were significant to normal network function.

Yet, dysfunction in the system components can lead to a perversion of that coordination which would in turn be represented as dysfunctional brain states exhibiting pathological rhythms. Aberrant oscillatory behaviors have been associated with a wide range of neuropsychiatric and neurologic disorders and have become the focus of intense examination over the last few years. The pathological presence of distinct frequency bands has been implicated in diseases from Parkinson's to depression, yet there are virtually no reports distinguishing the dynamics of neuronal activation with symptom dynamics.

We addressed this problem with chronic recordings from implanted electrodes in the thalamus of human subjects with Tourette syndrome receiving deep brain stimulation (DBS) therapy. TS is an idiopathic, neuropsychiatric disorder with an unknown pathophysiology which affects between 0.5%-4% of children worldwide. It is a debilitating disorder marked by the long term expression of multiple tics, which are sudden, purposeless, unvoluntary, repetitive movements and vocalizations. These tics can become severe, self-injurious, and even malignant. In treatment-refractory cases of TS (in which neither medicines nor behavioral therapies are effective), DBS has become a promising therapeutic option.

By recording from surgically-implanted DBS lead electrodes over many months while subjects were receiving therapy, we were able not only to find neural correlates of symptomatology, but also to track the dynamic changes in specific frequency bands with therapeutic efficacy. Temporal analysis of the spectral characteristics of local field potential recordings in the thalamus was correlated with the clinical benefit derived by each subject over several months. Our results reveal changes in coordination across scales manifested as correlated emergent neuronal and motor behaviors. We provide the first clinical evidence of a correlation between gamma-band oscillations and tic expression, suggesting functional relevance for oscillations in the pathophysiology of TS. Further evidence is indicated by preliminary results demonstrating cross-frequency coupling dynamics correlated with changes in impairment. The findings derived from this research have offered important insights into tic genesis and expression and, in fact, have begun to overturn some of the existing theories of the source of impairment in TS. Additionally, subjects in this study who responded to DBS therapy also show dynamic changes in thalamic network physiology, while those who did not respond well to DBS showed no change, suggesting the thalamus is an important therapeutic focus when addressing brain circuit dysfunction in TS. These data help elucidate some of the intricate dynamics of human brain disease states. Understanding of the functional dynamics of neuronal activity underlying the emergence of the symptomatology in TS and other neuropsychiatric disorders is critical to the development of effective therapies and will lead to improved patient care.

Critical properties of the Bose-Hubbard model

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The process-chain approach represents a powerful tool for carrying out perturbative calculations for many-body lattice systems in high order of the hopping strength [1]. In combination with the non-perturbative method of the effective potential [2,3], this technique allows us to study the superfluid-to-Mott insulator quantum phase transition of the Bose-Hubbard model [4,5]. For instance, the phase boundaries for various lattice geometries were determined with great accuracy in Refs. [6,7]. In this contribution we concentrate on the calculation of both the superfluid and the condensate density for the Bose-Hubbard model. We demonstrate how the aforementioned methods can be extended to two approaches for obtaining the critical exponents of the respective densities [8], which characterize the system near the critical point of the quantum phase transition. Whereas one approach allows the direct extraction of critical exponents via a numerical extrapolation scheme, the other method relies on the additional application of variational perturbation theory [9].

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Analysis of noisy spatio-temporal data

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We will discuss recent advances in the estimation of stochastic partial differential equations (SPDEs) from noisy spatio-temporal data. The SPDEs belong to the class of Langevin equations described by drift and diffusion terms. These terms, including spatial operators like the Laplacian or a spatial average of the field, can be estimated via conditional averages. In this context we discuss technical details like for example the dependence of the estimated drift and diffusion terms on the spatial correlation of the noise. We also discuss restrictions on the structure of the SPDEs which keep the problem treatable under the boundary condition of a limited amount of data.

Foam decay with incomparable Lorenz curves

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Foam is of great importance for modern industrial products, cosmetics and food industry. However, the scientific knowledge on the creation and decay of foam is of low level up to now. We were interested in the temporal development of bubble size distributions during the decay of beer frost. For this reason we used ultrasonic foaming up of beer to achieve a reproducible situation in which all bubbles are almost of the same size. The decay was documented photographically any second using a CCD device.

As a result we got 300 pictures with 190 to 80 bubbles per picture. In order to compare the bubble size distributions we formed a vector ordered monotonously with increasing bubble sizes for each picture. Taking the partial sums of all components of the vector as a function their corresponding running numbers one gets the discrete Lorenz function, which is correlated to the bubble size distribution of discourse.

This Lorenz method is well known from macroeconomics, where it is used to compare social and financial distributions. However, if two Lorenz curves cross each other, an additional criterion has to take into account in order to enable the comparison of these distributions (theorem of Rothschild and Stiglitz –1976). Their statement corresponds to the idea of incomparable diagram structures developed earlier by the theoretical chemist E. Ruch.

We observed crossing Lorenz curves of developing bubble size distributions which succeed temporarily. This is a very surprising result since incomparable states should not emanate from each other. These observations lead to our conviction that in the foam there might exist regions of incomparable structures with different histories.

Dipolar Bose-Einstein condensates in weak anisotropic disorder potentials

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Here we examine in detail the properties of a homogeneous dipolar Bose-Einstein condensate in an anisotropic random potential with Loretzian correlation at zero temperature. To this end we solve perturbatively the Gross-Pitaevskii equation up to second order in the random potential and obtain analytical results for the disorder ensemble averages of both the condensate and the superfluid depletion, the equation of state, and the sound velocity. For a pure contact interaction and a vanishing correlation length we reproduce the seminal results of Huang and Meng, which were originally derived within a Bogoliubov theory around a disorder averaged background field [1]. For dipolar interaction and isotropic Lorentzian disorder we obtain results which are qualitatively similar to the case of an isotropic Gaussian correlated disorder [2]. In case of a general anisotropic Lorentz-correlated disorder all these quantities show a characteristic behaviour which arises from the formation of fragmented dipolar condensates in the minima of the anisotropic disorder potential.

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Self-Organisation towards efficiency and criticality in speculative markets

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Financial markets are believed to be efficient in the sense that no profit can be made by speculation using only publicly available information. This implies that the behaviour of market participants collectively exerts a stabilising control on predictable price changes leaving only residual, unpredictable returns. In contrast, speculative markets occasionally exhibit extremely large price changes which indicates destabilising mechanisms. Here we investigate whether this long standing antinomy in economics can be resolved by a recent non-economic theory: Efficient adaptive control can in fact drive a dynamical system into a state of extreme susceptibility.

We demonstrate, that information efficient control naturally emerges in minimal market models as well as experiments with human participants speculating against each other. This control can not only coexist with, but even cause herding behaviour and intermittent instabilities. Hence, the extreme price fluctuations observed in speculative markets may be a direct consequence of the very mechanisms that lead to market efficiency.

Stability analysis for Bose-Einstein condensates under parametric resonance

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We conduct a detailed stability analysis for Bose-Einstein condensates (BECs) in a harmonic trap under parametric excitation by periodic modulation of the s-wave scattering length [1]. To this end we follow Ref. [2] and obtain at first equations of motion for the radial and axial widths of the condensate using a Gaussian variational ansatz for the Gross-Pitaevskii condensate wave function. Linearizing about the equilibrium positions, we obtain a system of coupled Mathieu equations, the stability of which has been studied extensively [3,4]. We carry out an analytic stability analysis for the Mathieu equations, and compare with numerical results for the nonlinear equations of motion. We find qualitative agreement between the Mathieu analytics and the nonlinear numerics, and conclude that the previously unstable (stable) equilibrium of a BEC might be stabilized (destabilized) by parametric excitation.

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Mean-Field theory for extended Bose-Hubbard model with hard-core bosons

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In this work we solve the extended Bose-Hubbard Model with hard-core bosons within mean-field theory for both a quadratic and triangular lattice. To this end the nearest neighbor terms involving both interaction and hopping are factorized into a mean field and an operator [1]. In this way, we obtain a natural divison of the lattice into sublattices, yielding a much simpler two- or three-site mean-field Hamiltonian for the quadratic and triangular lattice, respectively. An additional on-site hard-core interaction allows each site to be occupied by at most one boson, thus the two- or three-site mean-field Hamiltonian reduces to a 4x4- or 8x8-matrix. The resulting energy eigenvalues have to be extremized with respect to the order parameters, which represent the condensate density and the average number of particles for each of the sublattices. As a result we obtain a mean-field phase diagram, which consists of a Mott insulator phase, a density wave phase, a superfluid phase and, for the triangular lattice, also of a supersolid phase. Furthermore, we determine whether the respective transition lines in the phase diagram are of first or second order. Finally, we follow Ref. [2] and aim at investigating how quantum corrections affect the mean-field results within a field-theoretic motivated variational approach, thus reducing the errors in comparison with quantum Monte Carlo simulations [3].

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Functional architectures for complex behaviors: Analysis and modeling of interacting processes in a hierarchy of time scales

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The idea that human function (be it motoric, perceptual or cognitive) is composed of elementary processes acting as (functional) units or 'primitives' is often expressed in the biological and life sciences. Such units are brought into a meaningful relationship in time to compose complex behaviors comprising of multiple time scales. The present work builds on the scientific tradition of Synergetics in physics and Coordination Dynamics in the sciences of human behavior and cognition to propose a novel theoretical framework, *functional architectures*, aiming at modelling functional units as well as the composite multiscale behaviors, in order to reveal the organization of the latter ones.

We propose that when humans engage in a specific function, their functional dynamics adiabatically collapses from an inherently high-dimensional space onto a functionally relevant subset of the phase (state) space, the manifold. On the manifold, a phase flow is prescribed and a trajectory evolves for the duration of the functional process. Such *Structured Flows on Manifolds* provide the mathematical formalism to model elementary functional processes or units (namely *functional modes*) exhibiting the properties of invariance (among distinct instantiations) and compositionality. The ensemble of functional modes at an agent's disposal constitutes his/her functional repertoire, whereas the modes may be subjected to additional dynamics or external influences (namely *operational signals*) for complex behaviors to emerge.

Using the example of a relatively simple composite movement (two fingers playing a short musical phrase), we show how different functional architectures result depending on the time scale separation between modes and the operational signals involved. Moreover, by applying complexity measures upon modes and signals separately, we reveal a tradeoff of the interactions between them, which offers a theoretical justification for the efficient composition of complex processes out of non-trivial elementary processes or functional modes.

Subsequently, we illustrate a more elaborate functional architecture in the context of serial behavior, namely cursive handwriting. The functional modes that code for characters are subjected to two kinds of operational signals: instantaneous 'kicks' that play the role of functionally meaningful perturbations (used for instance to initiate a movement), and a mechanism that sequentially selects a mode, so that it temporarily dominates the functional dynamics. The instantaneous 'kicks' and the selection mechanism act on faster and slower time scales than that inherent to the modes, respectively, thus, forming, a hierarchy of time scales. The dynamics across the three time scales are coupled via feedback, rendering the entire architecture autonomous.

Finally, we investigate the possibility of recovering the contributions of functional modes and operational signals from the output, which appears to be possible only when examining the output phase flow (i.e., not from trajectories in phase space or time). Our results suggest that by focusing on phase space analysis and on the interactions between the distinct time scales of multiscale processes, the latter ones may be decomposed into their functional dynamical components, thus, revealing the organization of complex behaviors.

The Kuramoto model with time-varying parameters

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Biological examples provided the original motivation lying behind the Kuramoto model (KM) for coupled phase oscillators [1]. However, neither the original model [2], nor most of its extensions [3,4], have incorporated a fundamental property of living systems – their inherent time-variability. Thus, many important characteristics of open systems can be missed by not accounting for the non-equilibrium dynamics that stems from their time-dependent (TD) parameters. This, on contrary, is captured by a recent generalization of the KM that introduced explicit consideration of deterministically time-varying parameters [5].

In the generalized model that we propose the oscillators' natural frequencies and/or couplings are influenced by identical external force with constant or distributed strengths. The observed dynamics of the collective rhythms consists of the external system superimposed on the autonomous one, a characteristic feature of many thermodynamically open systems. This deterministic, stable, continuously time-dependent, collective behaviour is fully described using the recently introduced theory by Ott and Antonsen [6]. Additionally the external impact and the reduced dynamics are defined in both the adiabatic and non-adiabatic limits. In this way, the low-frequency filtering and the robustness of the system to external influence are explained. As a result, a large range of systems tackled by the Kuramoto model – spanning from a single cell up to the level of brain dynamics – can be described more realistically.

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Spiking neural networks: Pattern formation and plasticity

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We investigate spiking neuronal networks which consist of pulse-coupled phase oscillators described by a single neuron model introduced by H. Haken as the lighthouse model [1]. It is a model that falls between spiking neuron models and firing rate descriptions and thus combines the "best of both worlds". In the limit of very slow synaptic interactions it can be reduced to the classic Wilson-Cowan and Amari type firing rate models [2,3,4]; for fast synaptic dynamics, it shows some of the complex properties of real spiking neural networks. Here, we present two aspects of our work. On the one hand, we show some findings on pattern formation in these kind of spiking networks. Thereby, we concentrate on the formation of spatially localized states of persistent high neuronal activity – often referred to as "bumps" – which have been associated with working memory, i.e. the ability of temporary storage of information over the time-scale of a few seconds. On the other hand, we discuss the influence of spike timing dependent plasticity (STDP) which is considered to be linked to learning effects.

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Self-Assembled squaraine nano- and microcrystals for photovoltaics: Characterization of optical, electrical, and charge carrier properties

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Squaraine dyes are useful for various electronic and photonic applications such as two-photon absorbing materials, NIR emitting fluorescent probes, sensitizers for photodynamic therapy, photodetectors and solar cells. Here, nano- and microcrystals from different symmetric amino-substituted bisphenyl-squaraine dyes are grown from solution by means of self-organization processes. Local characterization is performed via polarized light microscopy (PLM), scanning electron microscopy (SEM), atomic force microscopy (AFM), and Kelvin probe force microscopy (KPFM). I-V-curves are recorded from aggregates grown on special four-point-probe platforms to determine charge carrier mobilities along different directions in the crystals. Furthermore, electron spin resonance (ESR) spectra are measured in dark and under illumination to detect charge transfer, i.e. polarons, in mixtures of the squaraine donors with an electron acceptor.

Spatiotemporal dynamics in the human brain during rest

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Over the past years the ongoing human brain activity at rest came into focus, emphasizing the role of the rest-state activity for brain functions such as planning and perception in both healthy and diseased brains. For instance, it has been shown that the alpha rhythm during rest can be affected (e.g., resetting, entrainment) using stimulations such as sensory or Transcranial Magnetic Stimulations (TMS). However, the origin and the mechanisms underlying the rest-state activity are not yet well understood.

In this study, we focus on the propagation of large-scale brain responses to stimulations such as TMS to identify sub-networks involved in the rest-state. Using The Virtual Brain (www.thevirtualbrain.org) we model the dynamics of the human brain as a network of neural masses (NMs), we systematically stimulate different brain areas and analyze the spatiotemporal responses of the model.

The results provide evidence for the existence of a low dimensional set of networks during rest. Stimulations of brain areas involved in resting-state networks produce stronger and longer lasting responses than stimulations of other areas. We found overlapping of the networks with the dominant connectivity structures as well as with experimentally known resting-state networks.

Dynamical inference of time-evolving coupled noisy systems

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Time-variability is characteristic of dynamics of interacting oscillators in nature. Attempting to analyse time series resulting from two or more interacting oscillatory systems subject to external deterministic influences poses a significant challenge. For example, the cardio-respiratory interactions are affected by other oscillatory processes as well as by noise [1].

We introduce a new method that (a) encompasses time-variable dynamics, (b) detects synchronization where it exists, (c) detects the predominant coupling direction and (d) determines the inter-oscillator coupling functions regardless of whether or not they are time varying [2]. Based on Bayesian inference for stochastic differential equations (SDE), the technique infers the multivariate phase dynamics of interacting oscillators. By reconstructing the phase dynamics in terms of a set of periodic base functions, we evaluate the probability that they are driven by a set of equations that are intrinsically synchronized, distinguishing phase-slips of dynamical origin from those attributable to noise. Estimation of the coupling is directly linked to the parameterisation of the base functions. The Bayesian probability lying at the core of the method is itself time-dependent via the prior probability as a time-dependent informational process. By considering complex interacting systems that are oscillatory and subject to noise, the method extracts their dynamical properties and functional relationships. In doing so, our method does not infer effects, but dynamical mechanisms.

We tested the method on numerically simulated systems and applied it to determine the time-varying nature of cardio-respiratory interactions. The method reveals details of phase dynamics, describes the inherent nature of the transitions to/from synchronization, and simultaneously deduces the characteristics of the noise that stimulated them. In addition, the time-varying nature of the coupling functions between non-autonomous oscillatory systems can be identified. In this way for the first time we demonstrate that in the cardio-respiratory system not only the parameters, but also the functional relationships, can be time-varying. By generalising the method to networks of oscillators we demonstrate its advantage in revealing time-varying relationships [3], both structural (network connectivity) and functional (coupling functions).

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Cell membrane potential: oscillations and self-regulation

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We consider dynamics of cell membrane potential and how it is linked to energy metabolism in the cell. In particular, we show how the oscillatory behaviour of the membrane potential can perform the regulatory function by adjusting its own frequency and metabolism. The theoretical work is based on recent observations of synchronized mitochondrial membrane potential oscillations in cardiac myocytes [1]. Apart from synchronization, it was observed that the frequency of mitochondrial oscillations changed during the time of measurements (from 16 mHz to 8 mHz over the course of 10 minutes). This phenomenon suggests the presence of a self-regulatory mechanism in the cell, however its theoretical description is not known yet. We show that such self-regulation is possible due to oscillatory behaviour of the cell membrane potential.

Based on the connection between the mitochondrial membrane potential and ATP production [2] we conjecture that the concentration of ATP in the cell also oscillates. Furthermore, oscillations of the intracellular concentration of ATP influence the work of Na/K pump. We then use the Michaelis-Menton approximation [3] of the dependence of the Na/K pump on ATP concentration. By considering the balance equation for ATP production and consumption we obtain the time-dependent ion current through the Na/K pump in cells with oscillating concentration of ATP. Finally, using the dynamical theory of the cell membrane potential [4] we show that the cell membrane potential oscillates when the intracellular concentration of ATP oscillates. Also, we show theoretically that such oscillations are stronger in cells with smaller volume and with smaller initial ATP concentration.

The ion concentrations in cells change much slower than the cell membrane potential during oscillations of ATP concentration. These relatively slow changes in the intracellular ionic concentration may influence the frequency of the mitochondrial oscillation. Therefore, we propose the following mechanism of self-regulation: the mitochondrial oscillations cause the oscillation of the cell membrane potential, which in turn slowly changes the ion concentrations around mitochondria. As a result, it may cause the frequency of mitochondrial oscillations to change.

Thus the mechanism of self-regulation, discussed here, is a good candidate for the mechanism used by the cell to regulate the frequency of the mitochondrial oscillations observed in the experiment [1].

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Large-scale neural network model for functional networks of the human cortex

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Well organized spatio-temporal low-frequency fluctuations (< 0.1 Hz) have been observed in blood-oxygen-level-dependent (BOLD) fMRI signal during rest i.e. under no stimulations and in the absence of any overt-directed behaviour [1,2]. These, spatio-temporal patterns of the brain activity form so called resting state networks which properties have been extensively used to investigate functional connections between region pairs in the brain. Resting state functional connectivity (FC) is commonly assumed to be shaped by the underlying anatomical connectivity. Furthermore, it has been suggested that its strength, persistence and spatial properties are constrained by the large-scale anatomical structure of the cortex [3,4]. However, strong FC is often observed between remote cortical regions suggesting that indirect connections, interregional distance and collective effects governed by network properties of the cortex play significant role in generation of the FC in the resting state. Here, we aim to address these questions studying topology of an empirically derived resting state network (RSN) from fMRI data and modelling dynamics on the network supported by the obtained measures. Our RSN was comprised of 64 cortical regions as adapted from a study of functional segmentation of the human cortex [5]. From each region mean time series of BOLD activity were extracted, and 64x64 FC matrix was constructed by calculating Pearson correlation coefficient on all possible pairwise combinations of the time series. The data were then averaged across 26 subjects. To explore network topology we used methods of the graph theory and examined global and local network properties across range of correlation thresholds [1]. Any correlation in the FC matrix greater than a given threshold was kept as a link between corresponding regions in the adjacency matrix. For the model, we simulated network dynamics as system of identical FitzHugh-Nagumo neural oscillators, placed in each network node. Simulations are carried out for the case when dynamics of a node exhibits damped oscillatory behaviour in the absence of connectivity while the noise applied drives network out from its equilibrium state. The distances between the nodes were taken as the Euclidean distances between the centres of the spherical regions from which BOLD time series were extracted. To account for the finite speed of the signal propagation along the axons, the interactions in the network are modelled with the time delays. We compared FC of simulated activity as a function of the signal speed, coupling strength and correlations threshold. We found that for the fixed values of correlations threshold the properties of FC network depends on the coupling strength.

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Anisotropic superfluidity of bosons in optical Kagome superlattice

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We study the boundaries of the quantum phase transitions for the extended Bose-Hubbard model with hard-core bosons on a Kagome superlattice which can be implemented by enhancing the long wavelength laser in one direction of the optical lattice [1]. To this end we combine the virtues of a Mean-Field theory with the Landau theory of Ref. [2] and work out a decoupled effective potential method. By comparing the corresponding analytic results with extensive quantum Monte Carlo simulations, we find that several striped solids emerge in this system. Due to the blockade effect of such a striped order, the resulting superfluid density turns out to be anisotropic and, thus, reveals its tensorial property [3]. Finally, we discuss the complete quantum phase diagram.

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On the signatures of self-organization in whole-brain dynamics

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A large body of computational and mathematical work in neuroscience addresses neural dynamics often using concepts of self-organization and low-dimensional attractor dynamics on micro- or mesoscopic scales. However, investigation of the attractor structure of macroscopic, so-called whole-brain, dynamics, based on empirically measured connectivity is still in its infancy [1, 2]. The presence of a matrix of delays in the system's coupling presents a singular challenge to analytic approaches. In the present work we numerically simulate a set of neural masses coupled based on measured connectivity and fiber track lengths, varying conduction velocity, global coupling scale, and excitability of the neural mass, for multiple human subjects. In particular, we 1) show how the different subjects' connectivities generate different critical dynamics, and 2) reconstruct the vector field of the dynamics.
3) show how the subspace of the attractor may evolve on a slow timescale.

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