
ARISTOTLE UNIVERSITY OF THESSALONIKI

# Περιλήψεις παρουσιάσεων

## Θερινό Σχολείο – Συνέδριο «Δυναμικά Συστήματα και Πολυπλοκότητα»,

Πανεπιστημιακή Κατασκήνωση Καλάνδρας Χαλκιδικής, 28/8 – 6/9/2024

# Abstracts of Presentations

## Summer School and Conference on Dynamical Systems and Complexity

University camping of Kalandra Chalkidiki,

28/8 – 6/9/2024

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Ευχαριστούμε όλους τους/τις ομιλητές/τριες που δέχθηκαν ή προσφέρθηκαν να παρουσιάσουν εισαγωγική ή ερευνητική ομιλία στο Θερινό Σχολείο – Συνέδριο «Δυναμικά Συστήματα και Πολυπλοκότητα» στην Πανεπιστημιακή Κατασκήνωση Καλάνδρας Χαλκιδικής, 28/8 – 6/9/2024.

Στη συνέχεια δίνονται οι περιλήψεις των εισαγωγικών και ερευνητικών παρουσιάσεων. Παρουσιάσεις που μπορούν να γίνουν στα Αγγλικά (παρουσία μη-ελληνόφωνου κοινού) δίνονται πρώτες στη λίστα περιλήψεων με όλα τα στοιχεία στα Αγγλικά με αλφαβητική σειρά ως προς τον πρώτο/η ομιλητή/τρια. Παρουσιάσεις που θα γίνουν στα Ελληνικά δίνονται στην συνέχεια με όλα τα στοιχεία στα Ελληνικά επίσης με αλφαβητική σειρά ως προς τον πρώτο/η ομιλητή/τρια. Στην κορυφή κάθε περίληψης υπάρχει ένδειξη αν η ομιλία είναι εισαγωγική ή ερευνητική.

Η τοπική οργανωτική επιτροπή

Καθ. Βουγιατζής Γιώργος

Καθ. Κουγιουμτζής Δημήτρης

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We thank all speakers who accepted or offered to present an introductory or research talk in the Summer School and Conference on Dynamical Systems and Complexity at the University camping of Kalandra Chalkidiki, 28/8 – 6/9/2024.

Below are the abstracts of the introductory and research talks. Presentations that can be given in English (provided the presence of non-Greek audience) are given first in the abstract list with all details in English at alphabetical order with respect to the (first) speaker surname. Presentations to be given in Greek follow and all details are given in Greek also at alphabetical order with respect to the (first) speaker surname. On top of every talk there is an indication of whether it is an introductory or research talk.

The local organizing committee

Prof. Kugiumtzis Dimitris

Prof. Voyatzis Giorgos

**Introductory talk**

## Complexity through networks and graphs

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Networks have been widely used in the past 25 years to enhance our understanding of a very large variety of systems pertaining to aspects of everyday life that belong practically to all sciences and all areas of studies. The impetus has definitively been given by the emergence of the internet, which has changed our lives irrevocably. The first question of interest that arose with the development of the internet was how is the connectivity between the nodes structured, and how does it affect the dynamics of the way that people communicate. Strangely and unexpectedly the connectivity distribution proved to be a simple power law. Subsequently, it was shown that a very large variety of systems also followed similar distributions. We will discuss the details of these structures and show several different examples ranging from the structure of the protein networks, the transportation network, the brain neural networks, the cinema actors network, the social networks, economical networks, and several more. While the new knowledge attained by the networks as complex systems has not solved any perennial problems in any field, still, networks have offered a new and different way of approaching of these systems, which has been very valuable in our understanding of nature.

**Research talk**

## Smart algorithms in statistical physics: the percolation problem

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We present the percolation model, which together with the Ising model are the two basic models in statistical physics. These models are made of units of two opposite entities that are randomly mixed in some geometric structures (e.g. 0 and 1, or conducting and insulating). The basic feature of these models is that they undergo a phase transition with a critical point. They are studied using Monte-Carlo simulation methods, so it is quite straight forward to obtain all critical parameters of the phase transition, such as the critical point, the critical exponents, etc. To avoid finite-size effects that appear in small size systems one needs to use a simulation of very large size made of several million or of billion units. However, this is very time-consuming. To solve such problems one has to use smart algorithms that keep only a minimal amount of information during the processing of the calculation. Such algorithms will be explained in detail.

**Introductory talk**

## Algorithmic Complexity and the Hard Limits of Artificial Intelligence: a tale of Chaitin's Omega, Fractal Basins & Bayesian Inference

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This year we celebrated a very special birthday, the birthday of a number, a very special number, called Omega by his father and known as Chaitin's Omega Number or Chaitin's Constant.
This number represents the probability that a random computer programme will come to a halt.
To approach Omega, we will begin by discussing Cantor's diagonal argument, or 'trick', to arrive at Gödel's undecidability of the 'truth problem' and Alan Turing's advance to the 'halting problem', then we will arrive at Chaitin's constant, Ω.
Chaitin's Ω is subtle: it is a definable real number in [0,1]. This means that it is uniquely specified by its description via a formal language, i.e. π, e, √2 etc., also called arithmetic numbers.
It is trancendental, i.e. it is not the root of a polynomial. It is also algorithmically random and normal, i.e. its digits are evenly distributed, i.e. its digits are unpredictable and random, like flipping a (fair) coin. But it is not computable because it is a halting probability. Omega is subtle because, as a whole, it encapsulates an infinite amount of information about the halting problem. As in an undecidable problem, there is no finite program that can fully describe the uncomputable Omega. It was discovered by Chaitin 50 years ago to the day, and there are very few of its kind in existence still today.
Similar problems of computational undecidability abound in fractals. Julia set membership is one of them. It encodes the halting problem due to the non-linear, complex behaviour of its iterations. The best known example is the search for roots of polynomials using Newton's method. Newton's fractals, due to their fractal boundary conditions, exemplify decision making where Bayesian methods would reach their limits and a non-algorithmic version of Bayesian inference has to be called for. We will briefly describe this case and argue that these are hard limits for the so-called artificial intelligence (AI) paradigm. And we will also see why biological intelligence would forever remain far beyond these hard limits of AI.

Selected Bibliography:
1. Gregory Chaitin, “Philosophical Computing: Reflections on the fiftieth anniversary of the halting probability”, Institute for Advanced Studies, UM6P Ben Guerir, August 6, 2024. https://uba.academia.edu/GregoryChaitin
2. Calude, Cristian S., ed. “Randomness and Complexity. From Leibniz to Chaitin”, World Scientific, 2007.
3. Gregory Chaitin, “Algorithmic Information Theory”, Cambridge University Press (2nd edition), 2009.

4. Basios, Vasileios, Yukio-Pegio Gunji, and Pier-Francesco Moretti. "Extending the Bayesian Framework from Information to Action". Int'l. Conf. on Complex Systems & Applications Network Summer School. Springer, 2022.
5. Gunji, Y. P., S. Shinohara, and V. Basios. "Connecting the free energy principle with quantum cognition." Frontiers in Neurorobotics 16 (2022): 910161-910161.
6. Gunji, Y. P., Murakami, H., Tomaru, T., & Basios, V. (2018). "Inverse Bayesian inference in swarming behaviour of soldier crabs'. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 376(2135), 20170370.
7. Basios, Vasileios &Yukio-Pegio Gunji. "Chaotic Dynamics in Biological Information Processing: Revisiting and Revealing its Logic (a mini-review)" Opera Medica et Physiologica 3.1 (2017): 1-13.

**Introductory talk**

## From Network Neuroscience to Network Neurology: 25 years of development and innovation

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The seminar will begin with an overview of the historical development of network neuroscience, which emerged from the mathematical formulation of network models using graph theory and its applications to the neural networks of the brain already known from anatomy and physiology. The results of mathematical analyses based on experimental data derived from modern brain imaging techniques helped to understand the importance of not only the existence of neurons in the brain, but also that the communication between them. In this way, we can monitor rapid phenomena such as cognition or the brain's response to external stimuli, and slow phenomena such as the progression of Alzheimer's disease, schizophrenia, depression, etc. In the second part, the speaker will present the important discoveries made with the application of connectivity analysis in the healthy brain and mental disorders. To name a few, (1) the discovery that brain plasticity is a matter of hours, not days, (2) the visualization of brain conditioning to perform repetitive tasks, (3) advances in the study of fatigue mechanisms, and (4) the brain response in autonomous driving.

**Research talk**

## Brain Heart Lung Communication. An organomics approach to complex neurological problems

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In this work, we investigate the nature of the brain heart lung communication and derive biomarkers that play an important role in various diseases. The interactions between the brain, lungs, heart involves intricate and highly coordinated mechanisms that ensure the maintenance of homeostasis and the overall functioning of the body. Their interactions are governed by complex feedback mechanisms that ensure adequate oxygenation, nutrient delivery, and waste removal, all while adapting to the body's varying demands. In more detail, the brainstem contains the respiratory center, which controls the rate and depth of breathing. In parallel, the brain regulates heart rate and blood pressure through the autonomic nervous system. The sympathetic nervous system increases heart rate and contractility during stress or physical activity, while the parasympathetic nervous system slows the heart rate during rest.

In this work, we present methods from linear and nonlinear sciences to investigate the nature of the three organ communication and derive biomarkers that play an important role in the progression of various brain disorders.

As a study case, we will present results from the application of the above methods to data collected from epileptic mice, with the ultimate goal of elucidating the mechanisms of sudden unexpected death in epilepsy (SUDEP).

SUDEP, the leading cause of death in epilepsy with an incidence rate of approximately 0.5% of the epilepsy population per year, has only recently begun to be addressed. To reveal the complex interactions between brain, heart and lungs and reveal the SUDEP mechanisms, we performed an experiment recording electroencephalogram (EEG), electrocardiogram (ECG) (from which the heart rate (HRV) variability was extracted) and whole body plethysmography signals in Wild Type (WT) and SUDEP prone Knock out (KO) animals. Firstly, using multivariate autoregressive models (MVAR) models, we estimated all three-organ effective directional interactions using generalized partial directed coherence (GPDC). Furthermore, to assess both the strength as well as the direction of phase relations between the signals, we used the directed phase lag index (dPLI). The statistically significant abnormalities in the SUDEP-prone KO animals measured by GPDC were between the brain-heart and brain-lung connectivity. The dPLI, which is sensitive to instantaneous changes in connectivity between the three organs, highlighted the differences in the network between normal conditions and seizure events.

**Introductory talk**

## Fundamental Concepts of Chaos and the Importance of Mathematics

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In this lecture, I will begin with a summary of fundamental mathematical concepts of Complexity in nonlinear dynamical systems, by outlining the mathematical meaning of chaos and its connections to fractal geometry. I will then proceed to examine the deep connection between the mathematical analysis of nonlinear ordinary differential equations and the emergence of chaos in their solutions. We will start with the concept of integrability, through the analysis of singularities of these solutions in the complex time plane. We will show that when these singularities are all movable poles, and the presence of the so-called Painlevé property is established, the equations are integrable on a single Riemann sheet and no chaos exists. However, in the general case, these singularities are logarithmic, the Riemann surface is infinitely sheeted in the complex time plane, and chaos emerges in real time!

References:

1. ''Dynamical Systems and Chaos'', volume 1, in Greek (G. Papasotiriou, Athens, 1995).
2. ''Dynamical Systems and Chaos'', volume 2, in Greek (University of Patras Press, Patras, 1997).
3. ''Nonlinear Ordinary Differential Equations'', in Greek (G. Pnevmatikos. Athens, 1997).
4. “The Wonderful World of Fractals”, in Greek (Leader Books, Athens, 2004).
5. “Dynamical Systems and an Introduction to the Theory of Chaos”, in Greek, with St. Anastassiou (A. Pnevmatikos, Athens 2021).
6. A. Ramani, B. Grammaticos, T. Bountis, ''The Painleve Property and Singularity Analysis of Integrable and Non-Integrable Systems'', Physics Reports, 180 (3), 159 (1989).
7. T. Bountis, ''What Can Complex Time Tell Us About Real Time Dynamics?'', Int. J. of Bifurcation \& Chaos, 2 (2), 217 (1992).
8. T. Bountis, ''Investigating Non-Integrability and Chaos in Complex Time'', Physica D86 , 256-267 (1995).

**Introductory talk**

## Energy Transport in 1-D Hamiltonian Lattices: from Physics to Engineering (Non-Analytic Potentials)

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Energy transport in 1-dimensional oscillator arrays has been extensively studied to date in the conservative case, as well as under weak viscous damping. When driven at one end by a sinusoidal force, such arrays are known to exhibit the phenomenon of supratransmission, i.e. a sudden energy surge above a critical driving amplitude. In this lecture, we will speak about 1-dimensional oscillator chains in the presence of hysteretic damping and include nonlinear stiffness forces that are important for many materials at high energies. We first employ Reid's model of local hysteretic damping, and then study a new model of nearest neighbor dependent hysteretic damping to compare their supra transmission and wave packet spreading properties in a deterministic as well as stochastic setting. The results have important quantitative differences, which should be helpful when comparing the merits of the two models in specific engineering applications.

References:
1. A. Bountis, K. Kaloudis and Ch. Spitas, "Periodically Forced Nonlinear Oscillators With Hysteretic Damping", Journal of Computational Nonlinear Dynamics, 15 (12) 121006 (2020).
2. A. Bountis, K. Kaloudis, Th. Oikonomou, B. Many Manda, Ch. Skokos, "Stability Properties of 1-D Hamiltonian Lattices with Non-Analytic Potentials", IJBC Volume No. 30, Issue No. 15, Article No. 2030047 (2020).
3. Bountis T., Kaloudis K., Shena J., Skokos Ch., and Spitas Ch., ``Energy Transport in 1-Dimensional Oscillator Arrays with Hysteretic Damping'', Eur. Phys. J. Spec. Top. 231: 225-236 (2022).

**Introductory talk**

## Geometry and String Theory Confronting Black Holes and Particle Physics

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In the past decades, String Theory has emerged as the prime candidate for quantum unification of electromagnetic, nuclear, and weak forces with gravitational ones. It has shed light on important fundamental questions of theoretical physics, such as the microscopic structure of black holes and the geometric origin of particle physics. We review these developments, such as the introduction of extended objects - Dirichlet branes - and highlight the important geometric and dual role these objects play in the microscopic structure of black holes as well as the Standard Model of particle physics. We focus on extremal black holes and also highlight some progress in studies of the internal structure of non-extremal black holes via the introduction of the so-called subtracted geometry and its connections to two-dimensional models of quantum gravity.

**Introductory talk**

## Fractal Geometry and its applications

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Fractal geometry is a subject that has enjoyed substantial growth over the past decades or so and has established connections with many areas of mathematics (including harmonic analysis, potential theory, partial differential equations, probability theory, operator algebra, number theory and dynamic systems) [1]. It is also intrinsically a cross-disciplinary subject, with motivations from and applications to physics, biology, geology, economics, and even some artistic fields, like painting and music [2]. Most physical systems of nature and many human artefacts are not regular geometric shapes of the Euclidean geometry. Fractal geometry offers almost unlimited ways of describing, measuring and predicting these natural phenomena [3]. Many people are fascinated by beautiful images of fractals. Extending beyond the typical perception of mathematics as a body of complicated, boring formulas, fractal geometry mixes art with mathematics to demonstrate that equations are more than just a collection of numbers [4]. What makes fractals even more interesting is that they are the best existing mathematical descriptions of many natural forms, such as coastlines, mountains or parts of living organisms [5]. The main purpose of this talk is to provide a brief introduction to fractals, with an emphasis on the distinction between different categories (self-affine versus self-similar and deterministic versus statistical) while, simultaneously, providing an overview of the application of fractals in different fields [6].

Keywords: Computer Graphics, Dimension, Dynamic System, Fractal, Interpolation, Chaos.

References:
[1] B. B. Mandelbrot, "The Fractal Geometry of Nature", W. H. Freeman and co., San Francisco, 1982.
[2] T. Μπούντης, "Ο Θαυμαστός κόσμος των φράκταλ", Leader Books, 2004.
[3] M. F. Barnsley, "Fractals everywhere", 3rd ed., Dover Publications, Inc., 2012.
[4] K. Falconer, "Fractal Geometry: Mathematical Foundations and Applications", 3rd. ed., John Wiley & Sons, Ltd, 2014.
[5] P. R. Massopust, "Fractal functions, fractal surfaces and wavelets", 2nd ed., Academic Press, San Diego, CA, 2016.
[6] V. Drakopoulos, "Fractal-based image encoding and compression techniques", Commun. – Scientific Letters of the University of Žilina, vol. 15 (3), 48–55, (2013).

**Introductory talk**

## Pink Noise is the Canonical Representation of Environmental Variability

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Environmental variability is a key feature of all our attempts to describe and predict natural or anthropogenic processes. So, we need a process which describes environmental variability, with memory ranging from timescales of microseconds to geological epochs. Pink noise (or 1/f-noise) contributes variability equally to all timescales, in contrast to the current widely-used models of variability. The ubiquity and dominance of pink noise was recognized and demonstrated in various disciplines. However, its ubiquity in natural data contrasts starkly with its absence in applications in the environmental sciences. Today most analysis in Ecology, for example, continue without a credible model of environmental variability, leading to various errors and problems. Both because of its widespread observation and because of inherent logic, pink noise is a credible null model of environmental variability which should be standard for ecological and other environmental models. In this talk I will explain the importance of this issue and why pink noise should have greater representation and why in fact it does not.

**Research talk**

## Complex dynamics of superconducting neurons

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Neuromorphic computing exploits the dynamical analogy between many physical systems and neuron biophysics. Superconductor systems, in particular, are excellent candidates for neuromorphic devices due to their capacity to operate at great speeds and with low energy dissipation compared to their silicon counterparts. In this talk, we present two types of Josephson-junction-based neuromorphic circuits, one resistively and one inductively coupled. We review the differences in their dynamical properties and identify how our findings relate to neurocomputation.

**Introductory talk**

## Application of non-linear time series analysis in physical, engineering and financial systems

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In the present lecture we review briefly several methods of temporal and non-linear time series analysis, mainly based on phase space reconstruction such as recurrence plots [1] as well as complex network transformed time series [2]. We discuss the main characteristics of the methods and the possible vision they can provide of the underlying physical, engineering, and financial systems with a special focus on system identification and transition detection. Several applications from turbulent flows [3, 4], incident detection in traffic data [4] are presented and explained in detail. We also present an example of change point detection using the backward degree of complex transformed networks [5] as well as a nonlinear methodology for financial bubble detection [6]. Moreover, we present also a combination of a deep learning recurrent neural network and Lyapunov time is proposed to forecast the consumption of electricity load, in Greece, in normal/abrupt change value areas [7].

References

[1] Marwan, N., Romano, M. C., Thiel, M., & Kurths, J. (2007). Recurrence plots for the analysis of complex systems. Physics reports, 438(5-6), 237-329.
[2] Lacasa, L., Luque, B., Ballesteros, F., Luque, J., & Nuno, J. C. (2008). From time series to complex networks: The visibility graph. Proceedings of the National Academy of Sciences, 105(13), 4972-4975.
[3] Fragkou, A., Karakasidis, T., Sarris, I., & Andreadis, I. (2023). Application of the visual boundary recurrence plots to magnetohydrodynamic turbulence channel flow. Physics of Fluids, 35, 105108,
[4] Charakopoulos, A., Karakasidis, T., & Sarris, I. (2021). Analysis of magnetohydrodynamic channel flow through complex network analysis. Chaos, 31(4).
[5] Charakopoulos, A., & Karakasidis, T. (2022). Backward degree a new index for online and offline change point detection based on complex network analysis. Physica A, 604, 127929.
[6] Papastamatiou, K., & Karakasidis, T. (2022). Bubble detection in Greek Stock Market: A DS-LPPLS model approach. Physica A, 587, 126533.
[7] Stergiou, K., & Karakasidis, T. E. (2021). Application of deep learning and chaos theory for load forecasting in Greece. Neural Computing and Applications, 33(23), 16713-16731.

**Introductory talk**

## On quadrirational pentagon maps

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The first part of this talk serves as an introduction to integrable systems, with a particular focus on the notion of discrete integrability [1]. In the second part of the talk we focus on the pentagon equation that serves as an important equation in mathematical physics [2,3,4]. It appears in two equally significant versions, the operator and the set-theoretical one. Here we will discuss the set-theoretic version of the pentagon equation where its solutions are referred to as pentagon maps. Firstly, we will introduce a specific class of matrices which participate in factorization problems that turn to be equivalent to pentagon maps, expressed in totally non-commutative variables [5]. Secondly, we will propose a classification scheme for rational solutions of a specific type of the pentagon equation. That is, we will give a full list of representatives of quadrirational maps that satisfy the pentagon equation, modulo an equivalence relation that is defined on birational functions on $CP^1xCP^1$ [6]. Finally, we will show how from a pentagon map that admits a partial inverse, we can obtain set theoretical solutions of the so-called entwining pentagon equation.

Keywords: Discrete integrable systems, Menelaus configuration, pentagon maps

References:
[1] N Hietarinta, J. Joshi and F.W. Nijhoff. Discrete Systems and Integrability. Cambridge Texts in Applied Mathematics (No. 54). Cambridge University Press, (2016).
[2] A. Dimakis. and F. Muller-Hoissen, Simplex and polygon equations, SIGMA 11 (2015), 042, 49 pages, arXiv:1409.7855.
[3] Doliwa, A. and Sergeev, S. The pentagon relation and incidence geometry, J. Math. Phys. 55, 063504 (2014)
[4] I.G. Korepanov. Algebraic integrable dynamical systems, 2 + 1-dimensional models in wholly discrete spacetime, and inhomogeneous models in 2-dimensional statistical physics. arXiv:9506003[solv-int], (1995).
[5] P. Kassotakis, Matrix factorizations and pentagon maps, Proc. R. Soc. A. 479, 20230276, (2023).
[6] Evripidou, C. and Kassotakis, P. and Tongas, A. On quadrirational pentagon maps, arXiv:2405.04945, (2024)

**Research talk**

# A novel epidemiologically informed particle filter for assessing epidemic phenomena.

## Application to the monkeypox outbreak of 2022

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Contagious diseases are constantly affecting more and more people every day, resulting in widespread health crises especially in developing nations. Previous studies have developed deterministic and stochastic mathematical models to investigate the spread of epidemics. In the present study, a hybrid particle filtering epidemiological model is presented, which combines the elements of a deterministic susceptible-exposed-infectious-recovered-deceased model with the inclusion of stochastic and penalty factors, in order to efficiently evaluate the dynamics of the disease. The inclusion of penalty factors stands out as the main novelty of the proposed methodology, guaranteeing estimations that align with the unique aspects of the examined natural phenomenon. The model is applied to the monkeypox data of the United States from 25 June to 21 November 2022. Our approach is compared to four alternatives, corresponding to deterministic and stochastic approaches that are associated with either fixed or time-varying parameters. In all cases, the particle filtering models displayed better characteristics in terms of infectious cases and deaths compared to their deterministic counterpart. The final version of the proposed epidemiologically informed particle filtering model exhibited significant potential and provided the best fitting/predictive performance compared to other examined methodologies. This modeling approach can be readily applied to other epidemics, both existing and emerging, where uncertainties in system dynamics and real-time observations hinder the accurate capture of the epidemic's progression.

Keywords: particle filtering, Bayesian estimation, epidemiological modeling, population dynamics, epidemics, monkeypox

**Research talk**

## Planar and three-dimensional retrograde periodic orbits of asteroids

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We study planar resonant retrograde periodic orbits, by using the model of the restricted three-body problem with the Sun and Jupiter as primaries. The position and the stability character of the periodic orbits are very useful for the study of the phase space structure. The starting point of the present study is the planar circular restricted three-body problem. Families of periodic orbits are computed at the interior mean motion resonances of 1st , 2nd and 3rd order with Jupiter and these are used as a guide to select the energy levels for the computation of the Poincar\'e maps. Thus, the most important resonances are included in our study. At the second stage of our work, we consider the second primary moves on an elliptic orbit around Sun. Families of retrograde symmetric periodic orbits of the planar elliptic restricted three-body problem are found. All these orbits bifurcate from the families of symmetric periodic orbits of the planar, circular, restricted three-body problem. The stability of all orbits is also examined.
At the third part of our work, we computed families of symmetric periodic orbits in the framework of 3D circular, restricted 3-body problem at 1st, 2nd and 3rd order mean motion resonances with Jupiter. We examined both direct and retrograde orbits. More precisely, we studied the stability character of periodic orbits and we constructed the diagrams e-I (eccentricity—inclination), on which they are presented. We applied our results to the asteroid 2009 HC82, which is currently located at 3/1 mean motion resonance with Jupiter and moves on a retrograde orbit. Finally, we constructed dynamical stability maps and we showed the stable and chaotic regions of motion.

**Introductory talk**

## Complex Networks Estimation from Multivariate Time Series

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In the study of complex dynamical systems, such as brain dynamics and financial market dynamics, from multivariate time series, a main objective is the estimation of the connectivity structure of the observed variables (or subsystems), where connectivity is also referred to as inter-dependence, coupling, information flow or Granger causality. Having selected a connectivity measure to estimate the driving-response connections among the observed variables, the complex network is then formed, called also connectivity or causality network, where the nodes are the observed variables, and the connections are the estimated inter-dependences. For a network with binary connections the inter-dependences are discretized to zero (not significant) and one (significant) by applying a criterion for the significance, e.g. arbitrary threshold or statistical testing.
There is a main and practical issue in the connectivity analysis: estimation of direct inter-dependence in the presence of many observed variables, where direct inter-dependence between two variables excludes the inter-dependence mediated by the presence of the other observed variables. To address this issue, inevitably one has to involve a dimension reduction scheme in the estimation of direct connectivity.
I will present the framework of connectivity analysis of multivariate time series and focus on direct connections and many observed variables. In our research group, we have developed appropriate methodology for this scope and in the last part I will attempt to introduce causality measures that apply dimension reduction. I will illustrate on simulated data the ability of causality measures using dimension reduction to identify the underlying complex network (connectivity structure of the underlying complex system) solely on the basis of the observed multivariate times series. I will then move to real-world applications and estimate changes of the connectivity structure in time series records of epileptic electroencephalograms and world financial markets.

Keywords: multivariate time series, complex systems, complex networks, Granger causality, dimension reduction

**Research talk**

## Magnetic Field Influence on Blood Flow in Pathological Vessels: A Computational Study

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This presentation discusses the implementation of advanced numerical methods for solving partial differential equations in the field of fluid mechanics. More specifically, a mathematical model is presented that describes the influence of a magnetic field on blood flow within a pathological vessel. Generalized curvilinear coordinates and the numerical method of the finite volume are utilized. The findings underscore the substantial influence of the magnetic field, particularly on parameters such as the velocity field q and pressure drop, $\Delta p$, offering valuable insights into the interplay between magnetic fields and blood flow dynamics.

**Research talk**

## Hidden attractors: new horizons in exploring dynamical systems

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Hidden attractors have been known since the 1960s when they were discovered and observed in various nonlinear control systems[1]. It is the last decade where several scientists have intensively studied hidden attractors.

Hidden are called the attractors whose basin of attraction does not intersect with small neighborhoods of the unstable equilibrium point, i.e., their basins of attraction do not touch unstable equilibrium points and are located far away from them[2]. They can be found in systems with no equilibrium points[3], with one stable equilibrium[4], or in systems with lines of equilibrium points[5].

Hidden attractors often have small basins of attractions, are strongly chaotic, and have complex dynamics. This property can be helpful or catastrophic, especially in technological applications.

In this talk, we will make a short review on this topic and present different systems with Hidden Attractors [6-7]

Keywords: Hidden attractors, chaotic dynamical systems, complex dynamics.

References:

[1] L. Markus, H. Yamabe, “Global stability criteria for differential systems”, Osaka Math. J. 12, 305, 1960.

[2] Dudkowski, D., Jafari, S., Kapitaniak, T., Kuznetsov, N. V., Leonov, G. A., and Prasad, A. “Hidden attractors in dynamical systems”. Physics Reports, 637, 1-50, 2016.

[3] Pham, V. T., Jafari, S., Volos, C., Wang, X., and Golpayegani, S. M. R. H. “Is that really hidden? The presence of complex fixed-points in chaotic flows with no equilibria”. International Journal of Bifurcation and Chaos, 24(11), 2014.

[4] Wang, Xiong, and Guanrong Chen. “A chaotic system with only one stable equilibrium”. Communications in Nonlinear Science and Numerical Simulation, 2012.

[5] Molaie, M., Jafari, S., Sprott, J. C., and Golpayegani, S. M. R. H. “Simple chaotic flows with one stable equilibrium”. International Journal of Bifurcation and Chaos, 23(11), 2013.

[6] Maaita, J. O., Volos, C. K., Kyprianidis, I. M., & Stouboulos, I. N. “The dynamics of a cubic nonlinear system with no equilibrium point”, Journal of Nonlinear Dynamics, 2015.

[7] Volos, C., Maaita, J. O., Pham, V. T., & Jafari, S. “Hidden Attractors in a Dynamical System with a Sine Function”. In Chaotic Systems with Multistability and Hidden Attractors (pp. 459-487). Springer, Cham, 2021.

**Introductory talk**

## Nonlinear Non-Hermitian Photonics

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We are going to examine the foundations of semiclassical nonlinear optics and its recent applications in non-Hermitian physics of complex media. Starting from the semiclassical Maxwell-Bloch Equations we will derive the effective non-Hermitian Hamiltonians that govern the propagation of light in structures that contain gain and/or loss and examine the emergence of optical saturable nonlinearity. The importance of various symmetries, as well as, the existence of exceptional points in particular experimental systems will be discussed in detail. The connection to open quantum systems and also nonlinear non-Hermitian optics will be presented.

**Research talk**

## Modeling Brain Diseases with Nonlinear Dynamical Systems to Optimize Medical Treatments

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Mathematical modeling is a crucial tool for understanding the fundamental mechanisms of the human brain. Models based on ordinary differential equations can capture and describe the dynamic interactions between neurons within specific brain regions or across different brain areas. Here, we present recent studies demonstrating the usefulness of these models in computationally understanding and mitigating symptoms of two brain diseases: Parkinson’s disease (PD) and epilepsy. PD is characterized by abnormally strong neuronal synchrony. Coordinated reset (CR) stimulation, developed to counteract this, alternates synchronizing and desynchronizing stimulation to stabilize neural networks. Despite clinical success, models couldn't reproduce the increased desynchronizing effects observed after long, stimulation-free periods. We show that incorporating structural plasticity (SP) into models, where synapses adapt to target firing rates over days to months, explains this phenomenon. CR stimulation appears to lower SP target firing rates, enhancing desynchronization after breaks. This underscores the importance of homeostatic set point modulation in therapy. The exact mechanisms of the onset and propagation of epileptic seizures remain still unclear. We here employ mean-field models to replicate key epileptic seizure features. To this end, we use The Virtual Brain framework and the Epileptor model, we examine how the location and connectivity of an Epileptogenic Zone (EZ) in mice relate to focal seizures, focusing on the hippocampus. We simulate treatments like tissue resection and neurostimulation to confine seizures. By targeting specific connections and reducing EZ connectivity, we constrain seizures to the EZ, minimizing interventions while preserving brain functionality. Such computational approaches highlight the potential for computational models to optimize treatments for brain disorders by targeting abnormal neuronal synchronization and connectivity.

Keywords: Mathematical neural modeling, Neuromodulation, Coordinated Reset stimulation, Synaptic and Structural Plasticity, Parkinson’s disease, Epilepsy, Seizures.

References:

1. M. Ebert, C. Hauptmann, P.A. Tass, Front. Comput. Neurosci. 8, 154 (2014)
2. S. Diaz-Pier, M. Naveau, M. Butz-Ostendorf, A. Morrison, Front. Neuroanat. 10, 57 (2016)
3. T. Manos, M. Zeitler, P.A. Tass, PLoS Comput. Biol. 14, e1006113 (2018)
4. T. Manos, M. Zeitler, P.A. Tass, Front. Physiol. 9, 376 (2018)
5. O.V. Popovych, T. Manos, F. Hoffstaedter, S.B. Eickhoff, Front. Syst. Neurosci. 12, 68 (2019)

6. T. Manos, S. Diaz-Pier, P.A. Tass, Front. Physiol. 12, 716556, (2021)
7. J. Courson, M. Quoy, Y. Timofeeva, T. Manos, Front. Comput. Neurosci. 18:1360009 (2024)

**Introductory talk**

## What are complex systems and what techniques can we use to analyze them?

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The 2021 Nobel Prize in Physics recognized the fundamental role of complex systems in understanding our climate and the origin of climate change. The key properties of complex systems are high dimensionality and nonlinearity. Furthermore, complex systems are heterogeneous and multiscale. When dealing with a complex system, progress in its characterization and forecast requires the use of appropriate data analysis techniques. Linear techniques often fail to characterize or predict behavior. In this talk, I will present our work in the characterization of complex systems in different fields (optics and photonics, neuroscience, climate and ecology), and I will discuss the nonlinear data analysis techniques that we have used to analyze them.

**Research talk**

## Limit cycles in two second order differential equations with a van der Pol perturbation

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We have two second order ordinary differential equations, the first one, third order with a van der Pol epsilon perturbation and a linear interaction. The second one has only a nonlinear interaction. We prove that the system has a limit cycles continued from the unperturbed system to the perturbed one through the implicit function theorem. We show the limit cycles for special values of the parameters in program figures and this shows also their stability. Finally, we conclude and discuss further work.

**Introductory talk**

## Free-Dimensional aer( )sculptures: the personification of Henri Poincarré's 'representative space'

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When you look on an aer( )sculpture made out of the nanomaterial silica aerogel, this 'foam of glass', it's up to you to decide where to focus your eyes. We can say that the space of silica aerogel is a personification of what the French mathematicien Henri Poincaré named a "representative space", a non-Euclidean space that you cannot measure, you just live in with all your senses. The author uses the pun ['free' – and not 'three'-dimensional] in determining the case of the indefinitive transparency of his aer( )sculptures. This vaporous and fragile substance breaks the conventional boundaries of the Euclidean space…The first time you look on a sculpture made of this extraordinary nanomaterial you think that it is not a 3-D object, you think that it is a gas, a projection, a hologram. However, this nebulous mass -that is also an optical, a tactile and a kinetic space- is there, like a memory, like a dream. You believe that it's an illusion, but the sculpture is there, waiting for the tips of your fingers…Seeing this ghost image, the first thing you want to do is to touch it! It's hard to believe it's a solid! Every aer( )sculpture looks blue in a dark background but when light passes through it then it cast a shadow in a golden-orange hue. These natural colours are coming from the captured light in its nanopores, as our own sky that we see it blue in front of the black chaos and orange when it is sunset time and our eyes, the atmosphere and the sun are aligned: thus, we can say that every aer( )sculpture is made of a moulded piece of sky that attracts not only your attention but also your amazed heart.

References
1. Michaloudis I.,"Aer( )sculpture: A Free-Dimensional Space Art", in Aegerter M.A, Leventis N., Koebel M., Aerogels Handbook, Springer 2011, ISBN 978-1-4419-7477-8, chapter 35, pp. 791–810.

**Research talk**

# Multifractal Analysis of Choroidal SDOCT Images in the Detection of Retinitis Pigmentosa

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The aim of this paper is to investigate whether a multifractal analysis can be applied to study choroidal blood vessels and help ophthalmologists in the early diagnosis of retinitis pigmentosa (RP). In a case study, we used spectral domain optical coherence tomography (SDOCT), which is a noninvasive and highly sensitive imaging technique of the retina and choroid. The image of a choroidal branching pattern can be regarded as a multifractal. Therefore, we calculated the generalized Renyi point-centered dimensions, which are considered a measure of the inhomogeneity of data, to prove that it increases in patients with RP as compared to those in the control group.

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**Research talk**

# Detecting structural breakpoints and causal interactions in time series of Energy and Financial markets, as a sequence of the Russo-Ukrainian war, by using the Bayesian Estimator of Abrupt change, Seasonal change and Trend–BEAST, HURST exponent and Partial Mutual Information with Mixed Embedding (PMIME) PMIME tools: the case of ten European electricity markets, two natural gas markets (TTF, NGNMX) and a foreign exchange market (USD/RUB).

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We investigate the impact of several critical events associated with the Russo-Ukrainian war, started officially on 24 February 2022 with the Russian invasion of Ukraine, on ten European electricity markets, two natural gas markets (the European reference trading hub TTF and N.Y.'s NGNMX market) and how these markets interact to each other and with USD/RUB exchange rate, a 'financial market'. We analyze the reactions of these markets, manifested as breakpoints attributed to these critical events, and their interaction, by using a set of three tools that can shed light on different aspects of this complex situation. We combine the concepts of market efficiency, measured by quantifying the Efficient market hypothesis (EMH) via rolling Hurst exponent, with structural breakpoints occurred in the time series of gas, electricity and financial markets, the detection of which is possible by using a Bayesian ensemble approach, the Bayesian Estimator of Abrupt change, Seasonal change and Trend (BEAST), a powerful tool that can effectively detect structural breakpoints, trends, seasonalities and sudden abrupt changes in time series. We perform also causality analysis using the Partial Mutual Information with Mixed Embedding (PMIME) and rolling Mutual information (rMI) approaches, to analyze the direction of flow of information between the markets to understand the nature of their interaction, especially during the period of crisis and intense – turmoiled economic and geopolitical conditions. The results show that the analyzed markets have exhibited different modes of reactions to the critical events, both in respect of number, nature, and time of occurrence (leading, lagging, concurrent with dates of critical events) of breakpoints as well as of the dynamic behavior of their trend components. The most critical event, in respect of causing a strong structural breakpoint, for most of the markets, is not that of 24 February 2022, the day of the Russian invasion, but other critical events before this date, because of each market's 'idiosyncrasy' and 'readiness'. Also, the interaction between TTF, NGNMX and USD/RUB markets is found to be strongly mutual i.e. bidirectional, the financial market (USD/RUB) affects both gas markets, that in turn affects, to a different degree, the electricity markets. These findings support the results of similar works in literature. The three tools of analysis provide consistent results, linking rationally the concepts of market efficiency ('readiness' and degree of independence from Russia gas inflows),

number of breakpoints, dynamic profile of trend and seasonality curves and the direction of 'causalities' in the complex interaction of the markets during the Russo-Ukrainian crisis.

**Introductory talk**

## Artificial Intelligence, System and Matter Complexity

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This lecture reviews the relationship between the complexity of matter and systems on one hand, and life, intelligence, and the environment on the other. First, the theoretical tools (systems theory and graph and network theory) are briefly examined. Then, their relationship is presented with: a) the structure of life, b) biological neural networks, c) artificial intelligence and artificial neural networks, d) social structure and evolution, and e) the environment. The measurement of the complexity of matter and systems is also discussed. Additionally, the Law of Complexity is presented. Finally, philosophical issues related to the evolution of life through design are introduced.

**Introductory talk**

## Complex behavior in classical and quantum chaos

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I shall explain how chaos (chaotic behaviour) can emerge in deterministic systems of classical dynamics. It is due to the sensitive dependence on initial conditions, meaning that two nearby initial states of a system develop in time such that their positions (states) separate very fast (exponentially) in time. After a finite time (Lyapunov time) the accuracy of orbit characterizing the state of the system is entirely lost, the system could be in any allowed state. The system can be also ergodic, meaning that one single chaotic orbit describing the evolution of the system visits any other neighbourhood of all other states of the system. In this sense, chaotic behaviour in time evolution does not exist in quantum mechanics. However, if we look at the structural and statistical properties of the quantum system, we do find clear analogies and relationships with the structures of the corresponding classical systems. This is manifested in the eigenstates and energy spectra of various quantum systems (mesoscopic solid state systems, molecules, atoms, nuclei, elementary particles) and other wave systems (electromagnetic, acoustic, elastic, seismic, water surface waves etc), which are observed in nature and in the experiments.

**Introductory talk**

## Introduction to quantum chaos

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Dynamical chaos in the sense of sensitive dependence on initial conditions (asymptotically positive Lyapunov exponents) does not exist in quantum or wave systems. Nevertheless, chaos is manifested in the eigenstates and energy spectra of various quantum systems (mesoscopic solid state systems, molecules, atoms, nuclei, elementary particles) and other wave systems (electromagnetic, acoustic, elastic, seismic, water surface waves etc), which are observed in nature and in the experiments. Here we review the basic aspects of quantum chaos in Hamiltonian systems. We shall focus on the most general (generic) systems, also called mixed-type systems, as their classical counterparts in the phase space exhibit regular regions coexisting with the chaotic regions for complementary initial conditions. We shall review the basic concepts of quantum chaos in the stationary picture, that is the properties of the eigenstates of the stationary Schrödinger equation, the structure of wave functions, and of the corresponding Wigner functions in the quantum phase space, and the statistical properties of the energy spectra. Before treating the general mixed-type case we shall review the two extreme cases, the universality classes, namely the regular (integrable) systems, and the fully chaotic (ergodic) systems. Then the Berry-Robnik (1984) picture will be presented, and the underlying Principle of Uniform Semiclassical Condensation (PUSC) of the Wigner functions. Next, we shall consider the effects of quantum (dynamical) localization, which set in when the classical transport time (like diffusion time) is longer than the Heisenberg time scale (defined as the Planck constant divided by the mean energy level spacing). It will be shown phenomenologically that in the case of chaotic eigenstates in the quantum phase space (Wigner functions) the energy spectra display Brody level spacing distribution, where the level repulsion exponent (Brody parameter) goes from zero in the strongest localization to 1 in the fully extended states. The Berry-Robnik picture is then appropriately generalized to include the localization effects. Furthermore, the localization measures of chaotic localized eigenstates have a distribution, which in the absence of stickiness structures in the classical phase space is well described by the beta distribution. Finally, we show that the relative fraction of mixed-type eigen-states (classified by their Husimi functions) decreases in the semiclassical limit as a power law with the decreasing effective Planck constant (or equivalent semiclassical parameter), in agreement with and confirming PUCS.

References

1. M. Robnik, in BOUNTIS, Tassos (Ed.). Chaos, fractals and complexity. Cham: Springer International Publishing AG, 2023, pp 83-108.
2. C. Lozej, D. Lukman, M. Robnik, Phys.Rev.E 106 (2022) 054203.

3. Qian Wang, M. Robnik, Phys.Rev.E 108 (2023) 054217; Phys.Rev.E 109 (2024) 024225.

**Introductory talk**

## An introduction to routes to chaos in dynamical systems

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When a simple attracting set for a dynamical system (like a fixed point or periodic orbit) becomes chaotic as an external parameter is varied, different routes for the emergence of chaos can be identified.
In this lecture, I will give an introductory overview of the most common and well-studied routes through which chaotic behavior may appear and I will discuss their universality characteristics.
Starting from the most known Feigenbaum period doubling route, I will also discuss quasi-periodic route generated from the frequency locking phenomena as well as intermittency and crisis routes.

**Introductory talk**

# An introduction to scientific machine learning for the solution of the forward and inverse problems in dynamical systems. Challenges and Perspectives.

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Part 1. Introduction to Deep Neural Networks. Biological neurons and artificial neurons. Perceptrons. The Gradient Descent algorithm and Gauss Newton. Deep Neural Networks (DNNs). Training DNNs with the backpropagation algorithm. Generalization. The k-fold cross-validation method.
Part 2. Introduction to the solution of the forward and inverse problems of dynamical and complex systems with DNNs. Introduction to Physics-Informed Neural Networks. Challenges. Introduction to Random Projection Neural Networks. Introduction to Manifold learning for finding latent spaces. Examples. Perspectives.

**Introductory talk**

## Gravitational Waves from Binary Black Hole Systems and their Detection

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The lecture aims to provide a comprehensive overview of gravitational waves produced by binary black hole systems, spanning from theoretical foundations to state-of-the-art detection methods and their implications for modern astronomy.

We will begin by introducing the fundamental concepts of gravitational-wave generation and exploring the dynamics of binary black hole systems, which serve as the most abundant sources of gravitational waves. We'll discuss how these massive objects orbit each other, gradually losing energy through the emission of gravitational waves and eventually merging in a cataclysmic event that sends ripples through the fabric of spacetime.

The presentation will introduce the mathematical formalism used to describe these systems, including the post-Newtonian approximation for the early inspiral phase and numerical relativity simulations for the final merger and ringdown. We'll examine how different parameters of the binary system, such as the masses of the black holes and their spin alignments, affect the gravitational waveform produced.

Moving from theory to observation, we'll explore the challenges and breakthroughs in gravitational wave detection. The talk will cover the principles behind laser interferometer detectors like LIGO, Virgo, and KAGRA, explaining how these incredibly sensitive instruments can measure distortions in spacetime smaller than the diameter of a proton. We'll discuss the noise sources that complicate detection and the advanced data analysis techniques, including matched filtering and Bayesian inference, used to extract gravitational wave signals from the noise. Special emphasis will be placed on the recent application of machine learning algorithms, which led to the discovery of new gravitational wave sources.

Finally, we'll look towards the future of the field, discussing upcoming improvements to existing detectors and plans for space-based interferometers like LISA. We'll explore how these advancements promise to revolutionize our understanding of the universe, from the physics of extreme gravity to cosmology.

**Research talk**

# Cannibalism in Ecological Models as a Response to Declining Availability of Prey

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In this work we will present the behaviour of a dynamical system that describes the behaviour of a predator-prey system, where the population of available prey is crucial for the appearance of interspecies cannibalism amongst the predator species. We generalise the different prey species as one subgroup, since the important factor in our model is the biomass dependant cannibalism that periodically appears amongst the predators. We did not include larval stages for the predators for simplicity. We focus on the non-linear behaviour of the system and the equilibrium points that appear. The base system upon which we add the cannibalistic behaviour is a classic Lotka-Volterra model.

**Introductory talk**

## Principles of Earthquake physics in terms of Complexity and Tsallis Entropy. Quo Vademus?

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The earthquake generation process is a complex phenomenon, manifested in the nonlinear dynamics and in the wide range of spatial and temporal scales that are incorporated in the process. Understanding the exact physics that govern the earthquake generation process and the subsequent prediction of future earthquakes still represent an outstanding challenge for scientists. The most prominent is scale-invariance, which is manifested in the size of faults, the frequency of earthquake sizes and the spatial and temporal scales of seismicity. Scale-invariance and (multi)fractality are also manifested in the temporal evolution of seismicity and the distribution of earthquake epicentres. The organization patterns that earthquakes and faults exhibit have motivated the statistical physics approach to earthquake occurrence.
Based on statistical physics and the entropy principle, a unified framework that produces the collective properties of earthquakes and faults from the specification of their microscopic elements and their interactions, has recently been introduced. This framework, called nonextensive statistical mechanics (NESM) was introduced by Tsallis (1988), as a generalization of classic statistical mechanics due to Boltzmann and Gibbs (BG), to describe the macroscopic behavior of complex systems that present strong correlations among their elements, violating some of the essential properties of BG statistical mechanics.
In this presentation, we provide a summary of the fundamental properties of NESM as used in Geosciences. Initially, we provide an overview of the collective properties of earthquake populations and the main empirical statistical models that have been introduced to describe them. An analytic description of the fundamental theory and the models that have been derived within the NESM framework to describe the collective properties of earthquakes is presented. The corner stones of Statistical seismology as that of Gutenberg-Richter (GR) and Omori law analyzed using the ideas of Tsallis entropy and its dynamical superstatistical interpretation offered by Beck and law.

Acknowledgments: We work is partly supported by the project “Seismological Action” of the Institute of Physics of Earth’s Interior and Geohazards, HMU Research & Innovation Center, Greece

**Introductory talk**

## Primes! An Informal Story

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We give an idea of the mystery and centuries long fascination of prime numbers, and some of the main mathematical insights gained over the centuries.

I hope to also give a more general idea on the great scope and history of mathematics as a whole (and why we do mathematics).

We keep the technical details at a level that is accessible for a general audience without mathematical knowledge beyond the first years of undergraduate study. The talk was specifically written for undergraduate students.

Further, we will give a brief look at rings and fields and discuss the consequences of allowing (or disallowing) division, followed by a discussion of Legendre's correct guess in 1808 of the Prime Number Theorem (PNT). Riemann surprised everyone in 1859 that you need complex analysis to produce a proof. That proof was finally realized in 1896 by De La Vallee-Poussin and Hadamard. However, the currently accepted proofs date from the 1980's and after when a simplification was introduced by Newman.

We also discuss some parallel developments. In 1837, Dirichlet studied how many primes occur in infinite sequences of the form {n+im} for i in {1,2,3,…}, the PNT for Arithmetic Progressions. This led to important advances in Abstract Algebra. Another complete surprise came in 1949, when Selberg and Erdos discovered a proof that does not use complex analysis.

We make use of the theory of continued fractions to visualize some of the results.

**Research talk**

## Chemical Reaction Networks

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We start by describing boundary operators and how they can be used to build a Graph Laplacian L.

Since the eigenvalues of a Laplacian L have non-negative real part, and so the long term behavior of the linear differential equations x dot = -L x is dominated by the zero eigenvalues and their eigenvectors. We discuss this in some detail.

The differential equations governing the behavior of chemical reaction networks can be built up using the boundary operators. This gives rise, very naturally, to a Laplacian formulation of the dynamics. But with a difference. These differential equations are nonlinear. In spite of that, in many cases, we show that the Laplacian approach can be used to describe the global dynamics of the network.

Graph Laplacians have a very wide applicability: traffic networks, banking networks, systems biology, google-type algorithms, social networks, data science, consensus, power grid, internet, are but a few examples.

**Introductory talk**

## Complexity in Electromagnetics Computations: Intelligent Metasurfaces and Wave Propagation

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Approaches to tackle complexity in large-scale engineering electromagnetic calculations are provided, regarding applications in modern and prospective wireless communications. A combination of techniques for handling complexity in large scale computation include the development of novel approximate, yet accurate fast semi-analytical techniques, consideration of novel formulations towards low complexity algorithms and the development of key techniques from machine learning, including recent advances in neural networks. An important application of the above techniques is the analysis and design of large reconfigurable intelligent metasurfaces (RIS), which is considered a hot topic in prospective (6G and beyond) wireless communications. The enormous complexity of the design calls for advanced methods that go beyond the state-of-the-art in computational EM techniques. In parallel, efficient deployment of new wireless communication standards include advanced features such as fast ore even proactive beamforming techniques, that also require good knowledge of the propagation environment and a fast learning approach to track multiple users. All these issues are dealt with proper tools, combining fast EM analysis, rigorous optimization and efficient learning approaches.

**Research talk**

## Συντονισμοί και χάος σε χαμιλτονιανά συστήματα

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Οι συντονισμοί διαδραματίζουν καθοριστικό ρόλο στην περιγραφή σύνθετων φυσικών φαινομένων, από τις κινήσεις των σωμάτων στο ηλιακό μας σύστημα και τη γαλαξιακή δυναμική μέχρι την κίνηση σωματιδίων σε επιταχυντές. Σε αυτήν την ομιλία θα εξετάσουμε τον τρόπο με τον οποίο μπορούν να μελετηθούν τα φαινόμενα συντονισμού που εμφανίζονται σε χαμιλτονιανά συστήματα. Ειδικότερα, θα παρουσιάσουμε τη διαδικασία κατασκευής απλοποιημένων μαθηματικών μοντέλων που προβλέπουν την κίνηση στην «γειτονιά» ενός μεμονωμένου συντονισμού, και θα αναλύσουμε την δυναμική τους μέσω των θεμελιωδών μοντέλων των συντονισμών και των ιδιοτήτων τους. Επιπλέον, θα διερευνήσουμε πώς οι συντονισμοί συνδέονται με την εμφάνιση χάους υπό την επίδραση διαταραχών, καθώς και σε περιπτώσεις αλληλοεπικάλυψης τους. Ως εφαρμογή, θα χρησιμοποιήσουμε το μοντέλο που περιγράφει την περιστροφική κίνηση ενός δορυφόρου γύρω από έναν πλανήτη και θα μελετήσουμε την περιστροφή του δορυφόρου του Κρόνου, Υπερίωνα, ένα από τα πρώτα παραδείγματα χαοτικής κίνησης στο ηλιακό μας σύστημα.

**Introductory talk**

## Χρόνος & Πολυπλοκότητα

***Καρακόλης Χρήστος***

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Μπορεί στην εποχή μας τα διαθέσιμα πολύπλοκα συστήματα - εργαλεία να επιταχύνουν την εξέλιξη προς τα πολυπλοκώτερα, αλλά στο βαθύ παρελθόν η εξέλιξη ήταν αργόσυρτη - πολύ αργόσυρτη... Δύο δισεκατομμύρια χρόνια "απαιτήθηκαν" για να εξελιχθούν, στη βιόσφαιρα της Γης, οι μονοκύτταροι οργανισμοί σε πολυκύτταρους! Χρειάστηκε πολύ χρόνο ο Χρόνος για να σταθεί ως ανθρώπινος νους - το γήινο αποκορύφωμα της πολυπλοκότητας - απέναντι στον εαυτό του και να διερωτηθεί τα δύσκολα!

Ο Χρήστος Καρακόλης, καθηγητής Φυσικής επί 40 έτη στα φροντιστήρια της Θεσσαλονίκης και συγγραφέας 16 Τετραδίων Φυσικής, θα παρουσιάσει κάποιες σκέψεις του πάνω στις σχέσεις του Χρόνου με την Πολυπλοκότητα.

**Research talk**

## Βιοφυσική και Ιατρική Συστημάτων: Μοντελοποίηση της Βιολογικής Γήρανσης και των Ασθενειών

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Στην παρούσα ομιλία θα εξεταστούν τα βασικά χαρακτηριστικά της βιολογικής γήρανσης, η οποία ορίζεται ως η αυξημένη πιθανότητα θανάτου και εμφάνισης ασθενειών με την πάροδο της ηλικίας. Η ομιλία θα επικεντρωθεί στο μοντέλο saturated removal και πώς αυτό μπορεί να εξηγήσει τον νόμο του Gompertz, καθώς και τις ασθένειες που σχετίζονται με τη γήρανση.

Το μοντέλο saturated removal παρέχει μια θεωρητική βάση για την κατανόηση της διαδικασίας γήρανσης μέσω της ανάλυσης της απομάκρυνσης των βλαβών που συσσωρεύονται στους οργανισμούς με την πάροδο του χρόνου. Σύμφωνα με αυτό το μοντέλο, η παραγωγή βλαβών αυξάνεται με την ηλικία και το ανοσοποιητικό σύστημα δεν μπορεί να εξακολουθήσει να παρέχει τον κατάλληλο ρυθμό απομάκρυνσής τους. Αυτό οδηγεί σε αυξημένη συσσώρευση βλαβών και κατά συνέπεια, σε υψηλότερο κίνδυνο ασθενειών και θανάτου.

Η εφαρμογή του μοντέλου αυτού επιτρέπει την εξήγηση του νόμου του Gompertz, ο οποίος περιγράφει την εκθετική αύξηση της θνησιμότητας με την ηλικία. Επιπλέον, θα αναλυθεί το πώς οι βλάβες που δεν απομακρύνονται αποτελεσματικά συμβάλλουν στην εμφάνιση ασθενειών που σχετίζονται με τη γήρανση, όπως οι καρδιαγγειακές παθήσεις, ο καρκίνος και οι νευροεκφυλιστικές ασθένειες.

Στόχος της ομιλίας είναι να αναδειχθεί η σημασία της βιοφυσικής και της ιατρικής συστημάτων στη μελέτη της γήρανσης και των σχετιζόμενων ασθενειών, προσφέροντας νέα προοπτική και κατανόηση για τη διαχείριση και την πρόληψη των προβλημάτων υγείας που προκύπτουν με την αύξηση της ηλικίας.

**Introductory talk**

## Περιοδικές Τροχιές στα Δυναμικά Συστήματα

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Στο μάθημα αυτό θα εξετάσουμε την ύπαρξη, τη σημασία και τις ιδιότητες των περιοδικών τροχιών στα Δυναμικά Συστήματα (ΔΣ) και κυρίως στα Χαμιλτονιανά Συστήματα (ΧΣ).
Πιο συγκεκριμένα θα ξεκινήσουμε εξετάζοντας τα ζητούμενα στη μελέτη των δυναμικών συστημάτων και γιατί οι περιοδικές τροχιές παίζουν βασικό ρόλο στη μελέτη αυτή.
Έπειτα, θα μελετήσουμε τη δυνατότητα ύπαρξης ή μη περιοδικών τροχιών ανάλογα με τη διάσταση του ΔΣ, ξεκινώντας από τη μία, προχωρώντας στις δύο και τέλος στις 3 και παραπάνω διαστάσεις.
Στη συνέχεια θα επικεντρωθούμε στα Χαμιλτονινά συσήματα και θα συζητήσουμε την εύρεση και την ευστάθεια των περιοδικών τροχιών στα συστήματα αυτά. Τέλος θα εξετάσουμε συγκεκριμένα παραδείγματα συστημάτων που οι περιοδικές τροχιές παίζουν καθοριστικό ρόλο.

**Research talk**

## Μοντέλο Πρόβλεψης με Αραίωση Εκτιμώμενη από τη Μερική Συσχέτιση και Εφαρμογή στην Πρόβλεψη του ΑΕΠ

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Το κλασικό γραμμικό μοντέλο πρόβλεψης πολυμεταβλητών χρονοσειρών είναι το διανυσματικό αυτοπαλίνδρομο μοντέλο (VAR). Ωστόσο, για πολλές μεταβλητές ή/και μεγάλη τάξη του VAR το μοντέλο θεωρείται υψηλής διάστασης. Οι πιο γνωστές προσεγγίσεις αραίωσης του VAR μοντέλου (μείωσης διάστασης) είναι η εξαγωγή νέων μεταβλητών, όπως η παλινδρόμηση κυρίων συνιστωσών (PCR), και η επιλογή μεταβλητών, όπως είναι ο τελεστής ελάχιστης απόλυτης συρρίκνωσης και επιλογής (LASSO). Στην παρούσα εργασία προτείνεται ένα νέο μοντέλο πρόβλεψης εφαρμόζοντας έναν αλγόριθμο σταδιακά προς τα εμπρός επιλογής μεταβλητών υστέρησης (μεταβλητή με κάποια χρονική υστέρηση σε σχέση με τη μεταβλητή απόκρισης). Ως κριτήριο επιλογής χρησιμοποιείται η μερική συσχέτιση, αναζητώντας μεταβλητή υστέρησης που έχει συσχέτιση με την απόκριση που δεν εξηγείται από τις ήδη επιλεγμένες μεταβλητές. Το κριτήριο τερματισμού χρησιμοποιεί παραμετρικό έλεγχο υπόθεσης εξασφαλίζοντας ισορροπία μεταξύ της πολυπλοκότητας του μοντέλου και της προγνωστικής ισχύος. Η αξιολόγηση της αξιοπιστίας του αλγορίθμου γίνεται με προσομοιωτική μελέτη και συγκρίνεται με άλλες προσεγγίσεις, όπως LASSO και PCR. Επιπλέον, ο αλγόριθμος εφαρμόζεται σε χρονοσειρές τριμηνιαίων μετρήσεων του ελληνικού Ακαθάριστου Εγχώριου Προϊόντος (ΑΕΠ) και των συνιστωσών του, που καταρτίζει η Ελληνική Στατιστική Αρχή (ΕΛΣΤΑΤ). Προσδιορίζονται οι μεταβλητές που επηρεάζουν περισσότερο τις διακυμάνσεις του ΑΕΠ και σχηματίζεται το αντίστοιχο μοντέλο πρόβλεψης. Η εργασία πραγματοποιήθηκε στο πλαίσιο του προγράμματος EMOS.

**Introductory talk**

## Μη γραμμική δυναμική του ηλιακού συστήματος

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Το ηλιακό σύστημα αποτελεί εδώ και 40 χρόνια το φυσικό, αστρονομικό "εργαστήριο", για τη μελέτη μη γραμμικών φαινομένων και χαοτικής συμπεριφοράς σε (σχεδόν) Χαμιλτονιανά συστήματα, με χαρακτηριστικές χρονικές κλίμακες από μερικά έτη (πχ φυσικοί δορυφόροι των πλανητών) μέχρι και δισεκατομμύρια έτη (ευστάθεια του συστήματος). Στην ομιλία μας θα αναπτύξουμε τους βασικούς μηχανισμούς που διέπουν τη δυναμική του συστήματος, στα διάφορα στάδια της εξέλιξής του. Ιδιαίτερα, θα περιγράψουμε τους διάφορους τύπους συντονισμών που καθοδηγούν τη δυναμική και ερμηνεύουν τις παρατηρήσεις. Η αποκάλυψη της μη γραμμικής ιστορίας του ηλιακού συστήματος μας βοηθά να κατανοήσουμε επίσης την "ποικιλία" των γνωστών  εξωηλιακών πλανητικών συστημάτων.