2^{nd} Slovenia-Japan Seminar

CAMTP
Center for Applied Mathematics and Theoretical Physics
University of Maribor

28 June - 5 July 2003

PROGRAMME

Sponsors and Donators:

Ministry of Education, Science and Sport
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Directors and Organizers:

Marko Robnik (CAMTP)

Yoji Aizawa (Waseda University)

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FOREWORD

Dear Colleagues, Dear Friends, Dear Participants,

Welcome to the 2nd Slovenia-Japan Seminar, which is taking place on 28 June through 5 July 2003 under the organization of CAMTP of the University of Maribor, and which is the follow-up meeting of the 1st Slovenia-Japan Seminar. It took place at the Waseda University in Tokyo, on 18-19 November 2002, under the direction of Professor Yoji Aizawa, and was was very successful. We had four participants from Slovenia and about 35 participants from Japan. The scientific programme was very rich and inspiring, and the hospitality of our Japanese colleagues and friends was really great and highly appreciated. I do hope that this 2nd meeting will be equally successful on the scientific side, and pleasant on the other side, as an extended social event. I have made every effort to make your stay in Slovenia interesting, comfortable and very much enjoyable. Apart from the main scientific stream of thought, we shall enjoy also cultural events (the chamber music concert by the String Quartet Feguš, Festival Lent), social events (conference dinner), touristic event (excursion to Lake Bled, Postojna Cave and Ljubljana), and even sportific events in the facilities of Terme Maribor.

Our Slovenia-Japan meetings are based on our joint Slovenia-Japan collaboration Programme, which always runs for two years, and is funded by the Ministry of Education, Science and Sport of the Republic of Slovenia, and by the Japan Society for the Promotion of Science. The principal investigator on the Japanese side is Professor Yoji Aizawa from Waseda University, Tokyo, and on the Slovenian side Professor Marko Robnik, director of CAMTP, University of Maribor. It provides funds also for the participation of Japanese colleagues - invited speakers - at our international Summer Schools and Conferences *"Let's Face Chaos through Nonlinear Dynamics"*, of which the most recent one, the 5th one, was on 30 June - 14 July 2002 in Maribor, under the organization of CAMTP. Our Slovenia-Japan cooperation meanwhile became very intense, rich and fruitful. The scientific topics covered in our meetings and individual contacts have a broad scope of nonlinear dynamics of classical and quantum chaos, synergetics and theory of complex systems. It thus covers theoretical and experimental physics, mathematics, astronomy and astrophysics, chemistry, physiology, biology, medicine, engineering, economics and even sociology. Nevertheless, the dominant core of topics is in the domain of physics. Our joint scientific activities are thus very strongly interdisciplinary. We do hope that soon we shall start also the collaboration in joint research projects resulting in joint publications.

Slovenia appreciates science in Japan very highly and certainly benefits a lot from our mutual contacts. Conversely, we believe that Japanese colleagues will be stimulated by the results of the Slovenian scientists, and also that Slovenia can provide a kind of European base for further interactions of Japanese colleagues with European countries, especially from European Union, of which Slovenia will become a full member on 1 May 2004. At that important event new possibilities open up, the possibilities to find further cooperation ties also through the European dimensions, namely through the European institutions in Brussels. So we have some very clear vision, which we would like to convert into reality before too long.

I wish you enjoyable stay in Maribor, Slovenia, a successful symposium and pleasant cultural entertainment at our international Lent Festival in Maribor.

Professor Dr. Marko Robnik
— Director of **CAMTP** —

Maribor, 23 June 2003

	Mon 30 June	Tue 1 July	Wed 2 July	Thu 3 July	Fri 4 July
Chairman	Robnik	Shudo	Robnik	Aizawa	EXCURSION
09:00-10:00	**Aizawa**	**Romanovski**	**Eckhardt**	**Song-Ju Kim**	08:30 departure
10:00-11:00	**Shudo**	**Kato**	**Aizawa**	**Romanovski**	11:00 arr Bled
11:00-11:30	——— Coffee & Tea ———				
11:30-12:30	**Stefanovska**	**Stefanovska** **Paluš**	**Prosen**	**Robnik**	
12:30-13:30	**Miyake**	**Bajec/Musizza** **Eržen/Bernjak**	**Shudo**	**Yamazaki**	
13:30-15:30	——— Lunch ———				13:30-14:30 lunch
Chairman	Aizawa	Stefanovska	Romanovski	Robnik	14:30 departure
15:30-16:30	**Prosen**	**Robnik**	**Miyazaki**	**Ruffing**	
16:30-17:00	——— Coffee & Tea ———				16:30 arr Postojna
17:00-18:00	**Horvat** **Jamšek**	**Umeno**	**Žnidarič**	**Veble**	17:00 Visit Cave
18:15-20:00	Dinner	Dinner	———	Dinner	18:30 departure
20:00-24:00	Festival	Festival	Conference Dinner Slow Food and Festival	Festival	19:30 arr Ljubljana 19:30-20:30 Old Town 20:30-22:00 dinner 24:00 arr Maribor

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Abstracts

Chaotic scattering by random potential

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The origin of chaotic scattering is analysed by the Riemannian geometrization method, and the essential role of positive curvature effects will be elucidated. In the compact dynamical systems, the orbital instability is induced in the negative curvature region, but in open systems the positive curvature region plays more essential roles to generate chaotic scattering. When we consider integrable potentials accompanied by random perturbations, it is expect that the chaotic scattering will be enhanced by the perturbations. Actually, by carrying out with 2-dimensional systems, some universal aspects of the chaotic scattering which can be induced by random potentials are demonstrated.

Logarithmic scaling in the stationary/nonstationary chaos transition

Statistical features in the transition process from stationary to nonstationary chaos are studied by carrying out with the modified Bernoulli maps. The temporal behaviors of the transition process are analysed by use of renewal functions, and it is shown that the logarithmic scaling is universally induced by the nonadiabatic change of the intermittent parameter. The detailed structure of the logarithmic scaling regime is discussed by means of the finite-range statistics, and it is shown that the diversity in the fluctuation of transition paths can be characterized by the log-Weibull distribution.

Noise and oscillations in a sequence of reaction times

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The reaction time is the period that elapses between the presentation of a stimulus (e.g. visual, auditory) and the subject's reaction (e.g. manual, oral) to it. It is often used in psychological experiments in which the nature of the processes that underlie human behaviour is studied. In this kind of experiment, the fluctuations in reaction time are traditionally regarded as being random. Recent studies, by Gilden, Thornton, and Mallon (1996), Clayton and Bruhns-Frey (1997), Gilden (1997 and 2001), and Kelly, Heath, and Longstaff (2001) show, however, that the reaction times in different tasks are correlated in time.

In the present study we characterize the dynamics in time series consisting of reaction times. Its purpose was to establish whether the reaction times are related to the complexity of the presented stimuli, or to the rhythm of their presentation. Eight females participated in seven experiments. In each case, reaction times were recorded to 1188 stimuli. The stimuli used were visual, either letters or the positions of the hour hand on a clock. The participants were instructed to identify the letter, or the position of the hand, on a computer screen. The participant's reactions were verbal and the reaction time was that which elapsed between the presentation of the stimulus and the oral answer. In one experiment with letters as stimuli participants were offered to choose their own pace of stimuli presentation; in one experiments one-second intervals elapsed between stimuli, and in two experiments two-second intervals were used. In the experiments with positions of the pointer of the clock self-paced rhythm of presentations was used once, and two-second intervals between presentations twice.

The results of this study show that a time series of reaction times consists of both stochastic and deterministic components. Several rhythmical components were observed. The most dominant rhythms differ to some extent between participants, but some of them appear consistently in all individuals: frequencies that are apparently connected with the rhythm of breathing, with learning in the experimental situation, and with the rhythm of stimuli presentation.

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Blood flow oscillations in congestive heart failure

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Congestive heart failure is a very common disease and is a pathophysiological state in which an abnormality of cardiac function is responsible for the failure of the heart to pump blood at a rate commensurate with the requirements of the metabolizing tissue. The heart is unable to meet the metabolic demands of the body either at rest or on exercise. Many patients are significantly impaired, with symptoms of fatigue and dyspnœa. It is recognised that heart-rate variability (HRV) in such patients is significantly reduced, but the effect on the complex interactions among the other oscillators remains unknown.

We discuss changes in blood flow oscillations in patients with congestive heart failure, and evaluate the response following beta blockade.

Nonlinear dynamics and the transition to turbulence in shear flows

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Hagen-Poiseuille flow through a pipe of circular cross section belongs to the class of shear flows that does not become linearly unstable. The situation is similar to Taylor-Couette flow with the inner cylinder at rest as well as to Taylor-Couette in the limit of large radii where the system approaches plane Couette flow [1]. In these cases the transition to turbulence is not related to series of symmetry-breaking linear instabilities but rather to the formation of nonlinear 3-d flow states. These states originate in saddle node bifurcations, are all unstable and connect to form a chaotic saddle. It is the aim of the lecture to discuss this scenario for the transition to turbulence, to present the numerical evidence and to relate it to experimental observations.

For pipe flow we have identified a family of three-dimensional **travelling waves** [2]. Their topology is dominated by downstream vortices and streaks. They originate in saddle-node bifurcations at Reynolds numbers as low as 1250, where Re is based on the mean downstream velocity and the pipe diameter. All states are immediately linearly unstable at the bifurcation.

For the life time experiments [3] we appeal to the experiments of Darbyshire and Mullin [4] and keep the volume flux constant. We extended our numerical investigations to times of 2000 or more (unit of time: mean streamwise velocity/radius), far exceeding the values accessible in the longest currently available laboratory experiment. As initial conditions we used a high amplitude uncorrelated superposition of spectral modes. The spatial structure is so rich and the amplitude so high that the probability to trigger turbulent dynamics is maximal for a wide range of Reynolds numbers.

Various conclusions can be drawn from our lifetime experiments: The minimum amplitude to trigger a long living turbulent dynamics decreases with Reynolds number. The life times depend very sensitively on the choice of parameters, resulting in large fluctuations even for fixed Reynolds number. The largest Lyapunov exponent is about 6.5×10^{-2} at transitional Reynolds numbers and increases slowly with Re. This corresponds to an amplification by roughly 10^6 over the 200 time units of a typical nonlinear regeneration cycle. The regions of quickly decaying and long-living trajectories are separated by complicated, fuzzy stability borders. The results are in agreement with experiments by Darbyshire & Mullin [4]. The median of the life times of the turbulent states increases rapidly with Reynolds numbers and reaches the cut-off time of 2000 at a Reynolds number of about ≈ 2200. This may serve as a statistical definition of the transitional Reynolds number.

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Synchronization of plasma potential relaxation oscillations by an external driving force

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If a current is drawn through a plasma various plasma instabilities can be excited. When electron current is drawn through a magnetized plasma column by a positive electrode **e**lectrostatic **i**on **c**yclotron (EICO) [1] or **p**otential **r**elaxation (PRO) [2] **o**scillations can be triggered.

In this work we discuss an experiment in which a planar anode is immersed in a weakly magnetized low pressure discharge plasma column with its surface perpendicular to the magnetic field lines. In order to have a better defined system we put additional grid into the plasma so that its surface is also perpendicular to the magnetic field lines. Both, the anode and the grid can be biased separately to arbitrary potentials with respect to the grounded vacuum vessel which is taken as the reference potential. When the anode is biased a few volts above the plasma potential and the grid is connected to the grounded vacuum vessel through a resistor, the electron saturation current to the anode starts to oscillate. The current modulation is caused by a traveling potential structure, which moves periodically from the grid to the anode. The mechanism of such PRO's is well described in the literature [2,3].

We have verified that the frequency of the oscillations is inversely proportional to the distance between the grid and the anode, which demonstrates that the frequency is determined by the transit time of ions from the grid to the anode. The spectrum of the electron current oscillations shows several higher harmonics. When a sinusoidal external voltage signal is applied to the grid, plasma oscillations can be synchronized to the external force even when the later has very low amplitude. We have observed synchronization of the plasma oscillations with the external force at the basic harmonic, higher harmonics (2:1), (3:1) and subharmonics (1:2) The corresponding Arnold tongues are presented. Experimental results are compared to approximate analytical solutions of the van der Pol equation with harmonical external force and good agreement is found. Phase diagrams of the experimental forces obtained by Hilbert transform method [4] are also presented. They show clear evidence that synchronization has indeed occurred.

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Uni-directional transport properties of a serpent billiard

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We present a dynamical analysis of a *classical billiard chain — a channel* with parallel semi-circular walls, which can serve as a prototype for a bended optical fiber. An interesting feature of this model is the fact that the phase space separates into two disjoint invariant components corresponding to the left and right uni-directional motions. Dynamics is decomposed into the *jump map* — a Poincare map between the two ends of a basic cell, and the *time function* — traveling time across a basic cell of a point on a surface of section. The jump map has a mixed phase space where the relative sizes of the regular and chaotic components depend on the width of the channel. For a suitable value of this parameter we can have almost fully chaotic phase space. We have studied numerically the Lyapunov exponents, time auto-correlation functions and diffusion of particles along the chain. As a result of a singularity of the time function we obtain marginally-normal diffusion after we subtract the average drift. The last result is also supported by some analytical arguments.

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Nonlinear cardio-respiratory interaction

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Most real systems are nonlinear and complex. In general, they may be regarded as a set of interacting subsystems; given their nonlinearity, the interactions can be expected to be nonlinear too.

The phase relationships between a pair of interacting oscillators can be obtained from bivariate data (i.e. where the coordinate of each oscillator can be measured separately) by use of the methods recently developed for analysis of synchronization, or generalized synchronization, between chaotic and/or noisy systems. Not only can the interactions be detected [1], but their strength and direction can also be determined [2]. The next logical step in studying the interactions among coupled oscillators must be to determine the nature of the couplings: the methods developed for synchronization analysis are not capable of answering this question.

Bispectral analysis, a technique based on high order statistics, was recently extended to encompass time dependence for the case of coupled nonlinear oscillators [3]. The method is applicable to univariate as well as to multivariate data obtained respectively from one or more of the oscillators.

The method will be first demonstrated for a generic model of interacting systems whose basic units are Poincaré oscillators. Their frequency and phase relationships are explored for different coupling strengths, both with and without Gaussian noise. The distinctions between additive linear or quadratic, and parametric (frequency modulated), interactions in presence of noise will be illustrated.

Then we will present results of bispectral analysis of blood flow signals and show that the cardiac and respiratory processes are apparently nonlinear phase coupled.

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Classical and quantum mechanics in SQUID and two confined hard disks

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Chaos and its signature in quantum mechanics have been studied in various physical systems. I focus here on two physical systems; superconducting quantum interference devices (SQUID's) and two confined hard disks.

The SQUID system has recently attracted interest as a physical candidate of quantum computer (for a review, see the article by Makhlin *et.al.*, 2001). I first review fundamental features of this system and recent experimental studies of SQUIDs. After that, I show that this systems can also give an ideal stage for study of both classical conservative system and pure quantum system. As an example of classical dynamics, I show that in SQUID's there appears a deterministic diffusion, which can be categorized into two kinds; a anomalous diffusion and a normal diffusion (Tanimoto *et.al.*, 2002). By changing experimental parameters, one can also discuss quantum mechanics in SQUID's. As an example of it, I study the signature of chaos in quantum mechanics through spectral statistics (Kato *et.al*, 2003).

Quantum chaos in billiard systems with one particle has been studied intensively, while the systems consisting of many particles have not been studied so much. As a simplest model including interacting particles, I study two hard disks confined by a circular hard wall. Classical dynamics shows dominantly a chaotic behavior, and spectral statistics of corresponding quantum system obeys the Wigner distribution. The avoid level crossings affect the pressure felt by the surrounding wall; there appears shoulders and dips in the pressure-volume plot. I conclude that this feature in pressures can be explained by the change in quantum correlation between two disks (Nakazono *et.al.*, 2003a, 2003b).

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Randomness Evaluation and Hardware Implementation of Cellular Automaton-based Pseudo Random Number Generator

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We shall review the cellular automaton (CA) -based pseudorandom number generators (PRNGs), and evaluate the randomness of sequences generated by them using the statistical test suite of National Institute of Standards and Technology (NIST). We show that one of CA-based PRNGs has good randomness which is comparable to well-known good PRNGs such as SHA1, AES, and MUGI.

Because of its simple construction, CA is well known to be suitable for hardware implementation. We show that this CA-based PRNG is able to work up to the high clock frequency, and has 4.2Gbps speed (15K gates) in the case of Field-Programmable Gate Arrays (FPGA).

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Two Types of Anticipation in Sensory-Motor Coupling

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The anticipatory timing control in sensory-motor coupling is indispensable to generate coordinative movement with dynamical environment, however its cognitive mechanism still remains obscure. In this study we used synchronization tapping task as a model system, and negative asynchrony phenomenon [1-4] where the tap onset precedes the stimulus onset was analyzed as an example of the anticipation. Especially, applying dual task method [5], the relationship between the anticipation mechanism and the higher brain function such as attention [6] and working memory [7] was investigated.

The results revealed two types of anticipatory timing control [8]. In the inter stimulus-onset interval (ISI) range of 450 to 1800ms, automatic anticipation that is not affected by attentional resources was observed and was based on feed forward process. In the 2400 to 3600ms range, the anticipation showed trade-off relationship in the allocation of attentional resources. Magnitude of synchronization error (SE) between tap onset and stimulus onset in this region was scaled by the ISI and the feed back process concerning ISI was suggested.

Furthermore, we used time-series analysis to clarify it in frequency response characteristics. As a result, it was shown that anticipatory behavior in sensory-motor coupling is composed of two different dynamics corresponding to the above two types of anticipatory timing control [9]. The former is characterized by the 1/f fluctuation between the power and the frequency, suggesting non-stationary process in unbounded variation [10]. The latter is characterized by the superimposition between white noise and the significant peak of periodic stimulus, suggesting stationary process in bounded variation.

Accordingly, anticipation dynamics in timing control was shown to be a dual processing between the attentional processing based on completeness and the embodied processing based on incompleteness. Not only psychophysical analysis but also some applications in the field of human-interface are mentioned in the lecture [11].

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Crossover analyses between anomalous diffusion and normal diffusion — Continuous-time random walk approach —

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Two kinds of crossover phenomena between anomalous diffusion and normal diffusion are investigated. As the first topic, anomalous diffusion caused by modulational intermittency, which is also known as on-off intermittency, is studied on the basis of the continuous-time random walk (CTRW) approach. There exists a characteristic time scale τ. For the time region $t \ll \tau$, anomalous diffusion is observed, which is followed by normal diffusion for $t \gg \tau$. Higher-order moments are analytically obtained by use of the saddle-point method, and it is found that they obey scaling relations that are reminiscent of extended self-similarity (ESS) and generalized extended self-similarity (GESS) found in turbulent behaviors. The results are compared with those obtained using the numerical inverse Laplace transform and from model simulations employing a coupled chaotic map. Good agreement between these results is obtained even for lower-order moments.

Anomalous diffusion found in fluid systems is studied as the second topic, inspired by experiments on soft-mode turbulence (SMT) by Tamura *et al.* and by numerical studies on oscillating convection flows by Sakaguchi. Diffusion constants and mean square displacements are analytically obtained based on the CTRW velocity model, and compared with those obtained based on the CTRW velocity model, and compared with those obtained from model simulations employing dissipative dynamics describing oscillating convection flows. Good agreement is also obtained.

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Neural and cardio-respiratory interactions during anaesthesia

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Little is known about the events that unfold during the temporary loss of consciousness corresponding to anaesthesia, so that there are still no reliable markers for depth of anaesthesia. Methods developed for studying interactions between nonlinear oscillators [1, 2, 3] offer a promising way of furthering our understanding of the complex mechanisms that come in to play. It has been shown for example that the cardio–respiratory system passes through a sequence of different phase–synchronized states during deep anaesthesia [4].

We now report results of the first simultaneous study of cardiac, respiratory and neural oscillations during anaesthesia in rats. We discuss the causalities of the interactions between these oscillations. This problem is approached from two different perspectives: first, we calculate the directionality of the couplings between the oscillators in question, using a method derived from information theory, i.e. we use a simple tool based on mutual information; and secondly, we try to approach the same problem by inferring the phase dynamics related to probe functions, again yielding information about the causal relationships.

The data analyzed indicate the presence of strong interactions between both the neural and respiratory oscillators, and also between cardio–respiratory oscillators. If the same events are at least partially reproducible in humans, this could then lead to the development of new markers for determining the depth of anaesthesia.

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Cardiorespiratory interactions

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A directionality index based on conditional mutual information will be introduced and applied to the instantaneous phases of weakly coupled oscillators. Its abilities to distinguish unidirectional from bidirectional coupling, as well as to reveal and quantify asymmetry in bidirectional coupling, will be demonstrated using numerical examples of quasiperiodic, chaotic and noisy oscillators, as well as cardiorespiratory data.

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Fidelity of quantum chaos

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Recently, we have witnessed a strong interest in the stability of quantum motion against small variations of the Hamiltonian characterized by fidelity. In this talk I will shortly review our theory on the behaviour of fidelity decay in different regimes characterized with several time-scales. It will be explained how the fidelity can be computed in terms of time-correlation function of the generator of perturbation. Interesting application of our ideas for the enhancement of the stability of quantum computation will be discussed in the end.

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Quantum fidelity decay of classically integrable dynamics with vanishing time averaged perturbation

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We discuss quantum fidelity decay (also known as the quantum Loschmidt echo) of classically *regular* dynamics, in particular for an important special case of *vanishing time averaged* perturbation operator, *i.e.* vanishing expectation values of the perturbation in the eigenbasis of unperturbed dynamics. A complete semiclassical picture of this situation is derived in which we show that quantum fidelity of *individual coherent initial states* exhibits three different regimes in time: (i) first it follows the corresponding classical fidelity up to time $t_1 \sim \hbar^{-1/2}$, (ii) then it *freezes* on a plateau of constant value which can be semiclassically computed, (iii) and after a time scale $t_2 \sim \min\{\hbar^{1/2}\delta^{-2}, \hbar^{-1/2}\delta^{-1}\}$ it exhibits fast ballistic decay as $\exp(-\mathrm{const}\,\delta^4 t^2/\hbar)$. All the constants are computed in terms of classical dynamics for sufficiently small effective value of Planck constant. A similar picture is worked out also for general initial states, and specifically for random initial states, where $t_1 \sim 1$, and $t_2 \sim \hbar^0\delta^{-1}$. Theoretical results are verified by numerical experiments on the quantized integrable kicked top.

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Quantum chaos in mixed type Hamiltonian systems

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We shall review the basic aspects of complete integrability and complete chaos (ergodicity) in classical Hamiltonian systems, as well as all the cases in between, the generic, mixed type systems, where KAM Theory is applicable, and shall illustrate it using the billiard model systems.

Then we shall proceed to the quantum chaos and its stationary properties, that is the structure and the morphology of the solutions of the underlying Schroedinger equation which in case of 2-dim billiards is just the 2-dim Helmholtz equation. We shall discuss the statistical properties of chaotic eigenfunctions, the statistical properties of the energy spectra, and show arguments and results in support of the so-called universality classes of spectral fluctuations, where in the fully chaotic case the Random Matrix Theory (RMT) is applicable.

First we discuss the universality classes of spectral fluctuations (GOE/GUE for ergodic systems, and Poissonian for integrable systems). We explain the problems in the calculation of the invariant (Liouville) measure of classically chaotic components, which has recently been studied by Robnik et al (1997) and by Prosen and Robnik (1998). Then we describe the Berry-Robnik (1984) picture, which is claimed to become exact in the strict semiclassical limit $\hbar \to 0$. However, at not sufficiently small values of $\hbar$ we see a crossover regime due to the localization properties of stationary quantum states where Brody-like behaviour with the fractional power law level repulsion is observed in the corresponding quantal energy spectra.

We shall mention the rich variety of applications in the domain of physics.

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Randomness of classical chaotic motion

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I shall discuss some new universal aspects of diffusion in classical deterministic and chaotic dynamical systems, especially in Hamiltonian systems. First ergodic (fully chaotic) systems will be discussed, and then the mixed type systems with a typical KAM scenario. Some generalizations by treating the correlations will be presented. Finally, I shall explain the relevance of these studies in the context of problems in stationary quantum chaos, namely the structure of stationary eigenfunctions and the statistical properties of the energy spectra.

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Local limit cycles bifurcations in polynomial systems

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Consider systems of the form

$$\frac{dx}{dt} = P_n(x, y), \quad \frac{dy}{dt} = Q_n(x, y), \tag{1}$$

where $P_n(x, y), Q_n(x, y)$ are polynomials of degree n, x and y are real unknown functions, and suppose that the coefficients of the polynomials P_n, Q_n are from a parameter space $\mathcal{E}$. In the case, when the origin of (1) is a non-degenerate center or focus, a limit cycle bifurcates from the origin when the linearized system (1) changes its stability. This is the well-known Andronov-Hopf bifurcation. The limit cycles bifurcations which depend on nonlinear terms of system (1) (sometimes such bifurcations are called degenerate Andronov-Hopf bifurcations) are much less investigated, but there is a method for their study suggested by Bautin.

Following Bautin we say that the singular point (x_0, y_0) of the system $E_0 \in \mathcal{E}$ *has cyclicity* k with respect to $\mathcal{E}$ if and only if any perturbation of E_0 in $\mathcal{E}$ has at most k limit cycles in a neighborhood of (x_0, y_0) and k is the minimal number with this property. The problem of cyclicity is often called the local 16th Hilbert problem.

We present a method to investigate the cyclicity problem for polynomial systems (1). The method, which we use, is based on the algorithms of computational algebra. In particular, we show that the problem can be reduced to the algebraic problem of computing a basis of the ideal generated by the coefficients of the Poincaré map, and demonstrate how to find such a basis for some systems of the form (1), resolving, therefore, the cyclicity problem for this these systems.

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Time-reversible Systems of Differential Equations

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Consider a system of differential equations

$$\frac{d\mathbf{x}}{dt} = P(\mathbf{x}), \tag{1}$$

where $\mathbf{x} = (x_1, \ldots, x_n)^T$, $P(\mathbf{x}) = (P_1(x_1, \ldots, x_n), \ldots, P_n(x_1, \ldots, x_n))^T$ and P_i are polynomials in $x_1, \ldots, x_n$ with real or complex coefficients. Denote by a the ordered vector of the coefficients of the polynomials $P_i(\mathbf{x})$. Let Q be a group of linear transformations of the phase space E^n (usually $E = \mathbb{R}$ or $\mathbb{C}$),

$$\mathbf{y} = q(\mathbf{x}).$$

The above substitution transforms (1) into the system

$$\dot{\mathbf{y}} = \tilde{P}(\mathbf{y}).$$

We denote by b the vector of the coefficients of $\tilde{P}(\mathbf{y})$. It is easily seen that every coefficient b_i is a linear function of a. We will write this as

$$b = L_q(a).$$

This relation defines the group L_Q homomorphic to Q or, in another words, defines a representation of the group Q.

Let G be a matrix group acting on $u_1, \ldots, u_n$. A polynomial $f(\mathbf{u}) \in k[\mathbf{u}]$ (where k is any field) is called an invariant of G if $f(\mathbf{u}) = f(A \cdot \mathbf{u})$ for any matrix A from G.

We consider the case when $n = 2$ and the group Q is the group of rotation of the phase plane. We give an algorithm to compute a finite basis of invariants $J(a)$ of the group L_Q and show that these invariants determine the set of all time-reversible systems within a given polynomial family (1). Moreover, they determine also the number of axes of symmetry of the phase picture of trajectories of system (1) and their location.

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Discrete Schrödinger Theory and its Orthogonal Function Systems

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Basic discrete analogs of Schrödinger's equation are investigated on a so-called q-linear grid or basic linear grid. A ladder operator formalism for a discrete harmonic oscillator analog is developed with a representation in the weighted Hilbert space $l^2(\mathbf{Z})$ over the q-linear grid. The moment problem for the corresponding modified discrete q-Hermite polynomials of type II is revised. Conditions on the existence of a ladder operator formalism in connection with the considered moment problem are developed. The results are evaluated with respect to an application for purposes of discrete Schrödinger theory.

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Existence of unique invariant measure in complex phase space and its manifestation in quantum mechanics

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Recent studies on complex dynamical systems in more than one dimension have revealed there exists a unique ergodic measure μ in complex phase space which is (weakly) hyperbolic and gives maximal entropy of the dynamics. On the basis of convergency theorem of currents, a basic theorem in complex dynamical systems, this fact was first proved in case of the Hénon family (Bedford & Smillie 1991a, 1991b, 1992, Fornæss & Sibony 1992), and recently extended to more generic settings (Dujardin 2003).

For hyperbolic systems, it is known that the support of an ergodic measure μ thus obtained is exactly the Julia set J of the dynamical system. The orbits showing chaos in complex plane are limited to the ones on the Julia set J, and so one can say that chaos appears only on the Julia set. A remarkable fact is that a unique invariant measure μ exists even in mixed systems. In real phase space, mixed system have infinitely many ergodic components such as quasiperiodic or chaotic orbits and no specific measure attaining maximal entropy can be found in general. On the contrary, the above claim suggests that one can access arbitrary regions using the complex space in spite of the lack of ergodicity in real phase space.

In this talk, we will give sufficient conditions to realize such a situation. That is, assuming that $\operatorname{supp}\mu = J$, together with the fact that the 4-dimensional volume of filled-in Julia set K, which is defined as a set of bounded orbits in complex phase space, is zero, we can show that for arbitrary two points, each of which is confined on different KAM circles and separated on real plane, there always exist complex orbits connecting them.

This situation is suggestive in the semiclassical description of quantum mechanics because quantum tunneling exactly realizes such (real) classically forbidden processes, and it was indeed proved that the orbits on the Julia set are responsible for quantum tunneling in the presence of chaos(Shudo,Ishii & Ikeda 2002, 2003a). Here we will further discuss that it would be natural to formulate the semiclassical trace formula and also quantum ergodicity problem in terms of the unique invariant measure thus constructed, since unstable periodic orbits are densely distributed on it(Bedford & Smillie 1993). It appears a realizable project since Stokes phenomena in chaotic systems are now controllable(Shudo & Ikeda 2003b).

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Inside-outside duality and isospectrality of planar billiards

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A famous question "Can you hear the shape of a drum?" posed by Kac(Kac 1966) was negatively solved several years ago(Gordon, Webb & Wolpert 1992), that is, they found some concrete examples of non-congruent but isospectral pairs of planar billiard domains. In this talk we shall discuss some novel aspects of this issue:

1. Isospectrality of the planar domains which are constructed by successive unfolding of a fundamental building block is discussed in relation to iso-length spectrality of the corresponding domains. Although an explicit and exact trace formula such as Poisson's summation formula or Selberg's trace formula is not known to exist for such planar domains, equivalence between isospectrality and iso-length spectrality in a certain setting can be proved by employing the matrix representation of *transplantation of eigenfunctions*(Okada & Shudo 2001). As an application of this fact, transplantable pairs of domains, which are all isospectral pair of planar domains and therefore counter examples of Kac's question are numerically enumerated and it is found at least up to the domain composed of 13 building blocks transplantable pairs coincide with those constructed by the method due to Sunada(Sunada 1985).

2. The quantum billiard problem, that is the Dirichlet problem for the Helmholtz equation, can be rewritten as a Fredholm integral equation of the second kind and the eigenenergies can be specified as the zeros of the Fredholm determinant on the real axis. However the Fredholm determinant also has complex zeros corresponding to the resonances when the billiard table is regarded as a scatterer against the exterior wave function. More precisely, the Fredholm determinant admits factorization into the interior and exterior contributions, where the former has zeros at interior Dirichlet eigenenergies and the latter at resonances of the Neumann scattering(Tasaki, Harayama & Shudo 1997). This fact naturally leads us, instead of the Kac's original one, a new question "can one determine the shape of billiard table through the interior eigenenergies and exterior resonances, i.e., all zeros of the Fredholm determinant?" We here discuss the possibility to distinguish isospectral pairs using information of outside scattering problem(Okada, Shudo, Harayama & Tasaki, 2003).

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How useful is the variability in cardiovascular dynamics?

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The cardiovascular system (CVS) continuously adjusts the cardiac output to match the need of the whole organism. The cardiac output is a product of the stroke volume, i.e. the amount of blood expelled in each cycle by the heart, and the heart rate. The stroke volume and the heart rate both vary in time.

The variations of the heart rate are known as heart rate variability (HRV). It consists of the frequency of cardiac oscillations at each instant in time. The stroke volume contains information about the corresponding amplitude.

Why should the frequency vary? Several physiological processes are involved in the regulation of cardiac output, acting on different time-scales. The physiological processes underlying them are of different characters (chemical, mechanical, electrical, or a combination), and are spatially distributed. In the blood distribution system, oscillations with frequencies spanning from 0.01 Hz to 1 Hz are involved. The cardiac frequency then varies as a result of couplings with the other oscillatory processes.

The CVS is a very complex system. The oscillators that govern its dynamics are coupled and as a consequence, not just the heart rate, but all the characteristic frequencies vary in time. In practice the time of observation of CVS dynamics is inevitably limited. Consequently, it is difficult to distinguish clearly between the deterministic and the stochastic components.

The variability of the cardiac frequency is of paramount importance and it demonstrates the adaptability of the CVS. We discuss the association between changes in HRV and cardiovascular disease, and how specific diseases can be characterized by modifications in specific oscillatory component(s) and their couplings.

Introduction to Chaotic Codes for Digital Communications

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We shall review the recent developments of spread spectrum communication systems with chaotic codes, achievements of the optimal CDMA systems with chaotic codes, and chaotic cipher(symmetric and asymmetric), as well as basic theory of exactly solvable chaos, Lebesgue spectrum analysis for chaotic sequence and recently proven theorems about digital chaos (chaotic mapping over module 2^n) .

We discuss various scientific issues about chaotic codes and their practical applications which link classical ergodic theory with modern digital signal processing technology.

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Fidelity of Perturbed Classical Evolution

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The stability of the evolution of Hamiltonian systems under the influence of a static perturbation attracted substantial attention recently, especially in the field of quantum computing. The main question is, how does the type of dynamics affect the divergence of the evolution of two slightly different systems. In our work we focused on classical dynamics. We compared the Liouville evolution of classical phase space densities in the original and the perturbed system, starting from the same initial condition. The overlap of the two evolved phase space densities is what is called classical fidelity.

We studied both chaotic and integrable systems. In chaotic systems the initial decay of the classical fidelity is exponential and given by the Lyapunov exponent. In our work, however, we focused on the asymptotic behaviour. It turns out that the asymptotic decay in chaotic systems can be related to the decay of correlations. This means that asymptotically the decay of fidelity can be either algebraic or exponential, where in the latter case the decay rate is not necessarily related to the Lyapunov exponent.

In the integrable case the initial decay of fidelity turns out to be mildly surprising as it can sometimes be even faster than exponential, while in the other case the initial decay is algebraic in nature. In our work we analytically showed that the type of decay depends on the shape of the perturbation but not its size. The fast type of decay can be related to the change of the frequency and therefore results in a ballistic divergence of the evolutions in the two systems, while the algebraic decay can be related to the perturbation of the shape of the tori.

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Cardiovascular variability and ageing

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We discuss changes with ageing in cardiovascular oscillations and their couplings. Analyses of heart rate variability, the propagation of cardiac oscillations within the system, cardio-respiratory couplings, and the direction of coupling, will be presented for a group of healthy subjects of all ages between 14 and 84 years.

Dynamical-Morphological Property of Adhesive Tape in Peeling

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We experimentally investigated the dynamical behavior of an adhesive tape in peeling at a constant speed with the emphasis on the emergence of slow and fast peeling motion. Especially focusing our attention on the whole pattern formed by the peeled adhesive on the tape, the dynamical-morphological phase diagram as a function of peel speed and spring constant was obtained. The spatio-temporal patterns turn out to be classified into four types: low-speed pattern, high-speed pattern, oscillatory pattern, and spatio-temporal intermittent pattern. We expect that we can understand the the dynamical property in peeling process adhesive tape by investigating the formation process of the spatio-temporal patterns.

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Anomalous Diffusion and Dynamical Localization in Polygonal Billiards

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As the Schrödinger equation is *linear*, it cannot posses exponential instability in time as do the classical equations of motion. Quantum time evolution is dynamically stable and all Lyapunov exponents are strictly zero. Still, the quantum evolution mimics classical exponential instability up to so-called *log-time* $\log 1/\hbar$. In some quantum systems there is another time scale, usually larger than log-time, connected with the phenomena of *dynamical localization*. This is purely quantum interference effect and results in a quantum suppression of classical diffusion. For times smaller than this *localization time*, quantum evolution follows the classical diffusion. Afterwards, the quantum system "notices" its discrete spectrum and the diffusion stops, resulting in a localized state. Since the localization time is usually much larger than the log-time, exponential instability may not be relevant for dynamical localization, although all known examples of dynamical localization, from kicked rotors and maps to quantum billiards, take place in classically chaotic systems. In view of that, it is important to see whether exponential sensitivity is at all necessary for dynamical localization. We will study numerically classical and quantum dynamics of a piecewise parabolic area preserving map on a cylinder which emerges from the bounce map of elongated triangular billiards. The classical map has no exponential sensitivity and exhibits anomalous diffusion. Quantization of the same map results in a system with dynamical localization and pure point spectrum.

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