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Abstracts

Theoretical Modeling of Field Vegetation Pattern Formation

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Since Macfadyen's discovery in 1950, many observational and theoretical studies have been done for the better understanding of the vegetation pattern formation. Now it is considered that spatially periodic patterns are generic in semi-arid regions with less rainfall (200mm/year), and that similar phenomena have been reported widely even in arid regions (50-100mm/year) and in sub-humid regions (400-700mm/year), e.g., in Africa, Australia, America, and Middle East countries. Furthermore, it is known that specific soil types as well as specific plant species are not necessary for those vegetation patterns. The universality in field vegetation was noticed by Lefever and Legeune (1997) in the context of the dissipative structure theory in nonequilibrium open systems, where an abstract model of propagator-inhibitor cooperation was successfully analysed. In 2001, we proposed a model for vegetation pattern formation by taking water transport and filtration to soil and biomass into account, to integrate the Lefever's mean-field idea and ecological viewpoints. In the present talk, the details of our model will be discussed including recent development; generalization to a nonlocal model, onset of growing patterns, and inhomogeneous effects.

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Semiempirical theory of level spacing distribution beyond the Berry-Robnik regime: Modelling the localization ant the tunneling effects

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What is the energy level statistics of the mixed type system, where regular and chaotic dynamics coexist? We discuss possible answers to this question, by constructing the proper random matrix model. The basic model generalizes the theory of Berry and Robnik, where the corresponding random matrix model is a two-block matrix, where one block corresponds to regular and other to chaotic states. Such classification of states appears in the semiclassical limit as a consequence of the principle of uniform semiclassical condensation (PUSC) of Wigner functions of eigenstates. The ratio between the sizes of the blocks equals the ratio between the phase space volumes occupied by the regular or chaotic orbits. Original assumption for the statistics of energy level spacings of the chaotic and regular part of the spectrum is GOE and Poisson statistics, respectively. Generalization of this picture replaces the GOE statistics with Brody statistics bringing additional parameter which quantifies the effects of the localization of eigenstates on the chaotic part of the phase space. In this generalization GOE statistics corresponds to the limiting case of the totally extended chaotic states. Another generalization compensates the assumption of the validity of PUSC by introducing a weak coupling between the regular and chaotic block, which is interpreted as the tunneling effect. We end up with the random matrix model with two free parameters (localization, tunneling strength) and one fixed parameter (size of the regular/chaotic phase space volume). We compare the numerical results with the rather successful analytical theoretical model.

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Dynamics of a partially inactivated ensemble of coupled nonlinear oscillators

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Large ensembles of coupled nonlinear oscillators have been playing crucial roles in a variety of disciplines of science and technology. Their coherent behaviors such as synchronization have been extensively studied recently. However, there is one point overlooked in such studies, which is the fact that real coupled oscillators, like any other systems, suffer from some kind of deterioration from the beginning or as time passes. This observation has led to our recent theoretical studies about the effect of "bad components"(inactive, i.e. non-self-oscillatory elements) on the behavior of a large ensemble of coupled oscillators. This problem may be important not only in understanding the robustness of diverse rhythmic phenomena, but in applications of the dynamics of coupled oscillators. The purpose of this talk is to review our recent results on this problem and present some results of our ongoing studies with an emphasis on distinctions between the behavior of globally coupled systems and that of locally coupled ones.

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Where is the 2nd Earth?

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Today there are about 370 extrasolar planets in almost 300 extrasolar systems confirmed. Most of these planets are of the size of Jupiter. Recently a very interesting planet with a radius between 1.75 and 2 Earth radii and a period of 0.85 days orbiting a K star was discovered by the European satellite CoRoT. A few month ago NASA launched the satellite KEPLER dedicated also to observe transits of planets especially to discover small planets in habitable zones. This is the report of the most interesting results of the two satellites in space with respect to new planetary systems.

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Non-linear Dynamics of an Optimal Information Processing

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Modern exploration of physical phenomena is performed by experimental systems that include arrays of sensors and memory cells and execute measurements automatically. At their application a question arises how to proceed also to automatic modeling of physical laws governing phenomena under exploration. For this purpose we consider modeling of physical laws by a joint probability distribution of measured variables and its estimation in terms of measured data. This task leads to an adaptable structure of the measurement system and a specification of a new dynamics of system memory cells that is driven by an optimal information processing. Consequently, the dynamics of the corresponding system is not governed by mechanical forces, but by the sensory signals and stored information.
We assume that sensory signals are transformed into discrete data samples of corresponding variables. Their joint probability density function (PDF) is statistically described by using the kernel estimator. However, the number of experimental samples can increase without limit, while the number of memory cells in a measurement system is generally limited! To avoid this discrepancy we introduce a statistical model comprised of representative samples of data and probabilities related to them. For an optimal adaptation of representative samples we derive an algorithm. With this aim we define the discrepancy between the experimental and the model PDF and the redundancy of representative samples in terms of the information entropy. By the sum of discrepancy and redundancy the information cost function of the model is defined. By looking for its minimum an optimal model can be obtained. In the article an iterative method is proposed for this purpose. At an application of this method a new experimental datum can cause: either just an adaptation of existing probabilities, or also a creation of a new representative sample.

The action that yields a lower information cost function is considered as a proper one. However, this procedure corresponds to an essentially non-linear dynamics of the model formation. When the PDF model is formed a relation between variables measured by various sensors can be extracted from PDF by using the conditional average estimator. Both steps provide for a rather general applicability of the proposed method and the basic task of an automatic modeling of a physical law is thus completed.

It is characteristic that the model obtained by adaptation to repeated experiments usually contains much lower number of representative samples as is the number of experimental samples. Consequently the proposed method can be used to properly compress overwhelming number of experimental data samples that are usually provided by automatic data-acquisition. In the article the method is demonstrated on the compression of analytically generated data as well as on the traffic data acquired on roads network in Slovenia. In the last example the traffic rate measured at some characteristic point during a particular day is described by a vector comprised of 24 components. The set of 365 measured vectors from a year of observation is after adaptation properly represented by just 4 representative vectors and related probabilities. The representative vectors approximately correspond to normal working days and days comprising weekends or holidays, while the related probabilities correspond to the relative frequencies of these days.

The adaptation process that follows the proposed iterative method resembles a self-organized, highly non-linear and non-autonomous dynamics of cooperation between neurons in biological neural networks that is driven by sensory data. A representative datum corresponds to a memorized content, while the related probability corresponds to the excitability of the neuron in which the datum is stored. In relation to this interpretation one could conclude that a neural network that follows the proposed method of memory formation performs as a general optimal modeler of physical laws.

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Dynamical system approach to physical random bit generation

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We show various types of physical random bit generators can be interpreted as dynamical systems which amplify small noises or fluctuations by dynamical instability. Entropies generated by integrable and chaotic dynamical system models are analyzed theoretically and numerically, and the role of chaos for physical random bit generation is elucidated. We also discuss random bit generation by chaotic lasers. It has recently been shown that bit sequences which passed statistical tests of randomness could be generated at fast rates up to 1.7 Gbps using chaotic semiconductor lasers. This is faster than any previous report of physical random sequence generation passing the same tests. We show that the relatively good performance of the chaotic state versus the steady state is due to the drift of the threshold in the analog-to-digital converting (AD) device. Accordingly, we conclude that it is possible to generate random bit sequences by the steady state in the following alternative ways; (a) Introducing another stage of broadband amplifier to amplify the steady state noise, (b) Improving the stability of the threshold of the AD device by an order of magnitude.

These results show that the chaotic laser is an efficient and robust mechanism for use in physical random bit generation in the sense that it did not require either (a) or (b). Moreover, the relative efficiency can be measured in bits per second per watts by measuring the minimum amplification required to achieve comparable randomness criteria, and device robustness can be measured as (1/ volts-per-second).

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Towards the Carnot efficiency in a classical cavity

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A simple classical dynamical model of a thermoelectric heat engine is presented which promises to give some theoretical general guidelines for future heat engine designs. It is composed two thermochemical baths connected with two conductors that are modelled as classical deterministic scatterers. The general features and especially the efficiency of the heat engine are studied as function of the dynamical properties of the conductors. In specific simple cases of one- and two-dimensional wires analytic results were obtained showing that in a certain limit the near to Carnot efficiency is reachable at the price of a low-power output. The latter can be improved by increasing the temperature gradient between baths.

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Co-emergence of ”Ba” by Rhythm Expression of Bodily Action

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In this study, authors examine the relationship between entrainment (subconscious synchronization of bodily action) and the co-emergence of ”Ba”. Here, ”Ba” defined as a type of space -not just a physical space, but an entire situation of the actual field in the mind. To realize it, a rhythm controller that introduces the subconscious bodily action for the operation of an avatar in image space is developed. Furthermore, ”Kendo” (Japanese fencing) robot system in which players play a simulated Kendo match through a Kendo robot (their own avatar in image space) is developed. When the co-emergence of Ba occurs in Kendo match, experimental results demonstrate that entrainment in multiple cycles is created. And, 1/f fluctuation is observed with the creation of this entrainment. These results mean that the co-emergence of Ba necessitates diversity of entrainment. And, in remote Kendo matches using both the coherence image expression (real-time presentation of degrees of the coherence of each other′ rhythm controller waveforms) and timing display device which transmits the opponent's operational rhythm of the rhythm controller, experimental results demonstrate that entrainment in multiple cycles is created. Furthermore, authors demonstrate that coherence image expression may be related to the emergence of co-existing feeling. As a result, it is demonstrated that there is a possibility that both actual and ontological communications play a role in the co-emergence of Ba.

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The role of endocrine tissue network topology in beta-cell bursting oscillations patterns

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Often a specialized physiological task, like control of nutrient storage, is entrusted to a limited number of cells in our body. When this cell task force fails we can face a serious health problem. An appropriate example is insulin-secreting tissue organized into groups or islets of beta-cells scattered within pancreas. Electrical activity in beta-cells exhibits a characteristic bursting pattern, which consists of slow oscillations in membrane potential between a depolarized plateau, on which calcium action potentials are superimposed, and a hyperpolarized electrically silent interval. The gap junctional coupling between pancreatic beta-cells is critical for synchronous glucose-dependent insuling secretion and bursting electrical activity. While the heterogeneity of beta-cells was shown to be important in modelling of electrical response of coupled beta-cell clusters most models consider only nearest neighbors coupling between the cells in specified geometries thus excluding any paracrine effects.

Here we take a different route and propose to introduce coupling between beta-cells based on the spatially embedded complex network cytoarchitecture model of an intact living islet. We used a fitness network model approach to construct complex networks connecting the beta-cells based on their electrophysiological state representing the ability to communicate with other beta-cells in the islet. The physiology of beta-cells was studied in cytoarchitectural intact islets using pancreas slice method. Under fixed electrophysiological conditions bursting oscillations of the membrane potential of beta-cells were computed in islets modeled as regular lattices with nearest neighbor interactions and as networks with complex topologies. We show that long range communication between beta-cells emerging from the scale-free topology of the islet cytoarchitecture can have important consequences for the beta-cells bursting patterns.

Control of bound-pair transport by periodic driving

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Simple many-body Hamiltonians, such as Heisenberg and Hubbard models, include a hopping term $-JH_h$ characterized by an exchange coupling strength J. If such a system is driven by a spatially-linear oscillating field, we have a total Hamiltonian:

$$H(t) = -JH_h + B\sin\omega t \sum_j j c_j^\dagger c_j.$$

For $B, \omega \gg J$, the exchange strength takes an effective renormalized value: $J_{\text{eff}} = J\mathcal{J}_0(B/\omega)$, where $\mathcal{J}_0$ denotes an ordinary Bessel function [1]. This arises from an effect known as Coherent Destruction of Tunneling (CDT): inter-site transport is blocked when $\mathcal{J}_0(B/\omega) = 0$. There is another similar transport effect called Dynamical Localization (DL). For DL, an initial wave packet oscillates around the initial value and there is no requirement for B or ω [2].
We demonstrate CDT and DL behavior in a doubly-excited XXZ ferromagnetic spin chain driven by a spatially-linear oscillating field. We also show that one can control the relative direction and speed of transport of bound-pair and magnon states [3].

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Emergence of contractive affine transformations in the hippocampal CA1

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The hippocampus is a brain region which is responsible for the formation of episodic memory. Based on the basic physiological and anatomical evidences, we previously constructed a mathematical model for the dynamic behaviour of hippocampus, and showed that a temporal structure of the orbits generated by chaotic dynamics (in CA3 sub-region) can be hierarchically encoded in the Cantor set generated in a contractive subspace (in CA1 sub-region) [1,2,3]. In this study, we conducted experiments using rat hippocampal slices to verify our theoretical predictions, especially, about CA1 sub-region [5,6]. The recording data from CA1 neurons were investigated using return map analysis. Each of the obtained return maps was well approximated by a set of contractive affine transformations. These findings provides direct evidence that the information of temporal sequences generated in CA3 can be self-similarly represented in the membrane potentials of CA1 neurons. Hence we obtain Cantor coding.

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On dynamics in planar discrete quadratic systems corresponding to algebras containing exactly one idempotent

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The dynamics in discrete homogeneous quadratic systems in the plane

$$\begin{array}{l} x_{k+1} = a_1 x_k^2 + 2b_1 x_k y_k + c_1 y_k^2 \\ y_{k+1} = a_2 x_k^2 + 2b_2 x_k y_k + c_2 y_k^2 \end{array} \; ; \; a_i, b_i, c_i \in \mathbb{R} \text{ for } i = 1, 2 \qquad (1)$$

is considered by algebraic tools using the one-to-one correspondence between systems (1) and two-dimensional commutative algebras defined by the following multiplication table(s):

$*$	$\vec{e}_1$	$\vec{e}_2$
$\vec{e}_1$	$a_1\vec{e}_1 + a_2\vec{e}_2$	$b_1\vec{e}_1 + b_2\vec{e}_2$
$\vec{e}_2$	$b_1\vec{e}_1 + b_2\vec{e}_2$	$c_1\vec{e}_1 + c_2\vec{e}_2$

; $a_i, b_i, c_i \in \mathbb{R}$ for $i = 1, 2$.

The basis for the algebraic treatment of (1) is Markus classification of 2D commutative algebras (c.f. [4, 5]) which results from the Kaplan-Yorke theorem (c.f. [1]) which ensures the existence of either a nilpotent element of rank two or an idempotent element in the corresponding algebra. The systems corresponding to algebras which contain some nilpotents are considered in [2] and [3]. In this talk we consider the dynamic in systems whose algebras contain exactly one (linearly independent) idempotent; i.e. we consider seven linearly nonequivalent (families) of systems (via the corresponding algebras) one of them being the system $x_{k+1} = x_k^2 - y_k^2$, $y_{k+1} = 2x_k y_k$ which corresponds to the algebra of complex numbers. The complex squaring is a classical example of a chaotic dynamical system. We will consider case-by-case the (non)chaotic dynamics in all other systems.

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On the Mass in Fundamental Theories of Physics and Complex Systems

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In Classical Newtonian Mechanics the Hamiltonian function consists of a sum of kinetic and potential energy, where the mass of a body enters as a parameter. Within gravity one does not distinguish between gravitational mass in the attraction of bodies in contrast to the inertial mass of objects in empty space; experimentally no difference can be found. In Special Theory of Relativity there appears the energy-momentum relation, where the value of the mass depends on the velocity; the rest mass is the same parameter as in Classical Mechanics. In Quantum Mechanics the mass stays as a parameter in the Hamiltonian; excited states in the Hydrogen atom are proportional to the rest masse. In Quantum Field Theory the mass becomes a (divergent) parameter, which has to be fixed to the experimental value via a renormalisation procedure. In the Standard Model of Particle Physics the masses depend on the vacuum expectation value of the Higgs Field. The fermions are additionally influenced from a Yukawa Coupling, being an open parameter.

In the Three Body Problem the mass of the interacting particles plays a decisive role. In general such systems are chaotic. A stability criterion is given by the Kolmogorov-Arnold-Moser Theorem. Approximate solutions can be derived if one mass of the bodies is small. It is also exactly sovable if the two heavy bodies are in equilibrium with respect to gravity. There exists an analytic solution for the special case of identical masses of the three bodies travelling on a special loop. We give an overview of the different definitions and measurements.

On algebraic approach to chaos in quadratic systems

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Algebraic approach to quadratic systems originates to Lawrence Markus [2] . He realized that there is a one-to-one correspondence between quadratic system (either continuous or discrete) with the right hand side $Q(\vec{x})$, where $\vec{x} \in \mathbb{R}^n$, and commutative (nonassociative in general) real algebra $(\mathbb{R}^n, *)$, where the algebraic multiplication $*$ is uniquely defined by the homogeneous form Q of degree 2 in the following way

$$\vec{x} * \vec{y} = \frac{1}{2}\left(Q(\vec{x}+\vec{y}) - Q(\vec{x}) - Q(\vec{y})\right).$$

Since $Q : \mathbb{R}^n \to \mathbb{R}^n$ is homogeneous of degree 2 in every component, we have $Q(\alpha\vec{x}) = \alpha^2 Q(\vec{x})$ for all $\vec{x} \in \mathbb{R}^n$. Therefore $\vec{x} * \vec{x} = \frac{1}{2}\left(Q(\vec{x}+\vec{x}) - Q(\vec{x}) - Q(\vec{x})\right) = \frac{1}{2}\left(Q(2\vec{x}) - 2Q(\vec{x})\right) = Q(\vec{x})$ and the system of ODEs $\vec{x}' = Q(\vec{x})$ becomes a Ricatti equation $\vec{x}' = \vec{x} * \vec{x} = \vec{x}^2$ in the corresponding algebra $(\mathbb{R}^n, *)$. The algebraic properties of the corresponding algebra of course result in the dynamical properties of the system [1] ; every $m-$dimensional subalgebra in $\mathbb{R}^n$ $(m < n)$ implies an invariant subflow in the corresponding $m-$dimensional subspace.
In [3] a large class of systems

$$\begin{aligned} x' &= a_1 z^2 + 2b_1 xz + 2c_1 yz \\ y' &= a_2 z^2 + 2b_2 xz + 2c_2 yz \\ z' &= a_3 z^2 + 2b_3 xz + 2c_3 yz \end{aligned} \;,$$

where a_i, b_i and c_i are real constants for $i = 1, 2, 3$, was considered and it is proven to be nonchaotic. We emphasize that the algebraic approach was crucial for the proof. We also consider algebras $(\mathbb{R}^3, *)$ of rank 3 and more together with the (non)chaotic dynamics in the corresponding system $\vec{x}' = \vec{x} * \vec{x}$.

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Nonlinear responses in hard disk systems

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Periodically driven shear flow of hard disks is numerically studied on a basis of the fluctuation theorem. Relations between the cumulants of integrated momentum flux, which can be derived from the fluctuation theorem, are used in the numerical analysis to clarify fluctuation-response relations. It is found that non-dissipative Fourier components of the momentum flux, as well as the dissipative component (entropy production), obey a relation between nonlinear responses and nonequilibrium fluctuations even for far from equilibrium states.

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On solving algebraic equations in quaternion algebra

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Quaternions are a 4-dimensional non-commutative real algebra, often used in computer graphics and associated geometric analysis to represent orientation and rotations of 3-dimensional objects [1]. Quaternion operations have extended applications in electrodynamics, general relativity, and 3D graphics programming. Representations with quaternions are usually smaller than others and operations on them can be performed more efficiently [2]. For these reasons there is an increasing use of quaternions in control theory, signal processing, attitude control, physics, bioinformatics and orbital mechanics [3, 5].
The non-commutativity of multiplication in the field of quaternions has some unexpected consequences. For instance, such polynomial equation can have more distinct solutions than its degree is [4]. We give an efficient algorithm for solving algebraic equations over the field of quaternions and using it completly describe the set of solutions of the square quaternion equation.

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Coevolution and cooperation: mechanisms pointing towards social welfare

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The widening gap between rich and poor is often painfully obvious from everyday news. But how did we get this far? While descriptive answers to this question from politicians and economists abound, physicists have recently made interesting contributions to enlighten the situation as well. In particular, methods of non-equilibrium statistical physics applied in the context of evolutionary game theory [1] indicate that social diversity is indeed beneficial for the evolution of cooperation [2, 3], and even more strikingly, highly heterogeneous social states may appear spontaneously via very simple coevolutionary rules from an initially completely non-preferential setup [4, 5, 6]. In essence, the findings convey the potentially disturbing message that large differences in status may arise spontaneously, and although they might evoke discomfort within the majority that is disprivileged, they are vital for keeping the population in a cooperative state, especially so if temptations to defect are large. Moreover, it seems just to ask of the less-fortunate to accept such social states, but only if the leaders act pro-cooperatively.

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Entanglement in the operator space

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The complexity of representation of operators in quantum mechanics can be characterized by the operator space entanglement entropy (OSEE). We show that the OSEE in the time evolution of any initially local operator in the homogeneous Heisenberg XY spin 1/2 chains grows at most logarithmically which allows efficient simulation by means of the t-DMRG method in terms of Matrix Product Operators. While the OSEE for operators of finite index i.e. written by a finite number of Majorana fermions in the thermodynamic limit is bounded in time, the OSEE of initial operators of infinite index grows logarithmically with a universal logarithmic prefactor. We show that the prefactor generally depends only on the number of stationary points of the quasi-particle dispersion relation and for the XY model changes from 1/3 to 2/3 exactly at the point of quantum phase transition to long-range magnetic correlations in the non-equilibrium steady state characterized by diverging operator space entanglement entropy. The entanglement properties of operator space dynamics can therefore be used to describe the critical behavior of quantum open systems as there is no such transition when the quantum XY chain is in the thermal equilibrium where at most logarithmic growth of OSEE of the density operator again allows efficient simulation by DMRG.

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Open quantum many body systems far from equilibrium:

From an exact solution of quantum master equations to efficient matrix product numerical methods

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Some recent analytical and numerical methods for treating open quantum spin chains far from equilibrium, in particular for calculation of the non-equilibrium steady states, shall be outlined. Two concepts that turn out to be particularly useful are Operator Fock Spaces [1,2], and Matrix Product Ansatz for the non-equilibrium steady state [3].
In addition, we shall discuss some interesting physics that has been discovered using these methods, in particular the emergence of negative differential conductivity in Heisenberg XXZ spin chains [4,5] and one-dimensional Hubbard model [5] in the regime of strong driving, and the emergence of quantum phase transition far from equilibrium in open XY chains [2].

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Topological Techniques for Constructing Chaotic Examples

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In this lecture (which will be a continuation of [2]) we shall further illustrate how *topological* techniques can be useful in the study of *chaos* and *dynamical systems*. There are two topological constructions yielding spaces that are homeomorphic. One is essentially 2-dimensional, and yields a space referred to as the *Knaster continuum*. The second one uses 3-dimensional linking to construct a space known as the *Whitehead continuum*. These spaces are homeomorphic, but are embedded in the 3-dimensional space in essentially different ways.
After providing some details and observations on the constructions, we shall outline why these two spaces are *homeomorphic*, but are embedded in a *nonequivalent* ways. We shall then show a standard way of constructing the Whitehead and related results on nonchaotic embeddings of continua. We shall describe some topological techniques - *inverse limits* and *isotopies*, that can be used to slightly modify the Whitehead and related constructions. After this modification, we shall show that the new construction, topologically equivalent to the old, is *chaotically* embedded. This shows that equivalent embeddings can have very different *dynamical* properties. (This is joint work with Dennis J. Garity.)

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Classical orbit correlations: the key to quantal properties of chaotic open normal and Andreev billiards

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During the last years the knowledge about subtle classical correlations between trajectories in chaotic Hamiltonian systems, and their role for understanding spectral statistics and transport properties of the corresponding mesoscopic quantum systems, has increased considerably. I will explain how these trajectory correlations allow for understanding random matrix results and so-called Ehrenfest-time effects beyond random matrix theory.
To this end I will more specifically address two quantal phenomena in open chaotic billiards, which have been puzzling during the last decade: (i) observed quantum deviations from the classical (exponential in time) survival probability [1], and (ii) the predicted gap in the density of states of a chaotic cavity (Andreev billiard) coupled to a superconductor. For the latter system we moreover conjecture the appearence of a second gap at energy scales dual to the Ehrenfest time [2].

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Introduction to quantum chaos in generic systems

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First I shall briefly review the basic elements of the stationary quantum chaos in Hamiltonian systems, the universality classes of energy spectra and eigenfunctions. Then I shall consider the problem of the generic systems whose classical dynamics and the phase portrait is of the mixed type, i.e. regular for certain initial conditions and irregular (chaotic) for other initial conditions. I shall present the so-called Berry-Robnik picture, the Principle of Uniform Semiclassical Condensation (of the Wigner functions of the eigenstates), and the statistical description of the energy spectra in terms of E(k,L) statistics, which is known and shown to be valid in the semiclassical limit of sufficiently small effective Planck constant and is numerically firmly confirmed. Then I shall show the numerical evidence for the deviations from that prediction in mixed type systems at low energies, due to localization and tunneling effects. The most recently developed random matrix model will be shown to apply in this regime, as it is in very good agreement with numerical and experimental data on variety of model systems.

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An approach to solving polynomial systems

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One of problems frequently arising in studies of various phenomena in physical, technical and other sciences is the problem of solution of system of polynomials

$$\begin{aligned} f_1(x_1,\ldots,x_n)&=0,\\ &\ldots\ldots\ldots\ldots\ldots\ldots\\ f_m(x_1,\ldots,x_n)&=0. \end{aligned} \tag{2}$$

In this talk we discuss the difficulty of this problem and present a method to solve system (2) using calculations modulo a prime number. The approach works especially efficiently in the case when $f_1,\ldots,f_m$ are homogeneous or quasi-homogeneous polynomials. We also discuss applications of the method to some problems of ordinary differential equations.

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Pancreatic islets are complex syncytia

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Beta-cells in pancreatic islets form complex syncytia. Sufficient cell-to-cell electrical coupling seems to ensure coordinated depolarization pattern and insulin release that can be further modulated by rich innervation or other endocrine inputs. The complex structure and coordinated action develop after birth during fast proliferation of the endocrine tissue. These emergent properties can be lost due to various reasons later in life and can lead to glucose intolerance and diabetes mellitus. Pancreas slice is a novel method of choice to study the physiology of beta-cells still embedded in their normal cellulo-social context. I will present recent advances in our understanding of the physiology of beta-cells as a nonlinear system.

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Time series analysis of molecular dynamics simulation for protein

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I present analysis of time series data of molecular dynamics for protein, Adenylate Kinase. We aim at extracting collective behavior corresponding to hierarchy of protein's structure such as alpha helix and beta sheet. Such collective behavior is supposed to play an important role for functions of proteins. In order to extract such collective behavior, we resort to wavelet analysis and singular value decomposition. These methods enable us to project the dynamics of proteins to a few degrees of freedom collective coordinates.

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Collective correspondence of resonant modes to ray description in optical microcavities

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Optical microcavities are, on one hand, a practical device with various potential applications in the field of lasers and photonics. On the other hand, they offer a good example of a real physical system where the concepts and results of the classical and quantum chaos theory play a significant role in understanding observed phenomena. In this talk, I show that experimental and wave-calculated emission patterns from ray-chaotic optical microcavities can be well described by the steady flux distribution of a weighted ray dynamical model incorporating the openness of a cavity. Deriving the counterpart distribution of the steady flux distribution for wave description, I discuss the correspondence between the ray description and resonant modes, where the latter is found to correspond to the former collectively, rather than individually. This collective correspondence mechanism provides an explanation for the good agreement between experimental multimode lasing emission patterns and a ray-calculated pattern.

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Role of natural boundaries of KAM curves in dynamical tunneling problems

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For dynamical tunneling problems, our preceding observations employing several analytical maps have suggested that dominant complex solutions contributing to the dynamical tunneling process are accumulated around the natural boundaries of KAM curves, implying that the natural boundaries of KAM curves are key objects to control the tunneling rate from regular to chaotic regions. By "complexifying" a piecewise affine map in an appropriate manner, we here develop some analytical arguments on the role of natural boundaries of KAM curves, especially to show;

1. The intersection points of unstable manifolds $W^s(p)$ for unstable periodic orbits p on the real plane with the manifold associated with the quantum initial state are indeed accumulated along the natural boundary. However, reflecting the stickiness around the tori, the accumulation rate is algebraically slow.

2. The most dominant family of tunneling orbits, which attain minimal imaginary action can explicitly be specified. Note that the tunneling flux is controlled by the imaginary action along the stable manifold $W^s(p)$ for unstable periodic orbits p on the real plane. It is not clear whether similar results follow in analytic systems as well, since there are strong degeneracies in the dominant family thus specified.

Scattering properties of open microwave resonators

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To study the properties of a system such as its spectrum it has to be opened leading to a modification of the system properties. Thus every measurement gives an unwanted combination of the properties of the system and the apparatus. Scattering theory is the method of choice to cope with this situation. Originally developed in nuclear physics [1], it meanwhile has found numerous applications also in mesoscopic systems [2]. An example is the study of the transport properties of open quantum dots. These measurements, however, are difficult: (i) it is non-trivial to determine the confining potential from the geometry of the gate electrodes, (ii) impurities are unavoidable and difficult to control, (iii) the systems typically are of sub-micron size, and (iv) temperatures of the order of mK or even lower are needed.
Here microwave resonators pose an alternative. For flat resonators there is a complete equivalence to the corresponding quantum dot system, as long as electron-electron interactions are negligible [3]. System sizes are of the order of centimeter, the measurements can be performed at room temperature, and the geometry is perfectly controllable. Furthermore, a detailed look into the system is possible, whereas standard quantum dot techniques only allow the study of global transport properties.
I shall illustrate these features of the microwave technique by three examples. First, I shall present some recent results on the analysis of the poles of the scattering matrix in the regime of strong overlap. There are numerous results on average quantities in open systems such as the distribution of reflection and transmission coefficients. The direct measurement of the poles, however, had not been accessible up to now. Here a recent progress had been achieved by using the method of Harmonic Inversion.

In this technique poles and residua of the scattering matrix are obtained from the eigenvalues of a matrix which can be generated from the experimental spectra. No foreknowledge on the number of contributing eigenvalues is needed for this purpose. First results on the distributions of line widths in the regime of strong overlap are presented [4].
From scanning probe microscopy studies the electron flow through quantum contacts does not show the diffraction pattern which might have been expected from elementary quantum mechanics but exhibits an intricate branching structure instead [5]. It had been conjectured that these features are a manifestation of caustics generated by the background potential due to impurities and charged donors. In my second example I show a microwave realisation of the flow through a potential landscape where the potential had been mimicked by a variation of the resonator height. Thus we had been able to verify the caustics conjecture. The result may be applied as well to the wave patterns produced in the ocean giving new insight into the formation of rogue waves.
Last some results on the fidelity decay in microwave billiards will be presented. The concept of fidelity has been introduced long ago by Peres [6] as a quantitative measure to characterise the quantum-mechanical stability of a system against perturbations. The fidelity amplitude is defined as the overlap integral of a wave packet with itself, after the evolution under two slightly different Hamiltonians H and $H + \lambda V$. There had been a renewed interest in fidelity because of its obvious relevance for quantum computing. Most perturbations studied up to now had been global, realised, e. g., in microwave billiards by shifting one wall. Local perturbations had been overlooked previously, which is surprising, since most perturbations in real systems are local, such as diffusive jumps, or spin-flips. Only recently the fidelity decay due to a local perturbation has been studied as well, again in a microwave billiard by shifting a small scatterer [7].

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Thermal conduction in quantum spin systems: universalities and their origins

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We study quantum spin chains coupled to two phonon heat baths with different temperatures [1]. Although the non-equilibrium steady state (NESS) of the system depends on the details of the reservoirs (spectral densities and coupling operators), it is known that local properties (e.g. local temperature and energy flow) of normal NESS are insensitive to the details of the reservoirs, and determined only by the temperatures of the heat baths. We investigate microscopic origins of this universal behavior.

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To higher semiclassical theory for quantum molecular dynamics

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We have been studying the semiclassical theory with the following Maslov-Bohm type wave function [1],

$$\Psi(q,t) = F(q,t) \exp\left[\frac{i}{\hbar} S(q,t)\right], \tag{3}$$

where $S(q,t)$ is assumed to satisfy the purely classical Hamilton-Jacobi equation. Substituting this wave function into the time-dependent Schrödinger equation leads to the determining equation for $F(q,t)$ on an action surface, which specifies the initial momentum of the dynamics. We call this the Action Decompoes Function (ADF). In our previous study, based on both the extention of the Fourier analysis of phase interference [2] and practical numerical calculations with the ADF-based correlation function, it has been proved that in the semiclassical regime the exponentially diverging amplitude factors arising from the stability matrix do not play an essential role in energy quantization [3]. Here in this talk, we are talking about the following studies based on the ADF theory.

The validity range of the Born-Oppenheimer approximation

With the use of the semiclassical quantization applied to a mass (m) variation series of (ppe), $(pp\mu)$, and $(pp\bar{p})$ under a constrained geometry, we have investigated the validity range of the Born-Oppenheimer (BO) approximation [4]. We estimated the energy difference of the non-BO vibronic ground state (with protons movable) from the BO counterpart (protons fixed in space).

In the energy quantization of the BO case, the Einstein-Brillouin-Keller (EBK) quatization condition was applied first to the electronic motion in the potential field made with fixed nuclei, and then to the nuclear motion on the potential energy curve. For the non-BO case, electronic and nuclear motions are treated simultaneously, with the classical scale invariance of the Coulomb interaction incorporated into the semiclassical correlation function [5]. It was found that the error in the BO approximation scales to the power of 3/2 to the mass of negative particles, that is, $m^{1.5}$. The origin of this clear-cut relation was analyzed based on the original perturbation theory due to Born and Oppenheimer, with which we have shown that the fifth order term proportional to $m^{5/4}$ is zero and thereby the first correction to the BO approximation should arise from the sixth order term that is proportional to $m^{6/4}$. Therefore, the validity range of the Born-Oppenheimer approximation is wider than that often mistakenly claimed to be proportional to $m^{1/4}$.

To higher semiclassical theory for multidimensions

In addition to the merit that the ADF equation of motion is linear, it turns out to be expressed as a sum of the spatial gradient of the classical velocity field (velocity gradient) and quantum diffusion kernel with an imaginary diffusion constant. Taking these theoretical advantaves of the ADF, a complex-valued Gaussian function is introduced to propagate the wavepacket, which we call the Normalized Variable Gaussian (NVG). It is evidenced that the use of velocity gradient indeed gives correct information with respect to the height of wave function, providing also the correct Maslov phase. Also, we show how the quantum diffusion term softens the divergence and bring the amplitude of ADF down to the finite values. Energy quantization with the ADF-NVG wavepacket dynamics is also reported for a two-dimensional chaotic system, peak positions of which have already been shown to be successfully reproduced with the phase quantization [3].

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Dramatic difference between deterministic and stochastic methods in nonlinear dynamics: Reaction-diffusion differential equations and cellular automaton in self-catalytic proliferation systems.

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Diffusion and noise (or fluctuation) are the key quantities in the study of pattern formation. The reaction diffusion equation approach (RD) with or without stochastic noise, which are often based on a mean-field description such as the rate equations in chemical reaction systems, and the cellular automaton (CA) resorting to "random walk" explicitly are among the most widely used methods in pattern formation dynamics. In studying such dynamical systems, one may usually choose either the deterministic approach like RD or the stochastic method like CA.

In linear dynamics like the simple diffusion equation and the Schrödinger wave equation, it is mathematically proved that the perfect integration (summation) of the path solutions based on random-walks gives a global (wave-like) distribution function of the differential equations (Feynman path integration). In nonlinear regime, Gillespie [1] argued that the stochastic approach has a firmer physical basis and therefore the stochastic method is physically more preferable. Despite this claim, it is generally assumed that the difference between the solutions of the deterministic and stochastic methods is small enough to the order of stochastic fluctuation.

However, it sometimes happens that these two methods give different solutions, namely, different pattern formation to the same problem. Indeed, we have reported and analyzed the origin of their difference in a very simple model study of static pattern formation of bacteria colony [2]. It turns out that the natural treatment of noise and its induced symmetry breaking in the CA algorithm are all favorable to generation of wide variety of patterns.

We here show another example of a dramatic difference between RD and CA results [3]. We first report our finding of a system that exhibits a self-sustained (i.e. not driven by external noise) generation of successive traveling waves but its mean-field counterpart is not oscillatory in contrast to the Belousov-Zhabotinskii

(BZ) reaction. But this sustained wave generation can be observed only when CA is applied, while the RD solutions fall into a stable fixed point quickly and therefore do not reproduce such a repeated wave propagation. We show what makes such a tremendous difference between the stochastic and deterministic methods.

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Universality in Dynamical Formation of Entanglement for Quantum Chaos

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I present universal characteristics in dynamical formation of entanglement for quantum chaos. Based on the theory of holonomic systems of differential equation developed by Kaneko, universality in one-level distribution of Schmid eigenvalues is revealed. We show a strikingly precise description of the distribution by the theoretical results. We will discuss the implications of the universality of entanglement for the foundation of statistical physics and the measurement theory.

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Chaotic Dynamics, Episodic Memory, and the Dynamic Model for the Hippocampus

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The hippocampus has been considered responsible for the formation of episodic memory. It has also been pointed out that the hippocampus plays an important role in imagination, which is related to future events. The fact that atrophy of the hippocampus could lead to Alzheimerfs disease implies that the network structure of the hippocampus may provide fields for the creation of internal time corresponding to the past, present, and future. We present a model that the hippocampus plays a role in the formation of episodic memory, producing chaotic and fractal dynamics.

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A hybrid method for calculation of Ruelle-Pollicott resonances

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We present a numerical method for calculation of Ruelle-Pollicott resonances of dynamical systems. It constructs an effective coarse-grained propagator by considering the correlations of multiple observables over multiple timesteps. The method is compared to the usual approaches on the example of the perturbed cat map and is shown to be numerically efficient and robust.

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Co-creation of Bodily Expression Focused on Sympathetic Body Awareness

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In the activity of bodily expression holding palms to others, it is known to be generated a sense of sympathetic body awareness as a relation with each other deepens gradually. The goal of this study is to capture a process of generating a sense of sympathetic body awareness. And so, we developed the system which measure force generated between both palms and position and acceleration of the palms in bodily expression holding palms. This measurement system comprised a slidable board which limits movement of the palms to front-back direction and a force sensor, acceleration sensor, and position tracking sensor. We focused on active/passive role and conducted the measurements in bodily expression holding palms with/without fixing the roles.

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Coherent propagation of waves in random media with weak nonlinearity

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In general, transport of waves in disordered media cannot fully be described as a simple diffusion process, since wave interference effects lead to a reduction or even complete suppression of the diffusion constant (weak or strong localization) and the appearance of a coherent backscattering peak.
In this talk, I present a diagrammatic theory for treating the impact of nonlinearities on coherent backscattering. The theory is applied to describe propagation of weakly interacting Bose-Einstein condensates in disordered potentials, on the one hand, and multiple scattering of light in nonlinear media, on the other one. In particular, the conditions under which nonlinear effects diminish or enhance the height of the coherent backscattering peak are discussed. Finally, I also talk about the possibility to incorporate quantum-mechanical many-particle effects (for example multi-photon scattering processes from strongly driven two-level atoms), which generally lead to decoherence, thereby affecting the disorder-induced localization effects.

Cantor Coding in a Model of Hippocampus

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Based on the theory that the hippocampus is responsible for formation of episodic memory, we proposed a mathematical model for the hippocampus. Because episodic memory includes a time series of events, an underlying dynamics for formation of episodic memory is considered to employ a mechanism of encoding sequences of events. The "Cantor coding" hypothesis in hippocampal CA1 has been proposed. Cantor coding is an information coding scheme for temporal sequences of events. It forms hierarchical structure in state space of neural dynamics. Here we constructed a model for the CA1 network which consists of conductance-based model neurons. It was assumed that the CA3 outputs temporal sequences of spatial patterns to CA1. It was shown that output patterns of CA1 were hierarchically clustered in a self-similar manner according to the similarity of input time series.

Humidity - Temperature Dependence of Domain Growth of Ascorbic Acid Crystal

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Humidity-temperature conditions for the emergence of various domain patterns of ascorbic acid crystal are identified, where the crystal grows from its thinly spreading aqueous solution by solvent evaporation. In particular, under a low-humidity condition, the coexistent pattern is formed by two domains having different growth rates. In the faster growing domain, there exists a clear time delay between the crystal growth in the solution and the drying of the crystal surface. From the shape of the domain boundary in the coexistent pattern, the growth rate ratio between the two domains can be estimated.

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Transport properties of one-dimensional strongly-interacting many-body systems

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Using time-dependent density matrix renormalization group method we calculate various properties of 1-dimensional quantum spin chains. Coupling boundary spins via appropriate Lindblad operators one can achieve equlibrium as well as nonequilibrium situations. Our main focus is spin and heat conductivity in chaotic and integrable chains where we can simulate systems of up-to 100 spin 1/2 particles.

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Exact solution of thermally driven open XY spin 1/2 chain.

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Using the quantization in the Liouville space of operators (third quantization) to solve the open XY spin 1/2 chain with Lindblad driving, a non-equilibrium phase transition in the spin-spin correlations at finite temperature was discovered [1,2]. However, it was unclear that this transition persist in a more realistic Redfield driving. This shown the minimal model of the thermal driving of one-dimensional problems quadratic in majorana fermions and is also exactly solvable using the same formalism of third quantization. In both cases (of non-thermal local Lindblad as well as of thermal Redfield driving) the phase of long-range magnetic correlations can be characterized by hypersensitivity of the non-equilibrium-steady state to external (bath or bulk) parameters. Various entropies, local energy density and local spin expectation values also reveal possible criticality. Studying the heat transport, we find negative thermal conductance for sufficiently strong thermal driving, as well as non-monotonic dependence of the heat current on the strength of the bath coupling.

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