Abstracts of Invited Lectures

Statistical aspects of weak chaos

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In non-hyperbolic dynamical systems, very slow dynamics is often generated, where the intrinsic features of weak chaos have been elucidated in the framework of the infinite ergodic theory. Universal aspects of weak chaos are reviewed carrying out with intermittent chaos and hamiltonian chaos. First, the nonstationarity of strong intermittency is described by some characteristic quantities, such as power spectral density, pausing time distribution, correlation function, Allan variance, 2-path correlation, etc. , which are successfully obtained from the renewal analysis in probability theory. However, the more detailed features in weak chaos can be derived by use of the infinite ergodic theorem, for instance, the Lyapunov exponent and the diffusion constant reveal inherent fluctuations obeying the Mittag-Leffler distribution. Secondly, the origin of slow dynamics (such as the Arnold diffusion) in hamiltonian systems is theoretically analysed based on the Nekhoroshev theorem, and it is shown that the pausing times universally obey the Log-Weibull distribution, and that the universal distribution clearly appears in some numerical simulations for high dimensional hamiltonian dynamics; in the cluster formation of gas molecules and in the FPU model of crystal lattice vibrations. Finally, a hamiltonian system, which manifests the infinite measure ergodicity, is discussed; the mixmaster universe model (Bianchi type IX) is completely analysed in terms of infinite ergodicity. This result seems to suggest that slow diffusions in generic hamiltonian cases might be also connected to infinite measure ergodicity, though we have not yet succeeded to find out the infinite ergodic sub-dynamics in the high dimensional systems.

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Lecture 1: Fundamental Concepts of Complexity Science

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Complexity is a property of large systems, consisting of a huge number of units involving nonlinearly interacting agents, which exhibit incredibly complex behavior. New structures emerge out of non-equilibrium and order can be born out of chaos, following a process called self-organization. Complex systems in the Natural, Life and Social Sciences produce new shapes, patterns and forms that cannot be understood by studying only their individual parts. In this first lecture I will mention briefly how the Theory of Chaos and the Geometry of Fractals formed the mathematical foundation for this new science making us realize how complex behavior can arise in simple models of low dimensionality. I will speak, in particular about the properties of self-similarity under scaling, sensitive dependence on initial conditions and the concept of bifurcations that by the 1980s had already revolutionized our ideas about the relationship between dynamics and geometry in surprisingly small systems, paving the way for the remarkable advances of Complexity Science that were soon to follow.

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Lecture 2: Granular Dynamics, Bird Flocking and Chimera States

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One of the most challenging and important properties of complex systems is their ability to "condense", form clusters, flocks or subgroups, apparently spontaneously during their time evolution. As it turns out, this type of behavior is not at all accidental, but occurs as a result of an internal instability, due to which the system undergoes a global "bifurcation", that one may well characterize as a dynamical phase transition. In the case of granular material flowing down an array of periodically shaken boxes, as the inflow rate at the top increases, this instability is "announced" by the appearance of a back-propagating wavy pattern, followed by a catastrophic "particle jam" at the top of the array. In a group of birds, flocking is a global feature of many models imitating the fascinating patterns we see them form in the sky; and yet, when a "noise" parameter crosses a certain threshold, flocking breaks down by a phase transition, whose order remains to date a hotly debated issue. Finally, in the brain of many mammals the sudden appearance of neighboring synchronous and asynchronous neuronal ensembles, termed a "chimera state", is thought to be the result of a global bifurcation, which has been verified on a wide variety of oscillating networks with long range interactions. As we will discuss, these chimera states can now be observed in realistic *Hindmarsh Rose* models of neuron oscillators as well mechanical networks of coupled pendulum-like systems.

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Lecture 3: Order and Chaos in Multi-Dimensional Hamiltonian Systems

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Hamiltonian systems have been studied extensively by mathematicians and physicists for more than a century producing a wealth of theoretical predictions that have been thoroughly verified by numerical experiments. In the case of few degrees of freedom, one might claim that most of their properties are well understood. And yet, in many dimensions, there remain many secrets to be revealed and surprises to be discovered. In this lecture, I will first discuss the basic facts about Hamiltonian systems, using as an example the famous Fermi-Pasta-Ulam (FPU) $\beta-$ model consisting of a one-dimensional chain of coupled oscillators with harmonic and quartic nearest neighbor interactions. I will focus on the continuation of their (linear) normal mode periodic solutions and seek to relate their (local) stability to more global phenomena such as FPU recurrences and energy equipartition in the thermodynamic limit. I will extend the method of Lyapunov exponents to the spectrum of GALI_k indicators to study the breakdown of invariant tori. We will thus discover that low-dimensional phenomena connected with localization properties in configuration as well as Fourier space give rise to hierarchies of order (low dimensional invariant tori) and disorder (weakly and strongly chaotic domains) of great dynamical and statistical complexity that is only now beginning to be explored.

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Lecture 4: Complex Statistics of Hamiltonian Dynamics

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In this lecture we shall adopt an altogether different approach to the study of chaos in Hamiltonian systems. We will consider, in particular, probability distribution functions (pdfs) of sums of chaotic orbit variables in different regions of phase space, aiming to reveal the statistical properties of the motion in these regions. If the orbits are strongly chaotic, these pdfs tend to a Gaussian and the system quickly reaches an equilibrium state described by Boltzmann-Gibbs statistical mechanics. There exist, however, many interesting regimes of weak chaos characterized by long-lived quasi-stationary states (QSS), whose pdfs are well-approximated by q-Gaussian functions, associated with nonextensive statistical mechanics. Here, we will discuss such QSS for a number of N dof FPU models, as well as 2D area-preserving maps to locate such weakly chaotic QSS, investigate the complexity of their dynamics and discover their implications regarding the occurrence of dynamical phase transitions and the approach to thermodynamic equilibrium. Going beyond lattice dynamics, we will describe the occurrence of QSS in dynamical transitions observed in a microplasma model and explain how nonextensive statistics can help us distinguish strongly from weakly chaotic orbits in a barred galaxy model for short time intervals dictated by the limitations of the age of the universe.

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Lecture 5: Chaotic Diffusion and the Role of Long Range Interactions

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The absence of diffusion in disordered media, often called Anderson localization, is a general phenomenon that applies to the transport of different types of classical or quantum waves. An interesting question is what happens to the diffusion if nonlinearity is introduced. Currently, a greatly debatable problem concerns the long time spreading of the wave packet. It has been conjectured that chaotically spreading wave packets will asymptotically approach KAM torus-like structures in phase-space. In this lecture, we start by using the concepts of Nonextensive Statistical Mechanics to show that for a high-dimensional Klein-Gordon disordered particle chain, the dynamics does not relax onto a torus-like structure, but continues to spread chaotically along the chain for arbitrarily long times. Finally, we revisit our one-dimensional Fermi-Pasta-Ulam (FPU) model and examine the role of short vs. long range interactions, by coupling all particles by quartic interactions whose coupling coefficients decay as $1/r^{\alpha}$ ($\alpha \geq 0$). Our computations show that (i) for $\alpha > 1$ the maximal Lyapunov exponent remains finite and positive for increasing numbers of oscillators, whereas, for $0 \leq \alpha \leq 1$, it asymptotically vanishes. (ii) The distribution of time-averaged velocities is Maxwellian ($q = 1$) for α large enough, whereas it is well approached by a q-Gaussian with the index $q(\alpha)$ decreasing to one, as α increases from zero to infinity, suggesting a remarkable transition from Boltzmann-Gibbs (BG) to Tsallis thermostatistics as we move from short range ($\alpha > 1$) to long range interactions ($\alpha < 1$).

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Mathematical modeling of complex systems

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These 5 lectures are meant to be introductory, with the main ideas presented in a pedagogical way by means of simple examples. They are aimed primarily at graduate students interested in complex phenomena occurring in various disciplines. In the first 2 lectures, we will be concerned with the emergence of collective behavior in the form of clustering, flocking, synchronization, etc. as they occur in dissipative systems of interest to Physics and Biology. Our approach will be to start from some crucial observation or experiment and seek to construct the appropriate mathematical model that captures the main features of the data. The remaining 3 lectures will focus on a class of conservative systems described by N-degree of freedom Hamiltonian functions, which are familiar to us from classical mechanics, astronomy and solid state physics. Our main point will be to show that despite a well established general theory, there are still many important local phenomena involving various degrees of order and chaos that need to be further understood, because of their global consequences regarding the physical properties of the system, especially for long times and large N. We will thus discover that to understand these complex aspects of Hamiltonian models, we need to combine the mathematical techniques of nonlinear dynamics with a statistical analysis of probability distributions of chaotic orbits in different regimes of the multi dimensional phase space, where the motion of the system evolves.

Challenges in Complex Systems: in particular in socio/economic sciences

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The lectures (7h) are organized in two main parts: Part I will be devoted to the broad initiative 'FuturICT', Part II will be devoted to the applications of fractal geometry for the analysis of big-data sets of socio-economic-enviromental interest.

Part I: Global Community for our Complex connected World

FuturICT is a visionary project that will deliver new science and technology to explore, understand and manage our connected world. This will inspire new information and communication technologies (ICT) that are socially adaptive and socially interactive, supporting collective awareness.

Our increasingly dense interconnected world poses every day new challenges that need to be approached in several dimensions, at different temporal and spatial scales. In particular, given the scope and scale of the world's future Internet of everything, new technologies with the lowest energetic impact, unconventional computational schemes, novel phenomena and paradigm should be figure out for understanding and managing such increasing complexity. Revealing the hidden laws and processes underlying our complex, global, socially interactive systems constitutes one of the most pressing scientific challenges of the 21st Century. Integrating complexity science with ICT and the social sciences, will allow us to design novel robust, trustworthy and adaptive technologies based on socially inspired paradigms. Data from a variety of sources will help us to develop models of techno-socioeconomic systems. In turn, insights from these models will inspire a new generation of socially adaptive, self-organised ICT systems. This will create a paradigm shift and facilitate a symbiotic co-evolution of ICT and society. Further info at www.futurict.eu

Part II: A non-Random Walk through our complex connected world

Time series are a tool to describe biological, social and economic systems in one dimension, such as stock market indexes and genomic sequences. Extended systems evolving over space, such as urban textures, World Wide Web and firms are described in terms of high-dimensional random structures.

A short overview of the Detrending Moving Average (DMA) algorithm is presented. The DMA has the ability to quantify temporal and spatial long-range dependence of fractal sets with arbitrary dimension. Time series, profiles and surfaces can be characterized by the fractal dimension D, a measure of roughness, and by the Hurst exponent H, a measure of long-memory dependence. The method, in addition to accomplish accurate and fast estimates of the fractal dimension D and Hurst exponent H, can provide interesting clues between fractal properties, self-organized criticality and entropy of long-range correlated sequences. Further readings and tips about the DMA algorithm at www.polito.it/noiselab

Classical dynamical localization

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We consider a class of purely classical kicked rotor models, designed so that kicks can change their momenta only by multiples of a constant. Their classical dynamics is numerically found to display slow logarithmic growth of momentum, or quadratic growth of energy, depending on the arithmetic nature of the constant. Such features mimic paradigmatic features of the standard quantum kicked rotor, notably dynamical localization in momentum, or quantum resonances, depending on the arithmetic nature $\hbar$ Such results command a reconsideration of generally accepted views, that dynamical localization and quantum resonances are a result of quantum interference

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String theory, particle physics and black holes

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In past decades, string theory has emerged as the prime candidate for a quantum unification of electromagnetic, nuclear and gravitational forces. Geometrical aspects of string theory, and in particular the existence of extra dimensions, shed light on important fundamental questions, including the microscopic structure of black holes and the geometric origin of particle physics. We review certain aspects of these developments such as introduction of extended objects - Dirichlet branes - and highlight an important geometric role that these objects play in deriving particle physics from string theory and review the role these objects play in elucidating the microscopic structure of black holes. We highlight the most recent progress made in deriving particle physics from F-theory, a string theory at finite coupling. We also review progress made on studies of internal structure of non-extremal black holes in string theory via so-called subtracted geometry.

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Introduction to nonlinear dynamics

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Lecture 1 & 2: Dynamics

We start with a recapitulation of basic notions of dynamics; flows, maps, local linear stability, heteroclinic connections, qualitative dynamics of stretching and mixing and symbolic dynamics.

The lecture notes and videos are available online, as parts of the advanced nonlinear dynamics course, `ChaosBook.org/version15/Maribor13.shtml`

Lecture 3 & 4: Periodic orbit theory

A motion on a strange attractor can be approximated by shadowing the orbit by a sequence of nearby periodic orbits of finite length. This notion is here made precise by approximating orbits by primitive cycles, and evaluating associated curvatures. A curvature measures the deviation of a longer cycle from its approximation by shorter cycles; the smoothness of the dynamical system implies exponential (or faster) fall-off for (almost) all curvatures. The technical prerequisite for implementing this shadowing is a good understanding of the symbolic dynamics of the classical dynamical system. The resulting cycle expansions offer an efficient method for evaluating classical and quantum periodic orbit sums; accurate estimates can be obtained by using as input the lengths and eigenvalues of a few prime cycles.

Lecture 5 & 6: Noise is your friend

All physical systems are affected by some noise that limits the resolution that can be attained in partitioning their state space. For chaotic, locally hyperbolic flows, this resolution depends on the interplay of the local stretching/contraction and the smearing due to noise. Our goal is to determine the 'finest attainable' partition for a given hyperbolic dynamical system and a given weak additive white noise. That is achieved by computing the local eigenfunctions of the Fokker-Planck evolution operator in linearized neighborhoods of the periodic orbits of the corresponding deterministic system, and using overlaps of their widths as the criterion for an optimal partition. The Fokker-Planck evolution is then represented by a finite transition graph, whose spectral determinant yields time averages of dynamical observables.

Lecture 7 & 8: Symmetries and dynamics

Dynamical systems often come equipped with symmetries, such as the reflection symmetries of various potentials. Symmetries simplify the dynamics in a rather beautiful way:

If dynamics is invariant under a set of discrete symmetries G, the state space $\mathcal{M}$ is *tiled* by a set of symmetry-related tiles, and the dynamics can be reduced to dynamics within one such tile, the *fundamental domain* $\mathcal{M}/G$. If the symmetry is continuous, the dynamics is reduced to a lower-dimensional desymmetrized system $\mathcal{M}/G$, with "ignorable" coordinates eliminated (but not forgotten). We reduce a continuous symmetry by slicing the state space in such a way that an entire class of symmetry-equivalent points is represented by a single point.

In either case, families of symmetry-related full state space cycles are replaced by fewer and often much shorter "relative" cycles. In presence of a symmetry the notion of a prime periodic orbit has to be reexamined: it is replaced by the notion of a relative periodic orbit, the shortest segment of the full state space cycle which tiles the cycle under the action of the group. Furthermore, the group operations that relate distinct tiles do double duty as letters of an alphabet which assigns symbolic itineraries to trajectories.

Lecture 9 & 10: Dynamical theory of turbulence

As a turbulent flow evolves, every so often we catch a glimpse of a familiar pattern. For any finite spatial resolution, the system follows approximately for a finite time a pattern belonging to a finite alphabet of admissible patterns. In “Hopf’s vision of turbulence,” the long term turbulent dynamics is a walk through the space of such unstable patterns.

Aging transition and other phenomena in large populations of dynamical units

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Dynamic activity such as periodic oscillation and chaos exhibited by large populations of coupled dynamical units plays an important role in many fields of science and technology. A crucial issue is to examine its robustness against the deterioration of those units caused by aging, accidents, and so on. The present talk will be concerned with theoretical studies of this issue, focusing on such a case that each unit remains active (i.e., self-oscillatory) until the deterioration makes it inactive (i.e., not self-oscillatory).

There are two typical scenarios for the onset of oscillation in a single unit: One is a Hopf bifurcation and the other what is called an SNIC (saddle-node bifurcation on an invariant circle). We begin with the case in which each unit follows the former scenario and review main results published so far on the behavior of the whole system as the ratio of inactive units increases (this process is defined to be *aging*). The most striking phenomenon is a transition of the system from the dynamic phase to the static which occurs when the ratio exceeds a critical value, termed an *aging transition.* Some other interesting phenomena will also be treated.

We then go on to the case of the latter scenario. A unique feature of this case is that a single unit can show *excitability* depending on the value of its bifurcation parameter. Although relevant to a number of areas, this feature is particularly important in biological and physiological contexts. Here we examine the behavior of a few populations, each composed of such units with a uniform distribution of the bifurcation parameter, by varying the mean value of the distribution as well as the coupling strength. Some model-independent results will be highlighted.

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Water transport in the early planetary system

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For an estimate of water transport in the early planetary system we investigate the degree of possible water delivery by means of asteroid collisions. Here we present a study of the distribution of impact velocities and angles of small bodies with a certain water content and initial mass of a tenth lunar mass that are distributed on orbits with semimajor axes between 1 and 2 AU, small eccentricities $e < 0.15$ and small inclinations. The bodies' initial water (ice) content increases with their distance to the Sun from 0.5 % to 3 %. By simulating mutual collisions via n-body calculations we trace how the masses and water contents of those bodies evolve depending on the presence of a perturbing Jupiter-like planet in different distances. We find that within 1 Myr the masses of the bodies increase up to one lunar mass and the inclination-distribution is widened while the water content closer to the Sun tends to increase from inward scattered objects. We also present means of verification of our present perfect merging assumption via simulating the collision processes using Smooth Particle Hydrodynamics (SPH).

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Perturbing Flat Bands

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Macroscopically degenerate flat bands (FB) in periodic lattices host compact local- ized states which appear due to destructive interference and local symmetry. Interference provides a deep connection between the existence of flat band states (FBS) and the appearance of Fano resonances for wave propagation. I will introduce generic transformations detangling FBS and dispersive states into lattices of Fano defects. Inverting the transformation, one can generate a continuum of FB models. That procedure allows to systematically treat perturbations such as disorder, quasiperiodic potentials, magnetic fields, nonlinearity and quantum many body interactions. The presence of weak uncorrelated disorder leads to the emergence of energy-dependent localization length scaling due to Fano resonances and renormalized disorder distributions with heavy Cauchy tails. In the presence of strong but correlated disorder (which respects the local FBS symmetry) logarithmic or square root singularities develop in the density of states around the FB energy due to quadratic energy renormalization of eigenstates. For strong quasiperiodic (Aubry-Andre) potential perturbations we obtain analytical expressions for the energy dependence of metal-insulator transitions (mobility edges). I will also present first results on the impact of magnetic fields, nonlinearity, and interactions between quantum particles on the FB and the FBS.

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Prospects and challenges of neurophysics: A physicist's view after 25 years

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As you read these lines, millions of neurons are active in your brain and communicate with each other by sending short pulses. It is a major aim and formidable challenge for neurophysics to understand the collective dynamics of large biological neural networks in order to determine how they carry out complex computations. This talk presents the challenges, prospects, and progress in pursuing this aim from the view of a physicist who has been observing the field over the last 25 years.

With recent advances of experimental techniques, the activity of large numbers of cells can now be monitored in parallel and with single cell resolution, even in freely moving animals. These techniques together with targeted optogenetic stimulation promise to considerably advance our insight into the function of collective neuronal dynamics in the near future.

Making sense of these huge data sets, however, requires theory, but these networks exhibit features that let them elude standard theoretical treatments. For example, the units of the network interact asymmetrically and at discrete times only, i.e. not continuously as in conventional many-body theory in physics. There are significant interaction delays, which formally make the systems infinite-dimensional. Complex connectivities give rise to novel multi-operator problems, for which new methods based on graph theory have been devised to obtain rigorous analytic results. Theoretical progress has already uncovered novel and amazing properties of nonlinear dynamics exhibited by such networks and is impacting experimental neuroscience.

Time reversibility, phase-space contraction rate and the second law of thermodynamics

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The Gallavotti-Cohen fluctuation theorem, which concerns a non-trivial symmetry of the steady states of some thermostated systems driven out of equilibrium, is among a number of intriguing theoretical results which were discovered some twenty years ago and have since had great influence on the field of non-equilibrium statistical physics, in particular with respect to the microscopic origin of the second law of thermodynamics—in other words, irreversibility.

Central to the relevance of the fluctuation theorem to non-equilibrium statistical mechanics is the identity between the phase-space contraction rate of thermostated systems and their entropy production rate (as specified by non-equilibrium thermodynamics). This identity, whose generality is by no means obvious, stems from the precise mechanism through which the 'thermostat' constantly removes energy from such systems when they are acted upon by an external forcing.

In this talk I shall review some of the key developments of this theory and offer a new, albeit modest, contribution in the form of the following analytic result: simple two-dimensional triangular maps that, for elementary reasons, verify the Gallavotti-Cohen symmetry, typically break the identity between phase-space contraction and entropy production rates. I will provide a number of examples of such systems and show that the difference between those two quantities is usually small and may in fact be rather difficult to detect through numerical measurements.

Introduction to Econophysics

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At first sight, it seems a bit far–fetched that physicists work on economics problems. A closer look, however, reveals that the connection between physics and economics is rather natural — and not even new! Many physicists are surprised to hear that the mathematician Bachelier developed a theory of stochastic processes very similar to the theory of Brownian motion which Einstein put forward in 1905. Bachelier did it in the context of financial instruments, and he was even a bit earlier than Einstein. Moreover, not all physicists know that financial time series were a major motivation for Mandelbrot when he started his work on fractals. Mathematical modeling in physics and economics, in particular finance, is similar!

In the last 15 or 20 years, the physicists' interest in economic issues grew ever faster, and the term "econophysics" was coined. Econophysics developed into a recognized subject. The crucial reason for this was the dramatic improvement of the data situation, a wealth of data became available and (electronically) accessible. Moreover, complex systems moved into the focus of physics research. The economy certainly qualifies as a complex system and poses serious challenges for basic research. Simultaneously, economics started to develop into a more quantitative science. From a more practical viewpoint, the need to quantitatively improve risk management in economics is a driving force in econophysics.

The presentation starts from scratch, no background in economics is needed, it consists of five lectures: (1) Basic Concepts, (2) Detailed Look at Stock Markets and Trading, (3) Financial Correlations and Portfolio Optimization, (4) Quantitative Identification of Market States, (5) Credit Risk.

The field develops quickly, implying that not all of the topics in the course can be found in text books appropriate for a physics audience. Some good text books written by physicists are listed below, further literature will be given in the course.

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Selfaveraging characteristics of spectral fluctuations

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The spectral form factor as well as the two-point correlator of the (quasi-)energy density of individual quantum dynamics are known not to be selfaveraging, even in the semiclassical limit. Only suitable smoothing turns them into reliable characteristics of spectral fluctuations. We present numerical data for two types of smoothing for a fully chaotic kicked top. One method uses imaginary parts of the quasi-energy variables while the other employs primitives of form factor and correlator. Universal behavior is found for the smoothed form factor and also for the correlator within quasi-energy ranges where correlations persist above a certain noise level. Noise is revealed as such by strong non-selfaveraging: Tiny changes of the effective Planck constant entail large changes in the smoothed spectral characteristics. Theoretical "predictions" of RMT behavior of spectral correlations outside the range now established appear to implicitly involve averages over ensembles of quantum systems sharing the same classical limit. Further theoretical work avoiding such $\hbar$-averages and aiming at selfaveraging spectral characteristics appears desirable.

Applications of Chaotic Billiard Lasers: Single Mode Operation and Compact Long Optical Paths

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For the last two decades, the research field of quantum chaos has involved two-dimensional (2D) microcavity lasers, which connected the mathematical chaotic billiard models with the actual devices and experimentally demonstrated the theoretical results of quantum chaos such as chaos-assisted tunneling. Here we call those 2D microcavity lasers whose ray dynamics is completely chaotic or partially chaotic "chaotic billiard lasers". Although integrable billiard lasers like microdisk lasers of circular shape and broad area lasers of rectangular shape have found practical applications for sensors and optical components, most of the researches on chaotic billiard lasers still remain fundamental. By both the experimental and theoretical results, we shall show the possibilities of novel and practical applications of chaotic billiard lasers for single mode operation and compact long optical paths.

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Intelligent design: shaping cellular gene circuits and molecules in synthetic biology (with help from mathematicians and computer scientists)

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Biological systems are complex systems for the exchange of energy and molecules using coordinated action of biopolymers. Most of the biopolymers that perform different activities are proteins, composed of a defined amino-acid sequence, which is encoded in the genes by the sequence of DNA constituting the cellular genome. Activation of each gene is regulated by transcriptional factors, proteins that bind to the selected sequences of each gene and activate or repress its transcription. Since genes can also code for transcriptional factors cellular genome can constitute complex regulatory networks, including feedback loops. If we want to harness cells to perform different functions, such as sensors or therapeutic devices we should be able to engineer cells for a predictable response to selected inputs, different from the existing cellular networks. Instead of relying on natural regulatory elements we selected to use designable modular DNA binding proteins, called TALEs, that can bind to almost any selected DNA sequence. The advantage of this approach is that we can make thousands of DNA binding domains. This allowed construction of genetic NOR gates in mammalian cells, each of which required two TALE proteins. Those logic gates can be introduced into cells through the synthetic recombinant DNA. NOR gate represents a functionally complete logic gate, which can be used to make any selected logic function. We demonstrated functionality of all 16 designed two-input logic gate in mammalian cells. Moreover TALEs also allow us to make bistable switch, where we needed to introduce nonlinearity by a feedback loop and competition. The ubiquitous use of proteins as smart materials in nature is based on their ability to self-assemble into a large number of different folds. Natural protein folds are very difficult to predict and design, since they depend on a large number of weak cooperative interactions among amino-acid residue constituents of polypeptides. We invented a new type of topological protein fold, which is based on assembling modular pairwise interacting segments called coiled-coil domains. We can design the selectivity of coiled-coil segments based on simple rules. The goal was to design the polyhedra, where each of their edges is composed of a coiled-coil dimer. Polyhedron is therefore self-assembled from a single chain that traverses each edge of the polyhedron exactly twice with some additional restrictions to ensure the stability of the polyhedron and compatibility with protein stability rules. The self-assembly is defined by the order of concatenated coiled-coil dimer-forming segments, that can form parallel or antiparallel dimers. This ability to select orientation allows prepare, in principle, any type of a polyhedron from polypeptides. We experimentally demonstrated this concept by making a polypeptide tetrahedron cage with 5 nm edges. The essence of synthetic biology is to design devices and molecules present in nature that have new interesting properties, but it also allows us to investigate the mechanisms of natural processes.

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Chaos and dynamical trends in barred galaxies: bridging the gap between time-dependent analytical models and N-body simulations

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Self-consistent N-body simulations are efficient tools to study galactic dynamics. However, using them to study individual trajectories (or ensembles) in detail can be challenging. Such orbital studies are important to shed light on global phase space properties, which are the underlying cause of observed structures. The potentials needed to describe self-consistent models are time-dependent. I will present a study on the distinction and quantification of chaotic and regular motion in a time-dependent Hamiltonian barred galaxy model and the role of the interplay between chaotic and regular behavior of star orbits as the parameters of the model evolve in time. A new way of using the GALI method as a reliable criterion to estimate the relative fraction of chaotic vs. regular orbits in such time-dependent potentials is here applied. I will then discuss the dynamical properties of a non-autonomous galactic system, whose time-dependent potential adequately mimics certain realistic trends arising from N-body barred galaxy simulations. Starting with its reduced time-independent 2-degrees of freedom model, I will show charts with different islands of stability (associated with certain orbital morphologies) and chaotic regions. In the full 3-degrees of freedom time-dependent case, I will show representative trajectories experiencing typical dynamical behaviors, i.e. interplay between regular and chaotic motion for different epochs. Finally, I will discuss its underlying global dynamical transitions, estimating fractions of (un)stable motion of an ensemble of initial conditions taken from the simulation and evolved with the time-dependent analytical potential. For such an ensemble, it turns out that the fraction of regular motion increases with time.

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Evolutionary Aspects of Fine-Tuning of Cellular Oscillators in the Networks

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Abstract

It is becoming progressively more evident that the understanding of the functioning of biological tissues does not only rely on the knowledge of individual cell behaviour, but requires thorough investigations of the mutual interactions among the cells [1]. There are examples where particular tissue dysfunctions cannot be explained on the basis of alterations in individual cells but the pathology results from changes in interconnections between the cells [2]. Mathematical modelling of the network dynamics is a convenient toll for analysing the role of individual cells and the emergent properties of the tissue. In particular, modelling of complex cellular oscillators in the networks plays important role. A decade ago we showed that individual oscillators exhibit different levels of flexibility, which characterizes their stability and susceptibility to external perturbations [3, 4]. We have elevated this knowledge to networks of cellular oscillators, and showed that cellular oscillators with different flexibility match different optimal topologies of the networks in which they provide their maximal coordination and efficiency [5]. The phenomenon relies on the remarkable fact that individual oscillators in the network change their flexibility, a kind of dynamical flexibility, in dependence on the wiring in the network. From the evolutionary point of view we might hypothesise that this fine-tuning of oscillators and their wiring in the network structures of appropriate topologies can be understood as a trade-off between minimal costs for individual oscillator regulation and maximal efficiency in the wiring of these oscillators in the network. Moreover, our current studies indicate that cell failures and the risk of kicking-off particular nodes in the network might play crucial role in the evolution of biological tissues. We provide model predictions indicating the importance of evolutionary developed robustness of biological tissues to random and targeted attacks. This study is conducted for networks of different topologies and cellular oscillators with different flexibilities. The results provide a clear evidence of natural optimisation, a trade-off between the efficiency and robustness.

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How ions get through biological ion channels

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We outline very briefly the role and function of biological ion channels: the natural nanopores that provide for fast and selective permeation of physiologically important ions (e.g. Na^+, K^+ and Ca^{2+}) through cellular membranes. Although a great deal is now known about ion channels, including their detailed atomic structure in some cases, this information has helped surprisingly little in understanding how they actually work: the central conundrum – their ability to conduct almost at the rate of free diffusion while remaining highly selective for particular ions – remains largely unresolved. It is known, however, that the channel's conductive properties are determined mainly by a short negatively-charged selectivity filter. We report recent progress in treating permeation as a problem in nonlinear dynamics under electrostatic and stochastic forces. We point out that, remarkably, the process is closely analogous to mesoscopic conduction in quantum dots. We discuss how this approach is able to account for the conduction bands recently discovered in Brownian dynamics simulations, for valence selectivity, and for unexpected changes in selectivity that occur when the charge at the selectivity filter is altered by mutation. We conclude by discussing the implications for the design of artificial nanopores.

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Bargaining with discrete strategies

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Imagine two players having to share a sum of money. One proposes a split (p), and the other can either agree with it or not (q). No haggling is allowed. If there is an agreement, the sum is shared according to the proposal. If not, both players remain empty handed. This is the blueprint of the ultimatum game [1]. Seminal experiments on ultimatum bargaining have revealed that humans are remarkably fond of fair play [2]. When asked to share something, unfair offers are rare and their acceptance rate is small. Traditionally, the ultimatum game has been studied with continuous strategies, and it has been shown that empathy and spatiality may lead to the evolution of fairness [3]. However, evolutionary games with continuous strategies often hide the true complexity of the problem, because solutions that would be driven by pattern formation are unstable. Discrete strategies in the ultimatum game open the gate to fascinatingly rich dynamical behavior. The phase diagram with continuous and discontinuous phase transitions as well as a tri-critical point, reveals the hidden complexity behind the pursuit of human fair play [4].

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Integrable non-equilibrium steady-state density operators and exact bounds on quantum transport

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I will explain a fundamental connection between integrability of non-equilibrium steady states of boundary driven markovian master equations for interacting quantum chains and existence of quasi-local conserved operators which lie outside the standard quantum inverse scattering theory. Namely, the novel conservation laws are expressed in terms of a family of *nonhermitian* (and non-normal, non-diagonalizable) commuting quantum transfer operators. I will then show how existence of quasi-local conserved operators can be implemented to yield strict lower bounds on transport coefficients, such as Drude weights or even diffusion constants.

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Quantum localization of chaotic eigenstates and the statistics of energy spectra

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Quantum localization of classical chaotic eigenstatets is one of the most important phenomena in quantum chaos, or more generally - wave chaos, along with the characteristic behaviour of statistical properties of the energy spectra. Quantum localization sets in, if the Heisenberg time t_H of the given system is shorter than the classical transport times of the underlying classical system, i.e. when the classical transport is slower than the quantum time resolution of the evolution operator. The Heisenberg time t_H, as an important characterization of every quantum system, is namely equal to the ratio of the Planck constant $2\pi\hbar$ and the mean spacing between two nearest energy levels ΔE, $t_H = 2\pi\hbar/\Delta E$.

We shall show the functional dependence between the degree of localization and the spectral statistics in autonomous (time independent) systems, in analogy with the kicked rotator, which is the paradigm of the time periodic (Floquet) systems, and shall demonstrate the approach and the method in the case of a billiard family in the dynamical regime between the integrability (circle) and full chaos (cardioid), where we shall extract the chaotic eigenstates. The degree of localization is determined by two localization measures, using the Poincaré Husimi functions (which are the Gaussian smoothed Wigner functions in the Poincaré Birkhoff phase space), which are positive definite and can be treated as quasi-probability densities. The first measure A is defined by means of the information entropy, whilst the second one, C, in terms of the correlations in the phase space of the Poincaré Husimi functions of the eigenstates. Surprisingly, and very satisfactory, the two measueres are linearly related and thus equivalent.

One of the main manifestations of chaos in chaotic eigenstates in absence of the quantum localization is the energy level spacing distribution $P(S)$ (of nearest neighbours), which at small S is linear $P(S) \propto S$, and we speak of the linear level repulsion, while in the integrable systems we have the Poisson statistics (exponential function $P(S) = \exp(-S)$), where there is no level repulsion ($P(0) = 1 \neq 0$). In fully chaotic regime with quantum localization we observe that $P(S)$ at small S is a power law $P(S) \propto S^{\beta}$, with $0 < \beta < 1$. We shall show that there is a functional dependence between the localization measure A and the exponent β, namely that β is a monotonic function of A: in the case of the strong localization are A and β small, while in the case of weak localization (almost extended chaotic states) A and β are close to 1.

We shall illustrate the approach in the model example of the above mentioned billiard family, where we can separate the regular and chaotic states. This presentation is based on our very recent papers.

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Integrability of autonomous systems of ordinary differential equations

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The problem of finding systems with one or few independent first integrals inside families of autonomous systems depending on parameters is discussed. Methods to construct first integrals or prove their existence in such systems are reviewed. Among them the main attention is paid to the Poincare-Dulac normal form method, the Darboux method and the interconnection of integrability and time-reversibility. An efficient computational technique to the problem of finding first integrals is proposed. Some examples of application of the theory and the computational approach are presented.

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New insights on coherent wave transmission through disordered systems

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In the first part of my talk I will speak about our theoretical and experimental studies on microwave scattering through systems which are so strongly disordered, that the effect of Anderson localization suppresses all but a single transmission channel [1]. As a result, we can describe the entire disordered sample in this deeply localized limit as an effective 1D system with a renormalized localization length. We show that the dominant transmission channel is formed by an individual Anderson-localized mode or by a so-called "necklace state".
In a second project, we study the wave transmission through wave guides with surface corrugations [2,3]. We show that for a quantitatively accurate description of such a situation, scattering processes need to be taken into account which are of higher order in the surface corrugation amplitude than those which are conventionally considered. Including these higher-order terms, we are able to provide fully analytical expressions for the multi-mode wave guide transmission which are in excellent agreement with numerical results [2]. Based on this comprehensive approach we find and explain pronounced reflection resonances in wave guides with a step-like surface profile – a robust effect which has been overlooked in previous studies of the same system. I will also explain how these insights allow us to design wave guides with transmission band gaps in predetermined frequency intervals [3].
In the last part of my talk I will explain how surface-disordered mirrors can be used to study ultra-cold neutrons bouncing in the gravitational field of the earth [4]. The quantized energy levels of these gravitationally bound neutrons can be employed for gravity resonance spectroscopy – a new technique to measure the law of gravity at short distances which is accurate enough to provide stringent constraints on certain scenarios for deviations from the Newtonian law of gravity.

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Quantum Difference–Differential Equations

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Differential equations which contain the parameter of a scaling process are usually referred to by the name Quantum Difference–Differential Equations. Some of their applications to discrete models of the Schrödinger equation are presented and some of their rich, filigrane und sometimes unexpected analytic structures are revealed.

A Lie-algebraic concept for obtaining basic adaptive discretizations is explored.

Some of the moment problems of the underlying basic difference equations are investigated. Applications to discrete Schrödinger theory are worked out and some spectral properties of the arising operators are presented, also in the case of Schrödinger operators with basic shift–potentials and in the case of ground state difference–differential operators.

For the arising orthogonal function systems, the concept of inherited orthogonality is explained. The results in this talk are mainly related to a recent joint work with Sophia Roßkopf and Lucia Birk.

Following a suggestion by Hans–Jürgen Stöckmann, the analogous situation on an equidistant lattice has now been worked out and leads to some amazing effects. These new results will also be presented.

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Chaos and Self-Organization in Human Change Processes

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Synergetics has arrived in psychology. More than this - it has proven to be an inspiring research paradigm for investigating and modelling complexity and dynamics of mental, behavioural, and social phenomena. The evolution of human systems is characterized by features as circular causality, the emergence and dynamics of order parameters, order transitions, and critical instabilities. Psychotherapy research was one of the most productive fields for empirical research on self-organization in psychology. Referring to several studies on psychotherapy processes we will demonstrate that human development and learning generate some kind of order. They are chaotic in a strict sense, i.e., they can be characterized by low-dimensional, complex, and changing dynamics. Other studies using different data sources, coding methods, and time scales focus on synchronization, non-stationarity, and local instabilities of psychotherapeutic processes. By this way and referring to the concept of order transitions, Synergetics offers an explanation to what is called sudden changes in psychotherapy. The internet-technology of the Synergetic Navigation System (SNS) allows for an application of these results and a feedback-based, data-driven control of therapeutic self-organization processes. Empirical evidence also exists for coordinated order transitions in the dynamics of subjective experiences and brain activity, measured by repeated fMRI scans. During the treatment of patients with obsessive-compulsive disorder (OCD), transitions started by the destabilization of current patterns and hence by critical fluctuations. The most important change rates of neural activity in different brain areas occurred during cognitive-affective order transitions.

Beyond the Parity and Bloch Theorem: A Systematic Pathway to the Breaking of Discrete Symmetries

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The parity and Bloch theorems are generalized to the case of broken global symmetry. Local inversion or translation symmetries are shown to yield invariant currents that characterize wave propagation. These currents map the wave function from an arbitrary spatial domain to any symmetry-related domain. Our approach addresses any combination of local symmetries, thus applying in particular to acoustic, optical and matter waves. Nonvanishing values of the invariant currents provide a systematic pathway to the breaking of discrete global symmetries. As examples of application we provide a classification of perfectly transmitting resonances in completely locally symmetric scattering setups. This includes sum rules on the invariant currents that provide resonance conditions.

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Strongly Coupled Field Theories and the Holographic Principle

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In this overview talk I shall discuss some of the progress made over the last 15 years in using string theory techniques to understand strongly coupled field theories. In particular I will discuss the AdS/CFT correspondence which tells us that a strong coupled and conformal field theory in four dimensions, has an alternative description as a weakly coupled theory of gravity in a higher dimensional curved space-time. This work has led to remarkable insights into Quantum Chromodynamics, Condensed Matter Physics, the emergence of space-time, the encoding of information in field theories, and much more besides. There is much which has been learnt and which is still to be learnt in relation to integrable theories using these holographic techniques and I will point out some of the directions which are on the cutting edge of this research topic

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Renormalized perturbative analysis of mixed quantum systems and dynamically induced diffraction

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Diffraction occurs in wave dynamics when an obstacle prevents smooth propagation of wave. More generally, if the system has a discontinuous or indifferentiable points not only in configuration space but in phase space, diffractive effects come into play. The so-called mushroom billiard is a typical example in which strictly sharp borders dividing regular and chaotic regions appear in phase space, and induces diffraction in the corresponding quantum mechanics.

Diffraction is a purely wave mechanical phenomenon since it is a transition to classical mechanically inaccessible regions, analogous to tunneling effects in quantum mechanics. However, we here distinguish diffraction from tunneling in respect of the validity of the leading-order semiclassical (WKB) approximation. Alternatively stated, we regard tunneling as a process that could be described by classical dynamics, whereas diffraction is beyond any interpretation based on classical dynamics.

The aim of the present talk is to show that diffraction is a main driving force causing the classically forbidden processes even in purely analytic systems, such as the standard or Hénon map. The situation we focus on is the system with mixed phase space, in which *dynamical tunneling* has so far been believed to control purely quantum phenomena. Our analysis is based on a renormalized perturbation theory using the Baker-Campbell-Hausdorff (BCH) expansion, and it is shown that the mismatch between classical KAM curves and the curves predicted by the shadow Hamiltonian appearing in the BCH expansion is a source of diffraction thus induced.

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Chaotic behavior of disordered nonlinear lattices

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First I shall briefly review some basic results on the effect of nonlinearity on wave packet spreading in one–dimensional nonlinear disordered lattices. I will describe the statistical characteristics of energy spreading in such systems and provide evidence that nonlinearity destroys localization. For this purpose I will consider the disordered variants of two typical one–dimensional Hamiltonian lattice models: the Klein-Gordon (KG) oscillator chain, and the discrete nonlinear Schrödinger equation (DNLS).

Then I shall present some recent results concerning the deeper understanding of the chaotic behavior of the disordered KG model. In particular, I will discuss computations of the time dependence of the maximum Lyapunov exponent and of the distribution of the associated deviation vector, which show a slowing down of chaotic dynamics. Nevertheless, a cross over into regular dynamics does not occur to the largest observed time scales, since chaos remains fast enough to allow the thermalization of the spreading wave packet. Strongly chaotic spots, which meander through the system as time evolves, play a central role in this phenomenon. These findings confirm that nonequilibrium chaos and phase decoherence persist, fueling the prediction of a complete delocalization.

At the end of my talk, I will present some recently developed high order symplectic integrators for Hamiltonian systems that can be split in three different integrable parts, instead of the usual case of two part split considered in traditional symplectic schemes. These new schemes proved to be ideal for the accurate integration of the DNLS model for very long time intervals in feasible CPU times. Such symplectic methods could provide effective means to numerically study the asymptotic behavior of wave packet spreading in the DNLS model; a hotly debated subject in current scientific literature.

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Heterocyclic compounds - Building blocks of life

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Heterocyclic compounds are very widely distributed in Nature and are essential to life; they play a vital role in the metabolism of all living cells. For example, the following are heterocyclic compounds: the pyrimidine and purine bases of the genetic material DNA; the essential amino acids proline, histidine and tryptophan; the vitamins and coenzyme pecursors thiamine, riboflavine, pyridoxine, folic acid and biotin; the B12 and E families of vitamins, the photosynthesizing pigment chlorophill; the oxygen transporting pigment hemoglobin and its breakdown products the bile pigments; the hormones kinetin, heteroauxin, serotonin, histamin and methoxatin, and most of the sugars. There are a vast number of pharmacologically active heterocyclic compounds, many of which are in regular clinical use. Some of these are natural products, for example antibiotics, such as penicillin and cephalosporin, alkaloids such as vinblastine, ellipticine, morphine and reserpin, and cardiac glycosides such as those of digitalis. However, the large majority are synthetic heterocyclics which have found widespread use as anticancer agents, analgetics, hypnotics and vasopressor modifiers, and as pesticides, insecticides, weedkillers and rodenticides [1,2].

There are also a large number of synthetic heterocyclic compounds with other important practical applications, as dyestuffs, copolymers, solvents, photographic sensitizers and developers, as antioxidants and vulcanization accelerators in the rubber industry, and many are valuable intermediates in synthesis [1,2].

Some examples of modern synthetic procedures, cyclizations, rearrangements and other ring transformations will be presented [2].

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Chronotaxic systems: A journey from the cell to the brain treated as ensembles of nonautonomous dynamical systems

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One of the main characteristics of living systems is their ability to exchange energy and matter with the environment, classifying them as thermodynamically open systems which have often been treated as stochastic. The main features of such systems are their ability to interact with other systems in the environment, and their complexity. The dynamics of these interactions is therefore one of the key features that become lost if the system is studied in isolation. Furthermore, the interactions result in variability in the rate of exchange of e.g. substances, which must be continuous, resulting in the time-variable oscillatory dynamics that characterises such systems.

Although we are witnessing rapid developments in the theory of nonautonomous and random dynamical systems, nonautonomous oscillatory systems with stable but time-varying characteristic frequencies have until recently not been considered. In this talk I will review the most recent work in the field and will discuss the newly introduced class of nonautonomous systems named chronotaxic (from *chronos* – time and *taxis* – order). Such systems are characterised by a time-dependent point attractor, and can maintain stable but time-varying amplitude and phase dynamics. I will introduce the cases of separable and non-separable amplitude and phase dynamics and will discuss methods for time-series analyses that are appropriate for capturing their features.

In the second part of my talk I will examine the biological cell as a chronotaxic system, paying particular attention to the role of adenosine triphosphate production in glycolysis and mitochondrial oxidative phosphorylation in oscillations of the membrane potential. At a higher level of complexity, I will approach the heart as a chronotaxic system. I will consider its interaction with the respiratory system and argue that ageing can be characterised by changes in the intensity of interaction between the two. The journey will end at the brain, with some recent results of brain dynamics, discussing how coupling functions between brain waves change in anaesthesia and in autistic spectrum disorder.

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On max-type difference equations

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Systems of difference equations of the following form

$$x_n^{(j)} = \max_{1 \le i_j \le m_j} \left\{ f_{ji_j}\left(x^{(1)}_{n-k^{(j)}_{i_j,1}}, \ldots, x^{(l)}_{n-k^{(j)}_{i_j,l}}, n \right) \right\}, \quad n \in \mathbf{N}_0,$$

where $l, m_j, k^{(j)}_{i_j,h} \in \mathbf{N}$, $j, h \in \{1, \ldots, l\}$, and $f_{ji_j} : \mathbf{R}^l \times \mathbf{N}_0 \to \mathbf{R}$, $j \in \{1, \ldots, l\}$, $i_j \in \{1, \ldots, m_j\}$, are called max-type systems. For $l = 1$ the system is reduced to a max-type difference equation. There has been some interest in such systems of difference equations in the last two decades. In this talk we present some recent results on the long-term behavior of solutions of some particular cases of the system.

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Microwave experiments in complex systems: From quantum chaos to monster waves

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Most of the phenomena observed in wave propagation are universal and are observed in a large variety of different systems such as matter waves, but also, e.g., in electromagnetic waves and water waves. By means of the microwave measuring technique pioneered in Marburg, it thus becomes possible to study questions extending from the quantum mechanics of chaotic systems to the propagation of waves in the ocean. In this talk recent microwave results are presented, including a microwave realization of graphene (Kuhl et al. 2010, Barkhofen et al. 2013a), the study of branched flow in potential landscapes (Höhmann et al. 2010, Barkhofen et al. 2013b), and the study of spectra and periodic orbits in microwave graphs (Allgaier et al. 2014).

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Many-body quantum theory beyond the semiclassics by quantum smoothing of singularity in quantum-classical correspondence

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A theory of many-dimensional real-time quantum dynamics is studied in terms of Action Decomposed Function (ADF), a class of wavefunction of the form

$$\Psi(\mathbf{q},t) = F(\mathbf{q},t)\exp\left(\frac{i}{\hbar}S(\mathbf{q},t)\right),$$

where $S(\mathbf{q},t)$ is assumed to satisfy the Hamilton-Jacobi equation at the outset, and a complex function $F(\mathbf{q},t)$ is thereby an unknown function to be studied [1]. It is shown that semiclassical dynamics for $F(\mathbf{q},t)$ in the Lagrange picture of phase-flow can be described with what we call deviation determinant and associated quantum phases without use of the stability matrix [2]. This talk is devoted to an analysis of the mechanism of quantum diffusion (quantum smoothing) that removes singularity inherent in semiclassics. We derive a Lorentzian form for the amplitude factor of $F(\mathbf{q},t)$ that is free of the semiclassical singularity, the real part of whose denominator comes from the deviation determinant, while the imaginary part reflects quantum diffusion and is proportional to the Planck constant ($\hbar$). Further, this imaginary part is shown to be attainable through a Wronskian relation with the deviation vectors. A number of theoretical advantages of the Loretzian form and the Wronskian relation are illustrated both theoretically and numerically. We will show that there is no essential difficulty in applications to many-dimensional heavy particle systems like molecules. We discuss the effects of the magnitude of $\hbar$ on the semiclassical quantization (of classical chaos [3]) in terms of the present $F(\mathbf{q},t)$ function, from which a new phase factor arises as a function of $\hbar$. We also discuss an interpretation of the quantum wavefunction.

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Unlearning abnormal neuronal synchrony by coordinated reset neuromodulation

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Several brain diseases are characterized by abnormal neuronal synchronization. To specifically counteract neuronal synchronization we have developed Coordinated Reset (CR) stimulation, a spatial-temporally patterned desynchronizing stimulation technique. According to computational studies CR stimulation induces a reduction of the rate of coincidences and, mediated by synaptic plasticity, an unlearning of abnormal synaptic connectivity. A sustained desynchronization is achieved by shifting the neuronal system from a pathological to a physiological attractor. Computationally it was shown that CR effectively works no matter whether it is delivered directly to the neurons somata or indirectly via excitatory or inhibitory synapses. Accordingly, CR stimulation can be realized by means of different invasive as well as non-invasive stimulation modalities. In accordance with theoretical predictions, electrical deep brain CR stimulation has pronounced therapeutic after-effects in Parkinsonian monkeys as well as cumulative and lasting therapeutic and desynchronizing after-effects in Parkinsonian patients. In tinnitus patients acoustic CR stimulation leads to a significant clinical improvement as well as a decrease of pathological neuronal synchrony in a tinnitus-related network of auditory and non-auditory brain areas along with a normalization of tinnitus characteristic abnormal interactions between different brain areas. In summary, the theory-based CR approach appears to be a promising novel therapeutic option for different brain dieseases.

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Time series analysis using wavelet to extract collective behavior of proteins

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We develop methods to extract collective behavior for time series data of molecular dynamics simulation of proteins. We use the wavelet transformation together with various tools such as the singular value decomposition (SVD) and the canonical correlation analysis (CCA). The wavelet analysis enables us to characterize non-stationary features of the dynamics. On the other hand, SVD enables us to reduce the degrees of freedom of the data, and CCA does to extract correlation among multiple groups of degrees of freedom. We apply our methods to time series data obtained by molecular dynamics simulation for *Thermomyces lanuginosa* lipase (TLL) and the PDZ domain.

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Quantum chaos in many-body quantum systems: interference, interactions and indistinguishability

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The field of *Quantum Chaos* studies the quantum effects that can be connected with the existence of classical chaos. During the past years, this connection provided a deep insight into a large variety of physical phenomena, from the emergence of universal spectral and transport fluctuations in the mesoscopic domain to the existence of dynamical localisation in driven quantum systems, passing from the role of classical chaos in the quantum-classical transition. The very root of this success is the possibility of using classical information to explicitly construct quantum mechanical objects that may not have themselves a well defined classical limit. The set of concepts and techniques that allows to follow this program is referred as the *semiclassical approximation*, and it is well justified when the classical actions are large.

In this presentation I will attempt to motivate our efforts to implement the semiclassical program in the framework of quantum systems of interacting, indistinguishable particles. In this scenario, the classical limit is a classical mean-field theory and it emerges in the limit of large total number of particles. After a general introduction to the semiclassical program in single-particle systems, showing the role of the classical limit in constructing quantum mechanical amplitudes (the celebrated van Vleck-Gutzwiller propagator), I will indicate how a similar object can be defined in the context of quantum fields. Then, I will show two applications of the semiclassical approach to bosonic systems: the prediction of many-body quantum interference in the dynamics of cold bosonic atoms in optical latices and the emergence of universality in the framework of the Boson Sampling problem.

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Automatic design of aerodynamic surfaces

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I will present methods for automatic optimisation of aerodynamic surfaces as developed at Pipistrel. These methods were used for the development of aerodynamics of the Taurus G4 aircraft, the winner of NASA 2011 Green Flight Challenge Sponsored by Google, as well as the four seat Panthera aircraft and the Eivie human powered vehicle. By a proper formulation of the optimisation criterion and parametrisation of surfaces, it is possible to design optimal wings, propellers, airfoils and fuselages, but also details such as wing root blending. I will mostly focus on two methods. The first method is used to find the optimal nonplanar shape of the wing (e.g. winglets), where it is demonstrated that there exists a critical point determining the optimality of the planar versus nonplanar configuration, depending on the parameter that determines the ratio between profile and induced drag. The second method uses an ideal fluid model and a pressure distribution based optimisation criterion. It is used to obtain three-dimensional shapes that result in laminar flow and prevent flow separation, and hence result in low drag.

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