26th Marian Smoluchowski Symposium on Statistical Physics

Complexity of Brain – Critical Behavior and Scaling

Kraków, Poland, August 28–31, 2013

organized by

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Proceedings

As usual, proceedings of the Symposium are going to be published as a special issue of *Acta Physica Polonica B*. Everybody is welcome to contribute, but please note that all submissions will go through a full editorial process, including peer review.

Our intend is to publish a topical issue devoted to neurocomplexity and signal analysis.
Please, send your submissions to the address of the **Organizers**

`zfs@th.if.uj.edu.pl`

Your submission should be in the LaTeX (or plain TeX) format, figures in Encapsulated PostScript. We are sorry but we will **not** be able to handle other formats, including Word. Please, visit the publishers' website `http://th-www.if.uj.edu.pl/acta/` for further instructions for authors.

The submission deadline is **January 4, 2014**.

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Wednesday, August 28th

Arrival Day

09:00 - 09:30	**Maciej A. Nowak**	Opening address
09:30 - 10:30	**Antonio Politi**	Onset of nontrivial collective behavior in neural networks
10:30 - 11:30	**Daniel Wójcik**	Current sources of electrical activity in the brain: modeling and reconstruction from data
11:30 - 12.00	*Coffee break*	
12:00 - 13:00	**Alessandro Torcini**	Sisyphus effect in neural networks with spike-timing dependent plasticity
13:15 - 15.00	*Lunch break*	
15:00 - 16:00	**Bogusław Tomanek**	Brain imaging: Functional MRI and neuronal fiber tracking - challenges and opportunities
19.00 - 21.30	*Get–together Party,* U Pęcherza*, Collegium Maius*	

Thursday, August 29th

09:30 - 10:30	**Włodzisław Duch**	Autism spectrum disorders and ADHD: some conclusions from computational simulations
10:30 - 10:50	**Michał Cieśla**	Click The Bomb! The implicit learning study using social networks
10:50 - 11:10	**Michał Sznajder**	Human learning abilities in using different types of physical human-computer interfaces
11:10 - 11:25	**Karol Trojanowski**	Frequency-locking and pattern formation in the Kuramoto model with Manhattan delay
11:30 - 12.00	*Coffee break*	
12:00 - 13:00	**Miguel Rubi**	Exocytosis of serotonin in the neuronal soma
13:15 - 15.00	*Lunch break*	

Session on fractals and synchronization

15:00 - 15:30	**Michał Kurzyński**	Fractal versus small-world networks of conformational transitions in protein molecular machines
15:30 - 15:45	**Monika Krasowska**	Fractal geometry characterization of polimeric materials
15:45 - 16:00	**Anna Strzelewicz**	Studies on fractal structure of magnetic membranes
16:00 - 16:15	**Krzysztof Siekański**	Modeling unsymmetrical synchronization with dominant agents
16:30 - 17.00	*Coffee break*	
19.00 - 22.00	*Conference Dinner,* Grand Hotel, *Sławkowska 5*	

Friday, August 30th

09:30 - 10:30	**Lutz Schimansky-Geier**	Stochastic phase oscillators in complex networks
10:30 - 11:00	**Simona Olmi**	Linear stability in networks of pulse-coupled neurons
11:00 - 11:30	**Marzena Ciszak**	Experimental study of firing death in a network of chaotic FitzHugh-Nagumo neurons
11:30 - 12.00	*Coffee break*	
12:00 - 13:00	**Dante Chialvo**	Criticality in brain's physics and mind dynamics
13:15 - 15.00	*Lunch break*	

Session on anomalous transport

15:00 - 15:30	**Bartłomiej Dybiec**	Universal and particular properties of anomalous diffusion
15:30 - 15:45	**Tadeusz Kosztołowicz**	Fractional hyperbolic subdiffusion-reaction equation
15:45 - 16:00	**Maciej Majka**	A model for environment induced interaction between interacting colloid particles
16:00 - 16:15	**Katarzyna Lewandowska**	Simulation of subdiffusion-reaction systems
16:15 - 16:30	**Mateusz Piwnik**	Nonlinear subdiffusion-reaction equation
16:30 - 17.00	*Coffee break*	
17:00 - 18:00	**Benjamin Lindner**	Complex patterns of neural interspike intervals - origin, function, and analytical approaches

Saturday, August 31st

09:30 - 10:00	**Angelo Di Garbo**	Sensorimotor stimulation and long-range correlation properties of cortical signals
10:00 - 10:45	**Jan Jacek Żebrowski**	Monitoring of autonomic nervous system development by multiscale multifractal analysis of fetal heart rate variability
10:45 - 11:30	**Danuta Makowiec**	Complexity of the heart rhythm after heart transplantation by transition networks for increments of RR -time intervals between heartbeats
11:30 - 11:45	**Dorota Wejer**	Signal preprocessing and assessment of signal complexity - case of signals with intervals between cardiac interbeats
11:45 - 12.15	*Coffee break*	
12:15 - 12:30	**Ryszard Wojnar**	Pinwheels and poles of meromorphic functions
12:30 - 12:45	**Piotr Weber**	Analysis of quantum and classical modified standard map
12:45 - 13.00	*Closing of the Conference*	
13:15 - 15.00	*Lunch*	

Invited Talks

Onset of nontrivial collective behaviour in neural networks

Antonio Politi, University of Aberdeen, United Kingdom

Abstract: Much of the efforts in understanding the behaviour of neural networks in the recent past has been devoted to the characterization of synchronization properties and much less so to the onset of collective (in the sense of statistical mechanics) properties. I show that even minimal models, involving phase oscillators, can exhibit a rather irregular macroscopic evoluion. The role of connectivity in sustaining this behaviour is also briefly discussed.

Current sources of electrical activity in the brain: modeling and reconstruction from data

Daniel Wójcik, Nencki Institute of Experimental Biology, Warszawa, Poland

Abstract: Extracellular electric potential is a convenient measure of brain activity: it is relatively easy to measure, it has submillisecond resolution, and recordings from a single site are stable over weeks. The downside is long range of the potential which leads to strong correlations between even remote electrodes. A better quantity to analyze is density of current sources (CSD) which reflects local activity. Unfortunately, it cannot be measured directly. In my lecture I will discuss relation between the potentials and the CSD and recent methods of estimation of CSD from potential recorded at arbitrary distribution of electrodes. I will also show how one can combine CSD analysis with Independent Component Analysis to recover activity of specific cell populations using simulated data from a large-scale network model.

Sisyphus effect in in Neural Networks with Spike-Timing Dependent Plasticity

Alessandro Torcini, Istituto dei Sistemi Complessi, Florence, Italy

Abstract: The collective dynamics of excitatory pulse coupled neurons with spike-timing dependent plasticity is studied. The introduction of spike-timing dependent plasticity induces persistent irregular oscillations between strongly and weakly synchronized states, reminiscent of brain activity during slow-wave sleep. We explain the oscillations by a mechanism, the Sisyphus Effect, caused by a continuous feedback between the synaptic adjustments and the coherence in the neural firing. Due to this effect, the synaptic weights have oscillating equilibrium values, and this prevents the system from relaxing into a stationary macroscopic state.

Brain imaging: Functional MRI and neuronal fiber tracking - challenges and opportunities

Bogułsaw Tomanek, Institute of Nuclear Physics, Polish Academy of Sciences, Kraków, Poland and University of Calgary, Canada

Abstract: Magnetic Resonance Imaging (MRI), introduced in 1970-ties, has been successfully applied to non-invasive diagnosis of various diseases based mostly on morphological imaging. As MR technology still develops, its boundaries have been extended beyond its primary applications. Currently MRI allows imaging of brain physiology and function using functional MRI (fMRI) and fiber tracking. While fMRI is relatively well established, neuronal fiber tracking is still being developed. The presentation will provide basics of MRI with emphasis on fMRI. The challenges associated with the fiber tracking technique, including statistical approaches to data analysis will be presented. Future directions and opportunities for improvement in this area will be discussed.

Autism Spectrum Disorders and ADHD: some conclusions from computational simulations

Włodzisław Duch, Department of Informatics, Nicolaus Copernicus University, Toruń, Poland

Abstract: Autism Spectrum Disorder (ASD) and Attention Deficit Hyperactivity Disorder (ADHD) are still poorly understood psychiatric disease of relatively high prevalence. Specific causes of these diseases are unknown and they have never been linked together. Many theories have been proposed, implicating genetics (over 100 genes have been linked to ASD), perinatal, environmental, stress, infections, vaccines, various chemicals, etc, but correlations have always been quite weak. Computational simulations of biologically motivated neural networks suggest that a whole spectrum of attention deficit problems may result from abnormal synchronization of neurons in the brain that may be due to the leak ion channels. Low leak currents lead to synchronization that is too strong, therefore once attention is focused it cannot be disengaged. In visual areas this leads to fixed gaze, in motor areas this leads to repetitive movements. Strong leak currents lead to synchronization that is easily perturbed and attention cannot be focused, resulting in ADHD-like symptoms. This basic mechanism contributes to abnormal development of brain connectivity and leads to many symptoms that ASD and ADHD theories treat usually as causes (for example, the mirror neuron hypothesis of autism). Models of development that focus on attention deficits should explain how basic synchronization processes may influence brain development and manifest in anomalous behavior. Abnormal synchronization in neural networks may also be due to synaptic properties influencing connectivity, neural membrane properties, ion channels, distribution of specific types of neurons. Many different problems may result in deceptively similar deficits at the behavioral level. In effect all correlations will be quite weak, and simple theories will not be possible but with deeper understanding of these processes discrimination of precise conditions should be possible. The key here is to find which properties of neurons may be responsible, and this can be done using large-scale computer simulations of semi-realistic neural networks. Simulations allow also to use the language of dynamical systems to discuss underlying processes. Damage to the leak ion channels lead to formation of deep attractors in neural networks, entrapping neural activity and making it hard to move to another state. The goal therefore should be to identify biophysical parameters that lead to such changes (for example specific ion channels or synapses), try to identify proteins involved in these structures, use molecular dynamics to understand these processes, and relate these proteins to specific genes. This can be done using results of animal model of autism, gene expression atlases, neuroscience databases and progressively more detailed computational simulations. The simulation level is at the center of this multidisciplinary neuropsychiatric phenomics research, pointing down to the molecular and genetic level, and up to the behavioral level.

Exocytosis of serotonin in the neuronal soma

J. Miguel Rubi, Department of Fundamental Physics, University of Barcelona, Spain

Abstract: Transmitter exocytosis from the neuronal soma is evoked by brief trains of high frequency electrical activity and continues for the following minutes. Here we studied how active vesicle transport towards the plasma membrane contributes to this slow phenomenon in serotonergic leech Retzius neurons, by combining electron microscopy, the kinetics of exocytosis obtained from FM1-43 dye fluorescence as vesicles fuse with the plasma membrane, and a diffusion equation incorporating the forces of local confinement and molecular motors. Electron micrographs of neurons at rest or after stimulation with 1 Hz trains showed cytoplasmic clusters of dense core vesicles at 1.5 +/- 0.2 and 3.7 +/- 0.3 μm distances from the plasma membrane, to which they were bound through microtubule bundles. By contrast, after 20 Hz stimulation vesicle clusters were apposed to the plasma membrane, suggesting their transport induced by electrical stimulation. Consistently, 20 Hz stimulation of cultured neurons induced spotted FM1-43 fluorescence increases with one or two slow sigmoidal kinetics, suggesting exocytosis from an equal number of vesicle clusters. These fluorescence increases were prevented by colchicine, suggesting a microtubule-dependent vesicle transport. Model fitting to the fluorescence kinetics predicted that 52-951 vesicles/cluster were transported along 0.60–6.18 μm distances at average 11-95 nms-1 velocities. The ATP cost per vesicle fused (0.4-72.0), calculated from the ratio of the $\Delta G_{process}/\Delta G_{ATP}$, depended on the ratio of the traveling velocity and the number of vesicles in the cluster. Interestingly, the distance-dependence of the ATP cost per vesicle was bistable, with low energy values at 1.4 and 3.3 μmm, similar to the average resting distances of the vesicle clusters, and a high energy barrier at 1.6-2.0 μm. Our study confirms that active vesicle transport is an intermediate step for somatic serotonin exocytosis by Retzius neurons and provides a quantitative method for analyzing similar phenomena in a variety of cell types.

Stochastic Phase Oscillators in Complex Networks

Lutz Schimansky-Geier, Humboldt University, Berlin, Germany

Abstract: We investigate how correlations between the diversity of the connectivity of networks and the dynamics at their nodes affect the macroscopic behavior. In particular, we study the synchronization transition of coupled stochastic phase oscillators that represent the node dynamics. Crucially in our work, the variability in the number of connections of the nodes is correlated with the width of the frequency distribution of the oscillators. By numerical simulations on Erdös-Rényi networks, where the frequencies of the oscillators are Gaussian distributed, we make the counterintuitive observation that an increase in the strength of the correlation is accompanied by an increase in the critical coupling strength for the onset of synchronization. We further observe that the critical coupling can solely depend on the average number of connections or even completely lose its dependence on the network connectivity. Only beyond this state, a weighted mean-field approximation breaks down. If noise is present, the correlations have to be stronger to yield similar observations.

Work done in collaboration with: Bernard Sonnenschein, Humboldt University, Berlin, Germany

Criticality in brain's physics and mind dynamics

Dante R. Chialvo, National Research Council (CONICET), Argentina

Abstract: Highly correlated brain dynamics produces synchronized states with no behavioral value, while weakly correlated dynamics prevents information flow, thus the working brain stays at an intermediate regime. This regime may be critical, since is known that dynamical systems posed near a second order phase transition are able to generate a bewildering variety of robust and flexible behavior, associated with the abundance of metastable states at the critical point. This universal feature led us to argue together with Per Bak, since the last millennium, that the most fundamental cognitive properties of the functioning brain are only possible because it is spontaneously located at the border of such instability. In this lecture we review the motivations and recent experimental results characterizing brain complex functional networks using magnetic resonance imaging and discuss which aspects of the dynamics can be usefully explained in terms of critical phenomena.

Complex patterns of neural interspike intervals - origin, function, and analytical approaches

Benjamin Lindner, Bernstein Center Berlin and Humboldt University, Berlin, Germany

Abstract: In my talk I review dynamical mechanisms at the single-cell and the network level that give rise to specific features in the spike train statistics of nerve cells, such as nonrenewal spiking, i.e. pronounced interspike-interval correlations. I sketch different analytical approaches to calculate the spike train statistics for simplified integrate-and-fire neurons. Furthermore, I demonstrate, that these theoretical results can be used to interpret data from auditory neurons from locust, from electroreceptors of the paddlefish, and from electroreceptors of weakly electric fish. Finally, I discuss implications of non-renewal spiking for the transmission of time-dependent signals in neural systems.

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[2] T. Schwalger, K. Fisch, J. Benda, and B. Lindner How noisy adaptation of neurons shapes interspike interval histograms and correlations PLoS Comp. Biol. 6 , e1001026 (2010)

[3] K. Fisch, T. Schwalger, B. Lindner, A. V. M. Herz, and J. Benda Channel noise from both slow adaptation currents and fast currents is required to explain spike-response variability in a sensory neuron J. Neurosci. 32 , 17332 (2012)

[4] C. Bauermeister, T. Schwalger, D.F. Russell, A.B. Neiman, and B. Lindner Characteristic Effects of Stochastic Oscillatory Forcing on Neural Firing Statistics: Theory and Application to Paddlefish Electroreceptor Afferents PLoS Computational Biology (accepted, 2013)

Monitoring of autonomic nervous system development by Multiscale Multifractal Analysis of fetal heart rate variability

Jan Jacek Żebrowski, Cardiovascular Physics, Complex Systems Division, Faculty of Physics, Warsaw University of Technology, Warszawa, Poland

Abstract: During the development of a fetus in the womb not only the organs form and grow but also the different regulating mechanisms come to be. At around the 22nd week of gestation the fetal ECG may be measured. However, the heart rhythm then is almost metronomic which indicates that the autonomic nervous system - the main moderator of the heart rate - has not developed fully yet. As gestation progresses heart rate variability (hrv) becomes more and more complex. It is known that there are quiet states of the fetus (roughly equivalent of the human non-REM sleep) and active states. As gestation progresses, heart rate variability becomes progressively more and more complex. We analyzed 158, 30 minute magnetocardiographic hrv recordings from healthy fetuses 21-38 weeks of age taking into account both quiet, active and mixed states of the fetuses. Magnetocardiography is a technique using SQUID magnetometers which uniquely allows an excellent separation of the fetal ECG from that of the fetus. Only several magnetocardiography centers exist in Europe and our data was gathered at Biomagnetic Center of the Jena University Hospital. In our study, we use a novel method to study the properties of hrv: the Multiscale Multifractal Analysis (MMA) [1], which calculates the Hurst surface. This surface describes in a very compact form, the scaling properties (i.e. the nonlinear correlation properties) of the fluctuations of the heart rate depending on the fluctuation's magnitude and on the time scale (i.e. the frequency range). Note that the MMA method is designed specifically to analyze the VLF band of heart rate variability. The two lowest bands (very low frequencies and ultra-low frequencies) of human heart rate variability (HRV) account for 95% of total signal power. Nonetheless their physiological background is still very uncertain. The problem is in the lack of methods capable of analyzing these bands, other than the basic power spectral analysis which is usually insufficient. Recently fractal scaling discovery methods, such as DFA, have been used to analyze fetal heart rate [2]. To show that the Hurst surface calculated from fetal heart rate indeed properly monitors the development, we formulated an efficient statistical model for predicting gestational age based only on heart rate variability recordings [3]. We are currently adding into the statistical prediction model also other parameters assigned to the baby at its birth such as the APGAR score or its weight. We aim to be able to estimate these parameters from the heart rate variability recordings made a few weeks before the child is born. These results will be discussed at the conference. We hope that our work will help to develop noninvasive, efficient and accurate prenatal diagnosis methods.

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[2] D. Hoyer, S. Nowack, S. F. Tetschke, S. Ludwig, L. Moraru, A. Rudoph, U.Wallwitz, F. Jaenicke, J. Haueisen, E. Schleußner, U. Schneider, Comput. Biol. Med. 42, 335-341 (2012)

[3] J. Gierałtowski, D. Hoyer, F. Tetschke, S. Nowack, U. Schneider, J. Żebrowski, Auton. Neurosci. (2013)

Talks

Click The Bomb! The implicit learning study using social networks

Michał Cieśla, Jagiellonian University, Kraków, Poland

Abstract: Implicit learning is one of the standard problems of cognitive sciences. Its systematical study has been started in 1967 by Reber, who analyzed unconscious learning of grammar rules by presenting only random words, which the grammar can generate. Here, we concentrate on another paradigm of implicit learning - the sequence learning. In contrast to typical psychological experiment, we implemented simple arcade game and we put it on a Facebook. By measuring peoples reactions in subsequent plays, we were able to analyze learning process of hidden game's rules. The poster presents preliminary results of our analysis.

Work done in collaboration with: Grzegorz Mazgaj, Jakub Barbasz and Michał Wierzchoń

Human learning abilities in using different types of physical human-computer interfaces

Michał Sznajder, J. Haber Institute of Catalysis and Surface Chemistry, Polish Academy of Sciences

Abstract: Human-computer interfaces are the key factor in our everyday use of modern consumer electronics and computers. Nowadays innovative physical interfaces change the way of using and thinking about electronic devices and make them more natural and direct by using movement. They also challenge both users and producers: the former to learn new interaction techniques and the latter to create easy to pick, modern and interesting HCI solutions. The purpose of the study was better understanding of how human adjusts and learns to use different kinds of inertial human-computer interfaces. In the study three different physical human-computer interfaces were designed using three most popular inertial sensors: accelerometer, gyroscope and magnetometer. The first interface type is gyroscopic mouse allowing user to control the device with tilting a hand. Controlled device reacts on every angle change and pauses in movement. Second type of created interface is accelerometer tilt mouse. In this kind of interface controller device also reacts on hand tilt but using changes in Earth gravity direction so it is not reacting directly to changes in tilt angle and it is not reacting on pauses in hand movement. Third type is mouse based on sensor fusion mechanism incorporating signals from all the three sensors. As a study reference point touchpad interface was also created. Results of conducted interfaces tests will be presented. Study test group had different computer usage skills. Whole group will use special test arcade game measuring participants reactions time using different kinds of interfaces and speed of learning process. Conducted research helps to better understand and choose proper solutions for specified kind of devices and targeted groups of users. The results give an important tool for decision making on interaction design level which nowadays many times decides about failure or success of created product.

Work done in collaboration with: Jakub Barbasz

Fractal versus small-world networks of conformational transitions in protein molecular machines

Michał Kurzyński, Faculty of Physics, Adam Mickiewicz University, Poznań, Poland

Abstract: It is now well established that most if not all enzymatic proteins display a slow stochastic dynamics of transitions between a variety of conformational substates composing their native state. A hypothesis is presented that the protein conformational transition networks have evolved in a process of self-organized criticality and, like higher level biological networks: the protein interaction network and the metabolic network, display both scale-free and fractal organization. All biological molecular machines can be formally considered as enzymes that simultaneously catalyze two chemical reactions: the free energy-donating (input) reaction and the free energy-accepting (output) one. For single input and output transition substates the degree of coupling between the output and the input reaction fluxes cannot exceed unity. As some experiments for myosin II, myosin V and the dynein motors suggest such exceeding, looking for conditions of increasing the degree of coupling value over unit y (realization of a "molecular gear") challenges the theory. Probably it holds also for the G-proteins and transcription factors, mutations of which can result in the cancerogenesis. Study simulations of random walks on several model networks involving more transition substates indicate that the case of the degree of coupling higher than one is realized in a natural way for the scale-free critical branching trees extended by long-range shortcuts thus having the small-world topology. For short-range shortcuts, the networks are fractal, and represent an ideal model for the molecular machines with the tight coupling, i.e. with the degree of coupling value equal exactly to unity.

Work done in collaboration with: Przemysław Chełminiak

Fractal geometry characterization of polymeric materials fracture

Monika Krasowska, Department of Physical Chemistry and Technology of Polymers Faculty of Chemistry, Silesian University of Technology, Gliwice, Poland

Abstract: Since Mandelbrot's publications (1-2), fractal geometry has been extensively applied to characterize roughness of fracture surfaces and correlate it with mechanical properties (3-5). In this work a fractal analysis was used for describing fractures of two types of polymeric materials. Polymer networks obtained from three popular dental dimethacrylate monomers: Bis-GMA, TEGDMA and UDMA as well as two copolymers of these monomers were analyzed (6). Dense polymer membranes with dispersed magnetic powder (magnetic membranes) for air separation were also investigated (7). In both cases profiles of fractures were described by a modified fractal dimension. It is based on scaling the length of a profile with the size of a measuring step. A quantitative description of the fracture surface is an important link in the investigation of the mechanisms of materials' decohesion and crack resistance.

Work done in collaboration with: Izabela Barszczewska-Rybarek, Anna Strzelewicz, Aleksandra Rybak, Gabriela Dudek and Roman Turczyn

[1] B.B. Mandelbrot, D.E. Passoja, A.J. Paullay, Fractal character of fracture surfaces of metals. Nature 308, 721 (1984)

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and polymeric composites Materials Science 40 No. 4, 491 (2004)
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Studies on fractal structure of magnetic membranes

Anna Strzelewicz, Department of Physical Chemistry and Technology of Polymers Faculty of Chemistry, Silesian University of Technology, Gliwice, Poland

Abstract: Great number of studies have been carried out in order to gain a better understanding of transport phenomenon in membranes with disordered structure [1-5]. Recently [4-6], we have discussed structure-morphology problems of ethylcelullose membranes with magnetic powder used to the air separation. In this paper, we go one step beyond the previous research by analyzing membranes with different type and granulation of magnetic powders. The concept of diffusion on fractal structure of polymer membrane with dispersed magnetic powder is discussed. Magnetic membrane, is a medium with penetrant-scale gaps whose size and position are changing randomly. It exhibits distinctive fractal characteristics and can be described by using the fractal geometry i.e. anomalous diffusion exponent, static fractal dimension and fractal dimension of the trajectory of the random walk.

Work done in collaboration with: Monika Krasowska, Aleksandra Rybak, Gabriela Dudek, Roman Turczyn and Michał Cieśla

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[6] A. Strzelewicz M. Krasowska, G. Dudek, A. Rybak, R. Turczyn, M. Cieśla, Anomalous diffusion on fractal structure of magnetic membranes, Acta Physica Polonica B, 44 (2013) 955-965

Frequency-locking and pattern formation in the Kuramoto model with Manhattan delay

Karol Trojanowski, Jagiellonian University, Kraków, Poland

Abstract: We investigate the synchronization process in a Kuramoto model of phase-coupled oscillators with distance-dependent delay. The oscillators occupy the nodes of a two-dimensional square lattice subjected to periodic boundary conditions. The mean-field interactions with velocity-dependent delays propagate along the lattice sites. This gives rise to a non-uniform distribution of delays and lattice dimensionality dependence, which is not present in mean-field models without delays. We find that the 'coupling strength-delay' phase diagram does not show up reentrant behavior present in models with uniform delay. A number of dynamic patterns, reported earlier for a generalized Kuramoto model with non-mean-field distance-dependent interactions, is also found.

Modelling asymmetrical synchronisation with dominant agents

Krzysztof Siekański, Jagiellonian University, Kraków, Poland

Abstract: We present an analytically and numerically simple model which can be potentially useful for some specific examples of synchronization (i.e. asymmetrical interactions in sets of oscillators). Simulations indicate that the model indeed illustrates synchronization and has interesting properties. Results of our research lead to a hypothesis that violating Newton's Third Law does not desynchronize previously synchronized systems.

Linear stability in networks of pulse-coupled neurons

Simona Olmi, Istituto dei Sistemi Complessi, Florence, Italy

Abstract: In the analytical study [1], we considered discontinuous velocity fields and we found that the stability of the splay state for finite networks was dictated by the sign of the discontinuity of the velocity field $F(X)$, namely for $F(1) > F(0)$ (resp. $F(1) < F(0)$) the state was unstable (resp. stable). Furthermore, we demonstrated for generic discontinuous fields that the short-wavelenght component of the spectrum vanishes as $1/N^2$. In a previous paper a numerical investigation of continuous fields in terms of an approximated event-driven maps has shown that the Floquet spectra scales as $1/N^4$ [2].

Now we extend such results by considering the exact model and by investigating the scaling properties of the Floquet spectrum of finite size systems for discontinuous, continuous and even analytic velocity fields. We investigate the stability properties of dynamical states characterized by a uniform firing rate (splay states) in a network of N globally pulse-coupled neurons subject to a generic velocity field. In particular, we estimate the Floquet spectra corresponding to the splay state solution for three different types of transmitted pulses, namely, for finite pulse width, for vanishingly small pulse width and for δ-pulses.

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Experimental study of firing death in a network of chaotic FitzHugh-Nagumo neurons

Marzena Ciszak, CNR-Istituto Nazionale di Ottica, Florence, Italy

Abstract: The FitzHugh-Nagumo neurons driven by a periodic forcing undergo a period-doubling route to chaos and a transition to mixed-mode oscillations. When coupled, their dynamics tend to be synchronized. We show [PRE 87, 022919 (2013)] that the chaotically spiking neurons change their internal dynamics to subthreshold oscillations, the phenomenon referred to as firing death. These dynamical changes are observed below the critical coupling strength at which the transition to full chaotic synchronization occurs. Moreover, we find various dynamical regimes in the subthreshold oscillations, namely, regular, quasiperiodic, and chaotic states. We show numerically that these dynamical states may coexist with large-amplitude spiking regimes and that this coexistence is characterized by riddled basins of attraction. The reported results are obtained for neurons implemented in the electronic circuits as well as for the model equations. Finally, we comment on the possible scenarios where the coupling- induced firing death could play an important role in biological systems.

Universal and particular properties of anomalous diffusion

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Abstract: Anomalous diffusion can be significantly different from the standard (Markovian and Gaussian) diffusion. Nevertheless, there are some very special situations when anomalous could look normal. Within the presentation main properties of anomalous diffusion will be presented with special attention to unexpected and universal properties of anomalous diffusion.

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Hyperbolic subdiffusion-reaction equation

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Abstract: A persistent random walk model (PRWM), which assumes a correlation between successive steps of particles, provides hyperbolic normal diffusion or fractional subdiffusion equation. In this contribution the hyperbolic subdiffusion-reaction equation for the reaction $A + B(static) \to B(static)$ is derived within the continuous time random walk formalism using the PRWM. We also find its solution over a long time limit. Based on the obtained results, we find the hyperbolic subdiffusion-reaction equation in the case in which mobile particles of species A and B can chemically react according to a more complicated formula.

A model for environment induced interaction between interacting colloid particles

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Abstract: The typical model of colloid is a system consisting of two particle species: one which can be observed and the other that acts as environment. The presence of environment results in additional, so-called, effective interaction between distinguished particles. This phenomenon is of central interest in the colloid studies, since it leads to various types of self-organization. The simplest example of such interaction is depletion interaction, predicted by Asakura and Oosawa for hard spheres, but more advanced theoretical tools, such as Dijkstra expansion, allows researchers to include a variety of interactions between observed particles and their molecular environment. However, these theories neglect the intra-environment interactions. We propose a new general model, which predicts the effective interactions including both particle-environment and environment-environment interactions. The effective interaction is expressed by a single compact-form formula combining the microscopic interactions. This result is not restricted to any specific potential type and can serve as a tool to design systems of desired characteristics. The theory is illustrated by several analytically or numerically solvable examples, including hard-sphere systems and systems based on „ion in the solution" interactions.

Simulation of subdiffusion-reaction systems

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Abstract: Subdiffusion–reaction processes can be described by means of the nonlinear partial differential equations with fractional derivatives, which are derived from the continuous time random walk formalism, or the nonlinear differential (or integral–differential) equations with derivatives of a natural order, which are based on nonadditive Sharma–Mittal, Tsallis or Gauss entropies. These equations are very difficult to solve and, as far as we know, their general solutions remain unknown (except in very special cases). For this reason, different assumptions and special methods which can oversimplify the problem are usually made in order to solve these equations analytically. Furthermore, there are also used the numerical methods and the computer simulations. We present the results of the computer simulations which are conducted for several cases of subdiffusion–reaction systems.

Nonlinear subdiffusion-reaction equation

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Abstract: TBA

Sensorimotor stimulation and long-range correlation properties of cortical signals

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Abstract: An interesting problem in neuroscience is to establish how sensory and motor stimuli affect the dynamics of neural activity. A recent study suggests that the intercommunication level between different cortical areas can be modulated by enhancing sensory, motor and cognitive stimulation using the environmental enrichment protocol [1]. However, how sensorimotor experience impact the dynamical properties of a signal locally recorded in a given cortical area (long-range correlation properties, scale-free dynamics, fractal dimension etc.) is currently not well known. To this aim, simultaneous recordings of local field potentials from primary visual and secondary motor cortices were performed on freely-moving mice reared in environmental enrichment since birth. The signals were analyzed with several methods. Detrended fluctuation analysis [2] was employed to characterize the possible long-range correlation properties and Higuchi's algorithm [3] was used to estimate fractal dimension. Moreover, the scaling properties of power spectra were also studied. Overall, the results of this study suggest that the improved sensorimotor experience resulting from environmental enrichment impacts on the dynamical properties of the neural activity.

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Complexity of the heart rhythm after heart transplantation by transition networks for increments of RR-time intervals between heartbeats

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Abstract: It is believed that heart accelerates due to activation of the sympathetic part of autonomic nervous system. Decelerations in the heart rhythm emerge because of the vagal tone of the autonomic regulation. Therefore investigations of patterns of changes in the heart rhythm offer insights into the control function of the neural regulation over the cardiovascular system.

Network models have been used to capture, represent and analyze characteristics of living organisms and general properties of complex systems. The use of network representations in the characterization of time series complexity is a relatively new but quickly developing branch of time series analysis. In particular, changes in beat-to-beat time intervals, called RR-increments, can be mapped into the directed and weighted network. The vertices in this network represent RR-increments and edges describe pairs of subsequent increments.

We show that community structure, called p-core analysis, is an effective measure which allows to quantify the information on dynamical processes underlying the networks constructed from records of healthy subjects and patients after heart transplantation. We also apply entropy measures to these networks to discriminate records of healthy subjects from heart transplant patients.

Work done in collaboration with: B. Graff and Z. Struzik

Signal preprocessing and assessment of signal complexity - case of signals with intervals between cardiac interbeats

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Abstract: Indices of the complexity of heart rate variability (HRV) are calculated from signals consisting of RR-intervals obtained from ECG recordings. But these signals suffer from the presence of abnormal RR-intervals of both origin technical and physiological. Therefore preprocessing of the signals is inevitable. However, the way of the error correction is crucial in estimates of HRV indices. In the following we test five methods of editing: (1)deletion of an abnormal RR-interval, (2)replacing of an abnormal RR by the median from the values surrounding, (3)replacing of an abnormal RR by the value chosen at random from normal RR-intervals surrounding, (4)replacing of an abnormal RR by the value which results from recurrence analysis, (5)finally, choosing at each abnormal RR-interval one of the method listed. Abnormal RR values usually appear in groups. Therefore, we examined many signals of healthy people to identify patterns of disorders that occur in natural nocturnal recordings. But we found only 5 patterns containing 1.8%-2% errors. To enlarge this set we performed the bootstrap-type simulation. Each pattern was cyclically shifted at random place. Then these patterns were applied to signals „clean", namely to signals consisting of 2500 normal RR-intervals recorded during the nocturnal rest of 21 healthy young people. For comparison, we prepared random patterns of perturbations and then applied them to the same signals. This way we obtained two large groups of signals for further preprocessing. The first group contained signals perturbed by the natural patterns of abnormal RR-intervals whereas the second group consisted of signals disturbed by artificial patterns. The signals from both groups were edited by the five methods of preprocessing. Finally, the popular nonlinear indices for the two groups were estimated separately. The following three observations can be formulated. Firstly, the nonlinear indices of fractality obtained in DFA analysis α_1 and α_2 were the most sensitive to editing. Secondly, the best stability of results was achieved by method (2). Thirdly, the signals with artificial annotations provided, in general, higher variability in the index values than the signals perturbed by natural patterns.

Pinwheels and poles of meromorphic functions

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Abstract: Through an experiment David Hubel and Torsten Wiesel found that cells in the visual cortex that had orientation selectivity. Further the pinwheel formations in the striate cortex were discovered. In 1985, Gary Blasdel discovered a technique to visualize these orientation structures in 2 dimensions, affording once again a new examples that some aspects of development of biological tissues in animals and plants can be described in a 2D space. The osteon growth and phyllotaxis are perhaps the best known examples of it. The Cartesius-Euler topological law is the reason of these analogies. In [1] it was indicated that in the above phenomena the dislocations can be interpreted as the vortices, and appear as poles of the meromorphic function. In description of the brain pinwheels this approach can be reversed and analogy between excitation of the neurons in striate cortex and crystallization process can be indicated.

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Analysis of quantum and classical modified standard map

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Abstract: In this paper we investigate a specific modification of the standard map in the framework of two alternative ways of description: quantum mechanics and classical statistical dynamics. The map under consideration has all specific properties of the standard map, i.e., it has the regular and chaotic areas in phase space, for some parameter values one observes cantori structures while for others one sees the emergence of accelerating modes. However, accelerating islands are much larger than for the standard map and may coexist with stable islands of regular periodic orbits. These properties cause the variety of transport processes in phase space for which we build statistical models based on Continuous Time Random Walk (CTRW) framework. In the quantum case we are mainly interested in observing the influence of the cantori structure and accelerating modes on quantum evolution. We use Husimi function, which allows us to compare quantum and classical evolution in phase space.

Work done in collaboration with: Piotr Pepłowski

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