11th International Scientific Conference on Physics and Control — PhysCon 2024 — Istanbul

PhysCon 2024

11th International Scientific Conference on Physics and Control

9-12 September 2024

Kadir Has University, Istanbul, Turkey

Dedicated to the memory of Hermann Haken (1927–2024)

Contents

About

PhysCon 2024 builds upon the foundation laid by previous conferences, which originated in 2003 in Saint Petersburg, Russia. With a focus on the intersection of Physics and Control and an emphasis on both theoretical developments and practical applications, PhysCon 2024 carries forward the tradition of fostering collaboration and knowledge exchange in the field. PhysCon 2024 is co-organized by the Network-Oriented Dynamics & Data Science (NODDS) Lab at Kadir Has University, together with Bilkent University, under the sponsorship of the International Physics and Control Society (IPACS).

PhysCon 2024 introduces a new approach to conference papers in comparison to previous versions of PhysCon conferences. This year, we are exclusively accepting only abstracts for oral and poster presentations, allowing for the presentation of already published works. However, post-conference novel contributions will be invited for publication in the European Journal of Physics Special Topics (EPJ ST) and Cybernetics and Physics (CAP). Further details about the journals can be found in the Author Guidelines section on our website.

PhysCon 2024 has been dedicated to the memory of Hermann Haken, founder of Synergetics and inspiring pioneer of groundbreaking work on nonequilibrium phase transitions and Honorary Member of the International Physics and Control Society (IPACS).

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Programme

The PhysCon 2024 programme (Monday 09/09 to Thursday 12/09) is presented in the following table.

11th International Scientific Conference on Physics and Control (PhysCon 2024)
Kadir Has University, Istanbul, September 9-12, 2024
Compact Schedule

	9 Sep - Monday		10 Sep - Tuesday		11 Sep - Wednesday		12 Sep - Thursday	
9:00			Coffee Time		Coffee Time		Coffee Time	
9:30			Lecture 1 Eckehard Schöll (Conference Hall)		Minisymposium 1.b Arpağ & Pusuluk (Cinema A)	Minisymposium 3.b Schöll & Andrzejak (Cinema B)		
10:00							Contributed Talks 5.a (Cinema A)	Contributed Talks 5.b (Cinema B)
10:30			Lecture 2 Alexander Fradkov (Conference Hall)		Minisymposium 2.b Omel'chenko & Bick (Cinema A)	Contributed Talks 4 (Cinema B)		
11:00	Registration (D Block - 2nd Floor)							
11:30	Lunch (A Block)		Lunch (A Block)		Lunch (A Block)		Lunch (A Block)	
12:00								
12:30	Opening (Conference Hall)							
13:00	Keynote Talk 1 Henrik J. Jensen (Conference Hall)		Keynote Talk 2 Marc Timme (Conference Hall)		Keynote Talk 3 Yamir Moreno (Conference Hall)		Keynote Talk 4 Michael Small (Conference Hall)	
13:30								
14:00	Invited Talk 1: Thomas Stemler (Conference Hall)		Invited Talk 2: Thomas Peron (Conference Hall)		Invited Talk 3: Hildegard Meyer-Ortmanns (Conference Hall)		Invited Talk 4: Jeff Moehlis (Conference Hall)	
14:30	Coffee Break		Coffee Break		Coffee Break		Coffee Break	
15:00	Contributed Talks 1.a (Cinema A)	Contributed Talks 1.b (Cinema B)	Contributed Talks 2.a (Cinema A)	Contributed Talks 2.b (Cinema B)	Minisymposium 4 Kourliouros (Cinema A)	Minisymposium 5 Li & Fradkov (Cinema B)	Lecture 3 Jürgen Kurths (Conference Hall)	
15:30								
16:00	Minisymposium 1.a Arpağ & Pusuluk (Cinema A)	Minisymposium 2.a Omel'chenko & Bick (Cinema B)	Minisymposium 3.a Schöll & Andrzejak (Cinema A)	Contributed Talks 3 (Cinema B)			Closing (Conference Hall)	
16:30					Bosphorus Boat Tour / Conference Dinner A guided boat tour and conference dinner will be held aboard a boat, cruising along the Bosphorus and Golden Horn.			
17:00	IPACS General Assemby (Cinema A)	Rezan Has Museum Tour Round I	Free Time for Dinner Recommended restaurants around Kadir Has University will be provided for participants to enjoy a self-paid dinner.					
17:30								
18:00	Rezan Has Museum Tour Round II							
18:30								
19:00								
19:30			Poster Presentations (D Block Entrance)					
20:00								
20:30								
21:00			Concert - Classical Music (Conference Hall)					
21:30								

Keynote Talks				
Monday	13:00	Keynote 1	Henrik J. Jensen	Self-Organised Criticality and Control
Tuesday	13:00	Keynote 2	Marc Timme	Fluctuation-Responses and Tipping in Strongly Perturbed Nonlinear Systems
Wednesday	13:00	Keynote 3	Yamir Moreno	Network Epidemiology: from modeling diseases to their control
Thursday	13:00	Keynote 4	Michael Small	Choosing Embedding Lag and Why it Matters

Lectures				
Tuesday	9:30	Lecture 1	Eckehard Schöll	Nonequilibrium Phase Transitions and Nucleation Phenomena in Synchronizing Networks (Dedicated to the memory of Hermann Haken, 12.07.1927 – 14.08.2024)
Tuesday	10:30	Lecture 2	Alexander Fradkov	Cybernetical Neuroscience
Thursday	15:00	Lecture 3	Jürgen Kurths	Stability of Power Grids Concerning Strong Perturbations – Tropical Cyclones and Increasing Resilience

Invited Talks				
Monday	14:00	Invited Talk 1	Thomas Stemler	statFEM -- dealing with imperfect models in a statistical learning framework
Tuesday	14:00	Invited Talk 2	Thomas Peron	Effects of clustering heterogeneity on the spectral density of sparse networks
Wednesday	14:00	Invited Talk 3	Hildegard Meyer-Ortmanns	Controlling the mean time to extinction for populations of bacteria
Thursday	14:00	Invited Talk 4	Jeff Moehlis	Controlling Populations of Neural Oscillators

MiniSymposia Sessions				
Monday	16:00	MiniSymposium 1.a	**Title** Burçin Ünlü Göker Arpağ	**Physics of Nonequilibrium and Complex Biological Systems - Part 1** Label-Free Characterization of Exosomes Using Raman Spectroscopy Microtubule Dynamics and Motor Protein Function: Stochastic and Langevin Dynamics Perspectives
Monday	16:00	MiniSymposium 2.a	**Title** Eckehard Schöll Istvan Z. Kiss	**Synchronization Phenomena in Interacting Dynamical Systems: Theory and Applications - Part 1** Interplay of Synchronization and Cortical Input in Models of Cortical Networks Pinning Control of Synchronized Oscillatory Networks: Stability Hyperbolas and Relocating Influential Nodes
Tuesday	16:00	MiniSymposium 3.a	**Title** Ralph Andrzejak Oleh Omel'chenko	**Control of Collective Dynamics and Partial Synchronization Patterns in Complex Networks - Part 1** Unbiased Quantification of the Degree of Partial Synchronization Phase Reduction Explains Chimera Shape: When Multi-Body Interaction Matters
Wednesday	9:30	MiniSymposium 1.b	**Title** Kamyar Roudakian Onur Pusuluk	**Physics of Nonequilibrium and Complex Biological Systems - Part 2** Information Transfer as an Evolutionary Feed for Emergence of Critical Brain Network Harnessing Classical and Quantum Correlations: From Thermodynamic Laws to Enhanced Biochemical
Wednesday	9:30	MiniSymposium 3.b	**Title** Galina Strelkova Frederico Costa	**Control of Collective Dynamics and Partial Synchronization Patterns in Complex Networks - Part 2** Lévy Noise Controlled Dynamics of Neural Networks Targeting Cellular Bioelectrical Differences with Non-Thermal Systemic Electromagnetic Fields in the Human Body
Wednesday	10:30	MiniSymposium 2.b	**Title** Zeray Hagos Gebrezabher Bruno Boaretto	**Synchronization Phenomena in Interacting Dynamical Systems: Theory and Applications - Part 2** Emergence of Hypernetworks via Higher-Order Phase Reduction from Weakly Coupled Oscillator Networks Control of Synchronization Due to Ion Conductance Variations: A Pathway to Synchronization in Neuronal Networks
Wednesday	15:00	MiniSymposium 4	**Title** Michal Fedorowicz Wei Hao Tey Konstantinos Kourliouros	**Attractors of Random Dynamical Systems with Bounded Noise: A Control Theoretic Approach** Regularity of Boundaries of Attractors for Linear Differential Equations with Bounded Noise Bifurcations of the Henon Map with Additive Bounded Noise Geometric Theory of Random Dynamical Systems with Bounded Noise: Boundaries of Attractors and Pontryagin's Maximum Principle
Wednesday	15:00	MiniSymposium 5	**Title** Xiaozheng Fu Alexander Fradkov Sergei Plotnikov	**Estimation and Optimization in Networks** Asymptotic Convergence of a Continuous-time Decentralized Online Estimation Algorithm with the Additive Communication Noises Parameter Estimation of FitzHugh-Nagumo Neural Networks Based on the Speed-Gradient and Filtering Adaptive Parameter Estimation for a Class of Neural Mass Networks

Contributed Talks				
Monday	15:00	Contributed Talks 1.a	Danila Semenov Alexander Aleksandrov	Synchronization Conditions of Disturbed Nonlinear Dynamical Networks with Delayed Coupling Based on Passification Method Stabilization of Nonlinear Mechanical Systems via Delayed Feedback
Monday	15:00	Contributed Talks 1.b	Alexandr Elsakov Cutberto Romero-Meléndez	On Asymptotic Properties of Indirect Control Systems with Periodic Nonlinearities Dissipativity and Turnpike Property in a Controlled Stochastic Lotka-Volterra Model with Lévy Jumps
Tuesday	15:00	Contributed Talks 2.a	Aliya Imangazieva Margarita Kovaleva	Chain Control of Nonstationary Networks Plant Breathers Propagation in the Granular Locally-Resonant Chains
Tuesday	15:00	Contributed Talks 2.b	Denis Goldobin Tatiana Bogatenko	Regimes of Global Oscillations Induced by Discrete Synaptic Events in Balanced Neural Networks Dynamics Peculiarities of Three Coupled Hodgkin-Huxley Neurons
Tuesday	16:00	Contributed Talks 3	Sondan Durukanoğlu Feyiz Andrey Ankilov	Uninterrupted Motion of Molecular Wheels on Cu Metal Surfaces Mathematical Models of System of Control of Pressure Variation in Combustion Chambers of Engines
Wednesday	10:30	Contributed Talks 4	Sergey Borisenok Bekzod Mirzakabilov	Effective Feedback Control Algorithms for Nitrogen-Vacancy-Cavity Quantum Sensing Flutter of the Transition Process of the Hereditary Deformable Elongated Plate
Thursday	9:30	Contributed Talks 5.a	Isabel Garcia-Planas Valeri Makarov Margarita Simonyan	Analysis of Controllability of Multiagent Singular Linear Systems Representing Brain Neural Networks Assessing the Irregularity of Multidimensional Biological Recording Local Nocturnal EEG Activity of Healthy People Depending on Chronotype
Thursday	9:30	Contributed Talks 5.b	Erbil Can Artun Andrea Lama Nikita V. Barabash	Spin-Glass Sponges: Spin Glasses with Fractal Surfaces Shepherding in Complex Systems: Integrating Control Theory and Statistical Physics Bifurcations of Smale Horseshoes' chains in a Double-Scroll

Poster Session September 10th - D Block Entrance 20:00	
Alexander Fradkov	Speed Gradient Control of Qubit States
Anissa Besbes	Investigation of Elastic, Optical and Transport Properties of Two Cerium-Based Perovskite Oxides
Assia Abdelouahed	Modeling of Fresh Properties of Concrete Mixed with Rubber and Plastic Waste
Boussaha El Hadi	Experimental Study and Modeling of Chemical Inhibitor Behavior in Acidic Environment Using MATLAB Software
Elena Rybalova	Chimera Resonance: Constructive Role of Noise in Ensembles Of Maps
Igor Shepelev	Role Of Intra-Layer Interaction in Spiking Neural Networks Under Training
Ivan Gorelyshev	Operational Control of the NICA Stochastic Cooling System
Julia Samuseva	Spatiotemporal Modulation of Complexity of Local Field Potentials
Karima Boukerma	Convective Heat Transfer of Nanofluids in A Backward-Facing Step
Lev Smirnov	Dynamics of Large Oscillator Populations with Random Interactions
Margarita Kovaleva	Anti-Resonance in The Essentially Nonlinear Systems
Margarita Simonyan	Features of Synchronization of ECG and EEG Signals in Patients with Obstructive Apnea Syndrome During Night Sleep
Maxim Bolotov	Breathing and Switching Cyclops States in Kuramoto Networks with Higher-Mode Coupling
Mecibah Wahiba	Optimizing and Modeling Malachite Green Removal Using Agro-İndustrial Waste Materials
Mounir Bouras	Improve Efficiency of Perovskite-Based Solar Cell by Photon Recycling
Nataliya Nikishina	The Effect of Delay on Waves in a Ring Of Fitzhugh—Nagumo Neurons Under The Influence of Lévy Noise
Oleg Yu. Sumenkov	Analytical Parameter Conversion of Serial Kinematic Chain Models
Parvin Karimi	Numerical Study of a 2D Permanent Magnetic Lattice Using Artificial Intelligence Algorithms
Polina Tkachenko	Optimal Control of Coupled Buildings Under Seismic Excitation
Radia Kalai	Synthesis and Characterization of Tin Oxide SnO2 Prepared by Ultrasonic Spray
Radouan Djelti	Insight Into Physical Properties of Silver-Based Half-Heusler Semiconductors
Sabrina Mattallah	Statistical Investigation of the Effect of Lubrican Viscosity on Surface Degradation of a Polluted Elastohydrodynamic Contact
Samia Aouici	Modeling Chemical Product Behavior for CIP Tubular Heat Exchangers Using MATLAB Software
Sergey Borisenok	Control on Epileptiform Regimes in the Statistical Model for Mesoscale Neural Population
Toufik Sebbagh	Comparative Analysis of Ceramic, and Composite Solid-State Electrolytes for Lithium-Ion Batteries
Wassila Boughamsa	Use of Plastic Waste as Sand in Concrete

Self-organized Criticality and Control

Henrik Jeldtoft Jensen[1,2]

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The term Self-Organised Criticality (SOC) was introduced by Bak, Tang and Wiesenfeld in in 1987 to describe systems consisting of many components where the natural dynamics drives the system into a stationary state exhibiting no characteristic spatial or temporal scale and therefore critical in the sense of statistical mechanics. In contrast to criticality in equilibrium statistical mechanics, which only occurs if parameters are carefully adjusted, it was suggested that no tuning is needed for SOC. Systems are expected to organised into the critical state as an inherent consequence of the dynamics.

The concept continues to attract substantial attention inspired by the observation of power laws in very many different systems, including brain dynamics, earthquakes, solar flares, forest fires, precipitation and many more [2]. There are, however, still various open questions concerning the behaviour of some of the defining models and concerning how model behaviour may relate in detail to observed behaviour.

After a brief review of SOC we will discuss a new analysis [3] of one of the paradigmatic models, the Forest Fire Model (FFM) [4]. The relation between observed power law behaviour and genuine criticality has been discussed ever since the model was introduced in 1992. Recent analysis indicates that it is indeed possible to establish critical scale invariance in the model if the relation between the driving and the system size is carefully controlled.

References

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Fluctuation-Responses and Tipping in Strongly Perturbed Nonlinear Systems

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M. Schröder[1],
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The collective nonlinear dynamics and reliable function of complex systems fundamentally underlie our daily lives, whether in biological cells, in power grids or in ecosystems. Many complex systems are strongly externally driven and may exhibit state tipping at large driving signals, yet state-of-the-art theoretical analysis methods have focused on linear responses suitable for weak driving signals. Here we report nonlinear responses emerging generically in driven nonlinear dynamical systems yet are absent from most text book examples. Moreover, at some critical (large) driving amplitude, responses cease to stay close to a given operating point and may diverge – the system tips. However, standard response theory fails to predict tipping amplitudes, even at arbitrarily high orders. We propose an integral self-consistency condition that captures the genuinely nonlinear response dynamics. and suggest to predict the tipping point by a large-perturbation expansion evaluated inside the self-consistency condition. The novel approach may help to quantitatively predict intrinsically nonlinear response dynamics as well as bifurcations emerging at large driving amplitudes in non-autonomous dynamical systems. We illustrate our approach for a minimal one-dimensional model and capture the nonlinear shift of voltages in the response dynamics of AC power grid networks.

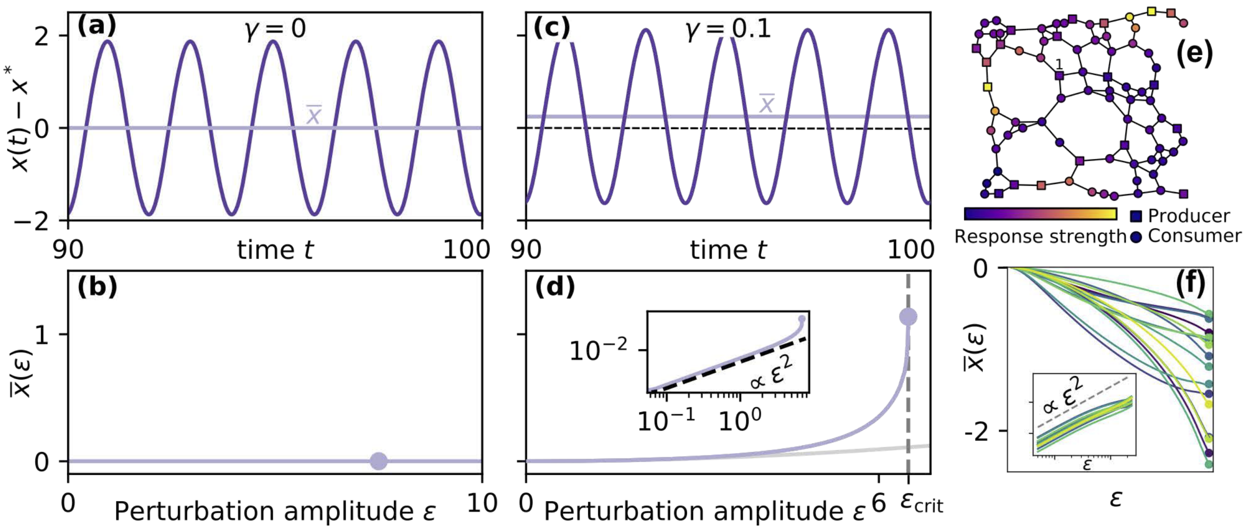

Fig 1. **Genuinely nonlinear system responses and tipping. a,b)** Due to symmetry, many classic model examples exhibit zero time-averaged shift $\bar{x}$ until first ceasing to respond only locally (solid disk in b), in accordance with linear response theory that predicts $\bar{x}(\epsilon) = 0$. **c,d)** In contrast, responses of generic systems are **intrinsically nonlinear**, first quadratic in ϵ for small ϵ (light gray line) and increasingly deviating from it with larger ϵ. Tipping (solid disk in d)) emerges at **large** ϵ_{crit}. a)-d) show response dynamics of the overdamped pendulum model $\dot{x} = \gamma - \sin x + \epsilon \sin \pi t$. Power grid models **(e)** with voltage variables x_n, $n \in \{1, \dots, N\}$ exhibit nonlinear responses **distributed across the network**, displayed in **(f)** for some sample nodes.

Network Epidemiology: From Modeling Diseases to Their Control

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Modern network science has greatly contributed to our understanding of many processes in diverse fields of science. Arguably, contagion dynamics -including network epidemiology- is the area in which network concepts have had a bigger practical impact. Nowadays, we are able to model how diseases unfold and spread with unprecedented precision, which also makes it possible to analyze other spreading-like processes [1], such as social contagion. In this talk, we revise this area of research by discussing how the modeling of spreading processes has evolved in the last two decades. We start by analyzing contagion dynamics in single populations that are described by different network topologies. Next, we discuss cases in which a multilayer approach is needed. We also introduce contagion dynamics in higher-order networks [2], which shows a richer phase space for the dynamics of the system. Finally, we discuss the recent COVID-19 pandemic through the lens of network epidemiology. In doing so, we present key results that combine theoretical models with data-driven simulations and network science tools. To round off, we also address the issue of controlling, or mitigating, real diseases either through better preparedness or via non-pharmaceutical interventions. We conclude the talk by discussing what are the challenges that remain for the future.

References

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Choosing Embedding Lag and Why It Matters

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Takens' theorem guarantees a faithful embedding of a deterministic nonlinear dynamical system from time series data under fairly generic conditions. Embedding, in this way, is the foundation of nonlinear time series analysis and modelling. Since the 1980s many methods have been proposed to estimate the time between observations to provide to an embedding - the embedding lag. The basic premise is that that time interval should insure independence but not irrelevance. Almost all methods to choose this lag are based on the application of some heuristic to this premise. I will review some of the more interesting ones and introduce a new topologically well-founded way of doing the same. The method I describe is based on using concepts from persistent homology and topological data analysis to ensure that one achieves the "best" attractor for the given data.

Nonequilibrium Phase Transitions and Nucleation Phenomena in Synchronizing Networks

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[3]Potsdam Institute for Climate Impact Research, Germany

Phase transitions in nonlinear dynamical systems far from thermodynamic equilibrium have been investigated since the 1970s and 1980s, and concepts from thermodynamics and statistical physics have been applied to describe self-organization, spatio-temporal pattern formation, phase coexistence, critical phenomena, and first and second order nonequilibrium phase transitions [1-3]. Much more recently, phase transitions and critical phenomena have been studied in dynamical networks, where synchronization transitions may arise, giving birth to a plethora of partial synchronization patterns and complex collective behavior, with applications to many natural, socioeconomic, and technological systems [4-7]. We review these developments, and draw some connections of tipping transitions, explosive synchronization, nucleation, critical slowing down, etc. with nonequilibrium thermodynamics. In particular, we study the Kuramoto model with inertia applied to power grids, which gives rise to first order phase transitions to synchronization via partially synchronized states, and show that it can be viewed as an adaptive network of phase oscillators similar to neural networks with plasticity. Moreover, we show that heterogeneous nucleation of partially synchronized patterns in adaptive networks leads to two scenarios of first order phase transitions.

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Cybernetical Neuroscience

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The lecture is devoted to introduction of a new scientific field - **cybernetical neuroscience** which is a branch of computational neuroscience [1] aimed at study of neurobiological systems by cybernetic methods. Cybernetical neuroscience is based on mathematical models adopted in computational neuroscience (Hodgkin-Huxley model, FitzHugh-Nagumo model, Morris-Lecar model, Hindmarsh-Rose model, Landau-Stuart model, neural mass model, etc.) and the methods of cybernetics - the science of control and communication in a living organism, machine and society [2], It also deals with practical applications of the results obtained during study of the mathematical models. In the lecture the main tasks and methods, as well as some results of cybernetical neuroscience are outlined. The main tasks of cybernetical neuroscience are as follows.

1. Analysis of conditions under which the models of neural ensembles possess some special regimes, corresponding to the behavior of neural ensembles: synchronization, spiking, bursting, solitons, chaos, chimeras and others.

2. Synthesis of external (controlling) actions that create the above regimes in the models.

3. Estimation of the state and parameters of the models based on the results of measuring input and output variables.

4. Classification of the human brain states and future behaviors based on observation results using adaptation and machine learning methods.

5. Finding control algorithms (synthesizing feedbacks) that provide specified properties of the closed loop system consisting of interacting controlled systems and controlling agents.

The controlled system in the neurobiological research is the human nervous system or brain. The controlling agent can be implemented in some kind of computer device. For the entire system to work, the nervous system or brain must be connected to external computer communication devices called neurointerfaces (brain-computer interfaces).

The methodology of cybernetical neuroscience has much in common with the methodology of cybernetical physics [3,4]. In the lecture some examples of the cybernetical neuroscience results mostly related to the works of the lecturer's research group will be presented.

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Stability of Power Grids Concerning Strong Perturbations – Tropical Cyclones and Increasing Resilience

Jürgen Kurths

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To Be Announced.

statFEM – Dealing with Imperfect Models in a Statistical Learning Framework

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keywords: Imperfect models, forecasting, Bayesian statistics

The incorporation of statistical learning into mathematically derived models rooted in physics is increasingly gaining attention in the literature. A recent strategy involves enhancing the fundamental physics of governing equations through data-driven Bayesian statistical techniques. Termed as statFEM, this method recognises a priori model misspecification by incorporating stochastic forcing into the governing equations. When additional data becomes available, classical Bayesian filtering techniques are employed to update the posterior distribution of the discretised finite element solution. The resulting posterior effectively captures the combined uncertainty related to the common issue of model misspecification and the data. We analyse the performance of the statistical learning method in a variety of cases drawn from fluid dynamics as well as reaction-diffusion equations.

Effects of Clustering Heterogeneity on the Spectral Density of Sparse Networks

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keywords: complex networks, random graphs, random matrix theory, disordered systems

We derive exact equations for the spectral density of sparse networks with an arbitrary distribution of the number of single edges and triangles per node. These equations enable a systematic investigation of the effect of clustering on the spectral properties of the network adjacency matrix. In the case of heterogeneous networks, we demonstrate that the spectral density becomes more symmetric as the fluctuations in the triangle-degree sequence increase. This phenomenon is explained by the small clustering coefficient of networks with a large variance of the triangle-degree distribution. In the homogeneous case of regular clustered networks, we find that both perturbative and non- perturbative approximations fail to predict the spectral density in the high-connectivity limit. This suggests that traditional large-degree approximations may be ineffective in studying the spectral properties of networks with more complex motifs. We illustrate our method on networks with different distributions of the number of single-edges and triangles. In particular, we show how, for a fixed average number of triangles, fluctuations in the triangle-degree sequence symmetrize the spectral density. This finding is unexpected, given that the skewness of the spectral density depends solely on the number of triangles, the number of edges and the average degree. We show that this phenomenon is a consequence of the decrease in the clustering coefficient as the variance of the triangle distribution increases. In addition, for sufficiently heterogeneous distributions of the number of triangles, the clustering coefficient is no longer a monotonic function of the averaged number of triangles. This implies that the highest clustering does not occur at the maximum average number of triangles, but at an intermediate value. The resolvent equations obtained in our work pave the way to the investigation of the effect of triangle fluctuations on the inverse participation ratio and the local density of states of sparse adjacency matrices. These quantities provide valuable information about the localization properties of eigenvectors. The resolvent equations can also be adapted to compute the spectral density of networks with random weights, which play a central role in the stability analysis of dynamical systems.

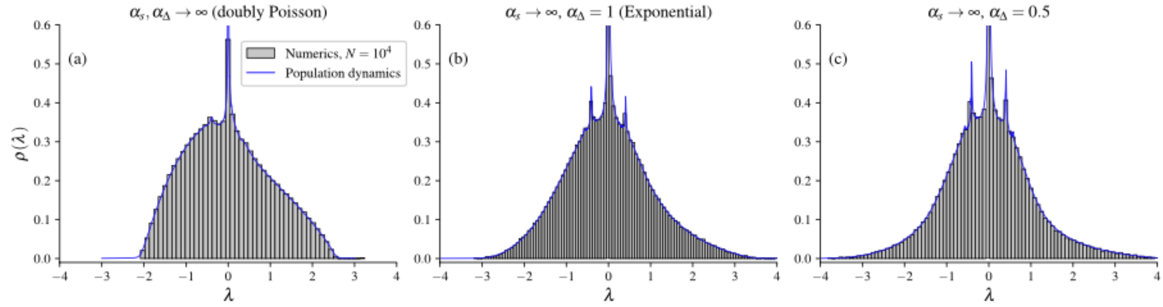

Fig 1. Spectral density of heterogeneous clustered networks with joint distribution $p_{st} = p_s^{(b)} p_t^{(b)}$ for different combinations of the heterogeneity parameters α_e and α_Δ, whose values are indicated on each panel. All results are obtained for a fixed average number of single edges and triangles ($\langle s \rangle = \langle t \rangle = 2$). In all panels, the solid lines are calculated by solving a set of distributional using a population dynamics algorithm with $\varepsilon = 0.01$ and a total number of 10^5 stochastic variables. The histograms are obtained by numerically diagonalizing a single realization of the adjacency matrix of a network with $N = 10^4$ nodes, randomly generated from the Newman-Miller model.

Controlling the Mean Time to Extinction for Populations of Bacteria

Hildegard Meyer-Ortmanns

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Populations of ecological systems generally have demographic fluctuations due to birth and death processes. At the same time, they are usually exposed to changing environments that we model in different versions. We discuss populations composed of two phenotypes of bacteria, normals and persisters. We analyze the impact that both types of fluctuations have on the mean time to extinction of the entire population. As a function of the frequency of environmental changes, we observe a non-monotonic dependence of the mean time to extinction. This allows to control this time scale to be as large as possible as desired from the perspective of bacteria, or as small as possible as appreciated from the hosts to which the bacteria are deleterious.

Controlling Populations of Neural Oscillators

Jeff Moehlis

Department of Mechanical Engineering, University of California, Santa Barbara, USA

Many challenging problems that consider the analysis and control of neural brain rhythms have been motivated by the advent of deep brain stimulation as a therapeutic treatment for a wide variety of neurological disorders. In a computational setting, neural rhythms are often modeled using large populations of coupled, conductance-based neurons. Control of such models comes with a long list of challenges: the underlying dynamics are nonnegligibly nonlinear, high dimensional, and subject to noise; hardware and biological limitations place restrictive constraints on allowable inputs; direct measurement of system observables is generally limited; and the resulting systems are typically highly underactuated. In this talk, I will highlight a collection of recent analysis techniques and control frameworks that have been developed to contend with these difficulties. Particular emphasis is placed on the problem of desynchronization for a population of pathologically synchronized neural oscillators, a problem that is motivated by applications to Parkinson's disease where pathological synchronization is thought to contribute to the associated motor control symptoms. Specific approaches to be highlighted include optimal chaotic desynchronization, optimal phase resetting, phase density control, and cluster desynchronization. This talk is based on the article "Recent advances in the analysis and control of large populations of neural oscillators" by D. Wilson and J. Moehlis, in Annual Reviews in Control, 54:327-351, 2022.

MiniSymposia Sessions

MiniSymposia 1:
Physics of Nonequilibrium and Complex Biological Systems

Organized by

Göker Arpağ[1],
Onur Pusuluk[1]

[1] Kadir Has University, Türkiye

The inherent complexity and deviations from equilibrium observed in biological systems often obscure the underlying physics and control mechanisms at work. Tackling this challenge requires advancements and integration across experimental, computational, and theoretical domains. This minisymposium will feature a series of presentations that highlight interdisciplinary progress in the analysis and understanding of complex biological systems. The topics covered will be diverse, ranging from the characterization of exosomes through Raman spectroscopy and the study of intracellular cargo transport within microtubule networks using dynamic models, to the validation of critical brain hypotheses via statistical approaches and the calculation of photoisomerization yields through quantum resource theory.

Talks included:

- Label-Free Characterization of Exosomes Using Raman Spectroscopy, by Burçin Ünlü
- Microtubule Network Dynamics and Motor Protein Function:A Stochastic and Langevin Dynamics Perspective, by Göker Arpağ
- Information Transfer as an Evolutionary Feed for Emergence of Critical Brain Network, by Kamyar Roudakian
- Harnessing Classical and Quantum Correlations: From Thermodynamic Laws to Enhanced Biochemical Processes, by Onur Pusuluk

Label-Free Characterization of Exosomes Using Raman Spectroscopy

Burçin Ünlü

Faculty of Engineering, Özyeğin University, Turkey

Exosomes are cell-secreted extracellular vesicles. They carry diverse molecular cargo reflecting their origin. Our study introduces a novel approach combining surface-enhanced Raman spectroscopy (SERS) and machine learning to classify exosomes from five cell lines and determine their origin. SERS provides label-free spectroscopic profiles of exosome content, which are then processed by an artificial neural network. Our method successfully differentiates cancer cell-derived exosomes from healthy counterparts and predicts the ratio of specific exosomes in mixtures. This label-free approach opens new avenues for studying extracellular vesicles through spectroscopic fingerprinting of their intrinsic cargo. The technique could enable non-invasive disease detection and monitoring by analyzing exosomes in biofluids, particularly for tumor-derived exosomes. By bypassing exosome purification or labeling, it accelerates analysis and classification. Our study demonstrates the potential of combining spectroscopic profiling with machine learning for rapid, label-free characterization of exosomes and discovery of new biomarkers.

Microtubule Network Dynamics and Motor Protein Function: A Stochastic and Langevin Dynamics Perspective

Göker Arpağ

Department of Molecular Biology and Genetics, Kadir Has University, Istanbul, Turkey

keywords: microtubule dynamics, motor proteins, intracellular cargo transport

Microtubules are self-assembling polymers that establish a network of protein filaments within cells and are crucial for numerous essential cellular functions, including maintaining cell shape and facilitating chromosome segregation during cell division. The microtubule network is subject to dynamic reorganization and exhibits distinct architectural configurations depending on the cellular context. A critical function of microtubules is to serve as pathways for intracellular transport, a process mediated by motor proteins. The first part of the presentation will describe the dynamic behavior of microtubules and the regulatory mechanisms exerted by other proteins on microtubule dynamics. A stochastic model for microtubule dynamics will be introduced, and its application in guiding reconstitution experiments will be discussed. The second part of the presentation will focus on motor proteins that traverse microtubules to transport cellular cargoes. A model for cargo motion based on the Langevin dynamics approach will be described, and how this model can offer a deeper understanding of the fundamental mechanisms underlying intracellular transport will be discussed.

Information Transfer as an Evolutionary Feed for Emergence of Critical Brain Network

Kamyar Roudakian[1],
Alkan Kabakçıoğlu[1]

[1]Physics Department, Koç University, Turkey

The critical brain hypothesis is a theory in neuroscience that suggests that the brain operates near a critical point between stability and instability where quantities like information flow diverge. In this work, we explore the brain's functional robustness and how its critical behavior relies on the structural components of its network. We demonstrate that the critical behavior of the brain network is linked to its Laplacian spectrum. Furthermore, we show that the brain's architecture can be reconstructed using Laplacian-based information maximization rewiring steps, referred to as adaptive rewiring. Through adaptive rewirings, the brain network undergoes an entropic phase transition, which allows it to maximize its functional abilities. These findings suggest a profound connection between the brain's structural determinants and its operational efficacy at the edge of criticality.

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Harnessing Classical and Quantum Correlations: From Thermodynamic Laws to Enhanced Biochemical Processes

Onur Pusuluk

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keywords: quantum thermodynamics, strong correlations, non-equilibrium systems, generalized Onsager relations, generalized second laws

In this talk, we will begin by exploring how systems that are locally in thermal equilibrium can nevertheless remain globally out of equilibrium due to classical and quantum correlations. We will then demonstrate how these correlations can be integrated into reciprocal Onsager relations using a quantum master equation framework [1]. Next, our discussion will shift to extending the second law of thermodynamics to encompass processes that involve both the consumption and generation of classical and quantum correlations [2]. Building on the resulting majorization-based generalization, we will show how quantum correlations can enhance the efficiency of the photoisomerization process that underlies visual perception [3]. Finally, we will consider the broader role of correlations in driving non-equilibrium chemical and biological processes.

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MiniSymposia 2:
Synchronization Phenomena in Interacting Dynamical Systems: Theory and Applications

Organized by

Oleh Omel'chenko[1],
Christian Bick[2]

[1] Universität Potsdam, Germany
[2] Vrije Universiteit Amsterdam, Netherlands

Many systems relevant to our daily lives—ranging from transport networks to the human brain—consist of interacting dynamical units. How the dynamical units interact determines their collective behavior. Synchronization phenomena in coupled oscillators are one of the most striking examples of such collective behavior, which occur in various natural and man-made systems and underlie their normal or abnormal functioning. This minisymposium will bring together experts to discuss recent developments how to understand and control the collective dynamics of interacting dynamical systems in theory and applications.

Talks included:

- Interplay of synchronization and cortical input in models of brain networks, by Eckehard Schöll
- Pinning control of synchronized oscillatory networks: Stability hyperbolas and relocating influential nodes, by Istvan Z. Kiss
- Emergence of hypernetworks via higher-order phase reduction from weakly coupled oscillator networks, by Zeray Hagos Gebrezabher
- Control of synchronization due to ion conductance variations: A Pathway to Synchronization in Neuronal Networks, by Bruno R. R. Boaretto

Interplay of Synchronization and Cortical Input in Models of Brain Networks

Eckehard Schöll[1,2,3],
Jakub Sawicki[3]

[1]Institut für Theoretische Physik, Technische Universität Berlin, Germany
[2] Bernstein Center for Computational Neuroscience Berlin, Germany
[3] Potsdam Institute for Climate Impact Research, Germany

It is well known that synchronization patterns and coherence have a major role in the functioning of brain networks, both in pathological and in healthy states. In particular, in the perception of sound, one can observe an increase in coherence between the global dynamics in the network and the auditory input. In this work, we show that synchronization scenarios are determined by a fine interplay between network topology, the location of the input, and frequencies of these cortical input signals [1]. To this end, we analyze the influence of an external stimulation in a network of FitzHugh-Nagumo oscillators with empirically measured structural connectivity, and discuss different areas of cortical stimulation, including the auditory cortex.

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Pinning Control of Synchronized Oscillatory Networks: Stability Hyperbolas and Relocating Influential Nodes

Istvan Z. Kiss [1],
Jorge Luis Ocampo Espindola[1]
Bharat Singhal[2]
Jr-Shin Li[2]

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keywords: synchronization, pinning control, networks

The spatiotemporal organization of networks of dynamical units can break down resulting in diseases (e.g., in the brain) or large-scale malfunctions (e.g., power grid blackouts). Re-establishment of function then requires identification of the optimal intervention site from which the network behavior is most efficiently re-stabilized. Here we consider one such scenario with a network of units with synchronized oscillatory dynamics, which can be suppressed by stabilizing a single unit, i.e., pinning control. We analyze the stability of the network with hyperbolas in the control gain vs. coupling strength state space and identify the most influential node (MIN) as the node that requires the weakest coupling to stabilize the network in the limit of very strong control gain. A computationally efficient method, based on the Moore-Penrose pseudoinverse of the network Laplacian matrix, was found to be efficient in identifying the MIN. In addition, we have found that in some networks the MIN relocates when the control gain is changed, and thus different nodes are the most influential for weakly and strongly coupled networks. A control theoretic measure is proposed to identify networks with unique or relocating MINs. We have identified real-world networks with relocating MINs, such as social and power grid networks. The results were confirmed in experiments with networks of electrochemical reactions, where oscillations in the networks were effectively suppressed through the pinning of a single reaction site determined by the computational method.

Emergence of Hypernetworks via Higher-Order Phase Reduction from Weakly Coupled Oscillator Networks

Zeray Hagos Gebrezabher

Faculty of Engineering and Natural Science, Kadir Has University, Turkey

keywords: phase reduction, hypernetworks, averaging, Oscillator networks

In this talk, we aim to show a case where, although the dynamics in the network are purely pairwise, we reveal non-pairwise interaction terms due to the nonlinearity of the coupling functions. Because of its simplicity and generality, we focus on weakly and nonlinearly coupled Stuart-Landau oscillators on a graph. We consider the case where all oscillators have different frequencies, that is, the heterogeneous case. We derive a second-order phase reduction. This reduction provides phase models capturing the dynamics in the weak coupling regime. The method permits the systematic obtaining of higher-order corrections, overcoming the limitations of the first-order phase reduction. In a paper recently published in [1], the authors showed that sparse regression will obtain dynamics in normal forms. Motivated by this, we show the emergence of higher-order interactions from weakly and nonlinearly coupled Stuart-Landau oscillators on a ring via the averaging mechanism. Our theoretical results were also verified numerically using sparse recovery methods. This is part of my PhD work.

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Control of Synchronization Due to Ion Conductance Variations: A Pathway to Synchronization in Neuronal Networks

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keywords: Control of Synchronization, Ion Channel Conductances, Neuron Dynamics, Phase Synchronization, Hodgkin–Huxley Neural Network

The cooperative behavior, often referred to as phase synchronization, of neurons is fundamental for understanding the brain's complex behavior. Both a lack and an excess of synchronization can lead to neurological disorders such as Parkinson's disease, epilepsy, and autism. This synchronization phenomenon is closely linked to the regular or chaotic dynamics of individual neurons, which are determined by ion channel conductances. These conductances are crucial in the neuron-synchronized processes of depolarization and repolarization, and many diseases are associated with alterations in these conductance properties. To normalize their functioning, drugs can be used to block or activate specific channels, thereby modifying their conductances. In our study, we investigate the synchronization process in a Hodgkin–Huxley-type neural network as a function of individual neuron conductance values. Our findings show that neuron dynamics must be considered in the synchronization process. Specific conductance sets can lead to non-chaotic neuron dynamics, enabling synchronization at very weak coupling strengths and resulting in non- monotonic transitions to synchronized states as coupling strength varies. Conversely, chaotic neuron dynamics lead to monotonic synchronization transitions. By analyzing the dynamics of isolated neurons, we can predict the network's synchronization behavior. Moreover, we propose alternative strategies to achieve desired network states (either phase synchronized or desynchronized) by making small adjustments to neuron ion-channel conductances without altering synaptic currents. The control mechanism is based on the relationship between ion-channel conductance and neuron dynamics. We also demonstrate that simultaneous adjustments of at least two conductances can enhance control efficiency, with the second conductance facilitating synchronization through minimal changes to the first. These insights provide new avenues for theoretical studies of neural networks and may significantly impact drug development research aimed at modulating neural synchronization through precise control of ion-channel conductances.

MiniSymposia 3:
Control of Collective Dynamics and Partial Synchronization Patterns in Complex Networks
Organized by

Eckehard Schöll[1],
Ralph G. Andrzejak[2]

[1] Technische Universität Berlin & Potsdam Institute for Climate Impact Research (PIK) & Bernstein Center for Computational Neuroscience (BCCN)
[2]Universitat Pompeu Fabra

This minisymposium focusses on collective dynamics and partial synchronization patterns emerging in complex networks in nature and technology. They can be controlled by a subtle interplay of node dynamics, network topology, delay in the coupling, periodic forcing, and noise. An intriguing example are chimera states in networks of nonlinear oscillators which consist of spatially coexisting domains of coherent (synchronized) and incoherent (desynchronized) dynamics, i.e., seemingly incongruous parts. A plethora of chimera patterns arise if one considers the Kuramoto phase oscillator model, or more complicated coupled phase and amplitude dynamics, and various complex topologies like nonlocally coupled one-dimensional ring networks, small world or fractal connectivities, or multi-layer structures. For the FitzHugh-Nagumo system, the Van der Pol oscillator, the Stuart-Landau oscillator, and other dynamic models various chimera patterns including amplitude-mediated phase chimeras, amplitude chimeras, chimera death, coherence resonance chimeras, double chimeras, and solitary states occur. Applications are, for instance, power grids or pathological states in brain networks, like epileptic seizure and Parkinson's disease, or unihemispheric sleep, or cognitive functions (learning, memory) of the brain where certain areas act as relay. In particular in these applications to such real-world dynamics, a reliable quantitative assessment of partial synchronization from measured signals is important. A recent approach to this end is therefore presented in one of our presentations. Other contributions deal with Lévy noise enhanced chimera states and with crisis and extreme events in epidemics.

Talks included:

- Unbiased quantification of the degree of partial synchronization, by Ralph G. Andrzejak
- Lèvy noise controlled dynamics of neural networks, by Galina Strelkova
- Phase reduction explains chimera shape: When multi-body interaction matters, by Oleh Omel'chenko
- Targeting Cellular Bioelectrical Differences with Non-Thermal Systemic Electromagnetic Fields in the Human Body, by Frederico P. Costa

Unbiased Quantification of the Degree of Partial Synchronization

Ralph G. Andrzejak

Department of Information and Communication Technologies, Universitat Pompeu Fabra, Barcelona, Spain

The degree of partial synchronization in networks of coupled oscillators is often quantified using the Kuramoto order parameter, a measure originally introduced in circular statistics as mean resultant length. For full synchronization, the Kuramoto order parameter attains its upper bound of one. However, for completely desynchronized dynamics, the expected value of the Kuramoto order parameter achieves its lower bound of zero only as the number of network nodes tends to infinity. Moreover, as the expected value of the Kuramoto order parameter depends on the network size, bias is induced when comparing the Kuramoto order parameters of networks of different sizes.

In order to ameliorate this problem, we introduced a re-normalized version of the Kuramoto order parameter [1]. Regardless of the network size, the re-normalized measure has an expected value that is essentially zero for completely desynchronized dynamics, takes intermediate values for partially synchronized dynamics, and attains its upper bound of one for full synchronization. The re-normalized measure retains the simplicity of the original mean resultant length and is, therefore, easy to implement and compute.

We illustrate the relevance and effectiveness of the proposed re-normalized measure for mathematical models and electroencephalographic recordings of an epileptic seizure.

References

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Phase Reduction Explains Chimera Shape: When Multi-body Interaction Matters

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Erik Mau[1],
Michael Rosenblum[1]

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keywords: phase reduction, higher-order phase model, chimera state

We present an extension of the Kuramoto-Sakaguchi model for networks, deriving the second-order phase approximation for a paradigmatic model of oscillatory networks - an ensemble of nonidentical Stuart-Landau oscillators coupled pairwisely via an arbitrary adjacency matrix. We explicitly demonstrate how this matrix translates into the coupling structure in the phase equations. To illustrate the power of our approach and the crucial importance of high-order phase reduction, we tackle a trendy setup of non-locally coupled oscillators exhibiting a chimera state. We reveal that our second-order phase model reproduces the dependence of the chimera shape on the coupling strength that is not captured by the typically used first-order Kuramoto-like model.

Lèvy Noise Controlled Dynamics of Neural Networks

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Elena Rybalova[1]
Natalia Nikishina[1]

[1] Institute of Physics, Saratov State University, Russia

Any real-world system is permanently subjected to random perturbations. Along with the generally accepted negative effect of noise on the dynamics of such systems, noise can also play a counterintuitive constructive role. The impact of noise is crucial in neural networks since ensembles of millions of coupled neurons in the brain always operate in a noisy background or experience strong (sometimes extreme) noise perturbations, which can both sustain their operating regimes or completely destroy them. Such excitations are typical for the real environment and are well modeled by the Lévy distribution.

In the present contribution, we present and discuss numerical results on how additive Lévy noise influences the spatiotemporal dynamics of a neural network of nonlocally coupled FitzHugh–Nagumo oscillators. Without noise, the network can exhibit various partial or cluster synchronization patterns, such as chimera and solitary states, which can also coexist in the network for certain values of the control parameters. Our studies show that these structures demonstrate different responses to additive Lévy noise. It is revealed that in the multistability regime, when the chimera state, the solitary state, and the combined pattern coexist, increasing the scale parameter of Lévy noise can first induce the chimera state and then increase the probability of their observation up to 100%. At the same time, the solitary state is suppressed by even weak noise. The number of solitary nodes monotonically decreases as the scale parameter and the stability index of Lévy noise decrease.

Thus, it is established that introducing Lévy noise in the network of coupled FitzHugh–Nagumo neurons appears to be beneficial for chimera states and undesired (degrading) for solitary states. Our results indicate that the dynamics of neural networks, which exhibit complex spatiotemporal structures, including their coexistence, can be effectively controlled by varying the main parameters of the Lévy distribution.

We believe that our findings can be useful in both neuroscience and medicine by enabling neural networks to be brought into a desired dynamical regime by applying noise perturbations with a certain intensity.

Acknowledgments E.R. and G.S. acknowledge financial support from the Russian Science Foundation (project No. 20-12-00119, `https://rscf.ru/project/20-12-00119/`).

Targeting Cellular Bioelectrical Differences with Non-Thermal Systemic Electromagnetic Fields in the Human Body

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keywords: non-thermal, electromagnetic fields, radiofrequency, cancer treatment, cancer cells, oscillations, resonance, synchronization

A growing body of research suggests that cellular bioelectrical properties are key drivers of cell proliferation and cell synchronization. This has spurred the development of novel cancer therapies utilizing pulsed or alternating electric fields and time-variant electromagnetic fields, which exploit the unique electrical properties of cells, particularly cancerous ones. These cells demonstrate autonomous oscillations that differ from normal cellular rhythms, highlighting a distinct signaling system. Building on this, this presentation will discuss how a shift from a static view of cellular processes is required for a better understanding of the dynamic connections between cellular metabolism, gene expression, post-translational modifications, cell signaling, membrane polarization, organelle traffic and pattern formation as states in constant flux in realistic human models.

Clinically, radiofrequency electromagnetic fields have shown potential in treating various conditions such as pain, bone fractures, and inflammatory diseases, and have facilitated improved wound healing. Specifically in oncology, these fields have led to significant improvements in patient quality of life with minimal side effects, marking them as a promising new modality in cancer treatment. This presentation will detail how targeting cellular dynamics with non-thermal systemic radiofrequency electromagnetic fields can induce favorable therapeutic responses at both cellular and tissue levels. Supporting data from in-vitro cell cultures, in-vivo xenograft models, and clinical patient outcomes will be presented.

However, the exact mechanisms behind these experimental results remain undefined. Upcoming experiments, including DNA and RNA sequencing at both multiple and single-cell levels, will be discussed alongside potential techniques to demonstrate signal demodulation and synchronization in cancerous and normal tissues.

MiniSymposia 4:
Attractors of Random Dynamical Systems with Bounded Noise: A Control Theoretic Approach

Organized by

Konstantinos Kourliouros

Imperial College London, United Kingdom

In this minisymposium we propose a control theoretic approach to the study of (deterministic) attractors of random dynamical systems with bounded noise, ie. of dynamical systems (either of discrete or continuous time) subject to random perturbations of a fixed size (bounded noise). Under rather mild assumptions on the system, these attractors are exactly the supports of stationary probability measures of (the Markov process associated to) the system, and thus they are of central importance in the understanding of the compound behaviour of all solutions of the system, ie. under all possible noise realisations. In particular, we will show that in most meaningful cases, the boundaries of such attractors can be described by the projections (fronts) of certain invariant (Legendrian) submanifolds of a deterministic dynamical system (which we call the "boundary dynamical system"), steming from the Pontryagin's maximum principle for the time optimal control problem. This geometric approach allows us to detect the regularity properties (resp. singularities) of the boundaries of such attractors (equivalently, of the boundaries of invariant attainability sets for the associated control system), a formidable problem, even in dimension two. It also allows us to study the (structural) stability properties of such attractors, as well as their bifurcations (both theoretically as well as numerically). The minisymposium will consist of three main talks which will cover most of the material described above.

Talks included:

- Regularity of Boundaries of Attractors for Linear Differential Equations with Bounded Noise, by Michal Fedorowicz
- Bifurcations of the Hénon map with additive bounded noise, by Wei Hao Tey
- Geometric Theory of Random Dynamical Systems with Bounded Noise: Boundaries of Attractors and Pontryagin's Maximum Principle, by Konstantinos Kourliouros

Regularity of Boundaries of Attractors for Linear Differential Equations with Bounded Noise

Michal Fedorowicz[1],
Jeroen Lamb[1]
Martin Rasmussen[1]

[1] Department of Mathematics, Imperial College London, United Kingdom

keywords: linear dynamical systems, reachable sets, invariant manifolds

In this talk, we explore the regularity properties of boundaries of minimal invariant sets of linear differential equations subject to bounded noise. This is naturally viewed as a set valued dynamical system. However we show how to state this as a minimal time optimal control problem. Using this approach we derive a differential equation describing time optimal paths. Focusing on stable and unstable manifolds of equilibria within this system, we derive and analyze the smoothness of the minimal invariant sets. We demonstrate that for a specific class of linear systems, the boundaries of the attractors are at least C^2 smooth. Additionally, we show that the smoothness of these boundaries depends on eigenvalues of the matrix corresponding to a system without noise. Our findings provide new insights into the geometric structure of attractors of set valued systems and have potential applications in control theory and dynamical systems analysis.

Bifurcations of the Hénon Map with Additive Bounded Noise

Wei Hao Tey[1],
Jeroen S.W. Lamb[1],
Martin Rasmussen[1]

[1]Department of Mathematics, Imperial College London, United Kingdom

We perform a numerical study of bifurcations of attractors of the Hénon map with additive spherical bounded noise. The bifurcations are analysed using a novel finite-dimensional boundary map, which is used to compute boundaries of attractors. We distinguish between two types of bifurcations of attractors: topological bifurcations and boundary bifurcations. Topological bifurcations describe discontinuous changes of attractors, and boundary bifurcations occur when singularities of an attractor's boundary are created or destroyed.

Our numerical results reveal that topological bifurcations can correspond to saddle node bifurcations and the emergence of heteroclinic orbits in the boundary map. We also identify two types of boundary bifurcations: the appearance of an isolated wedge singularity, and the birth of an infinite cascade of wedge singularities converging towards a shallow singularity. These are related to local and global bifurcations in terms of stability type in the boundary map.

Geometric Theory of Random Dynamical Systems with Bounded Noise: Boundaries of Attractors and Pontryagin's Maximum Principle

Konstantinos Kourliouros

Department of Mathematics, Imperial College London, United Kingdom

In this introductory talk, I will set forth the first steps towards a geometric theory for the study of (deterministic) attractors of random dynamical systems with bounded noise, i.e., bounded random perturbations of diffeomorphisms or vector fields. These attractors (whose existence can be guaranteed under rather mild assumptions on the nature of the system) are certain compact regions in the state space, each supporting a unique stationary probability measure for the Markov process associated with the system, and they are thus of central importance in understanding the long-term behavior of its solutions.

It turns out, though, that the geometric and topological properties of these attractors, mostly reflected in the structure of their boundaries (e.g., regularity and singularity properties), as well as their stability under perturbations or their bifurcations under parameter variation, present a formidable task (even in dimension two), and almost nothing is known up to date. This is mostly due to the inherent infinite dimensionality of the problem, as well as the lack of a linear (Banach) space structure in the hyperspace of all compact subsets of the state space, where these attractors naturally live and are realized as minimal invariant subsets of an associated set-valued (semi-)flow.

Here, I will report on recent work with my collaborators on how to overcome this difficulty. Our approach is geometric, control theoretic in nature, and it relies on an appropriate Pontryagin symplectization (or better) contactization functor, applied to an underlying optimal control problem (that of "extremal" noise realizations), naturally associated with the random dynamical system under consideration. This functor allows us to reduce the problem to a finite-dimensional one, and in particular to a problem of symplectic (in fact, contact) geometry and Hamiltonian dynamics.

In particular, using an appropriate contact version of the Pontryagin Maximum Principle, we show that under certain regularity (transversality) conditions, the boundaries of such attractors can always be obtained as the projections (fronts) of certain invariant Legendrian submanifolds (possibly with singularities) of an associated Pontryagin Hamiltonian dynamical system, which we call the *boundary dynamical system*. Moreover, under further conditions (guaranteeing the sufficiency of the Maximum Principle for the associated optimal control problem), the converse also holds, i.e., any (possibly singular) invariant Legendrian submanifold of the boundary flow projects to the boundary of an attractor of the random dynamical system.

In the next two talks following this section, given by M. Fedorowicz and W. H. Tey respectively, it will be shown in explicit (generic) examples how the non-wandering set of the Pontryagin boundary flow completely determines the structure of the boundaries of the corresponding attractors, as the latter can be reconstructed by the projections of the invariant Legendrian submanifolds of the former (e.g., the unstable sets of its fixed or periodic points).

Acknowledgments This is a joint work in progress with M. Rasmussen, J. S. W. Lamb, W. H. Tey, M. Fedorowicz, and Dmitry Turaev, supported by the EPSRC grant EP/Y020669/1.

MiniSymposia 5:
Estimation and Optimization in Networks

Organized by

Tao Li[1]
Alexander Fradkov[2]

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The theme of the minisymposium is related to developing and justifying new methods and algorithms for estimation and optimization in complex networks based on machine learning, optimization and control with application to distributed control of complex mechatronic systems, power networks and biological neural network models. Contributions to the theory of distributed online cooperative regularized learning algorithms under uncertain environment from the perspective of distributed cooperation in the context of distributed energy management of large-scale smart energy systems, to establish a set of convergence analysis methods for large-scale distributed learning and optimization algorithms based on spatio-temporal mean field and adaptive mean field game theory with massive heterogeneous decision makers under uncertain environment and to design adaptive and robust methods of power grid control and biological neural networks parameter estimation.

Talks included:

- Asymptotic convergence of a continuous-time decentralized online estimation algorithm with the additive communication noise, by Xiaozheng Fu
- Parameter estimation of FitzHugh-Nagumo neural networks based on the speed-gradient and filtering, by Alexander Fradkov
- Adaptive parameter estimation for a class of neural mass models, by Sergei A. Plotnikov

Asymptotic Convergence of a Continuous-time Decentralized Online Estimation Algorithm with the Additive Communication Noise

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keywords: decentralized online estimation, stochastic differential equation, random time-varying coefficient

We study a continuous-time decentralized cooperative online estimation algorithm over the fixed digraph. Each node has a linear observation of an unknown fix parameter with Markovian switching observation matrices. Each node runs a continuous-time online estimation algorithm consisting of a innovation term processing the new measurement and a consensus term taking a weighted sum of its estimate and its neighbours' estimates with the additive communication noise. We transform the convergence of the algorithm into the asymptotic stability of linear stochastic differential equations (SDEs) with random time-varying coefficients. Firstly, we construct numerical approximate solutions of this kind of equations and prove the equivalence of the mean square asymptotic stabilities between the discrete-time numerical approximate solution (DTNAS) and the continuous-time numerical approximate solution (CTNAS) by using stochastic analysis techniques. Secondly, we prove the mean square asymptotic stability of the DTNAS is achieved if the drift coefficient satisfies some persistence of excitation condition and its conditional high-order moment is upper bounded, based on which, we give the mean square upper bound of the CTNAS and an estimate of the mean square upper bound of the difference between the true solution and the CTNAS. Finally, we derive sufficient conditions for the mean square asymptotic stability of the true solution. Especially, we show that if the drift and diffusion coefficients are $\mathcal{O}\left(1/(t+1)^{\frac{1}{2}+\varepsilon_1}\right)$ and $\mathcal{O}\left(1/(t+1)^{\frac{1}{2}+\varepsilon_2}\right)$, respectively, and the drift coefficient satisfies some persistence of excitation condition, then the mean square asymptotic stability of the true solution is achieved. Furthermore, for a special case where the drift coefficient contains a Markov chain, we show that the mean square asymptotic stability of the true solution is achieved if the Markov chain is strongly 1-exponentially ergodic with the unique stationary distribution. By the above methods, we show that the mean square convergence of the continuous-time decentralized cooperative online estimation algorithm can be achieved.

Parameter Estimation of FitzHugh-Nagumo Neural Networks Based on the Speed-Gradient and Filtering

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In recent years, methods based on mathematical and computer modeling have become widespread in neurobiology. However, it requires the availability of information about parameters and state variable values, which are typically unmeasured. The problem becomes even more challenging when it is necessary to model not just individual neurons but entire neural networks, the use of which opens up new opportunities for the study of complex neural processes. In this paper the model of neural network composed from the diffusively connected single neuron FitzHugh-Nagumo models is considered. The FitzHugh-Nagumo model is a second-order nonlinear dynamical system and it is widely used in neuroscience due to its simplicity and generality. The problem is to estimate (identify) the parameters of this network under rough but realistic conditions of unmeasurability of one of the variables and both derivatives of the FitzHugh-Nagumo models. Moreover, we assume that the only one measured signal, namely, the membrane potential, is imprecise and has some unknown scaling factor. To solve this problem the FitzHugh-Nagumo network model is transformed to linear regression using second-order filter (real double-differentiator). All the variables are measured in this regression and its parameters consist of the FitzHugh-Nagumo model parameters, i.e. they are meant to be estimated. To this end, the speed-gradient method is employed. The correctness of the obtained solution is proved theoretically and illustrated by computer simulation in the Simulink environment. The sufficient conditions of asymptotically correct identification for the speed-gradient method with integral objective function are obtained. The key achievements of this paper is operating with the arbitrarily large neural network model in the most general case of diffusive connections. This approach opens up wide perspectives for modeling of complex processes in the human brain. For example, it may be applied for setting up the FitzHugh-Nagumo based mathematical network model to real EEG data.

Adaptive Parameter Estimation for a Class of Neural Mass Models

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keywords: adaptive parameter estimator, neural mass model, Lyapunov function method

In this paper the problem of designing a mathematical model to describe neural activity is considered. This problem is complex due to poor knowledge of the brain and lack of information available. To describe the electrical activity of the brain, various models of neural ensembles are used, one of which is the neural mass model proposed by Jansen and Rit in 1995.

To adjust the parameters of this model according to real data, it is proposed to use an adaptive parameter estimator (adaptive observer). An important condition for the synthesis of an adaptive observer is that only the system output, which is the potential difference between two points on the head, can be measured.

Initially, it is assumed that the entire state vector of the neural mass model is available for measurement. An identifier is synthesized to adjust the parameters of such a system, and its convergence is proved using the Lyapunov function method. Further, the obtained estimator is refined so that it uses only the output of the system. To do this, using the finite difference method, the output derivative of the neural mass model is approximately calculated. This derivative is used to make several replacements of unknown components of the state vector.

It is difficult to prove the convergence of the obtained adaptive parameter estimator analytically. Therefore, the possibility of using it to estimate the parameters of a neural mass model was checked using simulation. The synthesized estimator uses only the system output to tune the parameters. In the future, this will allow us to consider real data instead of the system output. Thus, this estimator can be used to tune the parameters of the neural mass model based on real data. The results can be extended to a class of neural mass networks modeled as in the paper "Dynamic causal modelling of induced responses" by C.C. Chen, S.J. Kiebel, and K.J. Friston, NeuroImage 41 (2008) 1293–1312.

Contributed Talks

Synchronization Conditions of Disturbed Nonlinear Dynamical Networks with Delayed Coupling Based on Passification Method

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keywords: synchronization of networks, passification method, nonlinear systems, time-varying delays, disturbances

The numerous studies of synchronization in networked systems have created a wide interdisciplinary area that encompasses various scientific fields and their applications [1,2]. Such systems include industrial, electrical, and manufacturing networks, robot networks, and various biological network systems. These systems often exhibit complex behavior: they are nonlinear, have time delays due to communication constraints between network nodes, and can be affected by disturbances of different natures. Therefore, the analysis of such systems needs to account for these behaviors and the uncertainties arising from them.

This paper is devoted to the approximate asymptotic synchronization of disturbed nonlinear networked dynamical systems with delayed coupling. Our analysis is based on passification theorems, the Agaev-Chebotarev theorem, and the improved Lyapunov-Krasovskii functional [4-6]. Numerical examples for a network of 100 interconnected FitzHugh-Nagumo models are presented to demonstrate the efficiency of the proposed approach [3].

This work was carried out at the Institute for Problems of Mechanical Engineering under support by the Russian Science Foundation (Project No. 23-41-00060).

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Stabilization of Nonlinear Mechanical Systems via Delayed Feedback

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The stabilization problem for nonlinear mechanical systems is studied. Using the Lyapunov direct method, conditions are derived under which a control with delayed feedback provides the asymptotic stability of the considered systems.

Let motions of a mechanical system be modeled by the equations

$$\frac{d}{dt}\frac{\partial T}{\partial \dot{q}} - \frac{\partial T}{\partial q} = -B\dot{q}(t) - G(q(t)) - \int_0^t D(t-s)\tilde{G}(q(s))\,ds. \tag{1}$$

Here $q(t), \dot{q}(t) \in \mathbb{R}^n$ are vectors of generalized coordinates and generalized velocities, respectively, $T = \dot{q}^\top A(q)\dot{q}$ is the kinetic energy of the system, the matrix $A(q)$ is continuously differentiable for $q \in \mathbb{R}^n$, B is a constant symmetric positive definite matrix, $G(q)$ and $G_e(q)$ are continuous for $q \in \mathbb{R}^n$ vector functions, and $D(\theta)$ is a continuous matrix for $\theta \geq 0$.

Assume that the estimates

$$b_1\|\dot{q}\|^2 \leq T \leq b_2\|\dot{q}\|^2, \qquad \left\|\frac{\partial T}{\partial q}\right\| \leq b_3\|\dot{q}\|^2, \qquad \left\|\frac{\partial T}{\partial \dot{q}}\right\| \leq b_4\|\dot{q}\|$$

hold for $q, \dot{q} \in \mathbb{R}^n$, where b_1, b_2, b_3, b_4 are positive constants and $\|\cdot\|$ is the Euclidean norm of a vector. Moreover, we consider the case where components of the vectors $G(q)$ and $G_e(q)$ are homogeneous functions of degree $\nu > 1$ with respect to the standard dilation. Thus, a holonomic mechanical system with linear dissipative forces and nonlinear homogeneous positional forces is studied.

Control System Interpretation. The system (1) can be interpreted as a closed-loop control system with a PID controller [1,2]. Application of PID controllers is a powerful tool for stabilization of mechanical systems. However, it is worth noticing that a general satisfactory theory and a general approach that can provide explicit design formulae for PID parameters are still lacking [3].

The system (1) admits the equilibrium position

$$q = \dot{q} = 0. \tag{2}$$

Our objective is to determine conditions ensuring the asymptotic stability of the equilibrium position (2). To solve this problem, we will use the Lyapunov direct method. It should be noted that in [4,5] special approaches to constructing complete-type Lyapunov–Krasovskii functionals for homogeneous systems with constant and distributed delays were proposed. In this work, we will extend these approaches to the system (1) with unbounded delay.

Results. We will show that, with the aid of the constructed functionals, not only new asymptotic stability conditions but also estimates for the convergence rate of solutions to the equilibrium position (2) can be obtained. Moreover, it is worth mentioning that the asymptotic stability conditions derived for the nonlinear system (1) are formulated in a more constructive and less conservative form compared with known asymptotic stability conditions for linear systems.

Furthermore, we will apply the developed approach to a problem of attitude stabilization of a rigid body. This research was supported by the Russian Science Foundation, project No. 24-21-00091.

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On Asymptotic Properties of Indirect Control Systems with Periodic Nonlinearities

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keywords: synchronization system, gradient-like behavior, high-frequency oscillations, frequency-domain conditions

In this paper we continue to the investigate the asymptotic behavior of a class of indirect control systems with distributed parameters. The systems examined can be represented as feedback interconnections of stable time-invariant linear block and periodic nonlinearity. They are described by integral-differential Volterra equations. They are featured by a denumerable set of equilibriums, both locally stable and unstable ones. Such systems are often called synchronization or pendulum-like systems as they include the models of phase-locked loops and the mathematical pendulum. We traditionally use Popov method of a priori integral indices. So the theorems are formulated in terms of the transfer function of the linear block and have the form of frequency-domain inequalities.

The main problem with synchronization systems is the convergence of solutions. In this paper we present novel frequency-domain conditions which guarantee the gradient-like behavior of the system, i.e. the convergence of its every solution to a certain equilibrium. Those new stability conditions have been generated by constructing the optimal Popov functional in the class of differentiable periodic nonlinearities. New frequency-domain conditions are exploited also to obtain the estimate of the distance between the limit equilibrium and the initial value of a solution, which gives the opportunity to get a constructive estimate for the number of slipped cycles.

If the system is not gradient-like it may have periodic orbits. We show that in case the frequency-domain conditions are fulfilled for the subinterval of frequencies, the system has no high-frequency oscillations. The frequency-domain conditions have been applied to phase-locked loops with the proportional-integrating filter and the sine-shaped detector in the case of positive time delays. The explicit estimates for the domains without preassigned large frequencies have been established.

Dissipativity and Turnpike Property in a Controlled Stochastic Lotka-Volterra Model with Lévy Jumps

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keywords: Lotka-Volterra model, stochastic optimal control, maximum stochastic principle, Lévy jumps, dissipativity

We consider a controlled stochastic Lotka-Volterra model for one- predator-two-prey with Lévy jumps. We study an optimal control problem for this model and the stability of its solutions. We discuss a type of stability for state trajectories, optimal control, and adjoint trajectories, called the turnpike property. The Turnpike property of a solution of an optimal control problem means that an optimal trajectory for most of the time could stay in a neighborhood of a balanced equilibrium path, corresponding to the optimal steady-state solution. Assuming linear growth and Lipschitz conditions in the drift and diffusion terms, applying the algebraic Riccati theory and the Stochastic Maximum Principle, we express the optimal control in terms of the Lévy process and state and adjoint variables and we prove the turnpike property. In addition, we introduce the definition of dissipativity for general stochastic systems and we prove the connections between dissipativity and turnpike property for our controlled stochastic Lotka-Volterra model with Lévy jumps. We illustrate our results performing a simulation to numerically solving the systems of stochastic differential equations, which to show that the Turnpike property is indeed satisfied for our model.

Chain Control of Nonstationary Networks Plant

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A chain control system for nonstationary network agents under uncertainty is proposed. The auxiliary loop method is applied to the chain plant. The output signal of the preceding agent is fed to the input of the subsequent agent. The signal from the leading agent goes only to the initial agent. Thus, the output signal of each agent is a synchronising signal for the subsequent agent. Perturbation compensation is performed by introducing an auxiliary loop and two Khalil observers. The obtained control laws in each of the agents of the chain ensure the achievability of the control objective with the required dynamic accuracy. The proposed control is applied to a network plant consisting of multiple agents. The modelling is performed in Matlab Simulink. The tracking error transients for each of the agents in the network are presented. The simulation results confirm the theoretical conclusions and show the effectiveness of the proposed chain control system under uncertainty.

Breathers Propagation in the Granular Locally-resonant Chains

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keywords: Granular locally resonant chains, breathers, anti-resonance

Today, the design of new metamaterials and the study of their properties is an urgent task, since the structures obtained with their help have extensive areas of application. In this work, a model of granular locally resonant metamaterial on a substrate is investigated. The talk addresses breathers propagation in the quasi-one dimensional model of locally-resonant granular lattice metamaterial on the substrate. The model is presented as one-dimensional mass-in-mass chain with hertzian type of nearest neighbor interaction and linear coupling with the inner elements. In the case of impact excitation on the side of the chain we demonstrate the formation of the breathers. We consider two types of traveling breathers and detect their existence in a wide range of system parameters. We report that the breathers propagation is accompanied by energy radiation to the oscillatory tails. We present asymptotic analysis of the propagation, formulate the criteria for the absence of the breathers energy loss. The outer granules of the system are located on a solid substrate, and the strength of their elastic interaction is linearly dependent on displacement, so the substrate is represented by an elastic spring with linear stiffness coefficient. The interaction of the outer granules with the corresponding internal granules is also linear. We can describe the dynamics of the resulting system using Newton's second law: $p = \frac{3}{2}$

$$\begin{cases} M\ddot{u}_n = k_1(u_{n-1} - u_n)_+^p - k_1(u_n - u_{n+1})_+^p - k_2 u_n - k_3(u_n - v_n) \\ m\ddot{v}_n = k_3(u_n - v_n) \end{cases} \tag{0.1}$$

where: u_n and v_n are the displacements of the n-th inner and outher elements of the chain; $p = \frac{3}{2}$, M, m are the masses of internal to outer granules, respectively; k_1 – coefficient of interaction of external granules with each other; k_2 – coefficient of interaction of external granules with the substrate; k_3 – coefficient of interaction of external masses with internal elements. The "+" sign means multiplication by the Heaviside function, which defines the absence of attraction between the elements.

It is well-known that the main energy carriers in granular AMMs are nonlinear waves [1], for a one-dimensional granular chain with internal resonators, these are breathers [2], localized nonlinear waves with an internal degree of freedom. One-dimensional granular chain of the mass-in-mass type without a substrate has been well studied, the existence of stable breathers is proved [3]. However, when a substrate is added, breathers become long-lived, as they radiate energy into the oscillating tail.

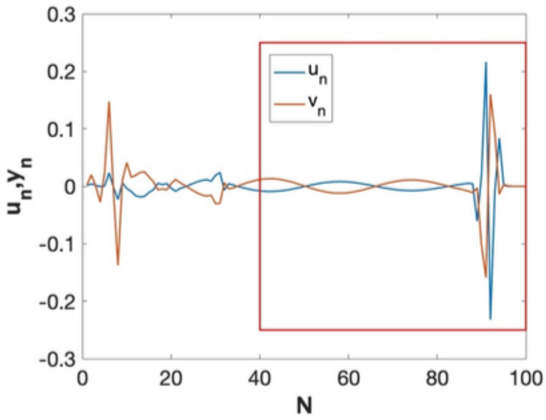

Fig 1. Space-profile for outer and inner elements of the chain. The velocities of outer (blue) and inner (orange) elements are shon by blue and orange respectively.

The system of equations (0.1) was solved numerically with initial conditions in the form of impact loading on one of the ends of the chain. Depending on the parameters of the system, it is possible to obtain solutions with in-phase and anti-phase dynamics of the inner and outer masses. Fig. 1 shows the spatial profiles of the outer (blue) and inner (orange) elements for the case of out-of-phase breathers. It can be seen that the breather moves along the chain with almost stationary amplitude and shape at a certain speed, and an oscillating tail spreads behind it.

Using travelling wave approximation and discrete discrete Fourier transform of the equations of motion, we obtain an integral equation. It is used to obtain an anti-resonant condition on parameters of the system, which allows to avoid the propagation of the oscillatory tails in the chain.

In conclusion, we note that the anti-resonant conditions allow to find the physical parameters of the locally resonant granular chain on the substrate when the travelling breathers do not radiate energy into oscillatory tail, i.e. they can propagate without energy loss.

The work was supported by the Russian Science Foundation (Grant No 24-23-00435).

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Regimes of Global Oscillations Induced by Discrete Synaptic Events in Balanced Neural Networks

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Neural dynamics is triggered by discrete synaptic events. Nonetheless, the neural response is usually obtained within the theoretical framework of the diffusion approximation representing the synaptic inputs as "continuous" white Gaussian noise. We present a mean-field formalism encompassing synaptic shot-noise for sparse balanced networks of quadratic integrate-and-fire neurons. For low (high) excitatory drive (inhibitory feedback) global oscillations emerge via continuous or hysteretic transitions, correctly predicted by our approach, but not from the diffusive approximation. Specifically, for the diffusive approximation, the transition is always continuous and exists for any positive value of the excitatory drive current; the critical value of in-degree grows to infinity as the excitatory drive current tends to zero. On the contrary, for the shot-noise mean-field formalism, the transition becomes hysteretic at small values of excitatory drive current; at even smaller excitatory current, one observes the "reentrance" of global oscillations for sparse networks below some critical value of the in-degree (in range 10-150); with further decrease of the current, one observes no stable asynchronous regime, here only global oscillations are possible (while the diffusive approximation not only suggests the presence of a stable asynchronous state, but also the unbound growth of the critical value of the in- degree required to observe the global oscillations). The theoretical predictions of the mean-field theory are underpinned with the results of direct numerical simulation for large finite networks. At sufficiently low in-degrees the nature of the global oscillations changes from drift-driven to cluster activation. The work was carried out as part of a major scientific project (Agreement No. 075-15-2024-535 by 23 April 2024).

Dynamics Peculiarities of Three Coupled Hodgkin-Huxley Neurons

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Currently, the representation of natural objects and phenomena as network elements is a widely used method that has proven itself in many areas of research [1-3]. Such an approach allows one to identify prominent properties of the objects under study and predict their behavior. One of the most obvious examples of objects that can be naturally represented as a network is the nervous system of a living organism. Numerical modeling becomes useful for studying such complex small-scale systems because, despite modern methods of studying the brain, technological difficulties can still hinder obtaining data from living organisms.

Thus, the present study focuses on the dynamics of three coupled Hodgkin-Huxley neurons. The system under study is determined by the following system of equations:

$$\begin{aligned}
\frac{dV_i}{dt} &= \frac{1}{C_m}\left(\overline{g}_K n_i^4(V_i - V_K) + \overline{g}_{Na} m_i^3 h_i (V_i - V_{Na}) + \overline{g}_l (V_i - V_l) + I_{\text{ext}}\right) + \sum_{j=0, j\neq i}^{N} w_{ij}(V_j - V_i), \\
\frac{dn_i}{dt} &= \alpha_{n_i}(V_i)(1 - n_i) - \beta_{n_i}(V_i) n_i, \\
\frac{dm_i}{dt} &= \alpha_{m_i}(V_i)(1 - m_i) - \beta_{m_i}(V_i) m_i, \\
\frac{dh_i}{dt} &= \alpha_{h_i}(V_i)(1 - h_i) - \beta_{h_i}(V_i) h_i.
\end{aligned} \tag{0.1}$$

System (0.1) describes three Hodgkin-Huxley neurons ($N = 3$) connected by a linear electrical coupling. The purpose of the study was to find out the influence of the coupling strength between the neurons and the individual characteristics of the neurons themselves, namely the initial conditions V_0 and external current values I_{ext}. To assess the degree of synchrony between neuron pairs, the Pearson correlation coefficient [4] is calculated:

$$\rho = \frac{\sum(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum(x_i - \overline{x})^2 \sum(y_i - \overline{y})^2}} \tag{0.2}$$

During the research, several coupling topologies were studied. Additionally, values of initial conditions, coupling strength, and external current values that allow the system to be synchronized in different regimes were defined. Regime maps were plotted for clarity.

Acknowledgments T.B. acknowledges financial support from the Ideas Research Centre (project no. ASP-09-2021/I).

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Uninterrupted Motion of Molecular Wheels on Cu Metal Surfaces

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keywords: Triptycene-based molecules, molecular motions, metal substrates

Recent developments in molecular motions on metal surfaces present a promising path for developing molecular-level devices. The critical factors for practical applications of these devices are the atomic-scale control of the motion and handling the temperature-driven instabilities in the system. In this work, we present the results of molecular dynamic simulations on the motion of wheel dimer molecules on corrugated Cu(110) and Cu(511) surfaces. We found that the perfect metal substrates for the uninterrupted rolling of triptycene-based molecular wheels are the regularly stepped surfaces, providing the pivot points along the motion and the space needed for stabilizing the molecule at high temperatures. In addition to the substrate-dependent factors, intermittent application of the external electric field is needed to control the molecule's motion on a metal-stepped surface.

Mathematical Models of System of Control of Pressure Variation in Combustion Chambers of Engines

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The system of control over the change of working medium pressure in the engine combustion chamber presented in Fig. 1 is considered. In the system, the sensor is located at some distance from the engine and connected to it by means of a pipeline, which makes it possible to mitigate the effects of temperatures and vibration accelerations. The system contains a pipeline 2 of length l and width H connecting the pressure sensor 3 to the combustion chamber 1. At one end of the pipeline ($x = -l$), fixed at the outlet of the engine combustion chamber, the pressure of the working medium 4 changes over time. At the other end of the pipeline is a sensing element 5 ($x \in [0, h]$) of a sensor designed to measure this pressure. The sensitive element of the sensor for measuring the pressure of the working medium in the combustion chamber of an aircraft engine is an elastic plate of length H and thickness h.

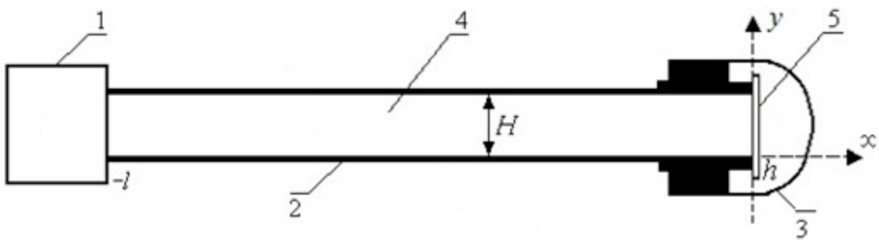

Fig 1. Pipe with sensor

The motion of the working medium in the pipeline is described by differential equations for the velocity potential $\Phi(x, y, t)$:

– in a compressible medium model:

$$\Phi_{tt} + 2\Phi_x\Phi_{xt} + 2\Phi_y\Phi_{yt} + \Phi_x^2\Phi_{xx} + \Phi_y^2\Phi_{yy} + 2\Phi_x\Phi_y\Phi_{xy} =$$

$$= \left[a_0^2 - (\gamma - 1)\left(\Phi_t + \frac{1}{2}\Phi_x^2 + \frac{1}{2}\Phi_y^2\right)\right](\Phi_{xx} + \Phi_{yy}), \quad x \in (-l, 0), \quad y \in (0, H), \ (0.1)$$

– in the incompressible medium model:

$$\Phi_{xx} + \Phi_{yy} = 0, \quad x \in (-l, 0), \quad y \in (0, H). \tag{0.2}$$

Conditions of non-leakage of the pipeline walls $y = 0$, $y = H$ and surface of the elastic element $g(x, y, t) = 0$, which is a part of the pressure sensor, respectively, have the form:

$$\Phi_y(x, 0, t) = \Phi_y(x, H, t) = 0, \quad x \in (-l, 0), \tag{0.3}$$

$$\Phi_x g_x + \Phi_y g_y = -g_t, \quad g(x, y, t) = 0, \;\; y \in (0, H). \tag{0.4}$$

At the outlet of the engine combustion chamber there is a pressure change $P_*(y, t)$ of the working medium:

$$P(-l, y, t) = P_*(y, t), \quad y \in (0, H). \tag{0.5}$$

The dynamics of the elastic element is described by the equation for the deformation of the elastic element of the sensor $w(y, t)$:

$$L(w(y, t)) = P(w(y, t), y, t) - \tilde{P}, \quad y \in (0, H), \tag{0.6}$$

where the pressure $P(x, y, t)$ is defined by the formula $P = P_0 - \rho_0(\Phi_t + \frac{1}{2}\Phi_x^2 + \frac{1}{2}\Phi_y^2)$ for an incompressible medium, and the formula $P = P_0 \left[1 - \frac{\gamma - 1}{a_0^2}\left(\Phi_t + \frac{1}{2}\Phi_x^2 + \frac{1}{2}\Phi_y^2)\right)\right]^{\frac{\gamma}{\gamma - 1}}$ for a compressible medium, and P_0, γ, ρ_0, a_0, $\tilde{P}$ are some physical constants.

To determine the thermal field in the system we have the following boundary value problem:

$$\rho_1 c_1 T_{1t} = k_1 T_{1xx} - \beta(T_1 - T_0), \tag{0.7}$$

$$T_1(-l, t) = T_*(t), \tag{0.8}$$

$$T_{1x}(0, t) = 0, \tag{0.9}$$

$$\rho_2 c_2 T_{2t} = k_2 T_{2xx}, \tag{0.10}$$

$$T_{2x}(h, t) = 0, \tag{0.11}$$

$$-k_2 T_{2x}(0, t) = \alpha(T_1 - T_2)_{x=0}. \tag{0.12}$$

Here $T_1(x, t)$ is the temperature distribution of the working medium along the length of the pipeline ($x \in (-l, 0)$); $T_2(x, t)$ is the temperature distribution along the cross-section of the elastic element of the sensor ($x \in (0, h)$); $T_*(t)$ is the law of temperature change at the inlet to the pipeline ($x = -l$); T_0 is the ambient temperature; ρ_1, ρ_2, c_1, c_2, k_1, k_2, β, α are some physical constants.

To describe the dynamics of an elastic element (deformable plate), linear and nonlinear mathematical models of a solid deformable body are used, for example

$$L\left(w(y, t)\right) \equiv M w_{tt} + D w_{yyyy} + N(t) w_{yy} + \gamma w + \beta_1 w_t + \beta_2 w_{yyyyt}; \tag{0.13}$$

$$L\left(w(y, t)\right) \equiv M w_{tt} + D w_{yyyy} + N(t) w_{yy} + \gamma w + \beta_1 w_t + \beta_2 w_{yyyyt} -$$
$$- w_{yy}\left(\mu \int_0^H w_y^2 dy + \eta \left(\int_0^H w_y^2 dy\right)_t\right); \tag{0.14}$$

$$L\left(w(y,t)\right) \equiv M w_{tt} + \left[D w_{yy}\left(1-\frac{3}{2}w_y^2\right)\right]_{yy} + N(t)w_{yy} + \gamma w + \beta_1 w_t + \beta_2 w_{yyyyt}; \quad (0.15)$$

$$L\left(w(y,t)\right) \equiv M w_{tt} + \left[D w_{yy}\left(1-\frac{3}{2}w_y^2\right)\right]_{yy} + N(t)w_{yy} + \gamma w + \beta_1 w_t +$$
$$+\beta_2 \left[w_{yy}\left(1-\frac{3}{2}w_y^2\right)\right]_{yyt}. \quad (0.16)$$

Assume that the ends of the plate are rigidly fixed and the temperature of the plate $T_2(x,t)$ is variable, then

$$w(0,t) = w_y(0,t) = 0, \quad w(H,t) = w_y(H,t) = 0, \quad N(t) = N_0 + \frac{E\alpha_T}{1-\nu}\int_0^h T_2(x,t)\,dx. \quad (0.17)$$

Here the coefficients M, D, E, ν, $N(t)$, N_0, γ, β_1, β_2, η, μ, α_T are the parameters of the mechanical system. The operator (0.14) takes into account the nonlinearity of the longitudinal force resulting from the elongation of the plate due to its deformation; the operator (0.15) takes into account the nonlinearity of the bending moment; the operator (0.16) refines the operator (0.15) in the case of taking into account the nonlinearity of the plate damping.

Numerical-analytical methods of solution are proposed for the considered initial boundary value problems. In particular, on the basis of the small parameter method, the asymptotic equations describing the joint dynamics of the working medium in the pipeline and the deformable element of the sensor are obtained, and then, using the Galerkin method, the solution of the obtained problems is reduced to the study of systems of ordinary differential equations, for which numerical experiments in Mathematica 12.0 for specific parameters of the mechanical system are performed.

The work was supported by a grant from the Russian Science Foundation №23-21-00517.

Effective Feedback Control Algorithms for Nitrogen-Vacancy-Cavity Quantum Sensing

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keywords: Nitrogen-vacancy-cavity system, Tavis–Cummings model, fidelity, Fisher parameter, feedback tracking

Ultrasensitive quantum detection of external weak signals at the nanoscale levels can be implemented in a variety of forms, preserving quantum coherence. Here we discuss the sensing scenario based on the semi-classical Tavis–Cummings model for N nitrogen vacancy (NV) centers located in the diamond. In the frame of this model, the sensing elements are considered as non-interacting two-level quantum systems, distributed inhomogeneously due to heterogeneous local magnetic and strain environments.

The dynamical system of ordinary differential equations corresponding to the model contains the set of control parameters: the detunings between the drive frequency and the cavity frequency and between the drive frequency and NV transition frequency, as well as the coefficients of the intrinsic relaxation rate, and of the coupling strength to a microwave probe line. Correspondingly, it opens a gate for developing feedback control algorithms for tracking the cavity field, the income signal, and the reflection signal in the model sensing system. The criteria of efficient tracking can be based on different system characteristics: fidelity or Fisher parameter.

Here we investigate alternative schemes of feedback (gradient methods, target attractor methods) to compare their pros and cons for effective control for nitrogen-vacancy-cavity quantum sensing based on different choices of the control parameter set. We also discus possible experimental implementations of the proposed model.

This work was supported by the Research Fund of Abdullah Gül University; Project Number: BAP FBA-2023-176 'Geribesleme kontrol algoritmaları ile kubit tabanlı sensörlerin verimliliğinin artırılması'.

Flutter of the Transition Process of the Hereditary Deformable Elongated Plate

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keywords: flutter phenomena, gas flow, elongated plate, elongated plate, transient process

The work considers the flutter of the transient process of a hereditarily deformable elongated plate. We assume that the plate is flown around, on the one hand, by a supersonic gas flow characterized by speed V. Geometrically nonlinear equations are taken as the initial dependencies, taking into account linear and nonlinear aerodynamic loads. The solution to a nonlinear integro-differential system of equations was obtained using the Rzhanitsyn–Koltunov kernel within a wide range of changes in the physical and mechanical parameters of an elongated plate with a numerical method based on a new approach of analytical transformations, which allows one to effectively calculate the weakly singular integral using quadrature formulas.

Computational experiments have shown that the influence of the damping parameter in the heredity kernel on the critical flutter speed in comparison with the viscosity and singularity parameters turned out to be insignificant, which once again confirms the well-known conclusions: the exponential relaxation kernel is unable to fully describe the hereditary properties of the construction material. Based on numerical results, it has been established that taking into account the hereditary deformable properties of the material in some cases leads to an almost 2.5-fold decrease in the critical velocity of the plate and a 1.7-fold increase in the critical flutter time.

Analysis of Controllability of Multiagent Singular Linear Systems Representing Brain Neural Networks.

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Broadly speaking, linear Hamiltonian systems are a type of systems of mathematical equations that describe the evolution of physical systems and are characterized by the existence of a symplectic structure on a differentiable manifold of even dimension. More specifically, linear Hamiltonian systems are linear differential equations represented by Hamiltonian matrices whose eigenvalues are located symmetrically in the complex plane concerning the real and imaginary axes. For this type of system, linear algebra is the cornerstone of many results that can be obtained. Linear Hamiltonian models are useful in several areas where linear approximations are appropriate. Some examples include harmonic oscillators, electrical circuits, or quantum systems. The control of Hamiltonian systems, a topic that has recently sparked significant interest and attention among researchers, holds promise for a wide range of applications. From practical engineering solutions to theoretical breakthroughs in physics and mathematics, the implications of this research are far-reaching and exciting. Controllability denotes the ability to move a system throughout its configuration space using only specific admissible manipulations. A switched linear Hamiltonian system is a system consisting of several linear Hamiltonian subsystems and a rule that organizes the switching between them. These systems are useful for representing complex behaviors of physical systems that interact with logical rules or controllers. Controllability analysis in switched systems has recently received some attention; Constructing a system formed by the combination of linear subsystems with a good interrelation law can achieve better performance than a single linear system, or certain control objectives that cannot be achieved by a single system can be achieved. Controllability analysis of switched linear systems is much more difficult because you must determine the control input and the switching rule. In this work the important and challenging controllability problem of switched linear Hamiltonian systems is considered. The problem is to find a control signal that drives any initial condition to a given final state, independently of the switching signal. The human brain can be mathematically understood as a linear dynamical system that transitions through various cognitive regions, facilitating varying complex behaviors. The brain's Neural network dynamics play a considerable role in cognitive function, so that is of interest to understand the learning processes and the evolution of possible disorders. In this work, the analysis of singular linear systems that represent brain neural networks is used to understand the complexity of the human brain. In this context, the digraph approach emerges as a powerful tool to unravel the intricate webs of neural interconnections. Digraphs, or directed graphs, offer an intuitive visual representation of the causal and influential relationships between different neural units, allowing a detailed analysis of the network dynamics. In this work, we will explore the digraph approach to analyzing singular linear multi-agent systems that model brain neural networks, highlighting its relevance and potential for advancing our understanding of cognition and brain function.

Assessing the Irregularity of Multidimensional Biological Recordings

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Modern biological recordings, such as EEG, MEG, or local field potentials (LFPs), provide physiological data of high spatial and temporal definitions. The temporal component of the data may exhibit either a high amplitude periodic activity or a complex, highly entangled dynamic. Such states usually change intermittently, affecting the spatial locations of oscillations, and represent the information processing occurring in neuronal circuits generating behaviors [1].

The standard assessment of such high-definition spatiotemporal data involves studying the frequency content of the oscillations (amplitude and sometimes phase), paying particular attention to high-amplitude events strongly localized in the frequency or time domains. However, most recordings exhibit dynamics strongly diffused over time scales, space, and time intervals, presenting a complex challenge in accurately characterizing these spatiotemporal dynamics and understanding their origin in the synchronization-desynchronization of neuronal circuits [2].

Taking LFPs as an example, we show that multisite recordings made in the rat hippocampus can be separated by independent component analysis into the activity of several generators. These LFP generators correspond to upstream neuronal populations [3], which enables studying the dynamics of neuronal circuits. Thus, we can use a linear mixture model to describe multisite recordings. It allows a significant reduction of the problem dimension and separation of the time and spatial domains.

To quantify the irregularity of temporal content, different measures can be employed, such as estimating the Kolmogorov-Sinai entropy [4], a lifetime of the phase autocorrelation function [5], or correlation dimension [6]. These methods hold great potential in providing a deeper understanding of the irregularity in biological recordings. We then discuss the theoretical principles of the methods and compare their advantages and disadvantages using synthetic simulations and electrophysiological data. Finally, we provide insights into the organization of functional circuits generating LFPs.

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Local Nocturnal EEG Activity of Healthy People Depending on Chronotype

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keywords: oscillatory patterns, polysomnogram, chronotype

Introduction. The type of daily regulation of the sleep-wake cycle (chronotype) has its own characteristics of EEG activity. For example, that morning types have greater spectral power of EEG signals in the low frequency range (12–14 Hz), and also have a greater rate of decay of slow-wave activity (1–5 Hz) compared to evening types ($P = 0.06$).

The purpose of this study is to study local EEG activity in 5 brain areas in healthy volunteers, depending on chronotype, in 20 frequency ranges: from 1 to 40 Hz.

Materials and Methods. We were investigated double recordings of an extended polysomnogram (19 leads) of 103 healthy volunteers 27.6 ± 8.2 years old, of which 40 (38.83%) were men. Each study participant was asked to complete the Morningness-Eveningness Questionnaire (MEQ) to determine chronotype. The entire time implementation of polysomnography was divided into time windows $\Delta t = 5$ sec., for each of the analyzed frequency ranges in this time window, the average values of the following characteristics were estimated: (1) the number of oscillatory patterns N, (2) the average lifetime of oscillatory patterns T and (3) average energy of oscillatory patterns E. The study of these indicators was carried out in 5 zones of EEG activity: zone No. 1 — central region, zone No. 2 — occipital region, zone No. 3 — frontal region, zone No. 4 — left hemisphere region, zone No. 5 — right hemisphere region. The EEG activity of each zone was assessed in 20 frequency ranges: from 1 to 40 Hz in steps of 2 Hz.

Results. Volunteers with different chronotypes did not represent statistical differences in sleep architecture. In the range of 4–6 Hz, significant differences in the duration and number of frequency patterns were revealed depending on the chronotype. The energy picture illustrated differences in almost all frequency ranges, most pronounced in zones 3 (frontal channel zone) and 4 (left hemisphere). Significant differences were revealed for zone 2 (occipital canals) in the states of awakenings from sleep and "drowsiness" (stage N1) when assessing the number of patterns in the ranges of 24–34 Hz. Analysis of the duration of the patterns demonstrates differences for zone 2 (occipital region of brain activity) throughout all stages of sleep for the frequency ranges 6– 8 Hz, 10–12 Hz. For the last frequency range, the maximum differences are characteristic of the N1 and N3 stages of sleep. For energy characteristics, the maximum differences can be seen when analyzing zone 4 (the left hemisphere of the brain). Here, differences begin to be observed in the frequency range of 8–10 Hz and continue throughout all stages of sleep up to 40 Hz. The maximum differences (above 50%) are observed for the highest frequency oscillations in the waking state and the REM stage of sleep.

The study was conducted with the financial support of the Russian Science Foundation (Project No. 22-72-10061).

Spin-Glass Sponges: Spin Glasses with Fractal Surfaces

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keywords: spin-glass sponge, spin-glass chaos, surface chaos, chaotic renormalization-groups

Using renormalization-group theory, we examined the chaotic behavior and phase transitions of spin-glass systems with fractal surfaces, termed "spin-glass sponges", in a three-dimensional bulk space. Unlike smooth surfaces, which require bulk spin-glass ordering to exhibit surface spin-glass phases, fractal surfaces can independently support spin-glass ordering. Our study identifies distinct phases: a solely surface spin-glass ordered phase, a combined bulk and surface spin-glass ordered phase, and a disordered phase, with a multicritical point where these phases converge. We quantify the chaos in these systems through Lyapunov exponents, highlighting stronger chaos in surface-only spin-glass phases compared to driven surface and bulk phases. These findings advance the classification of spin-glass chaos and suggest potential applications in systems with complex surface interactions.

Shepherding in Complex Systems: Integrating Control Theory and Statistical Physics

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keywords: shepherding, distributed control of complex systems, non reciprocal interactions

The emergence of collective behavior in complex systems has been widely studied in social, biological, and robotic systems, where large groups of agents exhibit a range of collective phenomena despite following simple local rules. However, the complex systems community has paid little attention to investigating whether and how a complex system can exhibit collective behavior suitable for achieving a global task of interest. A paradigmatic example of such a problem is the "shepherding control problem" (or herding problem), where a group of agents, known as herders, must cooperate to control the dynamics of a second group of agents, known as targets. This scenario is commonly observed in the animal world, such as dogs steering flocking sheep or dolphins hunting fish [1], and it is crucial for applications in crowd management, environmental cleanup, and many other fields [2]. In the first part of the talk, a minimal model of shepherding from an agent-based perspective is considered. Here, N herders need to corral M targets to a goal region in the plane. The model simplifies by assuming that targets exhibit cohesive collective behavior (e.g., flocking [3]) and that herders have unlimited sensing capabilities [4]. Instead, we choose a minimal setting with targets being stochastic random walkers repelled by nearby herders, and herders following simple rules based on local information within a limited sensing region of size ξ. We investigate the conditions for herdability, which allow N herders to successfully shepherd M targets. To establish herdability, we find that i) the number of herders must be sufficient to counteract the stochastic spreading of the targets, and ii) herders must be able to eventually observe all targets despite their limited sensing. The first condition is studied in the infinite sensing case ($\xi = \infty$), where we observe terms related to the percolation threshold M_{low} of a geometric graph termed the herdability graph. This graph has nodes representing the targets, and an edge connecting two targets if their mutual distance is smaller than ξ, indicating that one herder can observe both targets simultaneously. The percolation threshold M_{low} helps predict the critical threshold M_{low} and how it scales with the size of the system R and the sensing radius of the herders ξ. In the second part of the talk, ongoing work and results on deriving a continuum description of the shepherding problem are discussed, highlighting challenges and open problems. We analyze the resulting partial differential equations describing the dynamics of herders and targets. Noting that the interactions between herders and targets are non-reciprocal (e.g., herders are attracted to targets while targets are repelled by herders), we compare the results with literature on non-reciprocal interactions [3], where Newton's Third Law is violated.

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Bifurcations of Smale Horseshoes' Chains in a Double-scroll Attractor

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keywords: attractor, bifurcation, chaos, Smale horseshoe, piecewise-smooth system

In this talk, we consider bifurcations of the piecewise-smooth system A composed of three linear subsystems A_0, A_l, and A_r:

$$\begin{aligned}
A_0 : \dot{x} &= x, \\
\dot{y} &= -\nu y + \omega z, \\
\dot{z} &= -\omega y - \nu z, \\
A_l : \dot{x} &= -\alpha(x+h) - \Omega(z+1), \\
\dot{y} &= -\beta y, \\
\dot{z} &= \Omega(x+h) - \alpha(z+1), \\
\text{for } (x,y,z) &\in G_0, \\
A_r : \dot{x} &= -\alpha(x-h) - \Omega(z-1), \\
\dot{y} &= -\beta y, \\
\dot{z} &= \Omega(x-h) - \alpha(z-1), \\
\text{for } (x,y,z) &\in G_r,
\end{aligned}$$

where $h, \alpha, \beta, \nu, \omega$, and Ω are positive parameters, and the regions G_0, G_l, and G_r are defined as follows:

$$\begin{aligned}
&G_0 : |x| < h, \quad (y^2 + z^2 \leq r^2) \cap (|z| < 1), \\
&G_l : (z \leq -\text{sign}(x), y \in \mathbb{R}) \setminus G_0, \\
&G_r : (z \geq -\text{sign}(x), y \in \mathbb{R}) \setminus G_0,
\end{aligned}$$

for some positive parameter $r > 1$. This system was introduced in our recent paper [1] as a dynamical system with a double homoclinic loop to a saddle-focus, allowing a complete analytical study. We analytically obtained the Poincaré return map in explicit form and proved the existence of a double-scroll attractor. To describe the attractor structure completely, we introduced Smale horseshoe chains, revealing the true complexity of the double-scroll attractor. In this talk, we continue to use the analytical advantages of system above and examine the bifurcations of invariant sets belonging to the attractor and defined by Smale horseshoe chains. We show that an infinitesimal increase in the bifurcation parameter μ from zero leads to the birth and disappearance of a countable set of double-scroll attractors and spiral attractors. This work was supported by the Ministry of Science and Higher Education of the Russian Federation under Grant No. 0729-2020-0036.

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Speed Gradient Control of Qubit States

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keywords: semi-classical model, rotating-wave approximation, speed gradient feedback

We discuss the model of quantum bit driven by an external classical field without decay in the rotating wave approximation. In such model, the whole evolution of the qubit states takes place on the Bloch sphere. We reformulate the model as a unitless set of real ordinary differential equations, and use the normalized external field as a feedback control parameter. Based on the speed-gradient method the closed-loop control algorithm is designed, driving the dynamical system towards minimum of the given nonnegative goal function expressed via the qubit variables. We investigate the achievability of the control goal and focus on the most important features of the speed gradient algorithm applied to a quantum system in comparison with classical systems. Our approach is valid for the control over the ground and excited population levels, and over the qubit phase variables. We also demonstrate the ability to design certain quantum singie-qubit gates with appropriate shaping of the external control field.

Investigation of Elastic, Optical and Transport Properties of Two Cerium-Based Perovskite Oxides

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keywords: perovskite; semiconductor; elastic properties; optical properties; absorption coefficient; thermoelectric properties; merit factor

This research provides detailed information about the physical properties of two new perovskite oxides via density functional theory. Exchange and correlation effects are handled by the generalized gradient approximation (GGA) and the Tran-Blaha modified Becke–Johnson potential (TB-mBJ). The formation enthalpy and cohesion energy reveal clear thermodynamic stability. The band structures indicate a semiconductor nature with indirect band gaps. For both perovskites, the TB-mBJ approximation increased the band gap value by a rate close to 55%. The mechanical stability, given by the Born-Huang criteria, is entirely satisfied. The compounds exhibit rigid and elastically anisotropic behavior, and the chemical bonds that occur are a mixture of metallic and covalent types. The optical study indicates that these oxides are active in a wide area of the electromagnetic spectrum. The high reflectivity recorded in the near-infrared region allows these almost opaque perovskites to be used as effective shields in this area. Replacing beryllium with a magnesium atom improves the thermoelectric performance by decreasing the thermal conductivity and increasing the figure of merit. The overall analyses depict that the considered compounds are potential candidates for applications in optoelectronic and thermoelectric devices.

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Modeling of Fresh Properties of Concrete Mixed with Rubber and Plastic Waste

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keywords: concrete, rubber, plastic waste, fresh Properties

The use of waste in construction field is considered one of the most effective solutions for managing this material and to protect environment.

The aim of this work is to use the JMP pilot test program to show experimental results of different concrete formulations based with plastic waste, where cement was substituted with rubber with 2% and 4% ratios and sand was replaced with plastic as a mass substitute in proportions of 2%, 4%, and 6%. The tests were carried out on concrete with fresh properties.

The results indicated that workability and fresh density decrease with increasing percentages of rubber and plastic, and air content increases with increasing percentages of rubber and plastic. The numerical modeling is assessed to have an appropriate coefficient R2 close to 1 for the workability, fresh density, and air content.

Experimental Study and Modeling of Chemical Inhibitor Behavior in Acidic Environment Using MATLAB Software

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The reduction in the consumption of large quantities of corrosion-inhibiting products constitutes an asset that contributes to lowering expenses for oil companies. This paper focuses on the use conditions and analysis of doped NALCO inhibitors, aimed at improving performance and reducing consumed quantities. Using an acidic environment (H_2SO_4), we examined the behavior of these chemical inhibitors in the case of corrosion of carbon steel C1020. The gravimetric method was employed to study the influence of concentration, immersion time, and environmental temperature on corrosion processes, both in the absence and presence of the inhibitor. Analysis of data using MATLAB software revealed the optimal point of efficiency.

Chimera Resonance: Constructive Role of Noise in Ensembles of Maps

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Noise and random perturbations are inevitable in real-world systems and can have a significant impact on their dynamics. Additionally, noise can have both destructive and constructive effects on the spatiotemporal dynamics of systems [1]. The interest in studying the influence of noise on system dynamics has increased due to the discovery of new spatiotemporal regimes, such as chimera states, occurring not only in computer experiments but also in real systems [2-4]. Recent studies have shown that noise can induce new types of chimera states [5,6], as well as affect their lifetime [7-9]. These studies further emphasize the constructive role of noise in system dynamics.

In the present study, we investigate the impact of additive noise with different statistics, specifically Gaussian noise and Lévy noise, on chimera states in rings of nonlocally coupled chaotic maps. We conducted an extensive analysis to determine how the control parameters of the system itself and the noise sources influence the probability of establishing chimeras in systems with various partial elements, including logistic maps, Hénon maps, Ricker maps, and Hénon-Lozi maps. To obtain statistically significant results, we considered 50 to 100 pairs of initial conditions and noise generator implementations, and the cross-correlation coefficient was used to automatically detect chimera states.

Research has shown that there is a resonance-like effect that corresponds to the special dependency of the probability of establishing chimera states in rings of nonlocally coupled chaotic maps on the intensity of noise and the strength of coupling between elements. The studies reveal that there is an optimal value of the system parameters and external influence, where the probability of chimera states reaches its maximum value, although this was not observed in the absence of noise influence. We have named this effect "chimera resonance" in analogy with the effects of stochastic and coherence resonance. Additionally, the study demonstrates that the coupling strength at which the maximum probability is observed shifts to a larger range as the noise intensity increases. It has been discovered that there is a finite range of noise intensity within which chimera states are observed with a high or even maximum probability. This range is widest at a specific "resonant" value of the coupling strength.

Our results once again show the counterintuitive constructive role of noise in the dynamics of complex networks and the possibility of using external noise as an effective tool for controlling the formation and stability of the observed spatio-temporal structures.

Acknowledgments E.R. and G.S. acknowledge financial support from the Russian Science Foundation (project No. 20-12-00119, `https://rscf.ru/en/project/20-12-00119/`).

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Role of Intra-Layer Interaction in Spiking Neural Networks Under Training

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keywords: spiking neural networks, SNN, STDP, self-organization

In this work, we consider the effects of intra-layer coupling in the hidden layer of a spiking neural network (SNS) under training. In general, the topology of coupling for an SNN is considered the same as for an artificial fully-connected neural network, where each neuron of one layer with the whole next layer. In this case, elements of one layer do not interact with each other in any way. Such a topology is not biologically relevant. In real functional neural network in brain, neurons of one layer always have multiple interactions with each other. The "small-world" topology has a number of similar features as the real coupling topology of connectome. For this reason, we introduce the intra-layer interaction between neurons of the hidden layer with the "small-world" type of a coupling. The node of the SNN is a simple LIF neuron. It is described as follow:

$$\frac{dV}{dt} = -\frac{V - V_{\text{rest}}}{\tau_{\text{m}}} + \frac{I(t)}{C_{\text{m}}}, \qquad (0.1)$$

where V is the membrane potential of the neuron V_{rest} is the resting potential of the neuron, τ_{m} is the membrane time constant, $I(t)$ is the input current applied to the neuron, C_{m} is the membrane capacitance.

We train the SNN to classify pictures of the standart set "MNIST" with using spike-timing-dependent plasticity method (STDP). We change both inter-layer and intra-layer weight of synapses by STDP method. Thus, the intra-layer coupling can be either unidirectional or assymetric. We show that an introduction of the intra-layer interactions leads to effects of self-organization during the training. We study in detail the effects of clusterisation of neurons in the hidden layer, which occur when we train the SNN to classify a certain class of the MNIST pictures. Thus, we study the dynamic processes that arise in the SNS during its training process. It enables us to better control of network dynamics and to improve the networks ability to classify more complex objects, as well as a better understanding of the processes occurring in functional brain networks.

The work is supported by the Russian Science Foundation (project No. 23-12-00103, https://rscf.ru/en/project/23-12-00103/)

Operational Control of the NICA Stochastic Cooling System

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keywords: feedback, beam cooling

The heavy ion collider of the NICA accelerator complex is under commissioning at JINR, Dubna, Russia. The feedback system of stochastic cooling is one of the crucial collider subsystems to preserve the beam quality. During the collider operation the diagnostics of the stochastic cooling system will be monitoring the shot noise spectra of the circulating beam. Based on the obtained spectra, it is planned to maintain the parameters of the cooling system (i.e. gain, delays) near optimal values. This paper discusses approaches to such a control system.

Spatiotemporal Modulation of Complexity of Local Field Potentials

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Multisite recordings of local field potentials (LFPs) capture the synaptic activity of the principal cells excited by upstream neuronal populations. The obtained spatiotemporal data can untangle the architecture and function of circuits involved in information processing during specific behaviors. LFPs are commonly analyzed with spectral methods quantifying signal amplitude in different frequency bands. Special attention is usually given to macroscopic high-amplitude events such as theta oscillations or sharp waves. However, most LFP activity occurs at relatively low-amplitude irregular oscillations, which receive little attention in the literature. In this communication, we employ different measures of complexity to study the information content of irregular and regular LFPs recorded in the rat hippocampus. For this end, we first decompose 32-channel LFPs into generators using the independent component analysis. It allows for the reduction of data dimensions to 4-6 generators. Moreover, such LFP generators have a well-identified connection to presynaptic neuronal populations. Then, we use recently developed methods for estimating the correlation dimension, Kolmogorov entropy, and the lifetime of the phase autocorrelation function to quantify the irregularity of LFPs. Our results show a reasonable level of similarity between different techniques but also provide complementary insights into the complexity of the interaction of neuronal circuits contributing to LFPs. We observe how external information (tail pinch) affects neuronal dynamics and induces synchronization of neuronal clusters in specific LFP generators. The interplay of different upstream generators induces switches in their dynamic behaviors manifested in a nontrivial spatiotemporal modulation of complexity in LFPs.

Convective Heat Transfer of Nanofluids in a Backward-Facing Step

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keywords: backward-facing step, nanofluid, nanoparticle, base fluid, fluent

Our work focuses on the numerical study of a two-dimensional incompressible laminar flow of nanofluids adjacent to a sudden expansion in a rectangular duct. The study is parametric and concerns the effects of different types of nanoparticles (Cu, CuO, and NTC), with their volume fractions varying from 0 to 5%, as well as the effect of different base fluids (water and ethylene glycol) on the thermal and mechanical characteristics of the flow. For this purpose, we used the numerical simulation software *Fluent*.

The results obtained showed that the heat transfer increases with the increase in the nanoparticle volume fraction and that the ethylene glycol (EG)-based nanofluids have the highest values of the heat transfer coefficient. However, the types of nanoparticles have no significant influence on this coefficient.

Dynamics of Large Oscillator Populations with Random Interactions

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keywords: oscillator populations, collective synchronization, randomness of interactions

Populations of globally coupled oscillators appear in different fields of physics, engineering, and life sciences. In many situations, there is disorder in the coupling, and the coupling terms are not identical but vary, for example, due to different coupling strengths and phase shifts. While the phenomenon of collective synchronization in oscillator populations which attracted much interest in the last decades is well-understood in a regular situation, the influence of disorder remains a subject of intensive current studies. The disordered case is relevant for many applications, especially in neuroscience, where in the description of the correlated activity of neurons, one can hardly assume the neurons themselves to be identical and the coupling between them to be uniform.

We explore large populations of rotators $\varphi_k(t)(k = 1, \ldots, N)$ interacting via random coupling functions:

$$\mu\ddot{\varphi}_k + \dot{\varphi}_k = \omega_k + \sigma\xi_k(t) + H\left(\{\varphi_j(t)\}\right), \tag{0.1}$$

where each $\varphi_k(t)$ is assumed to be a phase or an angle variable with a first-order ($\mu = 0$) or a second-order ($\mu \neq 0$) in time dynamics, respectively. Here, we assume that the individual phase dynamics of an oscillator is described within the "standard" model as rotations with a natural frequency ω_k, possibly with individual Gaussian white noises $\sigma\xi_k(t)$. In Eq. (0.1), we separate this individual dynamics and the coupling terms $H\left(\varphi_1(t), \ldots, \varphi_N(t)\right) = H\left(\{\varphi_j(t)\}\right)$. Note that the model (0.1) with $\mu = 0$ corresponds to the model of coupled phase oscillators which is most popular because it can be directly derived for generic coupled oscillators from the original equations governing the oscillator dynamics, in the first order in the small parameter describing the coupling. The model (0.1) with $\mu \neq 0$ are discussed in the literature, for example, in the context of modeling power grads.

Next, we specify the coupling terms $H\left(\{\varphi_j(t)\}\right)$ according to the Kuramoto-Daido and the Winfree approaches. In both two cases, we assume that all the pairwise coupling terms are different, taken from some random distribution of random functions. In this assumption that all the coupling terms are generally different, the coupling function in the

Kuramoto-Daido form as a function of phase differences $(\varphi_j - \varphi_k)$ reads

$$H_{KD}\left(\{\varphi_j(t)\}\right) = \frac{1}{N}\sum_{j=1}^{N} F_{jk}(\varphi_j - \varphi_k). \tag{0.2}$$

For the Winfree-type model, in a such case of the general randomness case, the action on the oscillator k from the oscillator j is proportional to the product $S_{jk}(\varphi_k)Q_{jk}(\varphi_j)$, where $S_{jk}(\varphi_k)$ is the j-th phase sensitivity function of the unit k, and $Q_{jk}(\varphi_j)$ describe the force with which the element j is acting on the oscillator k:

$$H_W\left(\{\varphi_j(t)\}\right) = \frac{1}{N}\sum_{j=1}^{N} S_{jk}(\varphi_k)Q_{jk}(\varphi_j). \tag{0.3}$$

It is well known that, in the regular setups, the Kuramoto-Daido and the Winfree coupling functions can be reformulated in terms of the Kuramoto-Daido order parameters $Z_m(t)$ which are defined as

$$Z_m(t) = \frac{1}{N}\sum_{j=1}^{N} \mathrm{e}^{im\varphi_j(t)} = \langle \mathrm{e}^{im\varphi_j(t)} \rangle. \tag{0.4}$$

One can obtain these representations representing the 2π-periodic coupling functions as Fourier series. We use these expressions as "templates" for identifying the effective coupling functions in the case of random interactions.

Thus, we represent the functions $F_{jk}(x), S_{jk}(x)$ and $Q_{jk}(x)$ describing random pairwise interactions in the Kuramoto-Daido and the Winfree models via random complex Fourier coefficients $f_{m,jk}, s_{m,jk}$ and $q_{m,jk}$, respectively:

$$F_{jk}(x) = \textstyle\sum_m f_{m,jk}\mathrm{e}^{imx}, \tag{0.5}$$

$$S_{jk}(x) = \textstyle\sum_m s_{m,jk}\mathrm{e}^{imx}, \tag{0.6}$$

$$Q_{jk}(x) = \textstyle\sum_m q_{m,jk}\mathrm{e}^{imx}, \tag{0.7}$$

$$f_{m,jk} = \tfrac{1}{2\pi}\int_0^{2\pi} dx F_{jk}(x)\mathrm{e}^{-imx}, \tag{0.8}$$

$$s_{m,jk} = \tfrac{1}{2\pi}\int_0^{2\pi} dx S_{jk}(x)\mathrm{e}^{-imx}, \tag{0.9}$$

$$q_{m,jk} = \tfrac{1}{2\pi}\int_0^{2\pi} dx Q_{jk}(x)\mathrm{e}^{-imx}. \tag{0.10}$$

Next, we assume statistical independence of the phases and the corresponding Fourier coefficients. We expect this independence to be valid for a large population, where many different couplings influence each phase. This assumption allows us to obtain the reduced coupling terms and conclude that the interaction is described with an effective deterministic coupling. For the Kuramoto-Daido-type model, we arrive at the effective averaged coupling function, Fourier modes of which are just $\langle f_{m,jk} \rangle$:

$$\begin{aligned} \frac{1}{N}\sum_{j=1}^{N} F_{jk}(\varphi_j - \varphi_k) \Rightarrow \frac{1}{N}\sum_{j=1}^{N} \mathcal{F}(\varphi_j - \varphi_k) &= \frac{1}{N}\sum_{j=1}^{N} \langle F_{jk}(\varphi_j - \varphi_k) \rangle \\ &= \sum_m \langle f_{m,jk} \rangle \mathrm{e}^{-im\varphi_k} Z_m. \end{aligned} \tag{0.11}$$

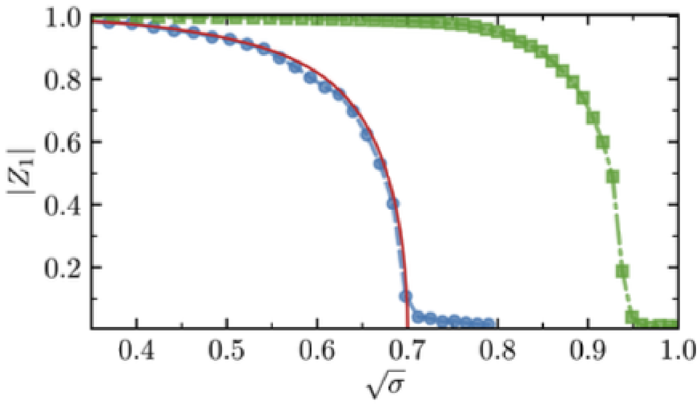

Fig 1. Behavior of the first order parameter $\langle|Z_1|\rangle$ an ensemble of $N = 12 \times 10^3$ noisy rotators (1) with equal natural frequencies ($\omega_k = \Omega$) and coupling function $F(x) = K\sin(x) + 4\sin(2x)$ with $K = 1$ in dependence on $\sqrt{\sigma}$ for the moment of inertia $\mu = 0.5$. Green squares and blue circles are simulations without and with phase shifts, respectively. We consider random phase shifts α_{jk} distributed according to $G(\alpha) = (1 + \cos(M\alpha))^{2\pi}$ with $M = 1$. Thus, the effective coupling function is $F(x) = 0.5K\sin(x)$. For such coupling, the analytical expression (solid red line) for the order parameter in dependence on the noise intensity σ^2 can be written in a parametric (parameter R) form: $|Z_1| = \frac{2\pi R I_0(R) I_1(R)}{2\pi R I_0(R) + \mu K I_1(R)}, \sigma^2 = \frac{K|Z_1|}{2R}$, where $I_0(R)$ and $I_1(R)$ are the principal branches of the modified Bessel functions of the first kind with orders 0 and 1, respectively.

For the random Winfree-type model, we have

$$\begin{aligned}\frac{1}{N}\sum_{j=1}^{N} S_{jk}(\varphi_k)Q_{jk}(\varphi_j) \Rightarrow \mathcal{S}(\varphi_k)\frac{1}{N}\sum_{j}\mathcal{Q}(\varphi_j) =&\langle S_{jk}(\varphi_k)\rangle\frac{1}{N}\sum_{j=1}^{N}\langle Q_{jk}(\varphi_j)\rangle \\ =&\sum_{m}\langle s_{m,jk}\rangle e^{im\varphi_k}\sum_{m'}\langle q_{m',jk}\rangle Z'_m.\end{aligned} \quad (0.12)$$

It is worth mentioning that because the Fourier transform is a linear operation, averaging the Fourier coefficients is the same as averaging the functions. Thus, our main theoretical result is that one can reduce the dynamics of a large population with random coupling functions to an effective ensemble without disorder, where the effective coupling functions are averages of the original random coupling functions.

The relations (0.11) and (0.12) are derived in the case of general randomness of interactions, which includes a situation where different coupling functions have different shapes. For example, some oscillators can be coupled via the first harmonic coupling function, while others are coupled with the second harmonic coupling function. A particular situation is one where all the shapes are the same, but the interactions differ in their coupling strengths and the phase shifts. Using (0.11) and (0.12) in the case where the randomness is restricted to coupling strength and phase shifts, one can see that the randomness of coupling strengths renormalizes the total coupling strength, but does not influence the shape of the coupling function. In contradistinction, the randomness of the phase shifts changes the form of the coupling function and the effective coupling function is the convolution operator of the original one with the phase shift distribution density. Our exhaustive numerical simulations confirm this theoretical prediction (e.g., see Fig. 1).

Summarizing the results, we have considered different models of globally coupled phase oscillators and rotators. In the case of a "maximal disorder", all the coupling functions are distinct and random, sampled from some distribution. Based on the assumption of independence of the phases and the coupling functions in the thermodynamic limit, we derived the averaged equations for the phases, where effective deterministic coupling functions enter. A more detailed consideration was devoted to the case where the shapes of the random coupling functions are the same, but the amplitudes and the phase shifts are random. Then, the effective functions are renormalized convolutions of the original coupling functions and the distribution densities of the phase shifts. In particular, if the distribution of the phase shifts possesses just one Fourier mode, the effective coupling function will possess only this mode, too. This property allows us to check the validity of the approach numerically because, for the one-mode coupling function, there are theoretical predictions for the behavior of the order parameters.

L.S. acknowledges support from the Russian Science Foundation (Grant No. 22-12-00348).

Anti-Resonance in the Essentially Nonlinear Systems

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keywords: nonlinear oscillations, Fano resonance, anti-resonance

The phenomenon of the resonance is one of most significant in the theory of the oscillations and waves. The analysis of the resonant curve for the waves, which are scattered by the atoms and structures, allows us to investigate structure and properties of the matter. Ugo Fano in 1935 [1] showed for the first time that the interference of the wave functions of the discrete leaky state and the continuum ones can results to the non-conventional asymmetric shape of the resonant curve. Further publications gave rise to the great number of the researches in the various fields of physics [2,3]. During the last decades the processes of the wave interference are intensively studied in the nanoscale physics [4], in particular, in view of development of the new generation materials - metamaterials [2]. In spite of the original work deals with the quantum mechanical problem, the effects of the asymmetrical resonance appear in the classical systems too. It was shown that two-channel resonant scattering of the elastic waves on the planar defect in the crystal can result to the full reflection even for the waves, the wavelength of which is essentially large than the defect's thickness [5]. The equivalent classical system has been considered in the papers [6,7].

We will consider the classical analogue of the Fano resonance by way of the example of two coupled oscillators with the nonlinearity of the soft as well as hard kinds. The oscillator excited by the external force is associated with the continuum state of the quantum mechanical system, while the driven oscillator corresponds to the leaky discrete state.

The Hamilton function of the system may be written in the form

$$H = \sum_{j-1,2} \left(\frac{p_j^2}{2m_j} + \Omega_j^2 \Phi_j(z_j) \right) + \beta V(z_1, z_2), \tag{0.1}$$

where m_j, p_j and z_j are the mass, momentum and displacement of the j-th oscillator from its equilibrium position, respectively. We assume that the potential functions Φ_j are characterized by parameters Ω_j, which are proportional to the linear rigidity. Parameter β is the frequency-scaling factor, which characterizes the rigidity of coupling function V.

The systems with nonlinear oscillators coupled by a linear spring have been discussed in [8]. Now we will consider the system of linear oscillators ($\Phi_j(z) \sim z^2$) with essentially nonlinear coupling V. In such a case the convenient variables are the sum and the difference of the oscillators' displacements. Using complex envelop variable approximation [9] we can obtain the closed expressions for the oscillators' amplitudes without any additional suggestions about the value of the nonlinearity. Taking into account a small damping in the form of viscous friction, we can write the equations of motion. After averaging over the period the follows equation for the complex envelopes are formed

$$\begin{aligned} \frac{\omega^2-\Omega_s^2}{2\omega}\psi-\frac{\Omega_d^2}{2\omega}\phi+\frac{i\nu}{2}\psi&=-\frac{f}{2\sqrt{2\omega}} \\ \frac{\omega^2-\Omega_d^2-2\Omega_c^2}{2\omega}\phi-\frac{\Omega_d^2}{2\omega}\psi+\frac{i\nu}{2}\phi&=-\frac{f}{2\sqrt{2\omega}}, \end{aligned} \tag{0.2}$$

where $\Omega_s^2=\Omega_1^2+\Omega_2^2, \Omega_d^2=\Omega_1^2-\Omega_2^2$ and $\Omega_c=\Omega_c(|\phi|)$ is the own frequency of the coupling spring, which depends on the difference of oscillators' displacements. The complex envelope variables ψ and ϕ correspond to the sum and the difference of displacements. Equations (0.2) allow us to write the stationary solution for the complex coordinates of the oscillators as follows

$$\begin{aligned} \chi_1&=\frac{f\sqrt{\omega}(-\Omega_c^2+\Omega_d^2+i\nu\omega-\Omega_s^2+\omega^2)}{\sqrt{2}(2\Omega_c^2(-\Omega_s^2+\omega(\omega+i\nu))+\Omega_d^4+(\omega(\nu-i\omega)+i\Omega_s^2)^2)} \\ \chi_2&=-\frac{f\sqrt{\omega}\Omega_c^2}{\sqrt{2}(2\Omega_c^2(-\Omega_s^2+\omega(\omega+i\nu)))+\Omega_d^4+(\omega(\nu-i\omega)+i\Omega_s^2)^2} \end{aligned} \tag{0.3}$$

where χ_j is the complex envelope of the displacement of j-th oscillator ($z_j=\frac{\left(\chi_j e^{-i\omega t}+\chi_j^* e^{i\omega t}\right)}{\sqrt{2\omega}}$). Expressions 0.3 per se are the transcendental equations for the amplitudes with the nonlinearity, which represents the natural oscillation frequency of oscillators. An example of resonant curves for oscillators with a soft nonlinearity is shown in Fig 1(a).

Fig 1(a) shows that the coupling nonlinearity results to the appreciable frequency shift of the left resonant peak but does not affect on its profile. However, the profile of the second resonant peak is changed essentially including the jump between stable branches of the resonant curve. The jump's frequency can be estimated in the framework of the limiting phase trajectory concept [8]. In aim of the comparision, Fig 1(b) shows the resonant curves for the system with nonlinear (hard-type) excited oscillator, but linear coupling and driven one.

In conclusion, one should to notice that the nonlinearity in the system of the oscillators affects on the resonant curves appreciably, but the infuence of the oscillator's nonlinearity and the nonleariyt of the coupling is essentially different.

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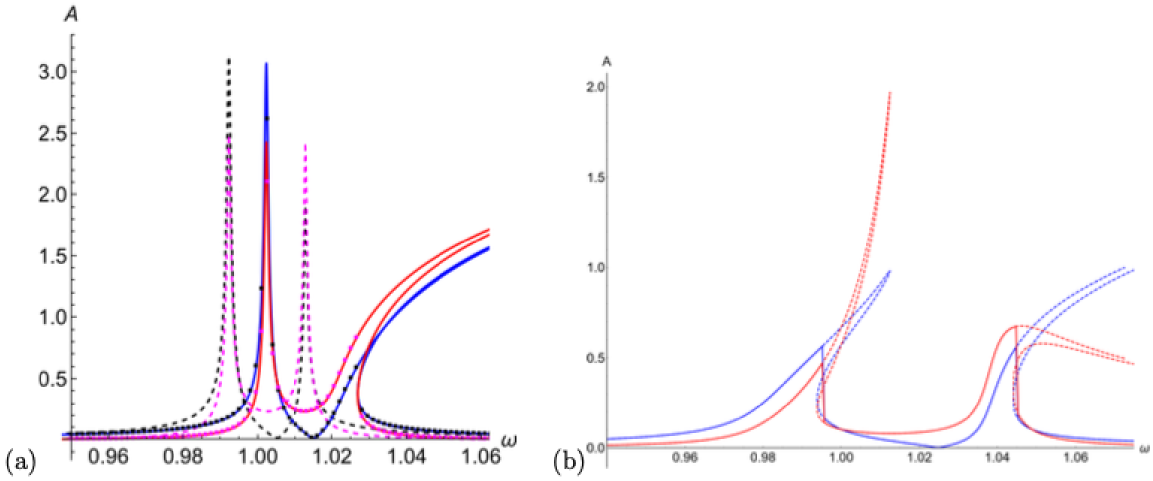

Fig 1. The anti-resonance in the pair of linear oscillators with a hard-type nonlinear coupling ($V(z) \sim \chi(z)$). The dashed curves show the resonance in the linear approximation while the solid ones correspond to the solution (0.3). The excited and driven oscillators are depicted in blue and red, respectively. Black and magenta circles shows the data of the direct numerical simulations. Parameters: $\Omega_1 = 1.0, \Omega_2 = 1.01, \beta = 0.02, \nu = 0.001, f = 0.005$. (b) The anti-resonance phenomenon in the system with excited nonlinear hard-type oscilator and the linear coupling and driven oscillator. The dashed and solid curves show the analytical results and numerical simulation data [8]. The colors are the same in (a).

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Features of Synchronization of ECG and EEG Signals in Patients with Obstructive Apnea Syndrome During Night Sleep

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keywords: synchronization, intermittency, electrocardiogram, electroencephalogram

Introduction. It is now known that there is a strong relationship between nocturnal breathing disorders and cardiovascular events. For example, there is a clear connection between obstructive apnea syndrome and the progression of hypertension, chronic heart failure and rhythm disturbances, up to episodes of asystole and sudden cardiac death. Respiratory disorders also affect the functional activity of the brain in the form of sleep defragmentation, destruction of normal sleep architecture, and changes in the frequency and time characteristics of nighttime EEG activity.

The aim of this study is to study the characteristics of synchronization of ECG and EEG signals in patients with obstructive sleep apnea syndrome according to polysomnography.

Materials and Methods. The study included 2 categories of volunteers: 5 healthy people and 5 patients with obstructive sleep apnea syndrome. All volunteers had a polysomnogram recorded twice (EEG signals are represented by bilateral central and occipital leads). Based on the concept of time scale synchronization, the intermittent dynamics of EEG and ECG signals during night sleep is considered. The instantaneous phase was introduced for EEG and ECG signals using a continuous wavelet transform at the heart rate frequency using the concept of timescale synchronization. Differences in instantaneous phases were considered for various pairs of EEG and ECG signals during night sleep.

Results. It is shown that in all cases the phase difference exhibits intermittent behavior, where the moments when phase synchronization is observed act as laminar sections of behavior, i.e., phase capture. The turbulent phase corresponds to a phase jump of 2π. When constructing the distribution of the duration of laminar sections of behavior, it was found that for all pairs of channels, the duration of laminar phases obeys an exponential law. Based on the analysis of the movement of the phase trajectory on a rotating plane at the moment of detection of the turbulent phase, it was established that in this case, eyelet intermittency is observed. These characteristics do not have statistical significance when comparing the indicators of healthy people and patients with apnea. However, it was found that changes in statistical characteristics in the phase synchronization of EEG and ECG signals correlate with blood pressure at the time of polysomnography, which is of scientific and clinical interest.

The study was carried out within the state task of the Ministry of Health of the Russian Federation "Development of a portable software and hardware complex for remote monitoring of the function of the cardiovascular system, as well as automation of the test with a 6-minute walk in patients with chronic non-communicable diseases" No 056-03-2024-071 from 24.01.2024.

Breathing and Switching Cyclops States in Kuramoto Networks with Higher-Mode Coupling

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keywords: cyclops states, Kuramoto model, higher-mode coupling

Cyclops states are intriguing cluster patterns observed in oscillator networks, including neuronal ensembles. The concept of cyclops states formed by two distinct, coherent clusters and a solitary oscillator was introduced in [1], where we explored the surprising prevalence of such states in repulsive Kuramoto networks of rotators with higher-mode harmonics in the coupling. This paper extends our analysis to understand the mechanisms responsible for destroying the cyclops' states and inducing new dynamical patterns called breathing and switching cyclops' states. We first analytically study the existence and stability of cyclops states in the Kuramoto–Sakaguchi networks of two-dimensional oscillators with inertia as a function of the second coupling harmonic. We then describe two bifurcation scenarios that give birth to breathing and switching cyclops states. We demonstrate that these states and their hybrids are prevalent across a wide coupling range and are robust against a relatively large intrinsic frequency detuning [2]. Beyond the Kuramoto networks, breathing and switching cyclops states promise to strongly manifest in other physical and biological networks, including coupled theta-neurons.

This work was supported by the Russian Science Foundation under project No. 24-72-00105.

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Optimizing and Modeling Malachite Green Removal Using Agro-Industrial Waste Materials

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keywords: adsorption, nonlinear equilibrium isotherm, error function analysis, Malachite Green

This study investigates the potential of prickly pear seed residue from the extraction of oil as an adsorbent for removing a cationic dye (Malachite Green). The residue was used in both its raw form (GFB) and after modification with the anionic surfactant sodium dodecyl sulfate (SDS) (GFB/SDS). Batch experiments were conducted to evaluate the impact of various factors on the dye adsorption efficiency by both raw and modified prickly pear seed residue.

Equilibrium data from batch experiments were analyzed using non-linear regression to fit various isotherm models (two-parameter and three-parameter) and kinetic models. Three error functions (Δq, χ^2, RMSE) were employed to evaluate the model performance. The results demonstrated a significant improvement in both adsorption kinetics and dye removal efficiency for GFB/SDS compared to unmodified GFB. The optimal conditions for Malachite Green (MG) removal were found to be an adsorbent dosage of 3 g/L, a solution pH of 6.12, and an equilibrium time of 2 hours. The pseudo-second-order model best described the kinetic behavior of dye adsorption for both materials. Thermodynamic parameters indicated that the adsorption process for both materials was spontaneous ($\Delta G < 0$) and endothermic ($\Delta H > 0$). These findings suggest that both GFB and GFB/SDS are effective for cationic dye removal and hold promise as alternative, cost-effective materials for wastewater treatment.

Improve Efficiency of Perovskite-Based Solar Cell by Photon Recycling

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In recent years, significant advancements have been made in thin-film planar heterojunction solar cells, emerging as cost-effective photovoltaic devices with high power conversion efficiency. Among the materials utilized, organometal trihalide perovskite (CH3NH3PbI3) stands out as a promising absorber material. Its appeal lies in the affordability of organic-inorganic perovskite compounds, readily available in nature, ease of fabrication, and compatibility with large-scale processing at low temperatures.

In addition to its effective absorption in the ultraviolet range, this material exhibits captivating optoelectronic properties, including high crystallinity, elevated carrier mobility, and extensive carrier diffusion lengths. Despite these advantages, the highest reported power conversion efficiency for perovskite solar cells is currently at 23.9%, as of 2017.

This study introduces a thin-film organometal trihalide perovskite solar cell featuring hybrid interfaces between carefully chosen materials. These selections are the result of an in-depth study aimed at minimizing recombination and optimizing performance. Furthermore, we enhance the absorption of the incident solar spectrum by incorporating a 1D photonic crystal at the cell's bottom, facilitating the photon recycling process.

The proposed solar cell parameters are numerically computed using the rigorous coupled wave algorithm through the SYNOPSYS RSOFT CAD tool. The thickness of each layer in the structure is optimized using the MOST scanning and optimization module of the RSOFT CAD tool, achieving the highest power conversion efficiency at a minimal device thickness (approximately 2.5 µm).

Remarkably, the power conversion efficiency achieved is 25.5%, with a fill factor of 87.4% at AM 1.5, showcasing great promise. This demonstrates the remarkable potential of the proposed design to achieve efficiencies exceeding 22%, positioning it as a competitive contender in the existing crystalline silicon photovoltaic market.

The Effect of Delay on Waves in a Ring Of Fitzhugh—Nagumo Neurons Under The Influence of Lévy Noise

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A system of connected neurons serves as a prototype for the human brain, which can experience a time delay [1] and is susceptible to the influence of noise [2]. The delay in a system of connected neurons can form different modes: system elements may enter synchronization mode, or they may switch to traveling wave mode, among others. Moreover, under the influence of noise, a transition between different states can be achieved. With the help of noise exposure and time delay, a therapeutic effect on both brain (Parkinson's disease) and heart (cardiac arrhythmias) diseases is possible.

To determine the nature of the influence of coupling delay parameters and Lévy noise on the dynamics of a network of coupled FitzHugh–Nagumo neurons, an ensemble represented by the following equations is studied:

$$\epsilon \dot{u}_i = u_i - \frac{u_i^3}{3} - v_i + \gamma \sum_{j=1}^{P} \left(u_j(t-\tau_j) - u_i(t) \right), \tag{0.1}$$

$$\dot{v}_i = u_i + a + \eta \alpha_L, \beta_L(t, \sigma_L), \tag{0.2}$$

where u_i and v_i are dynamical variables that describe the temporal dynamics of the activator (fast variable) and the inhibitor (slow variable), respectively; $i = 1, 2, \ldots, N$ is the element number with $N = 100$ being the total number of oscillators in the network. In our simulations, initial conditions are chosen to be randomly and uniformly distributed in the square $u_i(t=0) \in [-2; 2]$, $v_i(t=0) \in [-2; 2]$. The small parameter ϵ is responsible for the time-scale separation of fast activator and slow inhibitor and is fixed to $\epsilon = 0.01$ in our numerical simulation. The parameter a defines the excitability threshold and, depending on its value, an individual FitzHugh-Nagumo oscillator can demonstrate either excitable ($|a| > 1$) or oscillatory ($|a| < 1$) regimes. A parameter γ is the coupling strength, and P is the coupling range. A parameter τ is the delay time, and $u_j(t - \tau_j)$ is the value of the variable at the time moment $(t - \tau_j)$. The last term in the first equation specifies connections between neurons subject to periodic boundary conditions ($j + kN = j$ for any integer k). A parameter α_L is the stability index representing the rate at which the tails of the distribution narrow. When $\alpha_L = 2.0$, the Lévy noise generator shows a Gaussian distribution of random variables. The parameter $\beta_L \in [-1, 1]$ determines the skewness of the distribution, and σ_L is the distribution width. We use a symmetrical distribution with $\beta_L = 0$.

The ring of coupled FitzHugh–Nagumo neurons demonstrates traveling wave regimes, which are observed for different values of the delay parameter from 0 to a certain threshold value. The investigation concerns the robustness of traveling wave regimes under Lévy noise when the coupling delay parameter is changed. The results include conclusions about the influence of the delay parameter value on the robustness of traveling wave regimes towards Lévy noise.

Acknowledgments This work was supported by the Russian Science Foundation (Project No. 23-72-10040, `https://rscf.ru/project/23-72-10040/`).

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Analytical Parameter Conversion of Serial Kinematic Chain Models

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keywords: Denavit-Hartenberg (DH) convention, Hayati model, complete and parametrically continuous (CPC) model, product of exponentials (POE), Lie groups, Lie algebras, adjoint mapping, kinematic calibration

This paper proposes an analytical parameter conversion framework for Hayati, Complete and Parametrically Continuous (CPC), and Product of Exponentials (POE) kinematic models of serial chain mechanisms. The approach represents a generalization of the recent POE-DH results to include POE-CPC, POE-Hayati, and CPC-Hayati transitions, which, to the best of the authors' knowledge, have not been done yet. This framework enables the selection of any of the considered models tailored to the problem specifics, regardless of the initially given model. The framework's results are primarily applicable to manipulator calibration problems. It is also beneficial for analyzing and comparing results and methods within the calibration domain that are made in different conventions. The accuracy of the framework was validated through simulations on the well-known PUMA 560 model. To demonstrate the pipeline benefits, an experiment was conducted on the kinematic calibration of the ABB IRB 1600 industrial manipulator. The absolute accuracy of the manipulator with calibrated parameters was confirmed using the API Radian Laser Tracker EMSD3.

Numerical Study of a 2D Permanent Magnetic Lattice Using Artificial Intelligence Algorithms

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keywords: permanent magnetic lattices, ultracold atoms, artificial intelligence algorithms, machine learning, deep learning

Permanent magnetic lattices have been introduced as an array of periodic microtraps created by magnetic slabs in one, two, and recently three-dimensional schemes. These lattices are used for confining, manipulating, and controlling ultracold atoms and Bose–Einstein condensates (BECs). They can be applied to study quantum tunneling experiments, such as the superfluid to Mott insulator quantum phase transition.

Considering analytic expressions of three magnetic field components, including external bias magnetic field components (B_{1x}, B_{1y}, B_{1z}), we can obtain non-zero potential minima (B_{min}) and the central minimum coordinates of magnetic microtraps ($x_{\mathrm{min}}, y_{\mathrm{min}}, z_{\mathrm{min}}$) analytically. An alternative approach to obtaining these features is through numerical calculation methods, such as Artificial Intelligence (AI) algorithms.

Methodology. In this research, we use machine learning and deep learning algorithms as a new approach to calculate B_{min}, x_{min}, y_{min}, and z_{min} numerically based on predictions. We considered four AI algorithms: Support Vector Regression (SVR), K-Nearest Neighbors (KNN), eXtreme Gradient Boosting (XGB), and Generalized Additive Model (GAM).

Using software tools and three magnetic field components, we considered 1000 input data points (B_{1x}, B_{1y}, B_{1z}) and obtained output data ($B_{\mathrm{min}}, x_{\mathrm{min}}, y_{\mathrm{min}}, z_{\mathrm{min}}$). The dataset was divided into two parts: 85% for training data and 15% for validation data for prediction.

Optimal Control of Coupled Buildings Under Seismic Excitation

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keywords: optimal control, two-criterion control problem, generalized H2-norm

The structural control of seismic protection of structures has attracted the attention of the whole world. The main purpose of the seismic protection systems is to mitigate the response caused by earthquake. Although passive isolation systems have been used in civil structures, if earthquakes of such great magnitude occur that these systems arc ineffectual, a smart seismic protection system may be useful. Smart seismic protection system is a system which has sensor, data process and acquisition unit and controller devices including dampers and actuators to generate required control force. By incorporating these units, smart connection can monitor environmental changes and becomes an adaptive system.

Among the numerous ideas and technical implementations, the idea of connecting closely spaced structures with a control device for mutual damping of their vibrations occupies an important place. It is proposed to address the problem of finding optimal control by considering the example of two connected objects. The problem is formulated as a two-criteria optimization problem, where the criteria aim to minimize the maximum deformation of each object under the worst-case disturbance from the class L_2. For solving this two-criterion problem, a concept of generalized H_2-norm for linear invariant systems and LMI technique are utilized.

As part of the work, numerical modeling of the proposed solution was conducted on systems with two objects with similar and different characteristics. The results of the proposed method were also compared to a passive control in the form of a simple damper. To illustrate the results, Pareto optimal front were used, which display a set of optimal solutions for the problem. The findings indicate that the use of optimal control in most cases leads to a significant reduction in maximum deformation. Given the complexity of implementing this approach in real-world conditions, it is recommended to use the proposed method to evaluate other seismic protection methods and tools.

This work was supported by Russian Scientific Foundation (Project No. 24-11-20023)

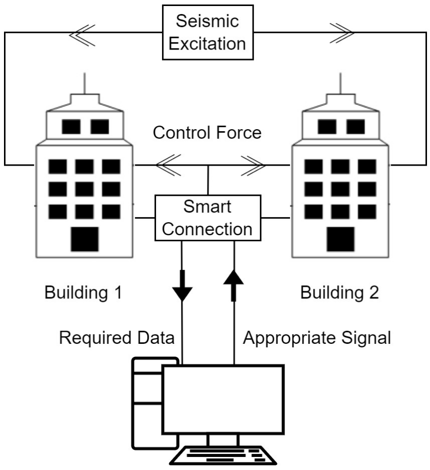

Figure 1: Model of a smart control

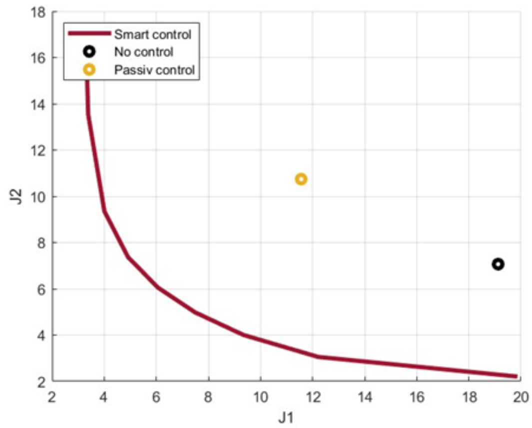

Figure 2: Comparison of the damper and optimal control

Synthesis and Characterization of Tin Oxide SnO_2 Prepared by Ultrasonic Spray

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keywords: hin film, SnO_2, doping, structure, conductivity, optical properties

SnO_2 (tin oxide) is a material widely used in various fields of electronic and optical applications, including in the design of photovoltaic cells. This material arouses industrial interest because of its physical-chemical properties which are closely linked to the processes and conditions of their elaboration.

The objective of this work consists in the synthesis and the study of the properties of SnO_2 doped with Al thin films developed by ultrasonic spray at different temperatures of the glass substrate. The obtained results show that SnO_2 layers are transparent in the visible domain with transmittance close to 80%, and their structure is of rutile tetragonal type with a preferential orientation along the axes (110), (101), (211). The influence of substrate temperature on the optical, structural, and electrical properties is studied. The thin layers of SnO_2 doped with aluminum exhibit improved conductivity.

Insight Into Physical Properties of Silver-Based Half-Heusler Semiconductors

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keywords: DFT Calculation; half-Heusler alloy; semiconductor; elastic properties; absorption coefficient; merit factor

In this study, we investigate the properties of AgYTe (Y = Li, Na, and K) half-Heusler compounds using density functional theory and semi-classical Boltzmann transport theory. The objective is to discover novel materials more suitable for optoelectronic and thermoelectric applications. The electronic property findings obtained using the TB-mBJ potential show that AgYTe compounds demonstrate characteristics of direct bandgap semiconductors, with gap values of 1.73 eV, 1.71 eV, and 1.59 eV for AgKTe, AgLiTe, and AgNaTe, respectively. The negative values obtained for both formation and cohesive energies emphasize the energetic and dynamic stability demonstrated by these alloys. Furthermore, they exhibit stability under shape deformation as they fully meet the Born elastic stability criteria. The optical calculations suggest that AgYTe half-Heusler alloys exhibit activity across a broad range of the electromagnetic spectrum, making them suitable for optoelectronic applications. Both AgLiTe and AgNaTe demonstrate high absorption coefficients of approximately 80×10^4 cm^{-1} in the visible range and around 142×10^4 cm^{-1} in the near UV. In contrast, AgKTe exhibits its peak absorption in the far UV, reaching 181×10^4 cm^{-1} at 23 eV. The high reflectivity of AgNaTe, surpassing 73% in the near-infrared region, and 68% for AgLiTe in the ultraviolet region, renders them effective shields in these spectral regions. The ZT values obtained across a broad temperature range, nearly approaching unity, indicate that these three new half-Heusler alloys show considerable promise as candidates for thermoelectric devices.

Statistical Investigation of the Effect of Lubrican Viscosity on Surface Degradation of a Polluted Elastohydrodynamic Contact

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keywords: contact, lubrication, solid pollution, wear, regression

The proper functioning of the mechanical components of elastohydrodynamic contacts is guaranteed by the preservation of a good surface condition. The experimental investigation focuses on the effect of viscosity and its interaction with the operating parameters on the degradation of the mechanical contact surfaces. In our study, Grubbs and Shapiro-Wilk tests are used to validate the experimental results obtained. Normality tests are used in different areas as parametric analysis. A regression study was approached in order to statistically model the roughness. This allows detecting the influence of viscosity and its interaction with the studied parameters: velocity, load, and solid pollution. The ANOVA analysis will provide more information by calculating the contribution values of the studied parameters. From this analysis, it can be observed that viscosity does not have a pure influence; rather, its interaction with the parameters speed, load, and pollution influences the degradation of the surfaces.

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Modeling Chemical Product Behavior for CIP Tubular Heat Exchangers Using MATLAB Software

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For tubular heat exchangers fouling is an economic problem which torments the industries for a long time. It results in loss of a rather important performance, the control of this phenomenon aims to foresee the right time for the cleaning in place of the equipment and the analysis of industrial products. A classic and efficient method is opted to validate the cleaning efficiency of the product produced, which is the gravimetric method. Presented experiments explaining the cleaning method used on samples of XC 38 steel of the same steel from heat exchangers to industry, taking into account the appropriate concentrations of the use of chemicals products regarding their efficiency and their cost, temperature and time. Data analysis has enabled us by using the MATLAB tool to optimize the results obtained experimentally and show the degree of cleaning efficiency of the product and following a well-defined protocol in terms of time and temperature.

Control on Epileptiform Regimes in the Statistical Model for Mesoscale Neural Population

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keywords: neural population, epileptiform behavior, Buice–Cowan model, generalized telegraph equation, feedback control

Developing different mathematical approaches for the detection and suppression of epilepsy in the human brain is a subject of great importance. To cover the temporal evolution of the hyper-synchronization in neural clusters and to combine it with spatial dynamics, we develop here a novel model for the space-and-time dynamics control on epileptiform regimes in mesoscale neural populations based on our two previously invented models.

The first source of our novel model for excitation and hyper-synchronization in the neural populations is the adaptation of the Buice-Cowan model, which describes transitions among different statistical groups of the neurons: low-level excited L, high-level excited H, and hyper-synchronized S. The transition coefficients in the corresponding master equations play the role of control parameters regulating the dominant regime in the neural cluster. The model has only the time component, and it is mostly designed to track the epileptiform behavior in small neural populations.

The second source is the modified Cattaneo equation (or generalized telegraph equation), which we used for the analysis of the spacial features of epileptiform fluxes in the form of traveling waves.

Here we add the spatial component of our Cattaneo-type approach to all three statistical groups of neurons: L, H, and S to study their spatial dynamics. Thus, in contrast to the standard Buice–Cowan model formulated on a lattice, our approach is based on the field-type traveling wave description. In other words, we focus on the mesoscale of the epileptiform regime with the continuous spatial component. Then we discuss basic feedback control algorithms to suppress the epileptiform hyper-synchronized regime.

This work was supported by the Abdullah Gül University Foundation, Project 'Feedback control of epileptiform behavior in the mathematical models of neuron clusters'.

Comparative Analysis of Ceramic, and Composite Solid-State Electrolytes for Lithium-Ion Batteries

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keywords: lithium-ion batteries, solid-state electrolytes, ionic conductivity, mechanical strength, energy density

This paper explores advancements in solid-state electrolytes (SSEs) for lithium-ion batteries (LIBs), focusing particularly on ceramic and composite variants. SSEs have gained prominence due to safety concerns associated with conventional liquid electrolytes, including flammability and leakage. Through simulations, this study investigates how varying dopant levels and processing temperatures impact the ionic conductivity, mechanical strength, and electrochemical stability of ceramic and composite electrolytes. Ceramic electrolytes, such as Li7La3Zr2O12 (LLZO), are highlighted for their exceptional ionic conductivity and electrochemical stability, making them well-suited for high-performance applications despite challenges related to brittleness and processing complexity. Meanwhile, composite electrolytes, which blend ceramic and polymer characteristics, aim to combine the high ionic conductivity and mechanical resilience of ceramics with the processing advantages of polymers.

Promising results from PEO-ceramic composites show moderate ionic conductivity, mechanical strength, and enhanced stability. The findings underscore ceramic electrolytes' potential to significantly enhance LIB performance, while composite electrolytes offer a balanced alternative with versatile properties. Future research directions should prioritize optimizing these materials for practical integration into commercial LIBs, focusing on improving safety, energy density, and cycle life metrics. This study highlights the critical role of SSEs in advancing next-generation LIBs, emphasizing improvements in safety and performance parameters such as energy density and storage capacity.

Use of Plastic Waste as Sand in Concrete

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keywords: valorisation, plastic waste, concrete, replacement, durability

Recycling and valorization of waste in civil engineering is an important sector, it has two sensitive targets: environment protection and economic improvement. Current study used plastic waste, which has become invasive worldwide and poses environmental hazards due to its bulky and unsightly nature.

The main objective of this work is to test the effect of partial replacement of natural sand by a powder of plastic waste in the composition of concrete, in order to preserve natural resource of sand. To achieve this study, in the composition of a reference concrete formulated using the "Dreux Gorisse" method, dune sand will be substituted by crushed PVC from false ceilings. The chosen substitution rates are: 1%, 2%, 3% and 4%. The behavior of the freshly prepared concretes (workability and density) as well as the hardened state (compressive and flexural strength) and chemical attacks (mass loss in chlorides, mass loss in sulfuric acid) will be evaluated and compared to those of a reference ordinary concrete composed initially of dune sand.

Based on the obtained results, it can be concluded that substituting sand by plastic powder leads to significant decreases in the density of all the studied mixtures, as well as a decrease in the mechanic performance but still acceptable, however, the mixes containing plastic waste were more resistant to sulfuric acid and salt attacks. This possibility represents a promising approach to valorize plastic waste in concrete, aiming to preserve natural resources, reduce concrete production costs, and contribute to environmental protection by limiting waste at its source.